

COURSEN

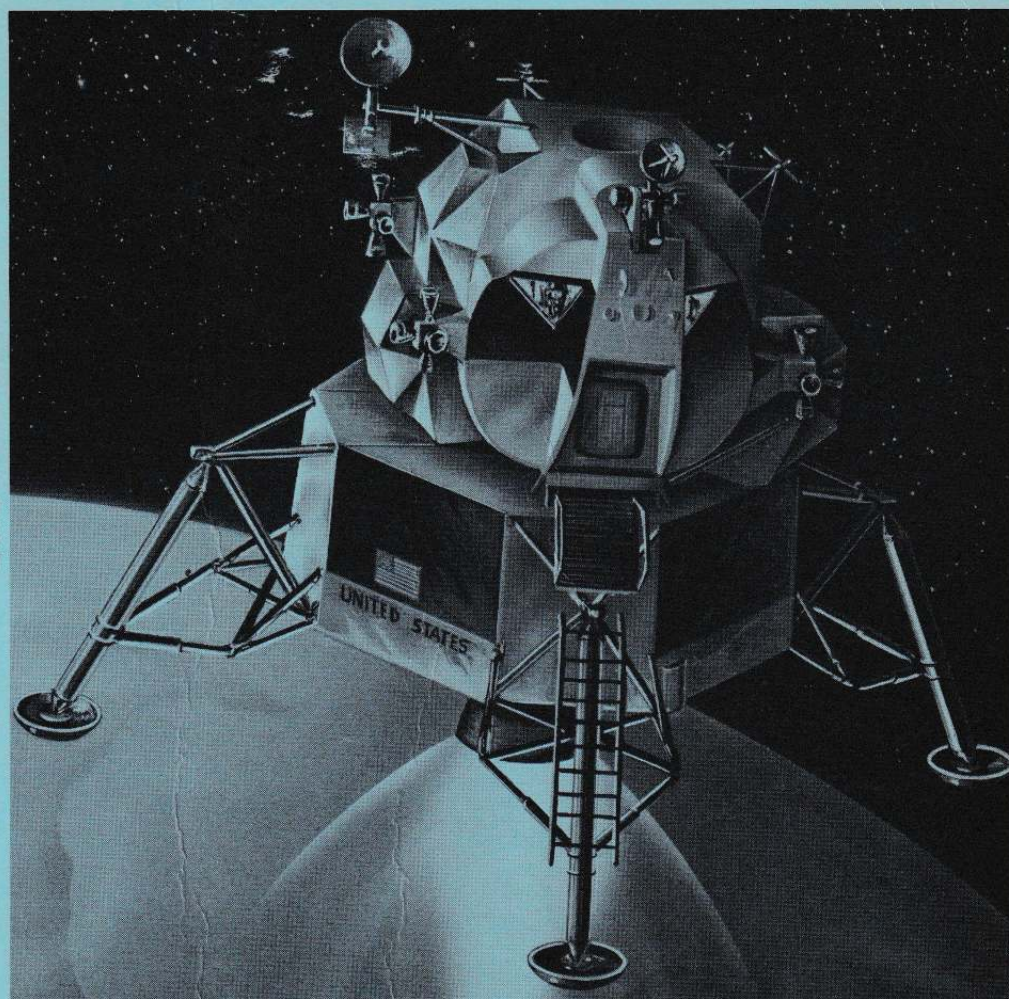
LMA790-3-LM3

Volume 1



APOLLO OPERATIONS HANDBOOK

Prepared Under Direction
of: SPACECRAFT SYSTEMS
BRANCH—FLIGHT CREW
SUPPORT DIVISION



LUNAR MODULE 3



LM PUBLICATIONS SECTION/PRODUCT SUPPORT DEPARTMENT/GRUMMAN AIRCRAFT ENGINEERING CORPORATION/BETHPAGE/NEW YORK

APOLLO OPERATIONS HANDBOOK

LUNAR MODULE

LM 3

VOLUME I

Contract NAS 9-1100
Exhibit E; Paragraph 10.4

Approved: J. K. Stotz, Jr.
J. K. Stotz, Jr., Manager
Test Operations Support
LM Program

Approved: W. J. Everett
W. J. Everett, Program Manager
LM Publications Section



TYPE I DOCUMENT

Prepared under direction of
THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
SPACECRAFT SYSTEMS BRANCH / FLIGHT CREW SUPPORT DIVISION

PUBLICATIONS SECTION/PRODUCT SUPPORT DEPARTMENT/GRUMMAN AIRCRAFT ENGINEERING CORPORATION/BETHPAGE/NEW YORK

1 JANUARY 1968

INSERT LATEST CHANGED PAGES. DESTROY-SUPERSEDED PAGES.

LIST OF EFFECTIVE PAGES

NOTE: The portion of the text affected by the changes is indicated by a vertical line in the outer margins of the page.

TOTAL NUMBER OF PAGES IN THIS PUBLICATION IS 836 CONSISTING OF THE FOLLOWING:

Page No.	Issue	Page No.	Issue
Title Page	Original	2. 7-1 thru 2. 7-38	Original
A thru C	Original	2. 8-1 thru 2. 8-24	Original
i thru x	Original	2. 9-1 thru 2. 9-110	Original
1-1 thru 1-24	Original	2. 10-1 thru 2. 10-20	Original
2. 1-1 thru 2. 1-12	Original	2. 11-1 thru 2. 11-24	Original
2. 2-1 thru 2. 2-212	Original	3-1 thru 3-156	Original
2. 3-1 thru 2. 3-54	Original	A-1 thru A-4	Original
2. 4-1 thru 2. 4-32	Original	B-1 thru B-2	Original
2. 5-1 thru 2. 5-38	Original	C-1 thru C-10	Original
2. 6-1 thru 2. 6-62	Original		

CHANGE INFORMATION

This handbook is subject to continuous change or revision, on a priority basis, to reflect current engineering or mission changes, or to improve content or arrangement. The content and the changes are accounted for by the above List of Effective Pages, and by the following means:

Record of Publication: The publication date of each basic issue and each change issue is listed on page B as a record of all editions.

Synopsis of Significant Changes: A two-part synopsis of significant changes is listed on page C of this publication. The information is:

Part I. Technical Changes: Describes the changes which have been made to technical information.

Part II. Content and Format Changes: Describes major addition to (or deletions from) the information presented, and also describes any rearrangement of content.

Page Change Date: Each page in this handbook has space for entering a change date. The latest publication date will be entered in this space each time a page is changed from the basic issue.

COMMENTS

NASA Comments: NASA comments or suggested changes to this handbook should be directed to M.E. Dement, Flight Crew Support Division, Spacecraft Operations Branch, Building No. 4, MSC, 2101 Webster Seabrook Road, Houston, Texas 77058.

GAEC Comments: GAEC comments or suggested changes to this handbook should be directed to the Product Support Department, LM Publications Section.

*The asterisk indicates pages changed, added, or deleted by the current change.

NASA

Manuals will be distributed as directed by the NASA Apollo Project Office. All requests for manuals should be directed to the NASA Apollo Spacecraft Project Office at Houston, Texas.

RECORD OF PUBLICATION

This publication is the basic Apollo Operations Handbook-LM 3.

After this issue, changes will be issued to maintain information current with LM 3 configuration through completion of its mission. If such changes are issued, their publication dates will be added to this record.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK

TABLE OF CONTENTS

Section		Page
1	SPACECRAFT	
	Introduction	1-1
1.1	LM 3 Configuration	1-1
1.2	Ascent Stage	1-6
1.2.1	General Description	1-6
1.2.2	Structure	1-6
1.3	Descent Stage	1-17
1.3.1	General Description	1-17
1.3.2	Structure	1-17
1.4	LM - SLA - S-IVB Connections	1-21
1.5	LM-CSM Interfaces	1-22
1.5.1	Crew Transfer Tunnel	1-22
1.6	Stowage Provisions	1-24
2	SUBSYSTEMS DATA	
	Introduction	2-1
2.1	Subsystem Interface	2.1-1
2.1.1	Guidance, Navigation, and Control Subsystem	2.1-1
2.1.2	Main Propulsion Subsystem	2.1-2
2.1.3	Reaction Control Subsystem	2.1-3
2.1.4	Electrical Power Subsystem	2.1-3
2.1.5	Environmental Control Subsystem	2.1-4
2.1.6	Communication Subsystem	2.1-5
2.1.7	Explosive Devices Subsystem	2.1-5
2.1.8	Instrumentation Subsystem	2.1-6
2.1.9	LM Mission Programmer	2.1-7
2.2	Guidance, Navigation, and Control Subsystem	2.2-1
2.2.1	Introduction	2.2-1
2.2.2	Functional Description	2.2-3
2.2.3	Major Component/Functional Description	2.2-9
2.2.4	Failure Modes	2.2-177
2.2.5	Performance and Design Data	2.2-185
2.2.6	Operational Limitations and Restrictions	2.2-190
2.2.7	Telemetry Measurements	2.2-194
2.3	Main Propulsion Subsystem	2.3-1
2.3.1	Introduction	2.3-1
2.3.2	Descent Propulsion Section Functional Description	2.3-3
2.3.3	Descent Propulsion Section Major Component/Functional Description	2.3-15
2.3.4	Descent Propulsion Section Failure Modes	2.3-26

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK

TABLE OF CONTENTS (cont)

Section	Page
2.3 Main Propulsion Subsystem (cont)	
2.3.5 Descent Propulsion Section Performance and Design Data	2.3-26
2.3.6 Descent Propulsion Section Operational Limitations and Restrictions	2.3-27
2.3.7 Descent Propulsion Section Telemetry Measurements	2.3-31
2.3.8 Ascent Propulsion Section Functional Description	2.3-35
2.3.9 Ascent Propulsion Section Major Component/Functional Description	2.3-41
2.3.10 Ascent Propulsion Section Failure Modes	2.3-46
2.3.11 Ascent Propulsion Section Performance and Design Data	2.3-47
2.3.12 Ascent Propulsion Section Operational Limitations and Restrictions	2.3-50
2.3.13 Ascent Propulsion Section Telemetry Measurements	2.3-50
2.4 Reaction Control Subsystem	2.4-1
2.4.1 Introduction	2.4-1
2.4.2 Functional Description	2.4-4
2.4.3 Major Component/Functional Description	2.4-17
2.4.4 Failure Modes	2.4-19
2.4.5 Performance and Design Data	2.4-21
2.4.6 Operation Limitations and Restrictions	2.4-23
2.4.7 Telemetry Measurements	2.4-24
2.5 Electrical Power Subsystem	2.5-1
2.5.1 Introduction	2.5-1
2.5.2 Functional Description	2.5-1
2.5.3 Major Component/Functional Description	2.5-20
2.5.4 Failure Modes	2.5-30
2.5.5 Performance and Design Data	2.5-32
2.5.6 Operational Limitations and Restrictions	2.5-33
2.5.7 Telemetry Measurements	2.5-34
2.6 Environmental Control Subsystem	2.6-1
2.6.1 Introduction	2.6-1
2.6.2 Functional Description	2.6-6
2.6.3 Major Component/Functional Description	2.6-23
2.6.4 Failure Modes	2.6-46
2.6.5 Performance and Design Data	2.6-49
2.6.6 Operational Limitations and Restrictions	2.6-55
2.6.7 Telemetry Measurements	2.6-56
2.7 Communications Subsystem	2.7-1
2.7.1 Introduction	2.7-1
2.7.2 Functional Description	2.7-1
2.7.3 Major Component/Functional Description	2.7-5
2.7.4 Failure Modes	2.7-30
2.7.5 Performance and Design Data	2.7-30
2.7.6 Operational Limitations and Restrictions	2.7-36
2.7.7 Telemetry Measurements	2.7-37
2.8 Explosive Devices Subsystem	2.8-1
2.8.1 Introduction	2.8-1
2.8.2 Functional Description	2.8-2
2.8.3 Major Component/Functional Description	2.8-4
2.8.4 Failure Modes	2.8-20

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK

TABLE OF CONTENTS (cont)

Section		Page
2.8	Explosive Devices Subsystem (cont)	
2.8.5	Performance and Design Data	2.8-22
2.8.6	Operational Limitations and Restrictions	2.8-23
2.8.7	Telemetry Measurements	2.8-24
2.9	Instrumentation Subsystem	2.9-1
2.9.1	Introduction	2.9-1
2.9.2	Functional Description	2.9-1
2.9.3	Major Component/Functional Description	2.9-2
2.9.4	Failure Modes	2.9-86
2.9.5	Performance and Design Data	2.9-87
2.9.6	Operational Limitations and Restrictions	2.9-94
2.9.7	Telemetry Measurements	2.9-94
2.10	Miscellaneous	2.10-1
2.10.1	Introduction	2.10-1
2.10.2	Functional Description	2.10-1
2.10.3	Major Component/Functional Description	2.10-2
2.10.4	Failure Modes	2.10-15
2.10.5	Performance and Design Data	2.10-15
2.10.6	Operational Limitations and Restrictions	2.10-15
2.10.7	Telemetry Measurements	2.10-19
2.11	Crew Personal Equipment	2.11-1
2.11.1	Introduction	2.11-1
2.11.2	Extravehicular Mobility Unit	2.11-1
2.11.3	Umbilical Assembly	2.11-13
2.11.4	Crew Life Support	2.11-13
2.11.5	Medical Equipment	2.11-15
2.11.6	Crew Support and Restraint Equipment	2.11-16
2.11.7	Docking Aids and Tunnel Hardware	2.11-17
2.11.8	Crew Miscellaneous Equipment	2.11-19
2.11.9	Stowage Locations	2.11-21

LIST OF ILLUSTRATIONS

Figure No.		Page
1-1	Apollo-Saturn Space Vehicle	1-2
1-2	LM 3 Configuration	1-3
1-3	LM 3 Overall Dimensions	1-4
1-4	Station Reference Measurements	1-5
1-5	Ascent Stage Configuration (3 Sheets)	1-7
1-6	Flight Stations	1-10
1-7	Forward Hatch	1-12
1-8	Front Window	1-13
1-9	Docking Window	1-14
1-10	Upper Hatch	1-16
1-11	Descent Stage Configuration	1-18
1-12	Landing Gear	1-20
1-13	LM-CSM Reference Axis	1-23
2-1	LM-3 Subsystems Functional Interface Diagram (5 Sheets)	2.1-9
2-2	LM Guidance, Navigation, and Control Subsystem - Equipment Location	2.2-2
2-3	Primary Guidance Path - Simplified Block Diagram	2.2-5
2-4	Abort Guidance Path - Simplified Block Diagram	2.2-7
2-5	LM Vehicle and Primary Guidance and Navigation Section Axes	2.2-8
2-6	Primary Guidance and Navigation Section - Block Diagram	2.2-10
2-7	Inertial Subsection - Functional Diagram	2.2-13
2-8	Navigation Base - Pictorial Diagram	2.2-14
2-9	IMU Gimbal Assembly - Pictorial Diagram	2.2-16
2-10	IMU Temperature Control	2.2-18
2-11	IMU - Forced Convection Cooling	2.2-19
2-12	IMU Failure - Detection Logic	2.2-20
2-13	CDU Digital-to-Analog and Analog-to-Digital Conversion Breakdown	2.2-21
2-14	CDU Failure Detection Logic	2.2-24
2-15	Inertial Subsection Power Distribution - Block Diagram	2.2-25
2-16	Stabilization Loops - Functional Diagram	2.2-27
2-17	Gyro Torquing Loop - Functional Diagram	2.2-29
2-18	Accelerometer Loop - Functional Diagram	2.2-30
2-19	IMU Turn-On and Cage Modes - Functional Diagram	2.2-34
2-20	Coarse Align Mode - Functional Diagram	2.2-35
2-21	Fine Align Mode - Functional Diagram	2.2-37
2-22	Attitude Error Display Mode - Functional Diagram	2.2-39
2-23	Display Inertial Data Mode - Functional Diagram	2.2-40
2-24	Gimbal Lock Mode - Functional Diagram	2.2-42
2-25	Inertial Reference Mode - Functional Diagram	2.2-43
2-26	Alignment Optical Telescope	2.2-44
2-27	Alignment Optical Telescope Articulation	2.2-45
2-28	Alignment Optical Telescope - Reticle Pattern	2.2-46
2-29	LM Guidance Computer - Functional Flow Diagram	2.2-49
2-30	Primary Guidance and Navigation Section - Functional Flow Diagram	2.2-81
2-31	Abort Guidance Section - Block Diagram	2.2-83
2-32	Abort Sensor Assembly - Block Diagram	2.2-87
2-33	Abort Electronics Assembly - Block Diagram	2.2-90
2-34	Abort Guidance Section - Functional Flow Diagram	2.2-105
2-35	Euler Angles	2.2-111
2-36	Rendezvous Radar - Block Diagram	2.2-119
2-37	Rendezvous Radar Antenna Assembly	2.2-122
2-38	Rendezvous Radar Digital Data Transfer - Flow Diagram	2.2-126

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK

LIST OF ILLUSTRATIONS (cont)

Figure No.		Page
2-39	Rendezvous Radar Antenna Orientation - Mode No. I	2.2-128
2-40	Rendezvous Radar Antenna Orientation - Mode No. II	2.2-129
2-41	Rendezvous Radar - Functional Flow Diagram	2.2-131
2-42	Rendezvous Radar Tracking Loop - Functional Diagram	2.2-133
2-43	Rendezvous Radar Antenna Positioning - Functional Diagram	2.2-135
2-44	Landing Radar - Block Diagram	2.2-136
2-45	Landing Radar Antenna Beam Configuration	2.2-138
2-46	Landing Radar Digital Data Transfer - Functional Diagram	2.2-141
2-47	Landing Radar Antenna Positioning - Functional Diagram	2.2-142
2-48	Landing Radar - Functional Flow Diagram	2.2-143
2-49	Control Electronics Section - Block Diagram	2.2-145
2-50	Attitude Controller Assembly	2.2-148
2-51	Attitude Controller Assembly - Functional Diagrams	2.2-149
2-52	Thrust/Translation Controller Assembly	2.2-150
2-53	Thrust/Translation Controller Assembly Interfaces	2.2-153
2-54	Attitude and Translation Control Assembly - Block Diagram	2.2-154
2-55	Attitude and Translation Control Assembly - Jet Select Logic	2.2-156
2-56	Rate Gyro Assembly - Schematic and Vector Diagrams	2.2-158
2-57	Descent Engine Control Assembly - Block Diagram	2.2-159
2-58	Descent Engine Control Assembly - Throttle Control Diagram	2.2-160
2-59	Descent Engine Control Assembly - Trim Control Diagram	2.2-161
2-60	Descent Engine Control Assembly - Engine Control Diagram	2.2-162
2-61	Throttle Control vs TTCA Displacement	2.2-163
2-62	Gimbal Drive Actuator - Pictorial Diagram	2.2-164
2-63	Control Electronics Section - 800 cps Synchronization Loop	2.2-165
2-64	Gimbal Angle Sequencing Transformation Assembly - Schematic Diagram	2.2-167
2-65	Control Electronics Section - Functional Flow Diagram	2.2-169
2-66	LM Mission Programmer - Block Diagram	2.2-176
2-67	Ascent Engine Arming Assembly	2.2-178
2-68	Orbital Rate Display - Earth and Lunar - Schematic Diagram	2.2-179
2-69	Main Propulsion Subsystem - Interface Block Diagram	2.3-2
2-70	Descent Propulsion Section - Component Location	2.3-4
2-71	Descent Propulsion Section - Simplified Functional Flow Diagram	2.3-7
2-72	Propellant Quantity Gaging System - Simplified Functional Block Diagram	2.3-11
2-73	Descent Engine Assembly - Flow Diagram	2.3-13
2-74	Descent Propulsion Section - Explosive Valves, Simplified Functional Diagram	2.3-16
2-75	Helium Isolation Valves, Cutaway and Circuitry	2.3-18
2-76	Descent Propulsion Section - Pressure Regulator	2.3-19
2-77	Relief Valve Assembly	2.3-20
2-78	Descent Engine and Head End Assembly	2.3-21
2-79	Throttle Valve Actuator - Cutaway and Block Diagram	2.3-22
2-80	Flow Control Valve	2.3-23
2-81	Variable-Area Injector - Quarter Section	2.3-25
2-82	Descent Engine Combustion Chamber and Nozzle Extension	2.3-26
2-83	Ascent Propulsion Section - Component Location	2.3-36
2-84	Ascent Propulsion Section - Simplified Functional Flow Diagram	2.3-37
2-85	Ascent Engine Assembly - Flow Diagram	2.3-40
2-86	Ascent Propulsion Section - Explosive Valves - Simplified Functional Diagram	2.3-42
2-87	Ascent Propulsion Section - Pressure Regulator Assembly	2.3-44
2-88	Ascent Engine Assembly	2.3-45
2-89	Reaction Control Subsystem - Component Location	2.4-1
2-90	Reaction Control Subsystem - Interface Block Diagram	2.4-3
2-91	Reaction Control Subsystem - Simplified Functional Flow Diagram	2.4-5
2-92	RCS System A - Ascent Feed Interconnect Valve Arrangement	2.4-8
2-93	Propellant Quantity Measuring Device	2.4-10

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK

LIST OF ILLUSTRATIONS (cont)

Figure No.		Page
2-94	Thrust Chamber Assembly Cluster	2.4-11
2-95	Thrust Chamber Assembly - Operation and Failure Detection System	2.4-12
2-96	Thrust Chamber Assembly - Thrust Versus Time	2.4-13
2-97	Thrust Chamber Assembly	2.4-15
2-98	Reaction Control Subsystem - Thruster-On Failure Correction	2.4-16
2-99	Propellant Tank Assembly	2.4-18
2-100	Reaction Control Subsystem - Telemetry Points	2.4-25
2-101	Electrical Power Subsystem - Functional Flow Diagram	2.5-3
2-102	Descent Power Distribution - Functional Block Diagram	2.5-5
2-103	Ascent Power Distribution - Functional Block Diagram	2.5-7
2-104	Battery Status-Monitoring Circuits - Simplified Schematic Diagram	2.5-9
2-105	Battery Voltage-and Current -Monitoring-Circuits- Simplified Schematic Diagram	2.5-11
2-106	Primary Bus Voltage-Monitoring Circuits - Simplified Schematic Diagram ..	2.5-13
2-107	Malfunctioning-Battery Isolation Circuitry - Simplified Schematic Diagram ..	2.5-14
2-108	Relay Function Box - Functional Block Diagram	2.5-16
2-109	CSM/LM Primary Power Transfer Logic - Simplified Schematic Diagram ..	2.5-18
2-110	Deadface Relay and Staging Logic - Simplified Schematic Diagram	2.5-19
2-111	Descent Stage Electrical Control Assembly - Simplified Schematic Diagram ..	2.5-22
2-112	Ascent Stage Electrical Control Assembly - Simplified Schematic Diagram ..	2.5-23
2-113	Inverter No. 1 - Block Diagram	2.5-25
2-114	Sensor Power Fuse Assemblies - Simplified Power Distribution Diagram ..	2.5-27
2-115	Environmental Control Subsystem - Component Locations (3 Sheets)	2.6-2
2-116	Environmental Control Subsystem - Aft Bulkhead Control	2.6-5
2-117	Environmental Control Subsystem Functional Flow Diagram	2.6-7
2-118	Environmental Control Subsystem Electrical Schematic	2.6-11
2-119	Atmosphere Revitalization Section Functional Flow Diagram	2.6-13
2-120	Oxygen Supply and Cabin Pressure Control Section Functional Diagram	2.6-14
2-121	Water Management Section Functional Flow Diagram	2.6-17
2-122	Heat Transport Section Functional Flow Diagram	2.6-19
2-123	Suit Gas Diverter Valve	2.6-24
2-124	Water Separator	2.6-25
2-124A	Suit Isolation Valve	2.6-27
2-124B	Carbon Dioxide Partial Pressure Sensor	2.6-28
2-124C	High-Pressure Oxygen Regulator	2.6-30
2-124D	Overboard Relief Valve	2.6-31
2-124E	Burst Diaphragm Assembly Functional Schematic	2.6-32
2-124F	Oxygen Control Module	2.6-34
2-124G	Oxygen Demand Regulators Functional Schematic	2.6-35
2-125	Cabin Repressurization and Emergency Oxygen Valve Functional Diagram ..	2.6-36
2-126	Cabin Relief and Dump Valve Functional Schematic	2.6-37
2-127	Water Control Module	2.6-40
2-128	Water Tank Selector Valve	2.6-41
2-129	Water Pressure Regulator	2.6-42
2-130	Cabin Temperature Control Valve	2.6-44
2-131	Communications Subsystem - Simplified Block Diagram	2.7-2
2-132	In-Flight Communications	2.7-4
2-133	S-Band Transmitter Receiver - Block Diagram	2.7-12
2-134	S-Band Transmitter - Block Diagram	2.7-14
2-135	S-Band Receiver - Block Diagram	2.7-15
2-136	S-Band Power Amplifier - Block Diagram	2.7-16
2-137	VHF Transmitter-Receiver Assembly - Block Diagram	2.7-18
2-138	VHF Transmitter - Block Diagram	2.7-19
2-139	VHF Receiver - Block Diagram	2.7-21
2-140	Signal-Processing Assembly - Block Diagram	2.7-23

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK

LIST OF ILLUSTRATIONS (cont)

Figure No.		Page
2-141	Premodulation Processor - Block Diagram	2.7-25
2-142	Audio Center No. 1 - Block Diagram	2.7-28
2-143	Communication Subsystem - Antenna Location	2.7-29
2-144	S-Band Steerable Antenna - Block Diagram	2.7-31
2-145	Communication Subsystem - Electrical Power Distribution	2.7-32
2-146	S-Band Steerable Antenna Gimbaling	2.7-37
2-147	Explosive Devices Subsystem - Overall Block Diagram	2.8-2
2-148	Explosive Devices - Component Location	2.8-3
2-149	Stage Sequence (Relays K2 through K6) Monitoring - Simplified Schematic Diagram	2.8-5
2-150	Bus - Arming Control - Simplified Schematic Diagram	2.8-8
2-151	Explosive Devices	2.8-10
2-152	Landing Gear Deployment - Simplified Schematic Diagram	2.8-12
2-153	Landing Gear Switches - Simplified Schematic Diagram	2.8-13
2-154	Descent Propellant Tank Prepressurization - Simplified Schematic Diagram	2.8-14
2-155	Stage Sequence - Simplified Schematic Diagram	2.8-16
2-156	Electrical Circuit Interrupter - Functional Block Diagram	2.8-18
2-157	Ascent Propellant Tank Pressurization - Simplified Schematic Diagram	2.8-19
2-158	Instrumentation Subsystem - Overall Functional Block Diagram	2.9-3
2-159	Data Format No. 1 (Normal Mode)	2.9-31
2-160	Data Format No. 2 (Reduced Mode)	2.9-32
2-161	Typical Analog Multiplexer Card - Simplified Logic Diagram	2.9-33
2-162	High-Level Analog Multiplexer Card - Simplified Logic Diagram	2.9-35
2-163	High-Speed Gates - Logic Diagram	2.9-36
2-164	Analog-to-Digital Converter (Coder) - Simplified Logic Diagram	2.9-37
2-165	Programmer - Block Diagram (51.2 Kilobits/Sec, Normal Mode; 1.6 Kilobits/Sec, Reduced Mode	2.9-40
2-166	Digital Multiplexer - Logic Diagram	2.9-41
2-167	Output Register	2.9-52
2-168	Caution and Warning Electronics Assembly - Functional Block Diagram	2.9-55
2-169	Caution and Warning Electronics Assembly Logic Detection Circuits (2 Sheets)	2.9-72
2-170	Data Storage Electronics Assembly - Functional Block Diagram	2.9-79
2-171	Development Flight Instrumentation - Overall Functional Block Diagram	2.9-81
2-172	Lighting Control Equipment	2.10-3
2-173	Exterior Lighting	2.10-7
2-174	Exterior Lighting - Simplified Block Diagram	2.10-8
2-175	Integral Lighting - Simplified Diagram	2.10-11
2-176	Numeric Lighting - Simplified Diagram	2.10-12
2-177	Annunciator/Component Lighting - Simplified Diagram	2.10-13
2-178	Floodlighting - Simplified Diagram	2.10-14
2-179	Lamp Tone Test - Simplified Diagram	2.10-16
2-180	Extravehicular Mobility Unit	2.11-3
2-181	Extravehicular Mobility Unit With OPS	2.11-4
2-182	Pressure Garment Assembly and PLSS Donning Rig	2.11-5
2-183	Extravehicular Visor Assembly	2.11-7
2-184	Portable Life Support System - Environmental Control Subsystem Interface	2.11-8
2-185	PLSS Controls	2.11-9
2-186	Waste Management System	2.11-15
2-187	Restraint Equipment	2.11-17
2-188	Crewman Optical Alignment Sight	2.11-18
2-189	COAS Schematic and Docking Target	2.11-20
2-190	Tool B	2.11-21
2-191	Stowage Locations (2 Sheets)	2.11-22

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK

LIST OF TABLES

Table No.		Page
2-1	Inertial Subsection - Modes of Operation	2.2-32
2-2	DSKY Verb List	2.2-53
2-3	DSKY Noun List	2.2-58
2-4	Checklist Reference Codes Used With Verb 50 Noun 25	2.2-70
2-5	DSKY Option Codes (V50 NO6)	2.2-71
2-6	DSKY Alarm Codes	2.2-71
2-7	Star Codes	2.2-74
2-8	LGC Programs	2.2-77
2-9	Primary Guidance and Navigation Section Routines	2.2-79
2-10	Abort Guidance Section - Input Signal Characteristics	2.2-84
2-11	Abort Guidance Section - Output Signal Characteristics	2.2-86
2-12	Data Entry and Display Assembly - Inputs	2.2-92
2-13	Data Entry and Display Assembly - Accessible Data	2.2-98
2-14	Downlink Data Update Sequence	2.2-113
2-15	Abort Guidance Section - Guidance Routines	2.2-115
2-16	Frequency Synthesizer - Output Frequencies	2.2-124
2-17	Control Electronics Section - Summary of Modes of Attitude Control	2.2-171
2-18	Guidance, Navigation, and Control Subsystem - Failure Modes	2.2-180
2-19	Primary Guidance and Navigation Section - Performance and Design Data ..	2.2-185
2-20	Abort Guidance Section - Performance and Design Data	2.2-185
2-21	Rendezvous Radar - Performance and Design Data	2.2-186
2-22	Landing Radar - Performance and Design Data	2.2-187
2-23	Control Electronics Section - Performance and Design Data	2.2-188
2-24	LM Mission Programmer - Performance and Design Data	2.2-190
2-25	Orbital Rate Display - Earth and Lunar - Performance and Design Data ..	2.2-190
2-26	Guidance, Navigation, and Control Subsystem - Telemetry Measure- ments	2.2-194
2-27	Descent Propulsion Section - Failure Modes	2.3-28
2-28	Descent Propulsion Section - Performance and Design Data	2.3-29
2-29	Descent Propulsion Section - Telemetry Measurements	2.3-31
2-30	Ascent Propulsion Section - Failure Modes	2.3-47
2-31	Ascent Propulsion Section - Performance and Design Data	2.3-47
2-32	Ascent Propulsion Section - Telemetry Measurements	2.3-50
2-33	Reaction Control Subsystem - Failure Modes	2.4-19
2-34	Reaction Control Subsystem - Performance and Design Data	2.4-21
2-35	Reaction Control Subsystem - Telemetry Measurements	2.4-27
2-36	Circuit Breaker Characteristics	2.5-26
2-37	Sensor Power Fuses - Characteristics	2.5-27
2-38	Electrical Power Subsystem - Failure Modes	2.5-30
2-39	Electrical Power Subsystem - Performance and Design Data	2.5-32
2-40	Electrical Power Subsystem - Telemetry Measurements	2.5-34
2-41	Environmental Control Subsystem - Failure Modes	2.6-46
2-42	Environmental Control Subsystem - Performance and Design Data	2.6-49
2-43	Deleted	
2-44	Deleted	
2-45	Deleted	
2-46	Deleted	
2-47	Environmental Control Subsystem - Telemetry Measurements	2.6-56
2-48	Communications Links	2.7-3
2-49	Communications Subsystem - General Switch and Circuit Breaker Configuration	2.7-6
2-50	Communications Subsystem - Equipment Groups	2.7-11
2-51	Communications Subsystem - Failure Modes	2.7-33
2-52	Communications Subsystem - Performance and Design Data	2.7-35
2-53	Communications Subsystem - Telemetry Measurements	2.7-38

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK

LIST OF TABLES (cont)

Table No.		Page
2-54	Explosive Devices Subsystem - Failure Modes	2.8-21
2-55	Explosive Devices Subsystem - Performance and Design Data	2.8-22
2-56	Explosive Devices Subsystem - Telemetry Measurements	2.8-24
2-57	ERA-1 Conditioned and Preconditioned Interfacing Signals	2.9-6
2-58	ERA-2 Conditioned and Preconditioned Interfacing Signals	2.9-17
2-59	Word and Channel Assignments - Normal Format (51.2 Kilobits Per Second)	2.9-42
2-60	Word and Channel Assignments - Reduced Format (1.6 Kilobits Per Second)	2.9-49
2-61	Caution and Warning Electronics Assembly - Malfunction Detection	2.9-57
2-62	Instrumentation Subsystem - Failure Modes	2.9-87
2-63	Instrumentation Subsystem - Performance and Design Data	2.9-87
2-64	Developmental Flight Instrumentation - Telemetry Measurements	2.9-94
2-65	Exterior Lights - Color, Brightness, and Lighting Method	2.9-95
2-66	Interior Lights - Color, Brightness, and Lighting Method	2.10-9
2-67	Heater Section - Failure Modes	2.10-17
2-68	Lighting Section - Failure Modes	2.10-17
2-69	Heater Section - Performance and Design Data	2.10-18
2-70	Exterior Lights - Performance and Design Data	2.10-18
2-71	Interior Lights - Performance and Design Data	2.10-19
2-72	Heating and Lighting Sections - Telemetry Measurements	2.10-20

SECTION 1
SPACECRAFT

INTRODUCTION

This section contains information relating to Lunar Module 3 (LM 3). The information includes descriptions of the ascent and descent stages, LM - SLA - S - IVB connections, LM-CSM interfaces, and LM stowage provisions. The Apollo-Saturn space vehicle configuration is shown in figure 1-1.

1.1 LM 3 CONFIGURATION. (See figure 1-2.)

LM 3 is designed for an earth-orbital mission. It consists of an ascent stage and a descent stage; the stages are joined together at four interstage fittings by explosive nuts and bolts. Subsystem continuity between the stages is accomplished by separable interstage umbilicals and hardline connections.

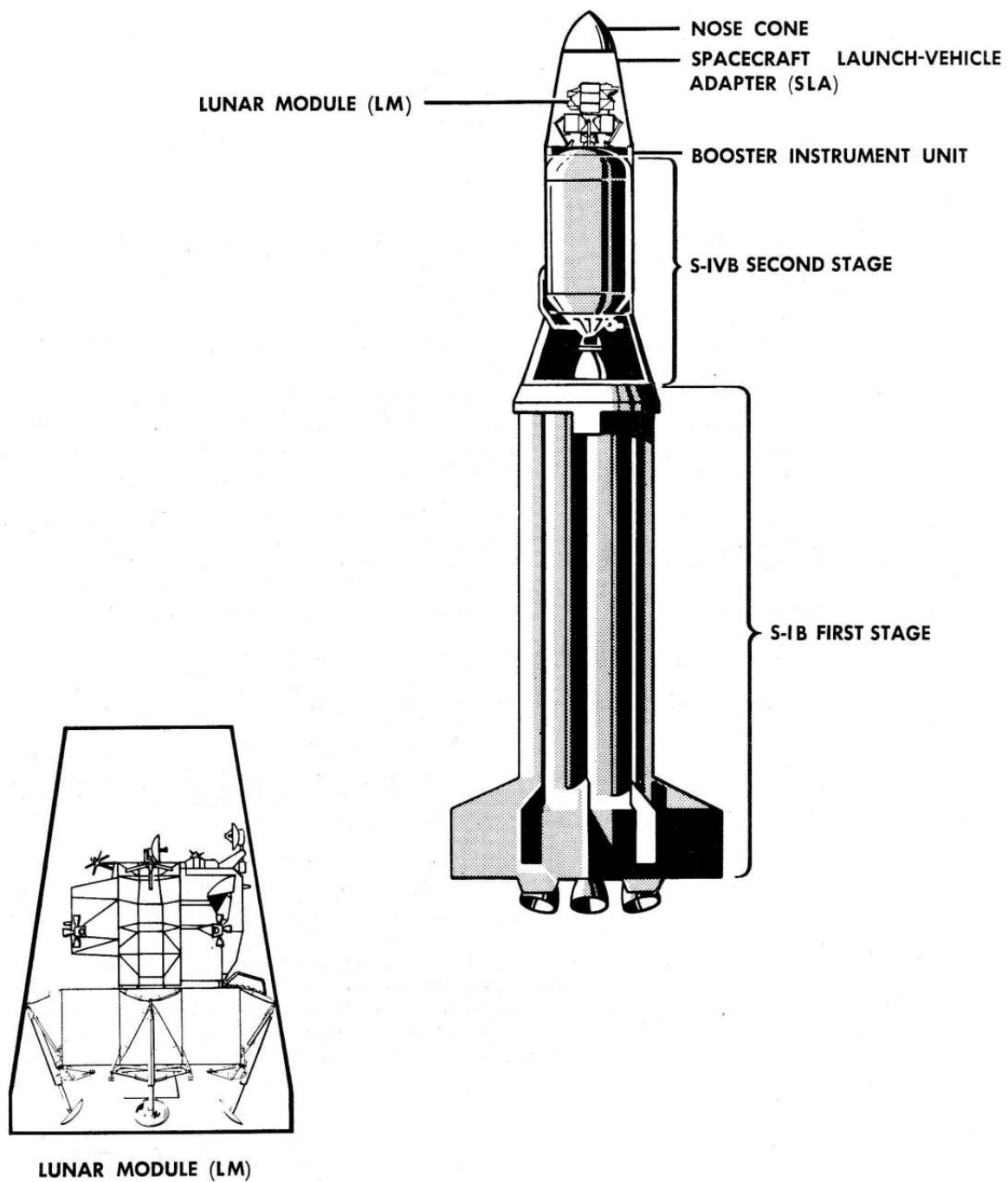
Both stages function as a single unit during earth orbit, until separation is required during the mission. Stage separation is accomplished by explosively severing the four interstage nuts and bolts, interstage umbilicals, and water lines. All other hardlines are disconnected automatically at stage separation. The ascent stage can function as a single unit to accomplish rendezvous and docking with the CSM.

The overall dimensions of LM 3 are shown in figure 1-3.

Station reference measurements (figure 1-4) are established as follows:

- The Z- and Y-axis station reference measurements (inches) start at a point where both axes intersect the X-axis at the centerline: the Z-axis extends forward and aft of the intersection; Y-axis, left and right. The point of intersection is established as zero.
- The +Y-axis measurements increase to the right from zero; the -Y-axis measurements increase to the left. Similarly, the +Z- and -Z-axis measurements increase forward (+Z) and aft (-Z) from zero.
- The X-axis station reference measurements (inches) start at a design reference point identified as station +X200.000. This reference point is approximately 70 inches below the bottom surface of the footpads (with the landing gear extended); therefore, all X-axis station reference measurements are +X- measurements.

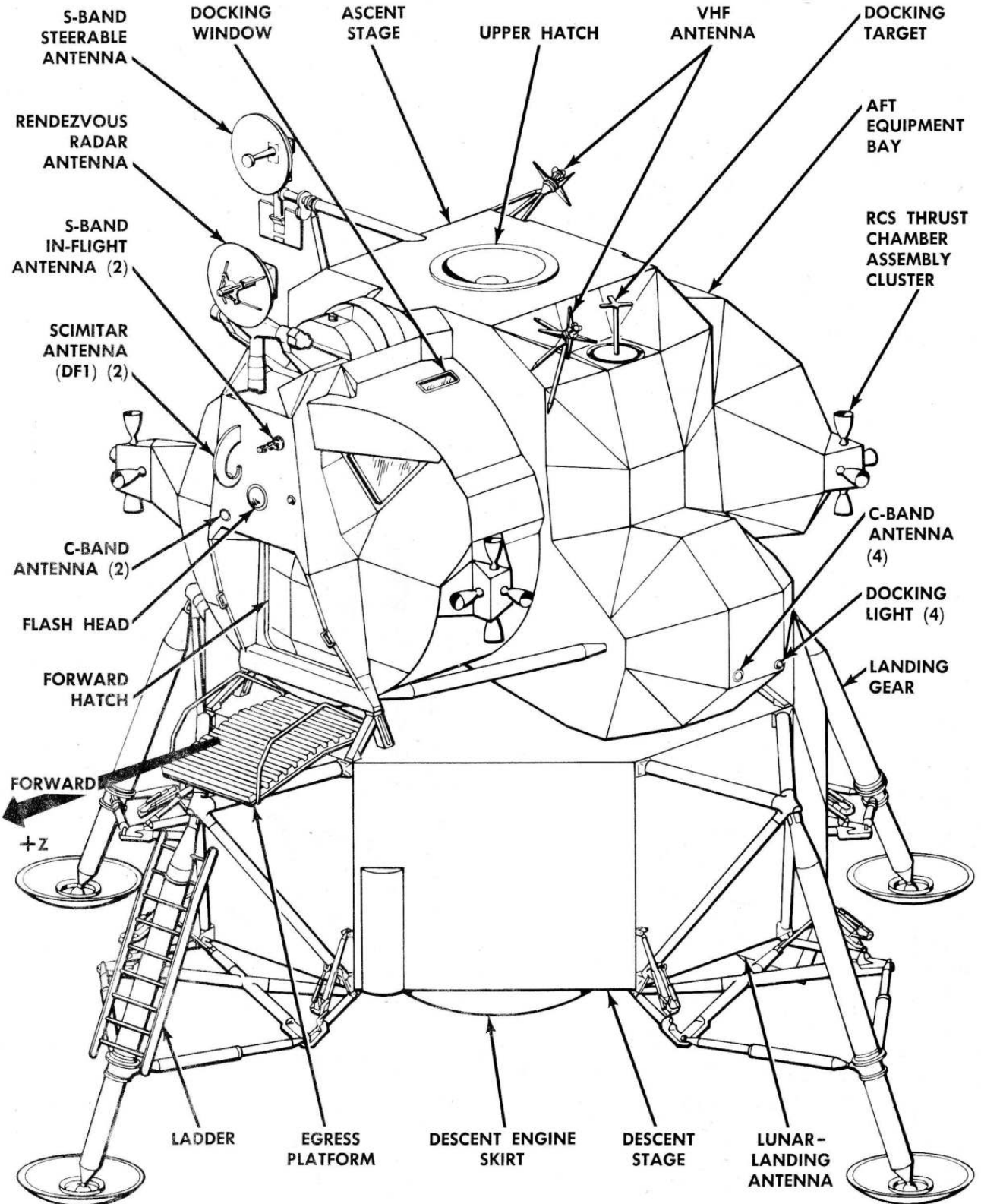
LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SPACECRAFT



300LM3-82

Figure 1-1. Apollo-Saturn Space Vehicle

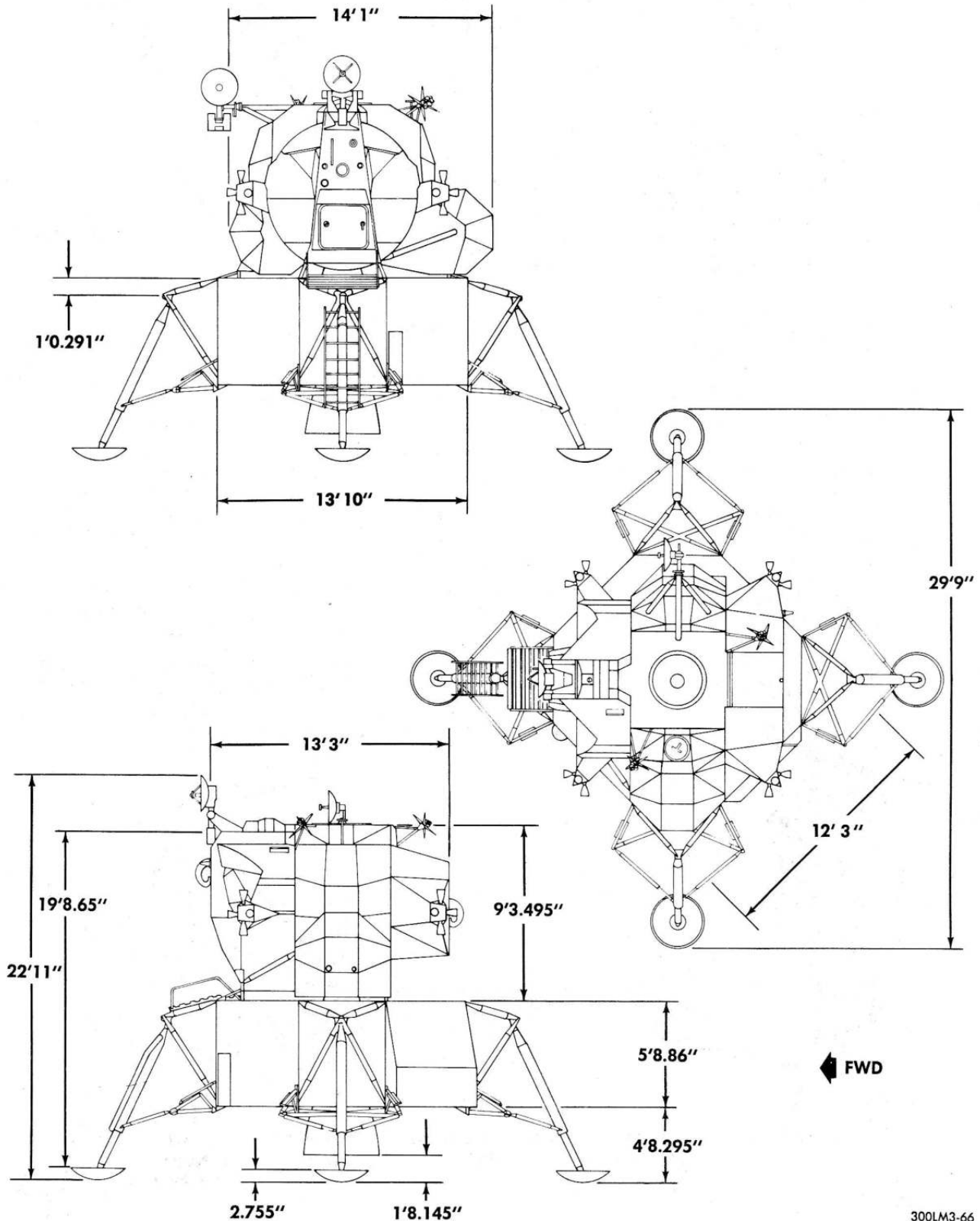
LMA790-3-LM 3
 APOLLO OPERATIONS HANDBOOK
 SPACECRAFT



300LM3-103

Figure 1-2. LM 3 Configuration

LMA790-3-LM 3
 APOLLO OPERATIONS HANDBOOK
 SPACECRAFT



300LM3-66

Figure 1-3. LM 3 Overall Dimensions

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SPACECRAFT

Note:
X-axis design reference
points start at + 200.000.

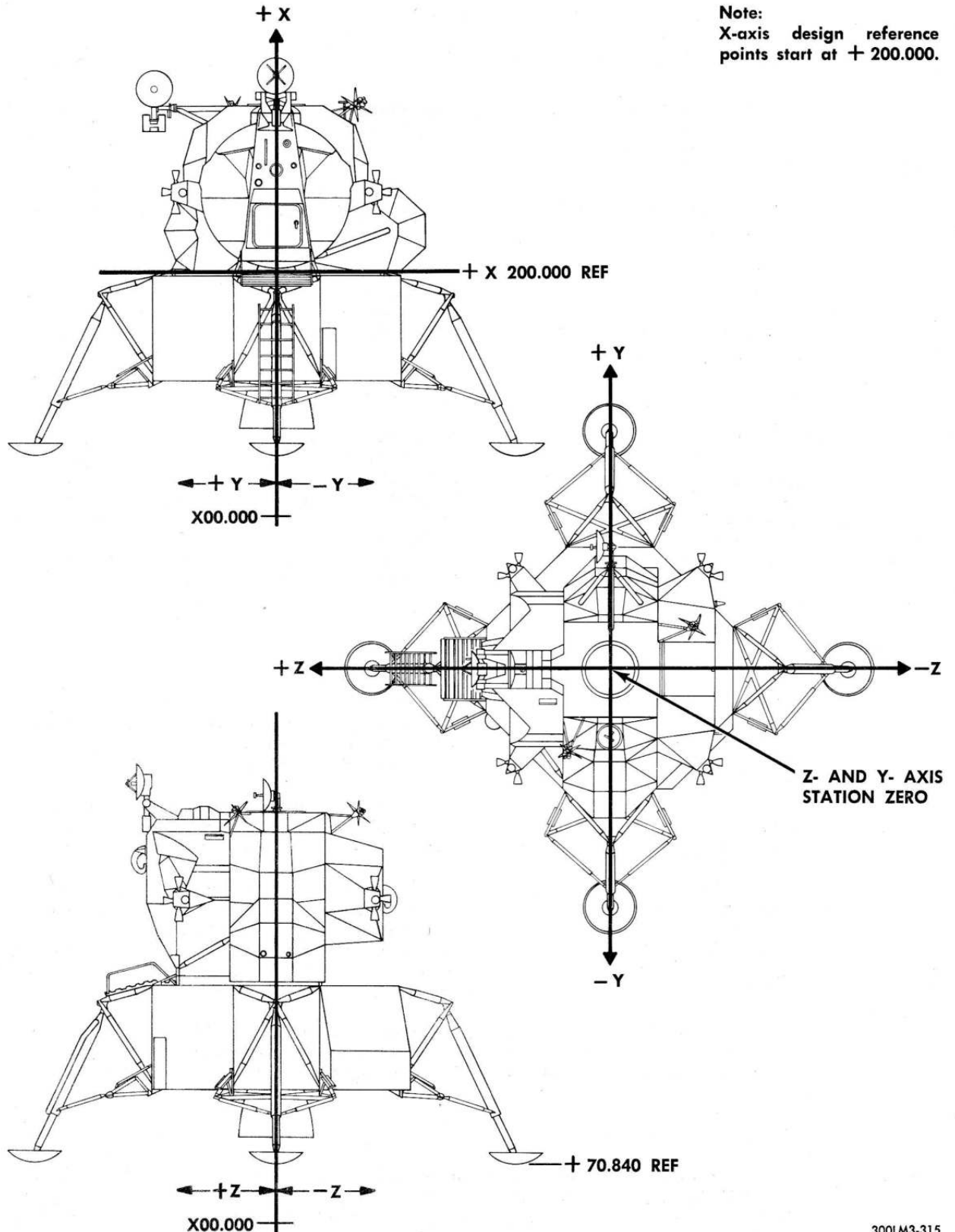


Figure 1-4. Station Reference Measurements

300LM3-315

LM 3 CONFIGURATION

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SPACECRAFT

1.2 ASCENT STAGE.

1.2.1 GENERAL DESCRIPTION.

The ascent stage, the manned portion and control center of the LM, accommodates two astronauts. It comprises three main sections: the crew compartment, midsection, and aft equipment bay.

The crew compartment and midsection make up the cabin, which has an approximate overall volume of 235 cubic feet. The cabin is climatic controlled, and pressurized to 4.8 ± 0.2 psig. Areas other than the cabin are unpressurized.

1.2.2 STRUCTURE. (See figure 1-5.)

The ascent stage has six structural areas: crew compartment, midsection, aft equipment bay, thrust chamber assembly (TCA) cluster supports, antenna supports, and thermal and micrometeoroid shield.

1.2.2.1 Crew Compartment. (See figures 1-5 and 1-6.)

The crew compartment is the frontal area of the ascent stage; it is 92 inches in diameter and 42 inches deep. This is the flight station area; it has control and display panels, armrests, body restraints, landing aids, two front windows, a docking window, and an alignment optical telescope. Flight station centerlines are 44 inches apart; each astronaut has a set of controllers and armrests. A design reference point (design eye) orients flight station geometry for the required balance between external visibility and visual and physical access to controls and displays. The main control and display panels are canted and centered between the astronauts to permit sharing and easy scanning.

The optical alignment station, between the flight stations, is used in conjunction with the alignment optical telescope (AOT).

The portable life support system (PLSS) donning station is also in the center aisle, slightly aft of the optical alignment station. A removable, height-adjusting PLSS supporting harness permits donning and doffing the PLSS. The PLSS is completely accessible from the crew compartment for recharging with water and oxygen.

The crew compartment shell is cylindrical and of semimonocoque construction. It is a fusion-welded and mechanically fastened assembly of aluminum-alloy sheet and machined longerons. The shell has an opening for the docking window.

The front face assembly of the crew compartment has openings for two triangular windows and the forward hatch. Two large structural beams extend up the forward side of the front face assembly; they support the structural loads applied to the cabin structure. The lower ends of the beams support the two forward interstage mounts; the upper ends are secured to additional beam structure that extends across the top of the crew compartment shell and aft to the midsection structure.

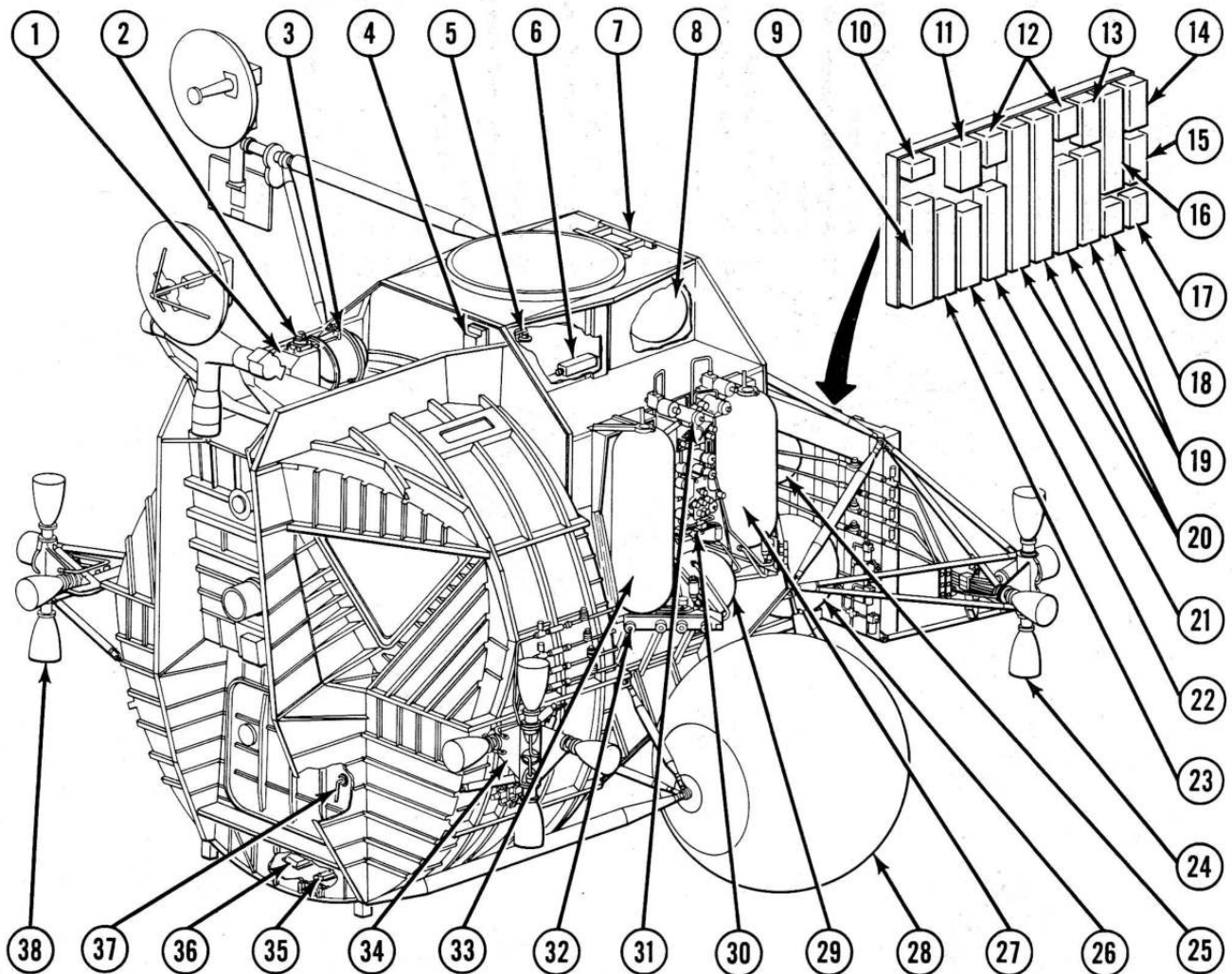
The crew compartment deck measures approximately 36 by 55 inches. It is constructed of aluminum honeycomb bonded to two sheets of aluminum alloy. Handgrips, recessed in the deck, aid the astronauts during egress and ingress through the forward hatch.

1.2.2.1.1 Control and Display Panels.

The crew compartment has 12 control and display panels: two main display panels (1 and 2) that are canted forward 10° , two center panels (3 and 4) that slope down and aft 45° towards the horizontal, two bottom side panels (5 and 6), two lower panels (8 and 12), two center side panels (10 and 14), and two upper side panels (11 and 16).

ASCENT STAGE

LMA790-3-LM 3
 APOLLO OPERATIONS HANDBOOK
 SPACECRAFT



KEY

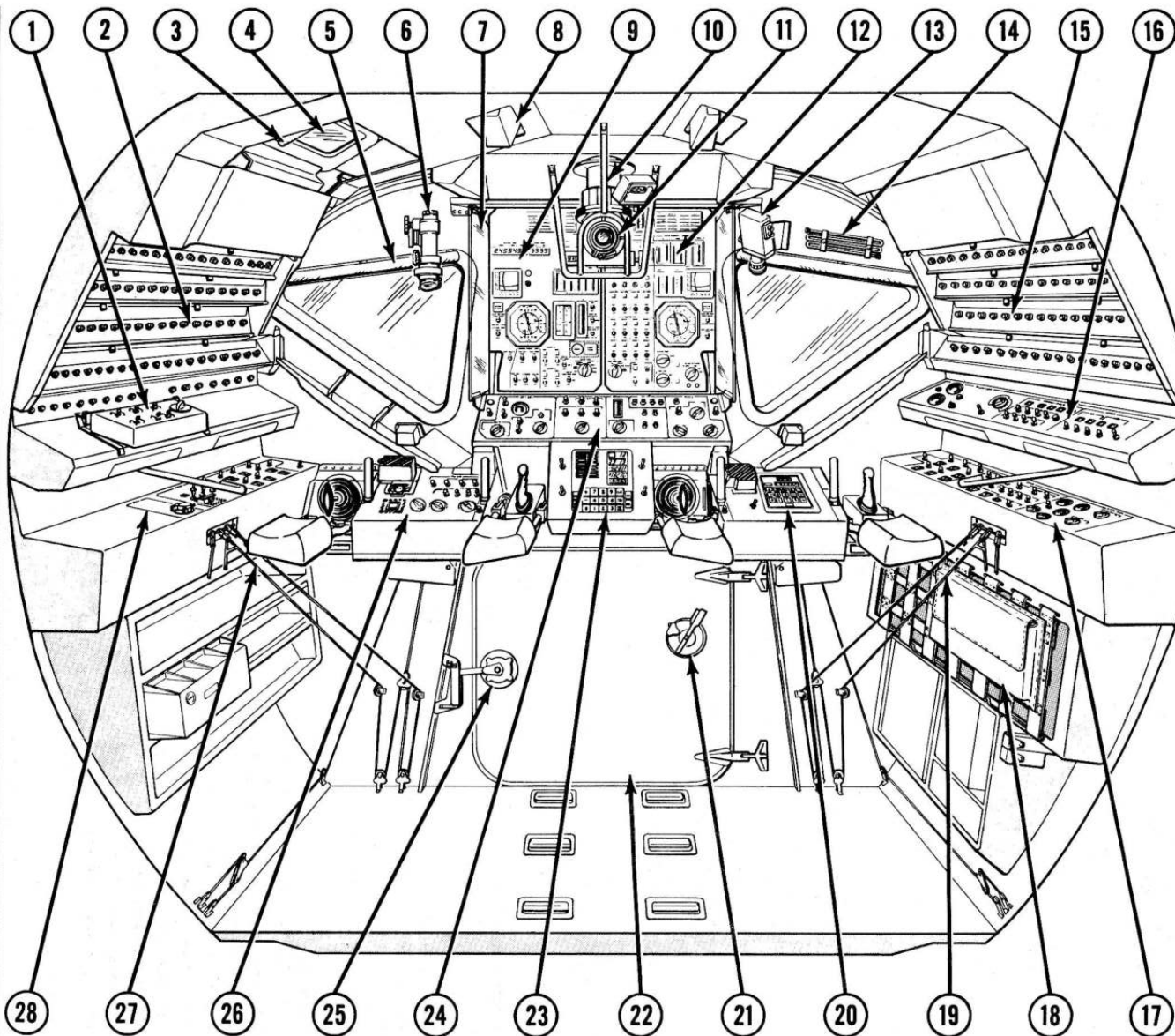
- | | |
|--|---|
| 1. Abort sensor assembly | 21. Signal-conditioning and electronic replaceable assembly No. 2 |
| 2. Alignment optical telescope | 22. Pulse-code-modulation and timing equipment assembly |
| 3. Inertial measurement unit | 23. Signal-conditioning and electronic replaceable assembly No. 1 |
| 4. Pulse torque assembly | 24. RCS quadrant II |
| 5. Cabin dump and relief valve (upper hatch) | 25. Gaseous oxygen tank |
| 6. CSM/LM electrical umbilical fairing | 26. Helium tank |
| 7. Aft equipment bay bulkhead | 27. RCS fuel tank |
| 8. Water tank | 28. APS fuel tank |
| 9. Rendezvous radar electronics assembly | 29. RCS helium tank |
| 10. Propellant quantity gaging system control unit | 30. RCS tank module |
| 11. Caution and warning electronics assembly | 31. Helium pressurization module |
| 12. Electrical control assembly | 32. Oxidizer service panel |
| 13. Attitude and translation control assembly | 33. RCS oxidizer tank |
| 14. S-band power amplifier and diplexer | 34. RCS quadrant I |
| 15. S-band transceiver | 35. Lighting control assembly |
| 16. Abort electronic assembly | 36. Auxiliary switching relay box |
| 17. Signal processor assembly | 37. Cabin dump and relief valve (forward hatch) |
| 18. VHF transceiver and diplexer | 38. RCS quadrant IV |
| 19. Inverter | |
| 20. Batteries | |

300LM3-206-1

Figure 1-5. Ascent Stage Configuration (Sheet 1 of 3)

ASCENT STAGE

ASCENT STAGE



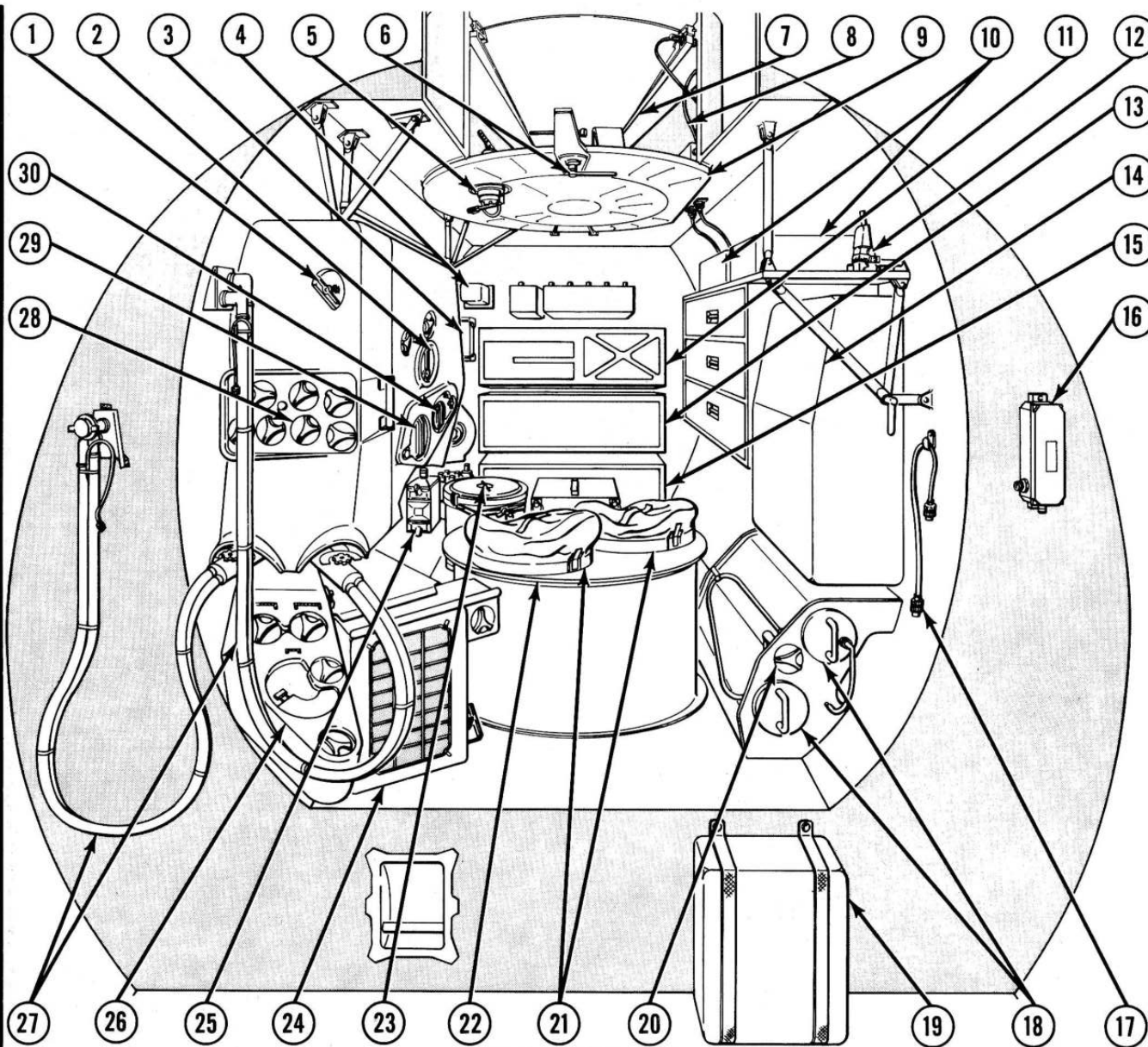
KEY

1. ORDEAL panel
2. Panel 11
3. Docking window shade
4. Docking window
5. Window shade
6. Crewman optical alignment scope
7. Glareshields
8. Main panel/cabin floodlight
9. Panel 1
10. Alignment optical telescope guard
11. Alignment optical telescope
12. Panel 2
13. Sequence camera
14. Power cable (sequence camera)
15. Panel 16
16. Panel 14
17. Panel 12
18. Stowage pocket
19. Systems Engineer's restraint (stowed)
20. Panel 6
21. Cabin relief and dump valve
22. Forward hatch
23. Panel 4
24. Panel 3
25. Forward hatch handle
26. Panel 5
27. Commander's restraint (stowed)
28. Panel 8

VIEW LOOKING FORWARD

Figure 1-5. Ascent Stage Configuration (Sheet 2 of 3)

ASCENT STAGE



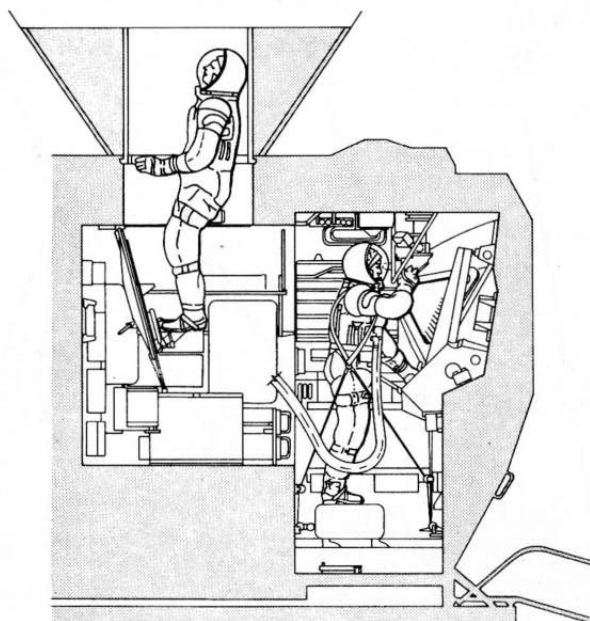
VIEW LOOKING AFT

Figure 1-5. Ascent Stage Configuration (Sheet 3 of 3)

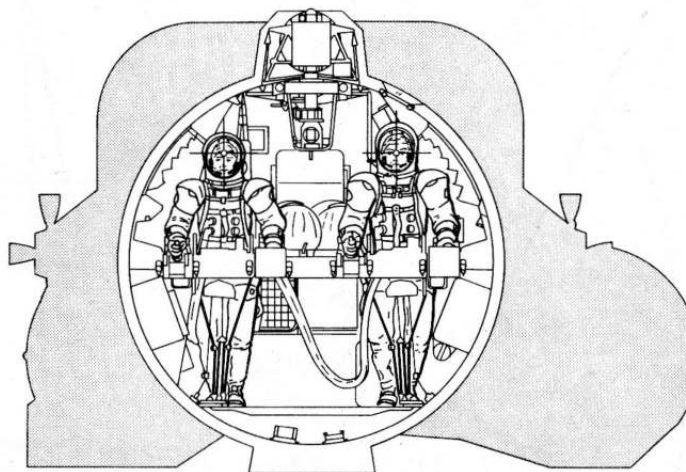
KEY

1. Suit gas diverter
2. Suit circuit and canister controls
3. Cabin pressure switch
4. ECS relay box
5. Cabin relief and dump valve
6. Upper hatch handle
7. Drogue
8. Electrical umbilicals
9. Upper hatch
10. Food storage container
11. LM guidance computer
12. Water dispenser (probe)
13. Coupling data unit
14. Portable life support system
15. Power servo assembly
16. Data storage electronics assembly
17. Oxygen hose
18. LiOH cartridge assembly
19. Alignment optical telescope mount platform
20. Waste management
21. Helmet storage bags
22. Ascent stage engine cover
23. ECS LiOH cartridge stowage
24. Cabin recirculation assembly
25. Water solenoid valve assembly
26. Water control module
27. Oxygen umbilical hoses
28. Oxygen control module
29. ECS LiOH cartridge
30. PLSS LiOH cartridge

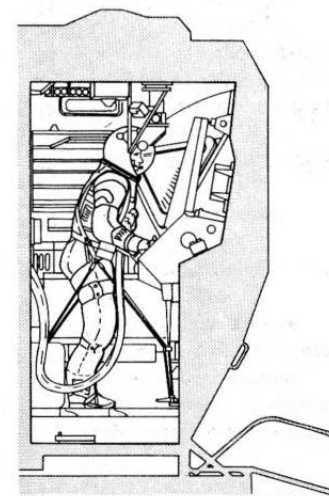
300LM3-207



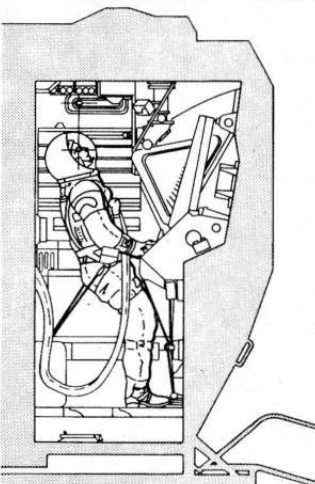
ASTRONAUT EGRESS THROUGH UPPER HATCH, AND
 ASTRONAUT USING ALIGNMENT OPTICAL TELESCOPE



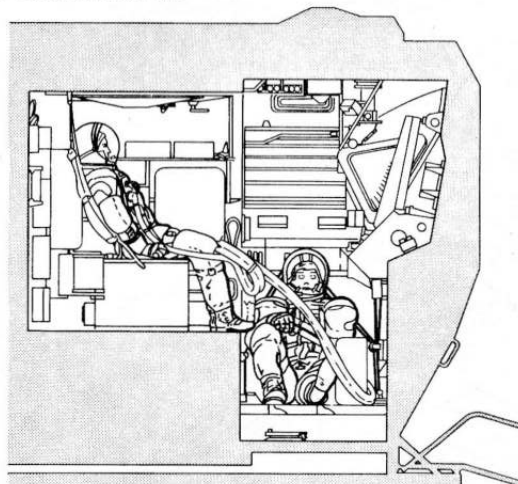
ASTRONAUT FLIGHT STATIONS



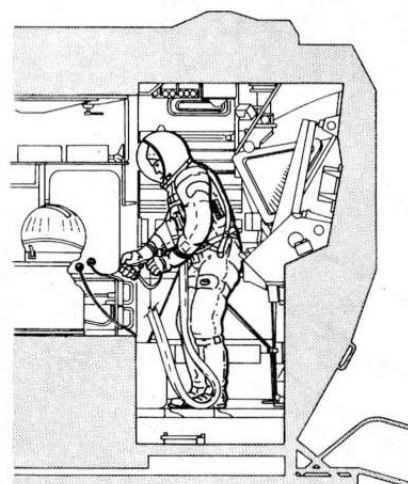
ASTRONAUT FLIGHT STATION



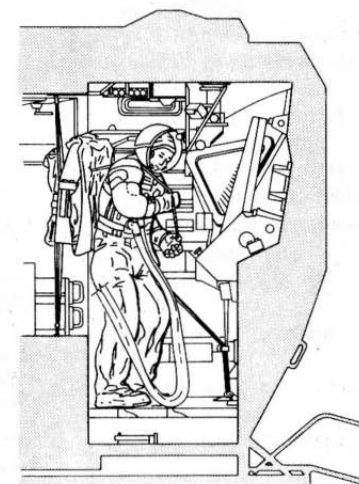
ASTRONAUT LOOKING
 THROUGH DOCKING WINDOW



ASTRONAUT REST POSITIONS



ASTRONAUT PLSS
 RECHARGE STATION



ASTRONAUT DONNING STATION

Figure 1-6. Flight Stations

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SPACECRAFT

Panels 1 and 2 are constructed of two 0.015 aluminum-alloy face sheets, spaced 2 inches apart; they are reinforced and spaced by formed 0.015 channels. This forms a rigid box-like construction with a favorable strength-to-weight ratio and a relatively high natural frequency. Four shock mounts support each panel on the structure. Panel instruments are bezel mounted to the back surface of the bottom sheet of the panel. The instruments are cushioned where they protrude through the top sheet of the panel, to damp vibrations. All dial faces are flush with the forward face of the panel. Panels 1, 2, 3, and 4 are within easy reach and scan of both astronauts.

Panels 5 and 6 are in front of the astronauts, at waist height. Panel 5 contains lighting and mission timer controls, engine start and stop pushbuttons, and x-translation pushbutton. Panel 6 contains abort guidance controls.

Panel 8 is at the left of the commander. The panel is canted up 15° from the horizontal; it contains controls and displays for explosive devices, audio controls, and the TV camera connection.

Panel 11, directly above panel 8, has five angled surfaces that contain circuit breakers. Each row of circuit breakers is canted 15° to the line of sight so that the white band on the circuit breakers can be seen when they open.

Panel 12 is at the right of the LM Pilot. The panel is canted up 15° from the horizontal; it contains audio, communications, and communications antennas controls and displays.

Panel 14, directly above panel 12, is canted up 36.5° from the horizontal. It contains controls and displays for electrical power distribution and monitoring.

Panel 16, directly above panel 14, has four angled surfaces that contain circuit breakers. Each row of circuit breakers is canted 15° to the line of sight so that the white band on the circuit breakers can be seen when they open.

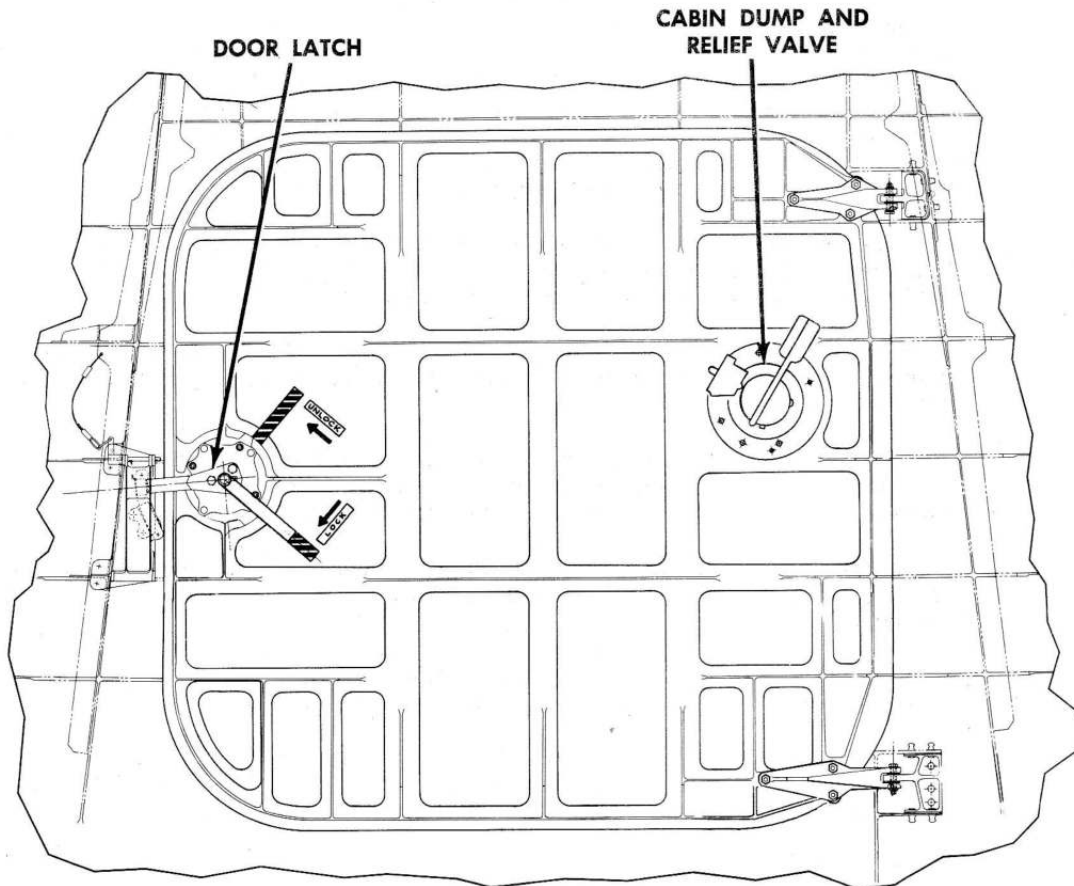
1.2.2.1.2 Forward Hatch. (See figure 1-7.)

The forward hatch is in the front face assembly, just below the lower display panels. Handgrips are on the exterior of the hatch. The hatch is approximately 32 inches square; it is hinged to swing inboard when opened. A cam latch assembly holds the hatch in the closed position; the assembly forces a lip, around the outer circumference of the hatch, into a preloaded elastomeric silicone compound seal that is secured to the LM structure. Cabin pressurization forces the hatch lip further into the seal, ensuring a pressure-tight contact. A handle is provided on both sides of the hatch, for latch operation. To open the hatch, the cabin must be completely depressurized by opening the cabin relief and dump valve on the hatch. When the cabin is completely depressurized, the hatch can be opened by rotating the latch handle. The cabin relief and dump valve can also be operated from outside the LM.

1.2.2.1.3 Windows. (See figures 1-8 and 1-9.)

Two triangular windows in the front face assembly provide visibility during descent, ascent, and rendezvous and docking phases of the mission. Both windows have approximately 2 square feet of viewing area; they are canted down to the side to permit adequate peripheral and downward visibility. A third (docking) window (figure 1-9) is in the curved overhead portion of the crew compartment shell, directly above the Commander's flight station. This window provides visibility for docking maneuvers. All three windows consist of two separated panes, vented to space environment. The outer pane is made of Vycor glass, with antireflective and thermal (multilayer blue-red) coatings. The inner pane is made of structural glass. It is sealed with a dual Racor seal and bolted to the window frame through an edge member bonded to the pane. The inner pane has antireflective, thermal (multilayer blue-red), and defogging coatings.

ASCENT STAGE



300LM3-239

Figure 1-7. Forward Hatch

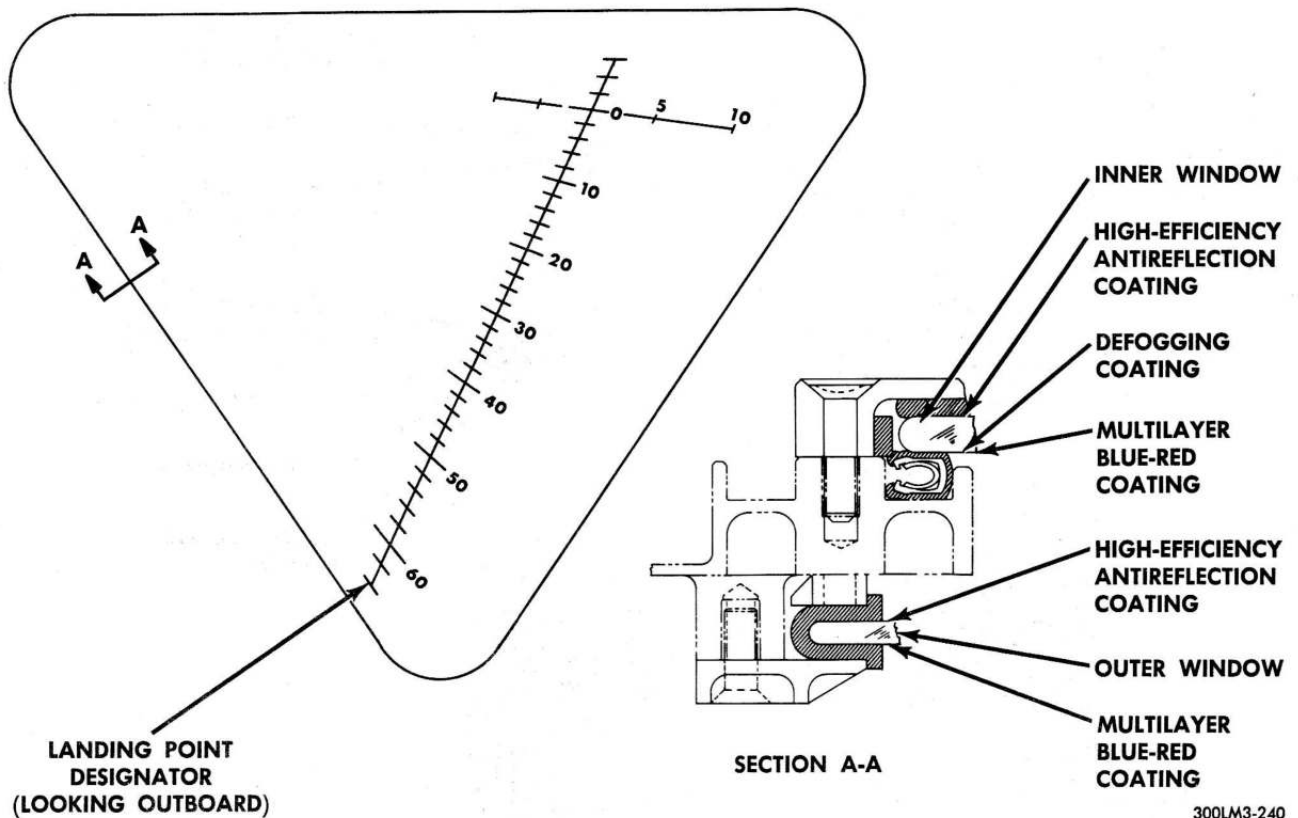
1.2.2.2 Midsection. (See figure 1-5.)

The midsection structure is a ring-stiffened semimonocoque shell. The bulkheads consist of aluminum-alloy, chemically milled skin with fusion-welded longerons and machined stiffeners. The midsection shell is mechanically fastened to flanges on the major structural bulkheads at stations +Z27.00 and -Z27.00. The crew compartment shell is mechanically secured to an outboard flange of the +Z27.00 bulkhead.

The upper and lower decks, at stations +X294.643 and +X233.500, respectively, are made of aluminum-alloy, integrally stiffened and machined. The lower deck provides structural support for the ascent stage engine. The upper deck provides structural support for the docking tunnel and the upper hatch.

Two main beams running forward and aft, integral with those above the crew compartment, are secured to the upper deck of the midsection; they support the outboard end of the shell. The aft ends of the beams are fastened to the aft bulkhead (-Z27.000); they have provisions for bolting the tubular truss members to both aft interstage fittings.

Ascent stage stress loads applied to the front beam are transmitted through the two beams on the upper deck to the aft bulkhead and through the aft interstage support



300LM3-240

Figure 1-8. Front Window

members to the fittings. The combination of beams, bulkhead, and truss members forms a cradle around the cabin assembly; it takes up all the stress loads applied to the ascent stage.

Two canted beam assemblies, secured to the bottom of the lower deck and to the forward and aft bulkheads, form the ascent stage engine compartment. The engine support ring truss members are bolted to the lower deck.

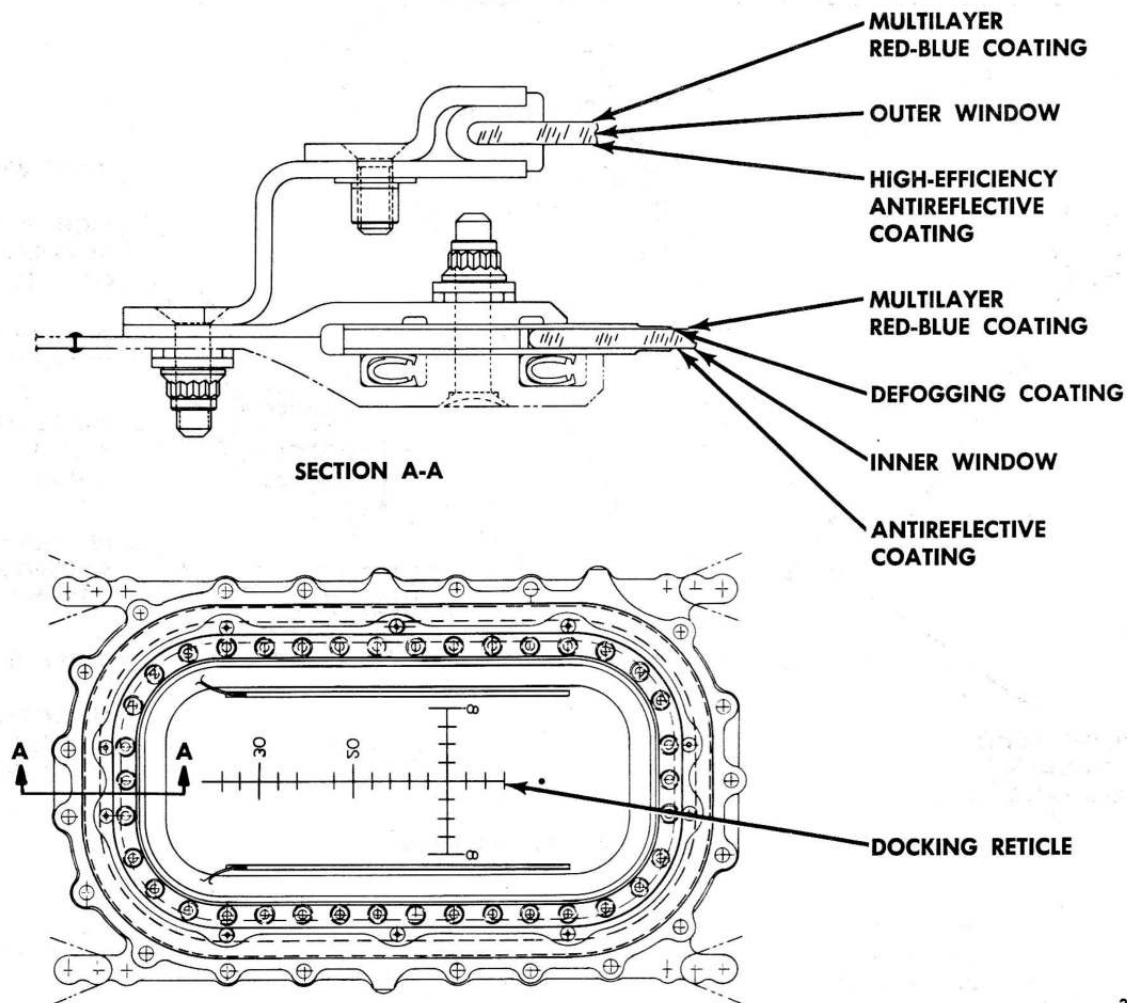
The right side of the midsection contains most of the ECS controls and most of the heat transport section water-glycol plumbing. Valves for operation of the ECS equipment are readily accessible from the crew compartment. The left side of the midsection contains the waste management section. Approximately 9 cubic feet in the lower side consoles is used for stowage of crew provisions.

To minimize cable runs, several electronic units that do not require access by the astronauts are located in the midsection. These units include the LM guidance computer, and the power and servo assembly.

RCS propellant tanks are installed between the midsection bulkheads, on each side, external to the docking tunnel. The ascent engine propellant tanks are mounted in the midsection, beneath the RCS tanks.

A ring at the top of the ascent stage is compatible with the clamping mechanisms in the CSM; it ensures structural continuity for transmitting midcourse correction and orbit-injection loads. This ring is concentric with the X-axis, which is also the nominal centerline of thrust of the ascent and descent engines. The drogue portion of

ASCENT STAGE



300LM3-241

Figure 1-9. Docking Window

the docking mechanism is secured below this ring during the docking operation to mate with the CSM-mounted probe. It is also stored in this area when storage is required out of the crew compartment.

1.2.2.2.1 Docking Tunnel.

The docking tunnel, at the top centerline of the ascent stage, is 32 inches in diameter, and 16 inches long. The lower end of the tunnel is welded to the upper deck structure; the upper end is secured to the shell. The tunnel is used for docking after rendezvous in earth orbit, for transfer of two astronauts to the LM from the CSM after injection into earth orbit, and for transfer to the LM astronauts and equipment to the CSM. This tunnel is compatible with its counterpart in the CSM when in the docked configuration; it allows for transfer of an astronaut, without exposure to space, in a pressurized or unpressurized extravehicular mobility unit (EMU). Environmental Control Subsystem (ECS) equipment is installed on the right side of the tunnel; crew provisions, on its left side.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SPACECRAFT

1. 2. 2. 2 Upper Hatch. (See figure 1-10.)

The upper hatch is directly above the ascent engine cover, on the +X-axis. Provisions for crew transfer through upper hatch are based upon a head-first passage. Handgrips in the aft section of the docking tunnel and three steps in the hatch cover are used for crew and equipment transfer in the docked configuration. The hatch has an off-center latch that can be operated from either side of the hatch. The latch has a common shaft on the +Z-axis, adjacent to the forward edge of the hatch. The hatch is opened from within the cabin by rotating the handle approximately 90° counterclockwise; by turning the handle 90° clockwise, to open the hatch from outside the LM. A maximum torque of 35 inch-pounds is required to disengage the latching mechanism to open the hatch. The hatch is closed by rotating the handle in the opposite direction. The hatch has a preloaded elastomeric silicone compound seal mounted in the ascent stage structure. When the latch is closed, a lip near the outer circumference of the hatch enters the seal, ensuring a pressure-tight contact. Normal cabin pressurization forces the hatch into its seal. To open the hatch, the cabin must be depressurized through the cabin relief and dump valve; the latch is then unfastened.

1. 2. 2. 3 Aft Equipment Bay. (See figure 1-5.)

The aft equipment bay, aft of the -Z27.000 bulkhead, is unpressurized. The main supporting structure of the bay consists of tubular truss members bolted to the aft side of the -Z27.000 bulkhead. The truss members, used in a cantilever type of construction, extend aft to the equipment rack. The equipment rack assembly is constructed of a series of vertical box beams, supported by an upper and lower Z-frame. The beams have integral cold plates that transfer heat from the electronic equipment mounted on the equipment racks. The cold plates are mounted vertically in the structural frame, which is supported at its upper and lower edges by the truss members. A water-glycol solution (coolant) flows through the cold plates.

Two gaseous oxygen tanks and two helium tanks are secured to the truss members and brackets between, and to, the -Z27.000 bulkhead and the equipment rack. Support mountings and brackets are secured to the aft side of the -Z27.000 bulkhead, for valves, plumbing, wiring, ECS components, and propellant tanks that do not require a pressurized environment.

1. 2. 2. 4 TCA Cluster Supports.

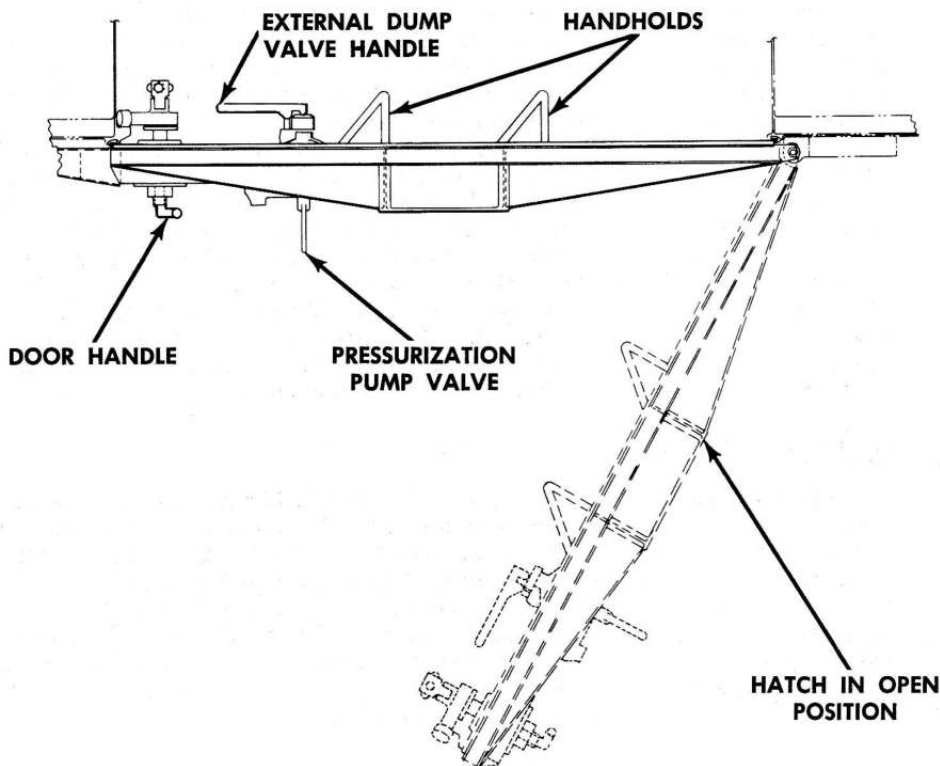
Aluminum-alloy tubular truss members for external mounting of two forward TCA clusters are bolted to both sides of the front face assembly and to the crew compartment shell. Aluminum-alloy tubular truss members for external mounting of two aft TCA clusters are bolted to the upper and lower corners of the equipment rack assembly and to the -Z27.000 bulkhead.

1. 2. 2. 5 Antenna Supports.

The ascent stage provides mounting accommodations for an S-band steerable antenna, two VHF antennas, two S-band in-flight antennas, two C-band antennas, a rendezvous radar antenna, and two scimitar (DFI) antennas.

The S-band steerable antenna has tubular truss members; it is mounted on top of the right side of the midsection. One VHF antenna is mounted on the top right side of the front of +Z27.00 bulkhead; the other one on the left side of the top left side of the -Z27.00 bulkhead. One S-band in-flight antenna is mounted on the front face assembly; the other one, on the aft equipment bay rack. One C-band antenna is mounted on each side of the midsection. The rendezvous radar antenna is mounted on the upper beams of the crew compartment. One scimitar antenna is mounted on the front face assembly; the other one, on the right side of the aft equipment bay rack.

ASCENT STAGE



300LM3-238

Figure 1-10. Upper Hatch

1. 2. 2. 6

Thermal And Micrometeoroid Shield.

The entire ascent stage structure is enveloped with a thermal and micrometeoroid shield, which is a composite of multiple layers of aluminized 0.0005-inch-thick mylar and an outer 0.004-inch-thick sheet (skin) of aluminum. The shield is mounted on low-thermal-conductive supports, which keep it at least 2 inches from the main structure. The aluminum skin acts as a micrometeoroid bumper. The aluminized mylar acts as thermal shielding; it is formed into 25-layer blankets of various sizes and shapes. Where the blankets meet, the mating edges are sealed with mylar tape. Vent holes are provided in the blankets. Tubular frames are installed around the ascent propellant tanks so that mylar blankets can be firmly secured, away from the tanks.

The aluminized mylar blankets insulate the structure against temperatures up to +350° F. On the TCA support truss members, which are subjected to temperatures in excess of +350° F due to engine radiation, an additional 25 layers of H-film are installed. H-film is aluminized polyimide with an insulating capability up to +1,000° F. Additional H-film blankets are also used in other areas of the ascent stage that will be subjected to temperatures in excess of +350° F.

During earth prelaunch activities, various components and areas of the ascent stage must be readily accessible. Access panels in the outer skin and insulation provide this accessibility.

ASCENT STAGE

1.3 DESCENT STAGE.

1.3.1 GENERAL DESCRIPTION

The descent stage is the unmanned portion of the LM. It has equipment for a lunar-landing mission. The descent stage structure provides attachment and support points for securing the LM within the spacecraft launch-vehicle adapter (SLA).

1.3.2 STRUCTURE. (See figure 1-11.)

The descent stage is constructed of aluminum-alloy, chemically milled webs. It consists of two pairs of parallel beams arranged in a cruciform, with a deck on the upper and lower surfaces. The beam webs are at stations +Y27.000, -Y27.000, +Z27.000, and -Z27.000. The lower deck is at station +X131.140; the upper deck, at station +X196.000. The ends of the beams are closed off by end closure bulkheads at stations +Z81.000, -Z81.000, +Y81.000, and -Y81.000. A four-legged truss (outrigger) at the ends of each pair of beams serves as a support for the LM in the SLA and as the attachment point for the main strut of the landing gear. The outriggers are constructed of tubular aluminum alloy. Aluminum-alloy fittings on the +Y27.000 and -Y27.000 beams, at station +Z65.906, serve as the forward attachment points for the ascent stage. Joints are fastened with standard mechanical fasteners.

Compartments formed by the descent stage structural arrangement house equipment required by LM subsystems. The center compartment houses the descent stage engine, which is supported by eight tubular truss members secured to the four corners of the compartment and by the engine gimbal ring. The descent oxidizer tanks are housed between the +Y27.000 and -Y27.000 beams; the descent fuel tanks, between the +Z27.000 and -Z27.000 beams.

The areas, between the main beams, that give the descent stage its octagon shape are referred to as quadrants. Quadrant I is formed by the intersection of the +Z27.000 and -Y27.000 beams, quadrant II by the -Z27.000 and -Y27.000 beams, quadrant III by the -Z27.000 and +Y27.000 beams, and quadrant IV by the +Z27.000 and +Y27.000 beams.

Quadrant I houses the S-band antenna and the PLSS batteries.

Quadrant II houses the Environmental Control Subsystem (ECS) water tank. The landing radar antenna is supported externally on additional structure below the lower deck. Components for the landing radar are mounted on the -Z27.000 beam.

Quadrant III houses the supercritical helium and ambient helium tanks, the descent engine control assembly of the Guidance, Navigation, and Control Subsystem, and the ECS gaseous oxygen tank.

Quadrant IV houses the Electrical Power Subsystem and Explosive Devices Subsystem components (batteries, interstage hardline disconnects, and the umbilical cable cutter).

Fill and drain ports and vents for the fuel, oxidizer, helium, water, and gaseous oxygen tanks are external to the descent stage outer skin. The descent stage includes a thermal and micrometeoroid shield, the landing gear, and an external platform.

1.3.2.1 Thermal And Micrometeoroid Shield.

The entire descent stage structure is enveloped with a thermal and micrometeoroid shield, which is a composite of multiple layers of aluminized 0.0005-inch-thick mylar and an outer 0.004-inch-thick sheet (skin) of aluminum. The shield is mounted on low-thermal-conductive supports, which keep it at least 2 inches from the main structure. The skin acts as a micrometeoroid bumper. The aluminized mylar acts as thermal

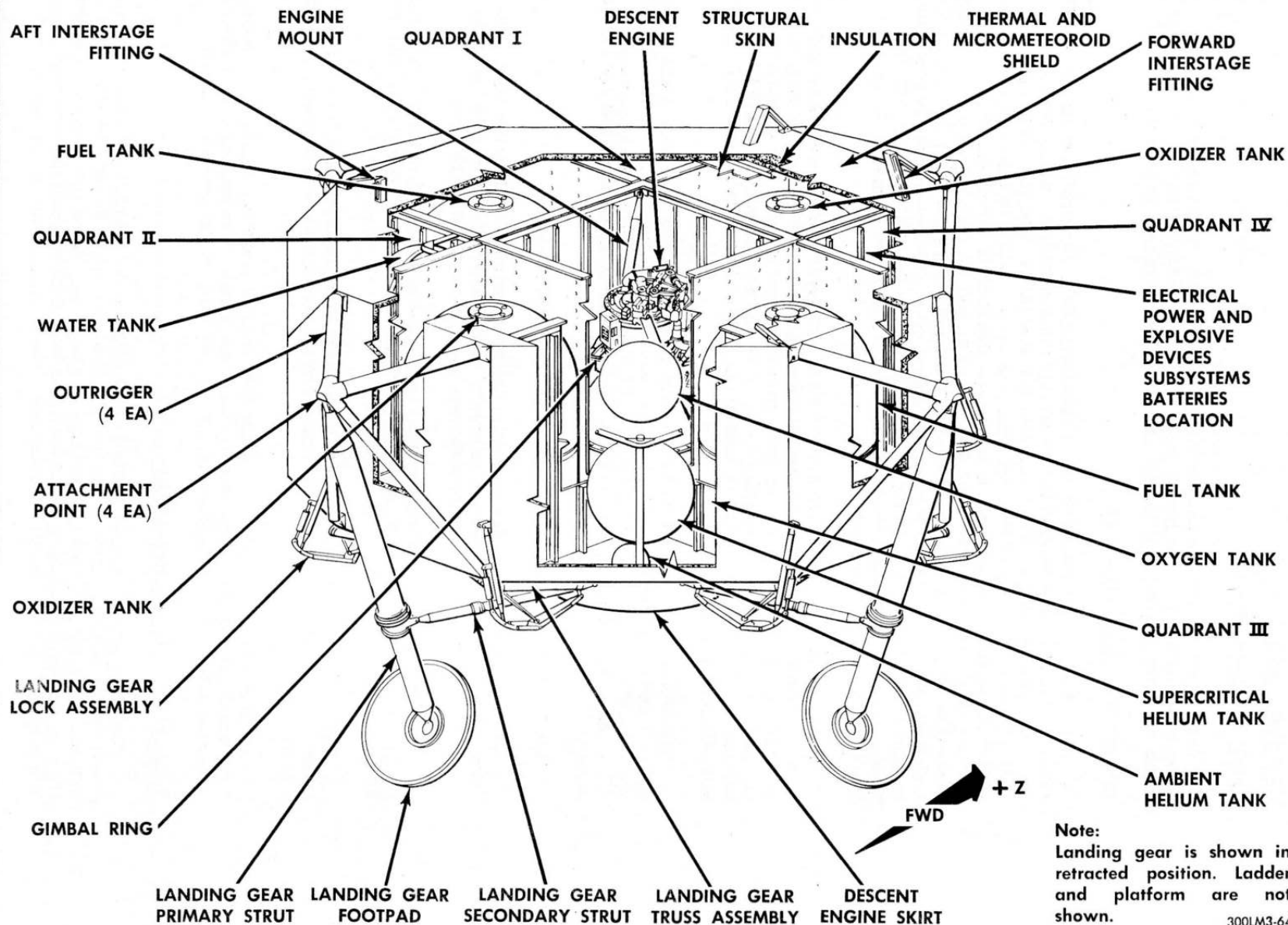


Figure 1-11. Descent Stage Configuration

shielding; it is formed into 25-layer blankets of various sizes and shapes. Where the blankets meet, the mating edges are sealed with mylar tape. Vent holes are provided in the blankets. In areas subjected to temperatures in excess of +350° F, an additional 25 layers of H-film is used.

On the upper deck and side (outer) panels of the quadrants, a combination of Inconel sheet and mesh plus nickel-steel foil is used. This is in addition to the thermal and micrometeoroid shield, because the upper deck and side panels of the quadrants are in direct line of RCS thruster firing.

A titanium blast shield is secured to the upper edge of the descent engine compartment; it deflects the ascent engine exhaust blast out, and away from, the descent engine compartment.

The bottom of the descent stage, and the engine compartment, are subjected to very high temperature due to radiation from the descent engine. A base heat shield protects the area. It is a composite of alternate layers of nickel-steel foil, Fibrocel, and Refrasil, supported by standoffs. A support ring of columbium, titanium, and Refrasil around the engine skirt, supports the heat shield at an adequate distance. Within the engine compartment, a protective layer of titanium is added over the heat shield.

1.3.2.2 Landing Gear. (See figure 1-12.)

The landing gear provides the impact attenuation required to land the LM on the lunar surface, prevents tipover on a -5° to +5° pitch and roll angle, and supports the LM during lunar stay and lunar launch. (The landing gear is not used for landing during this mission.) Impact attenuation is accomplished at load levels that preserve the structural integrity of the LM. At launch, the landing gear is stowed in a retracted position; it remains retracted until shortly after the astronauts enter the LM during earth orbit. The landing gear uplocks are then explosively released and springs in the drive-out mechanism extend the landing gear. Once extended, each landing gear is locked in place by two downlock mechanisms.

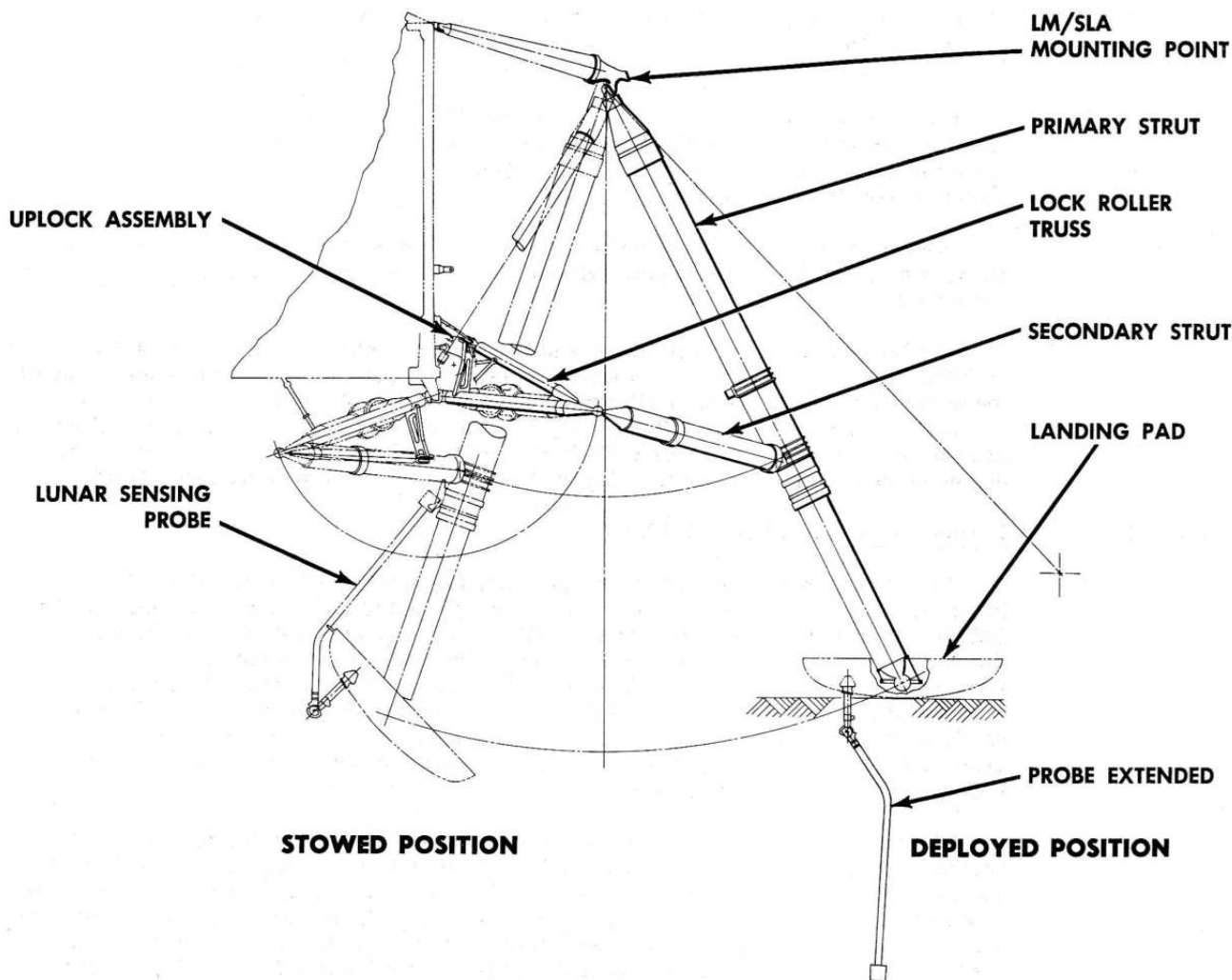
The landing gear is of the cantilever type; it consists of four leg assemblies connected to outriggers that extend from the ends of the descent stage structural beams. The legs extend from the front +Z, rear and both sides of the LM. Each leg assembly consists of a primary strut, a footpad, two secondary struts, an uplock assembly, two drive-out mechanisms (spring bungees), two downlock mechanisms, a cross truss assembly, and the lunar-surface sensing probe. A ladder is affixed to the forward leg assembly.

1.3.2.2.1 Primary Strut.

The primary strut upper end attaches to the descent stage outrigger fitting; the lower end has a ball joint support for the footpad. Crushable aluminum honeycomb inside the primary strut is used as the shock-absorbing medium. The primary strut absorbs compression loads only.

1.3.2.2.2 Footpad.

The footpad provides for vehicle flotation on a surface with a 12-psi bearing strength under the maximum landing gear reaction force. Each footpad has a diameter of 37 inches; it can pivot at the end of the primary strut. The footpad contains crushable honeycomb for additional shock absorption. A lunar-surface sensing probe is attached to each footpad.



300LM3-242

Figure 1-12. Landing Gear

1. 3. 2. 2. 3 Secondary Struts.

The outboard end of each secondary strut attaches to the primary strut; the inboard end, to the deployment truss. The secondary struts contain crushable aluminum honeycomb for shock attenuation. These struts absorb compression and tension loads.

1. 3. 2. 2. 4 Uplock Assembly.

The uplock assembly, attached between the descent stage and the primary strut, is an adjustable tie rod that restrains the landing gear in its retracted position (stowed). A manually operated switch (LDG GEAR DEPLOY) on panel 8 activates the uplock assemblies, permitting the landing gear to be deployed. Two explosive cartridge assemblies are installed in each uplock assembly. Either cartridge supplies sufficient energy to sever the uplock assembly to permit the landing gear to deploy.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SPACECRAFT

1.3.2.2.5 Drive-out and Downlock Mechanisms.

The drive-out mechanism consists of two spring-loaded devices and connecting linkages, which deploy the landing gear after the uplock assembly is severed. Downlock springs retain the landing gear downlocks in the secured position under all vibration and shock loads. Each downlock mechanism contains two independent switches that are actuated when the downlock is in the gear-locked-down position. The LDG GEAR DEPLOY flag on panel 8 presents a gray indication when all the landing gear leg assemblies have been downlocked and at least one switch on each of the eight downlocks has been actuated.

1.3.2.2.6 Lunar-Surface Sensing Probe.

The lunar-surface sensing probe, attached to each landing gear footpad, is an electromechanical device. The probes (not used during LM 3 mission) are retained in the stowed position until landing gear deployment. During deployment, mechanical interlocks are released, permitting spring energy to extend the probes below the footpad. At lunar contact (just before landing gear impact), two mechanically actuated switches (in each probe) energize the LUNAR CONTACT lights to advise the crew to shut off the descent engine. Deployment time for the probe, from uplock severance to down-and-locked position, is less than 2 seconds. Immediately after sensing the lunar surface, the probe collapses or disengages, to prevent damage to, or malfunction of, any other portion of the LM. Each probe has a luminescent patch, which, when visible, indicates that the landing gear is deployed and locked. The patch can be seen, day or night, for at least 100 feet. Each probe has sufficient contact area to provide a signal on contact with a surface that has a bearing strength of 12 psi.

1.3.2.2.7 Ladder.

The ladder affixed to the forward leg assembly has steps and railings. It extends from a platform below the forward hatch to the footpad. The ladder is used to climb to and from the hatch during extravehicular activity on the lunar surface.

1.3.2.3 Platform.

The external platform, on the LM centerline immediately below the forward hatch, provides the astronauts with work space for handling equipment, and aids ingress to and egress from the LM. The platform is approximately 3 feet square; it is attached to the descent stage structure.

1.4 LM - SLA - S-IVB CONNECTIONS.

At earth launch, the LM is within the SLA, which is connected to the S-IVB booster. The SLA has an upper section and a lower section. The outriggers, to which the landing gear is attached, provide attachment points for securing the LM to the SLA lower section. The LM is mounted to the SLA support structure on adjustable spherical seats at the apex of each of the four landing gear trusses; it is held in place by a tension hold-down strap at each mounting point.

Before the LM is removed, the upper section of the SLA is explosively separated into four segments. These segments, which are hinged to the lower section, fold back. The LM is then explosively released from the lower section.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SPACECRAFT

1.5 LM-CSM INTERFACES.

A ring at the top of the ascent stage provides a structural interface for joining the LM to the CSM. The ring is compatible with the clamping mechanisms in the CSM, and ensures structural continuity. The drogue portion of the docking mechanism is secured below this ring. The drogue is required during docking operations to mate with the CSM-mounted probe. See figure 1-13 for orientation of the LM to the CSM.

1.5.1 CREW TRANSFER TUNNEL.

The crew transfer tunnel (LM-CSM interlock area) is the passageway created between the LM upper hatch and the CSM forward pressure hatch when the LM and the CSM are docked. The tunnel permits intervehicular transfer of crew and equipment without exposure to space environment. The tunnel, LM, and CSM, are pressurized from the CSM.

1.5.1.1 Final Docking Latches.

Twelve latches are spaced equally about the periphery of the CSM docking ring. They are placed around and within the CSM tunnel so that they do not interfere with probe operation. When secured, the latches provide structural continuity and pressurization between the LM and the CSM, and effect sealing of the tunnel interface.

1.5.1.2 Umbilical.

An electrical umbilical, in the LM portion of the tunnel, is connected by an astronaut to the CSM. This connection can be made without drogue removal.

1.5.1.3 Docking Hatches.

The LM has a single docking (upper) hatch; the CSM has a single, integral, forward hatch. The LM upper hatch is not removable. It is hinged to open 75° into the cabin.

1.5.1.4 Docking Drogue.

The drogue assembly is a conical structure with provisions for mounting in the LM portion of the crew transfer tunnel. The drogue may be removed from either end of the crew transfer tunnel and may be temporarily stowed in the CSM or the LM, during SPS burns.

1.5.1.5 Docking Probe.

The docking probe provides initial CSM-LM coupling and attenuates impact energy imposed by vehicle contact. The docking probe assembly consists of a central body, probe-head capture latches, pitch arms, tension linkages, shock attenuators, a support structure, probe stowage mechanism, probe extension mechanism, probe retraction system, an extension latch, a preload torque shaft, probe electrical umbilicals, and electrical circuitry. The assembly may be folded for removal and stowage from either end of the CSM transfer tunnel.

1.5.1.6 Docking Aids.

Visual alignment aids are used for final alignment of the LM and CSM, before the probe head of the CSM makes contact with the drogue. The LM +Z-axis will align 50° to 70° from the CSM -Z-axis and 30° from the CSM +Y-axis. The CSM position represents a 180° pitchover and a counterclockwise roll of 60° from the launch vehicle alignment configuration.

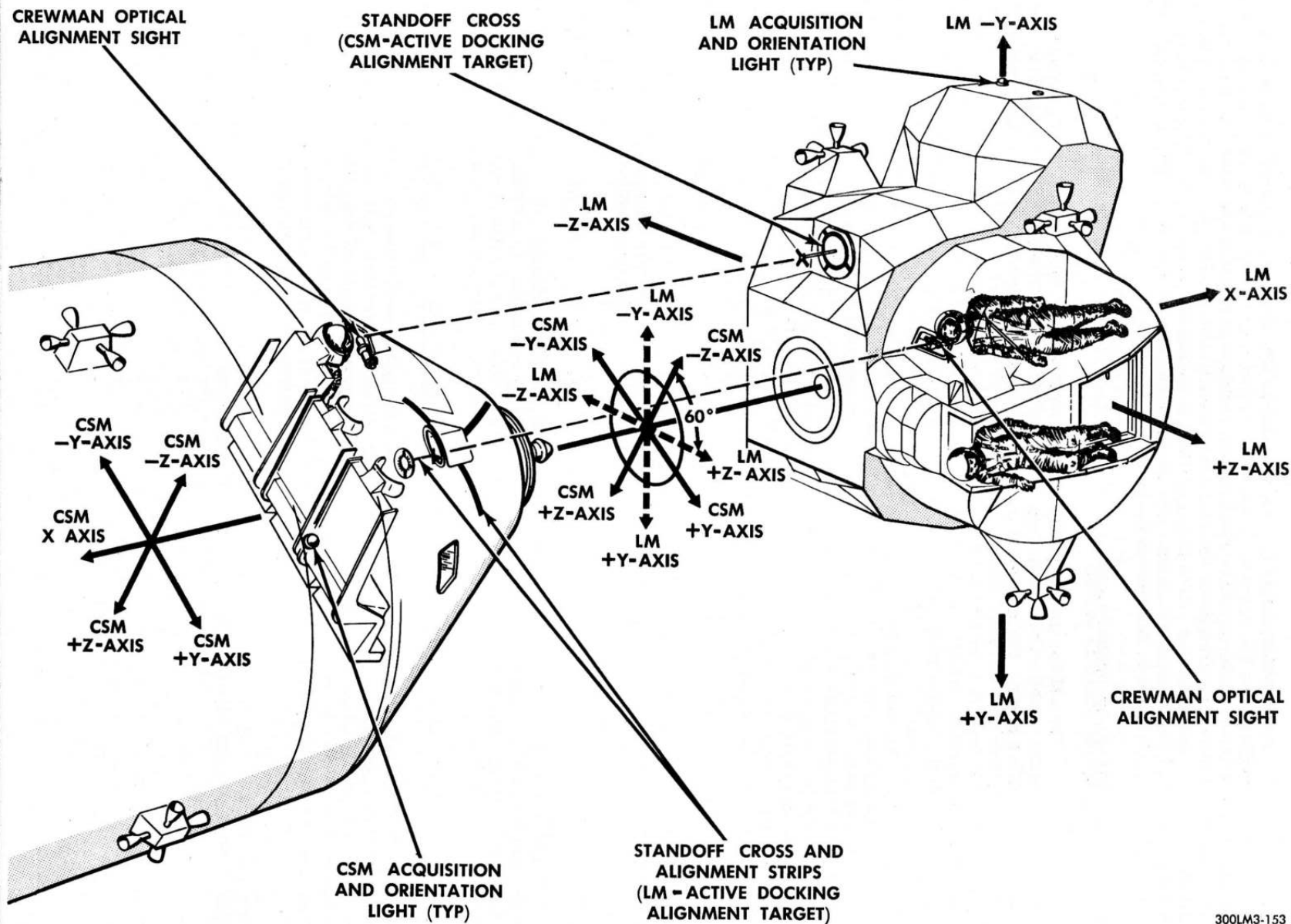


Figure 1-13. LM-CSM Reference Axis

300LM3-153

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SPACECRAFT

An alignment target is recessed into the LM so as not to protrude into the launch configuration clearance envelope or the postexcursion contact maximum envelope. It indicates centering of the crossmembers within the target circle when viewed at the intercept parallel to the -X-axis and perpendicular to the Y-axis and Z-axis. The target has contrasting colors, one of which is radioluminescent green. The target, a three-dimensional standoff cross at approximately stations -Y46.300 and -Z0.203, is 17.68 inches in diameter at the base.

1.6

STOWAGE PROVISIONS.

The LM has provisions for stowing crew personal equipment. The equipment includes umbilicals, an emergency wrench, star charts, checklists, a medical kit, and other items. For a detailed list of crew personal equipment, refer to paragraph 2.11.

SECTION 2

SUBSYSTEMS DATA

INTRODUCTION

Subsystems data include description of functions and components, and design data, operational limitations, and telemetry measurements. Subsection 2.1 describes the interfacing of LM-3 subsystems. Subsections 2.2 through 2.9 present data grouped by subsystems as follows: guidance, navigation, and control; main propulsion; reaction control; electrical power; environmental control; communications; explosive devices and instrumentation. Subsection 2.10 deals with miscellaneous subsystems data, Subsection 2.11 presents the details of crew personal equipment.

Telemetry code numbers for measurements that are not displayed are given in the individual subsystem telemetry measurements tables.

2.1 SUBSYSTEM INTERFACE. (See figure 2-1.)

Most LM-3 functions are fulfilled by a subsystem, or a section of a subsystem, functioning with other subsystems to provide a highly reliable system capable of accomplishing the mission. The interfacing of the LM subsystems is described in paragraphs 2.1.1 through 2.1.9.

2.1.1 GUIDANCE, NAVIGATION, AND CONTROL SUBSYSTEM. (See figure 2-1, sheets 1 and 2.)

The Guidance, Navigation, and Control Subsystem (GN&CS) is used with other subsystems to provide automatic, semiautomatic, and manual control of LM 3. This control is accomplished through one of two GN&CS guidance sections, the primary guidance and navigation section (PGNS) or the abort guidance section (AGS), used in conjunction with the GN&CS radar sections and control electronics section (CES). The PGNS generates commands, based on data supplied from other GN&CS sections, and computes guidance and navigation data for control of the LM. If the PGNS malfunctions, the AGS provides semiautomatic, preprogrammed control; the astronauts perform functions usually performed by the PGNS. GN&CS interface with other subsystems is covered in paragraphs 2.1.1.1 through 2.1.1.5.

2.1.1.1 Main Propulsion Subsystem.

The GN&CS supplies on and off commands to the descent and ascent engines. These commands are generated in the LM guidance computer (LGC) or the abort electronics assembly, depending on the guidance section selected. The CES routes the commands to the engines. The descent engine receives the following commands: automatic or manual on and off commands, automatic or manual throttle commands, arm commands (engine fire enabling signals selected with the ENG ARM or ABORT switches and routed through the descent engine control assembly), and trim commands via the gimbal drive assembly.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

2.1.1.2 Reaction Control Subsystem.

The GN&CS selectively fires the 16 thrust chamber assemblies (TCA's) of the Reaction Control Subsystem (RCS) to control LM attitude and translation during rendezvous and docking, and during simulated lunar-landing maneuvers. In the PGNS mode, the attitude and translation control assembly (ATCA) implements LGC-generated automatic on and off commands. In the AGS mode, the on and off commands are issued via the ATCA from attitude error, rate, and hand controller signals. In either mode, on and off commands can be issued manually through the two attitude controller assemblies (one for each astronaut). The attitude controller assemblies (ACA's) and the thrust/translation controller assemblies (TTCA's) provide attitude and translation commands through the LGC or through the ATCA. The ACA's can also control the TCA's directly when the ROLL, YAW, or PITCH ATTITUDE CONTROL switches are set to DIR.

2.1.1.3 Electrical Power Subsystem.

The Electrical Power Subsystem (EPS) supplies primary d-c power for the PGNS, AGS, CES, and the radar sections of the GN&CS. The EPS also supplies primary a-c power for alignment optical telescope lighting, the rendezvous radar servo assembly, the data entry and display assembly, and the descent engine control assembly.

Pressing the ABORT STAGE pushbutton routes a power switchover command to the EPS, causing the ascent batteries to be turned on, after which the descent batteries are turned off.

2.1.1.4 Explosive Devices Subsystem.

The CES supplies automatic descent and ascent engine on and off commands, and stage commands to the Explosive Devices Subsystem (EDS) firing circuits. When selected, the AGS also automatically supplies abort and abort-stage commands. In response to GN&CS commands routed through the CES, the EDS firing circuits route descent engine pressurization commands to the Main Propulsion Subsystem (MPS). The abort-stage and stage commands also effect separation of the ascent stage from the descent stage by firing explosive devices through the EDS firing circuits.

2.1.1.5 Instrumentation Subsystem.

The GN&CS supplies the Instrumentation Subsystem (IS) with subsystem data that are processed for telemetering to the Manned Space Flight Network (MSFN) and/or for display in the LM cabin. The LGC supplies a 1.024-mc primary timing signal to the pulse-code-modulation and timing electronics assembly in the IS for use in generating timing and sync signals required by other subsystems. The IS supplies telemetry data start and stop commands to the LGC along with sync pulses for clocking out telemetry data.

2.1.2 MAIN PROPULSION SUBSYSTEM. (See figure 2-1, sheet 5.)

The Main Propulsion Subsystem (MPS), under control of the GN&CS, provides the main thrust capability, through two propulsion sections: ascent propulsion section (APS) and descent propulsion section (DPS). MPS interface with other subsystems is covered in paragraphs 2.1.2.1 through 2.1.2.5.

2.1.2.1 Guidance, Navigation, and Control Subsystem.

Refer to paragraph 2.1.1.1 for MPS interface with the GN&CS.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

2.1.2.2 Reaction Control Subsystem.

The APS can supply fuel and oxidizer to the TCA's through ascent interconnect valves in the RCS, during thrusting or when a positive "g" force is exerted. This provides backup for the RCS propellant supply.

2.1.2.3 Electrical Power Subsystem.

The EPS supplies primary d-c power to the ascent and descent helium solenoid valves, and to the liquid-level sensors in the fuel and oxidizer tanks of the DPS. The EPS also supplies a-c power to the helium, oxidizer, and fuel digital displays.

2.1.2.4 Explosive Devices Subsystem.

The EDS provides pressurization commands to the APS and DPS pressurization sections. These commands open normally closed explosive valves before engine start, to pressurize the propellant tanks.

2.1.2.5 Instrumentation Subsystem.

The MPS supplies the IS with subsystem data that are processed for telemetering to MSFN and/or for display in the LM cabin.

2.1.3 REACTION CONTROL SUBSYSTEM. (See figure 2.1, sheet 5.)

The RCS provides attitude and translation control about or along all LM axes, under control of the GN&CS. RCS interface with other subsystems is covered in paragraphs 2.1.3.1 through 2.1.3.5.

2.1.3.1 Guidance, Navigation, and Control Subsystem.

Refer to paragraph 2.1.1.2 for RCS interface with the GN&CS.

2.1.3.2 Main Propulsion Subsystem.

Refer to paragraph 2.1.2.2 for RCS interface with the MPS.

2.1.3.3 Electrical Power Subsystem.

The EPS supplies primary d-c power to the oxidizer and fuel valves in the TCA's; to the isolation valves and main shutoff valves, and ascent fuel and oxidizer interconnect valves in RCS systems A and B; to the crossfeed valves, to the pressure-volume-temperature system; to the RCS displays; and to the quad heaters.

2.1.3.4 Explosive Devices Subsystem.

The EDS provides pressurization commands to the RCS pressurization section. These commands open normally closed explosive valves in RCS systems A and B, pressurizing the propellant tanks.

2.1.3.5 Instrumentation Subsystem.

The RCS supplies the IS with subsystem data that are processed for telemetering to MSFN and/or for display in the LM cabin.

2.1.4 ELECTRICAL POWER SUBSYSTEM. (See figure 2-1, sheet 4.)

The EPS provides electrical power to all LM subsystems. Primary d-c power (28 to 32 volts) is supplied by two batteries in the ascent stage and four batteries in the descent stage. Primary a-c power (112 to 118 volts, 400 cps) is supplied by two

SUBSYSTEM INTERFACE

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

redundant solid-state inverters. EPS interface with other subsystems is covered in paragraphs 2.1.4.1 through 2.1.4.7.

2.1.4.1 Guidance, Navigation, and Control Subsystem.

Refer to paragraph 2.1.1.3 for EPS interface with the GN&CS.

2.1.4.2 Main Propulsion Subsystem.

Refer to paragraph 2.1.2.3 for EPS interface with the MPS.

2.1.4.3 Reaction Control Subsystem.

Refer to paragraph 2.1.3.3 for EPS interface with the RCS.

2.1.4.4 Environmental Control Subsystem.

The EPS supplies primary d-c power to the Environmental Control Subsystem (ECS) for operation of the suit and cabin fans, the glycol pumps, valves, regulators, sensors, and ECS displays.

2.1.4.5 Communications Subsystem.

The EPS supplies primary d-c power to the Communications Subsystem (CS) for operation of all voice, television, and telemetry transmitting and receiving devices, which include the VHF section, the S-band section, and the signal-processing assembly. Primary a-c power from the EPS is used as a 400-cps reference signal in the S-band steerable antenna driver logic circuits.

2.1.4.6 Explosive Devices Subsystem.

The EPS supplies primary d-c power to the EDS for activation of the redundant firing circuits, which control operation of the explosive devices used to stage the LM, deploy the landing gear, and pressurize the MPS and RCS. A pair of redundant batteries in the EDS provides power for operation of the explosive devices.

2.1.4.7 Instrumentation Subsystem.

The EPS supplies primary d-c power to the IS for operation of the signal-conditioning electronics assembly, pulse-code-modulation and timing electronics assembly, and caution and warning electronics assembly, and to the Developmental Flight Instrumentation (DFI) used in qualifying the LM during earth-orbital missions. It supplies primary a-c power to the data storage electronics assembly (tape recorder) for its tape drive motors. The IS supplies a 6.4-kpps sync signal to control the 400-cps output of the EPS inverters.

The EPS supplies the IS with subsystem data that are processed for telemetering to MSFN and/or for display in the LM cabin.

2.1.5 ENVIRONMENTAL CONTROL SUBSYSTEM. (See figure 2-1, sheet 5.)

The ECS provides life support for the astronauts and thermal control of certain electronic sections and assemblies during the mission. ECS interface with other subsystems is covered in paragraphs 2.1.5.1 and 2.1.5.2.

2.1.5.1 Electrical Power Subsystem.

Refer to paragraph 2.1.4.4 for ECS interface with the EPS.

2.1.5.2 Instrumentation Subsystem.

The ECS supplies the IS with subsystem data that are processed for telemetering to MSFN and/or for display in the LM cabin.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

2.1.6 COMMUNICATIONS SUBSYSTEM. (See figure 2-1, sheet 4.)

The CS operates in conjunction with the microphones, headsets, and biomedical sensors in the pressure garment assembly (PGA) and with the IS, CSM, and MSFN. The PGA microphones and headsets permit the astronauts to transmit and receive voice. The voice signals are processed in the signal-processing assembly of the CS, where they are routed, via hardline, between the astronaut and the selected RF equipment.

Voice and data (other than biomedical) are transmitted between the LM and the CSM via the VHF transmitter-receiver assemblies. Simplex voice operation is provided by a 296.8-mc carrier. Normally, a 259.7-mc carrier is used for PCM data transmission at the low bit rate or it may be used as a voice backup channel. Communication between the LM and MSFN is provided by the S-band transmitter-receiver assemblies. Duplex voice, television, tracking and ranging, emergency keying, subsystems data from the IS, and biomedical data from PGA sensors are provided (2282.5 mc transmit, 2101.8 mc receive).

CS interface with other subsystems is discussed in paragraphs 2.1.6.1 and 2.1.6.2.

2.1.6.1 Electrical Power Subsystem.

Refer paragraph 2.1.4.5 for CS interface with EPS.

2.1.6.2 Instrumentation Subsystem.

The subsystem data processed in the IS for telemetering are supplied to the CS in nonreturn-to-zero (NRZ) (at 51,200 or 1,600 bits per second rate) or split-phase (1,600 bits per second rate) form for transmission via S-band or VHF, respectively. The IS also supplies a sync signal and a reference signal, used by the CS to generate two subcarriers. A 1.024-mc subcarrier is generated from the 512-kc square-wave reference signal supplied by the pulse-code-modulation section of the pulse-code-modulation and timing electronics assembly of the IS. This subcarrier, which is phase referenced to the NRZ data supplied by the IS, is modulated by the NRZ input for transmission to MSFN. The second subcarrier (1.25 mc) is generated from the 512-kc square-wave sync signal supplied by the timing electronics section of the pulse-code-modulation and timing electronics assembly, mixed with a 113-kc voltage-controlled oscillator in the signal-processing assembly. Normally, this subcarrier is modulated by voice and biomedical data for S-band transmission. The split-phase data supplied to the VHF transmitter directly modulates the VHF B carrier (259.7 mc) when the VHF B XMTR switch is set to DATA.

The data storage electronics assembly (a voice tape recorder) in the IS interfaces with the CS. A voice-operated relay (VOX) keying signal is supplied from the signal-processing assembly to turn on the tape recorder. Voice is routed to the tape recorder through the intercommunication bus.

The CS also supplies the IS with subsystem data that are processed for telemetering to MSFN and/or for display in the LM cabin.

2.1.7 EXPLOSIVE DEVICES SUBSYSTEM. (See figure 2-1, sheet 4.)

The EDS provides landing gear deployment, MPS and RCS pressurization, and separation of the ascent and descent stages by means of explosive devices. EDS interface with other subsystems is discussed in paragraphs 2.1.7.1 through 2.1.7.5

2.1.7.1 Guidance, Navigation, and Control Subsystem.

Refer to paragraph 2.1.1.4 for EDS interface with the GN&CS.

SUBSYSTEM INTERFACE

Mission LM 3 Basic Date 1 January 1968 Change Date Page 2.1-5

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

2.1.7.2 Main Propulsion Subsystem.

Refer to paragraph 2.1.2.4 for EDS interface with the MPS.

2.1.7.3 Reaction Control Subsystem.

Refer to paragraph 2.1.3.4 for EDS interface with the RCS.

2.1.7.4 Electrical Power Subsystem.

Refer to paragraph 2.1.4.6 for EDS interface with the EPS.

2.1.7.5 Instrumentation Subsystem.

The EDS supplies the IS with subsystem data that are processed for telemetering to MSFN and/or for display in the LM cabin.

2.1.8 INSTRUMENTATION SUBSYSTEM. (See figure 2-1, sheet 4.)

Sensors in the LM subsystems continuously check subsystem status by sensing temperature, valve action, pressure, switch position, voltage, current, and quantity. These sensed data, converted to electrical signals, are routed to the IS, where they are processed for telemetering to MSFN and/or display in the LM cabin.

The DFI, considered part of the IS, has additional subsystem sensors, which are sampled periodically; their output is conditioned, and transmitted by four VHF FM/FM transmitters to MSFN. The DFI has a fifth VHF FM/FM transmitter, which transmits the NRZ data also transmitted by the CS S-band transmitters. Uplink commands from MSFN, received via the DFI communications section, are routed to the LM mission programmer (paragraph 2.1.9) for ground control of the LM in certain modes.

IS interface with other subsystems is discussed in paragraphs 2.1.8.1 through 2.1.8.7.

2.1.8.1 Guidance, Navigation, and Control Subsystem.

Refer to paragraph 2.1.1.5 for IS interface with the GN&CS.

2.1.8.2 Main Propulsion Subsystem.

Refer to paragraph 2.1.2.5 for IS interface with the MPS.

2.1.8.3 Reaction Control Subsystem.

Refer to paragraph 2.1.3.5 for IS interface with the RCS.

2.1.8.4 Electrical Power Subsystem.

Refer to paragraph 2.1.4.7 for IS interface with the EPS.

2.1.8.5 Environmental Control Subsystem.

Refer to paragraph 2.1.5.2 for IS interface with the ECS.

2.1.8.6 Communications Subsystem.

Refer to paragraph 2.1.6.2 for IS interface with the CS.

SUBSYSTEM INTERFACE

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

2.1.8.7 Explosive Devices Subsystem.

Refer to paragraph 2.1.7.5 for IS interface with the EDS.

2.1.9 LM MISSION PROGRAMMER. (See figure 2-1, sheet 3.)

The extent to which the LM mission programmer will be used during this mission has not been defined. When these data are available, they will be included as part of the subsystem interface description.

SUBSYSTEM INTERFACE

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

(To be supplied)

Figure 2-1. Subsystems Functional Interface Diagram (Five Sheets)

GUIDANCE, NAVIGATION AND CONTROL SUBSYSTEM

MAIN PROPULSION SUBSYSTEM

REACTION CONTROL SUBSYSTEM

ELECTRICAL POWER SUBSYSTEM

ENVIRONMENTAL CONTROL SUBSYSTEM

COMMUNICATIONS SUBSYSTEM

EXPLOSIVE DEVICES SUBSYSTEM

INSTRUMENTATION SUBSYSTEM

MISCELLANEOUS

CREW PERSONAL EQUIPMENT

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

2.2 GUIDANCE, NAVIGATION, AND CONTROL SUBSYSTEM.

2.2.1 INTRODUCTION.

The Guidance, Navigation, and Control Subsystem (GN&CS) provides vehicle guidance, navigation, and control required for successful completion of a manned LM mission. The subsystem is an aided inertial system whose principal sensors are an alignment optical telescope (AOT), an inertial measurement unit (IMU), landing radar (LR), and rendezvous radars (RR). The GN&CS consists of the following sections: primary guidance and navigation section (PGNS), abort guidance section (AGS), radar section, control electronics section (CES), the LM mission programmer (LMP) and the orbital rated display - earth and lunar (ORDEAL). Figure 2-2 shows the location of the LM-3 GN&CS equipment. (Refer to paragraph 2.2.3 for a detailed description of the equipment.)

The PGNS establishes the inertial reference used for measurements and computations, provides inertial reference alignment by entering optical sighting data into the LM guidance computer (LGC), provides position and velocity calculations by inertial techniques, enables a LM and CSM rendezvous by radar-aided inertial techniques, generates attitude control and thrust commands to ensure satisfactory trajectory, controls descent engine throttling and gimbaling, and displays pertinent guidance-status data.

The AGS provides independent backup for the PGNS. It has its own inertial sensor and computer assemblies.

The radar section consists of two separate radars. The RR provides the LGC with CSM range, range rate, and line-of-sight angles for computation of guidance and navigation data during rendezvous maneuvers. The LR provides the LGC with velocity and altitude data during lunar landing. The LR for LM3 will not furnish these data, because the LM-3 mission is earth orbital and only monitoring of LR performance will be performed.

The CES controls LM attitude and translation about, and along, the three LM axes. The CES also controls descent engine, ascent engine, and RCS operation with commands generated by the PGNS during automatic operations, or with commands generated by the attitude controller assemblies (ACA's) and thrust/translation controller assemblies (TTCA's) during manual operations.

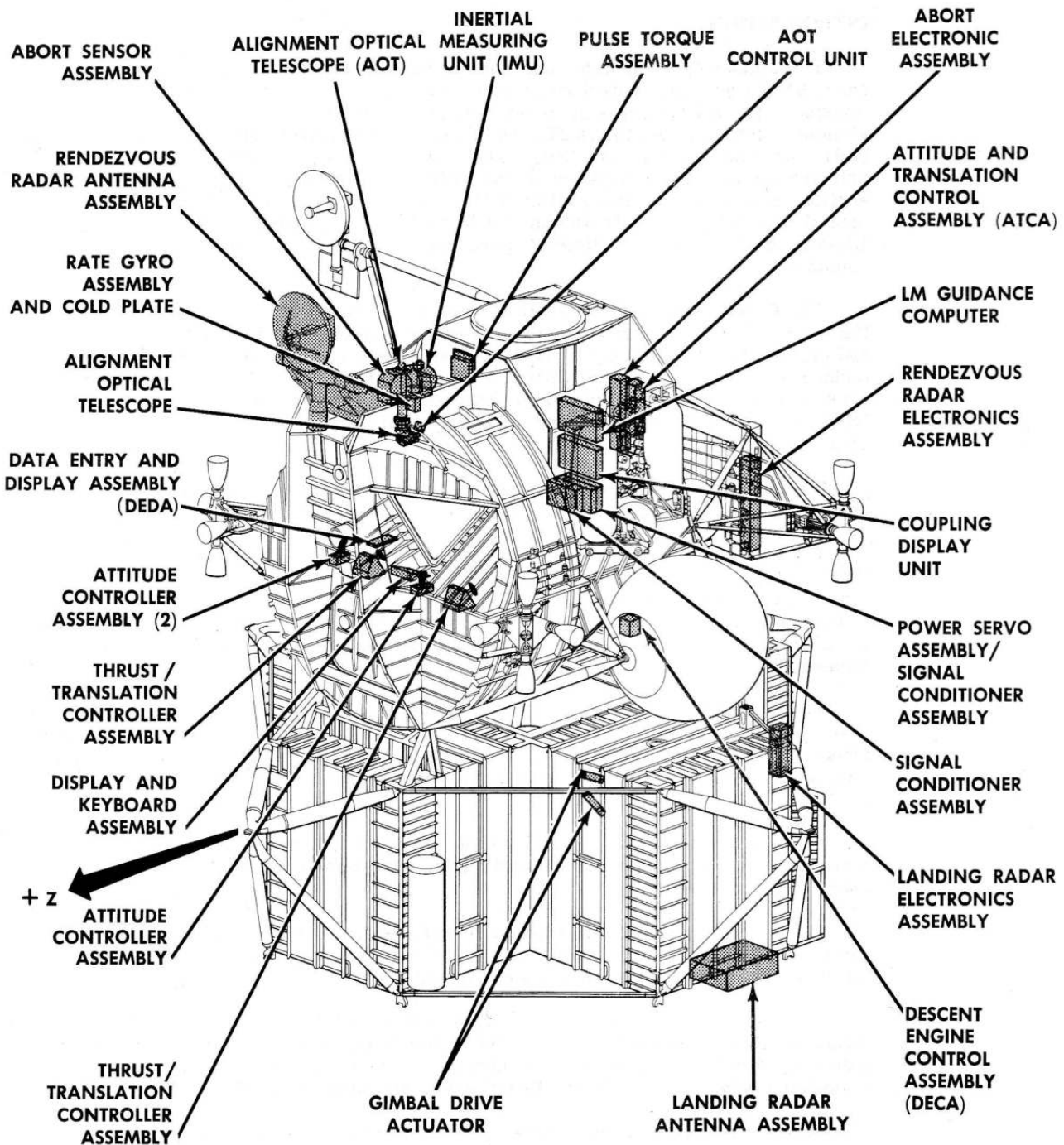
The LM-3 mission has the option of using the LMP. When used, the LMP provides a ground capability to command ascent engine operation during the manned or unmanned phase of the mission.

The ORDEAL provides an alternative to the inertial attitude display, in pitch only. The ORDEAL produces an FDAI display of the computed local vertical attitude during circular orbits around the earth when selected.

The GN&CS interfaces with the Electrical Power Subsystem (EPS), Environmental Control Subsystem (ECS), Instrumentation Subsystem (IS). It interfaces indirectly with the Communications Subsystem (CS) and issues commands to the Main Propulsion Subsystem (MPS) and Reaction Control Subsystem (RCS).

The EPS provides primary power (28 volts) to the PGNS. The ECS circulates an ethylene glycol-and-water solution (coolant) about temperature-sensitive electronics equipment in the GN&CS, to provide thermal stability. Coolant circulates through the case of the IMU. The other major components of the PGNS are mounted on cold plates through which coolant circulates to provide temperature control. The IS monitors the various sections of the GN&CS, performs in-flight checkout, prepares status data for transmission to earth, provides timing frequencies, and stores voice data when required.

LMA790-3-LM 3
 APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA



300LM3-91

Figure 2-2. LM Guidance, Navigation, and Control Subsystem - Equipment Location

GUIDANCE, NAVIGATION, AND CONTROL SUBSYSTEM

The CS provides the link between the astronauts, the orbiting CSM, and MSFN stations. The CS has two RF portions, one operating in the VHF range and one operating in the UHF (S-band) range. The RF sections provide two-way voice transmission between the LM and CSM, between the LM and MSFN, and between the LM and the EVA. In addition, the UHF portion receives and transmits tracking and ranging signals from MSFN and transmits data pertinent to the LM to MSFN.

The GN&CS interfaces with the MPS to issue on and off commands to the ascent and descent engine and to control descent engine throttling and gimbaling (thrust vector). The GN&CS also supplies on and off commands, through the CES, to valves of the RCS thrust chamber assemblies (TCA's) during various modes of operation. The CES also routes staging and pressurization commands to the Explosive Devices Subsystem (EDS).

2.2.2

FUNCTIONAL DESCRIPTION.

The GN&CS comprises two functional loops, each of which is a completely independent guidance and control path. The primary guidance path performs all the functions necessary to complete the LM mission. If a failure in the primary guidance path occurs, the abort guidance path can perform all the functions necessary to effect a safe rendezvous with the orbiting CSM.

2.2.2.1

Primary Guidance Path. (See figure 2-3.)

The primary guidance path comprises the PGNS, CES, and the radar section. The PGNS is an aided inertial guidance device whose principal aids are the LR, RR, and AOT. The CES routes the guidance and navigation data from the PGNS and applies them to the descent or ascent engine, and selected TCA's.

The IMU, which continuously measures attitude and acceleration, is the primary inertial sensing device of the LM. The LR senses LM slant range and velocity. The RR coherently tracks the CSM to derive line-of-sight (LOS) range, range rate, and angle rate. The LGC is the central data-processing device of the LM. The LGC uses AOT sighting data to align the IMU. Using inputs from the LR, IMU, RR, TTCA's and ACA's, the LGC solves guidance, navigation, steering, and stabilization equations necessary to initiate on and off commands for the descent and ascent engines, throttle commands and trim commands for the descent engine, and on and off commands for the TCA's.

Control of the LM, when using the primary guidance path, ranges from fully automatic to manual. The primary guidance path operates in the automatic mode or the attitude-hold mode. In the automatic mode, all navigation, guidance, stabilization and control functions are controlled by the LGC. When the attitude-hold mode is selected, the astronaut uses his ACA to bring the LM to a desired attitude. When the ACA is moved out of the detent position, proportional attitude rate or minimum impulse commands are routed to the LGC. The LGC then calculates steering information and generates TCA commands that correspond to the mode of operation selected via the display and keyboard assembly (DSKY). These commands are applied to the primary preamplifiers in the attitude and translation control assembly (ATCA), which routes the commands to the proper TCA. When the astronaut releases the ACA, the LGC generates commands to hold this attitude. If astronaut commands four-jet direct operation of the ACA by going to the hardover position, the ACA applies the command directly to the secondary solenoids of the corresponding TCA.

In automatic mode, the LGC generates descent engine throttling commands, which are routed to the descent engine via the descent engine control assembly (DECA). The astronaut can manually control descent engine throttling with his TTCA. The DECA sums the TTCA throttle commands with the LGC throttle and applies the resultant signal to the descent engine. The DECA also applies trim commands, generated by the LGC, to the gimbal drive actuators to provide trim control of the descent engine. The LGC supplies on and off commands for the ascent and descent engines to the S&C control

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

assemblies. The S&C control assemblies route the ascent engine on and off commands directly to the ascent engine, and the descent engine on and off commands to the descent engine via the DECA.

In the automatic mode, the LGC generates +X-axis translation commands to provide ullage. In the manual mode, manual translation commands are generated by the astronaut, using his TTCA. These commands are routed, through the LGC, to the ATCA and on to the proper TCA.

2.2.2.2

Abort Guidance Path. (See figure 2-4.)

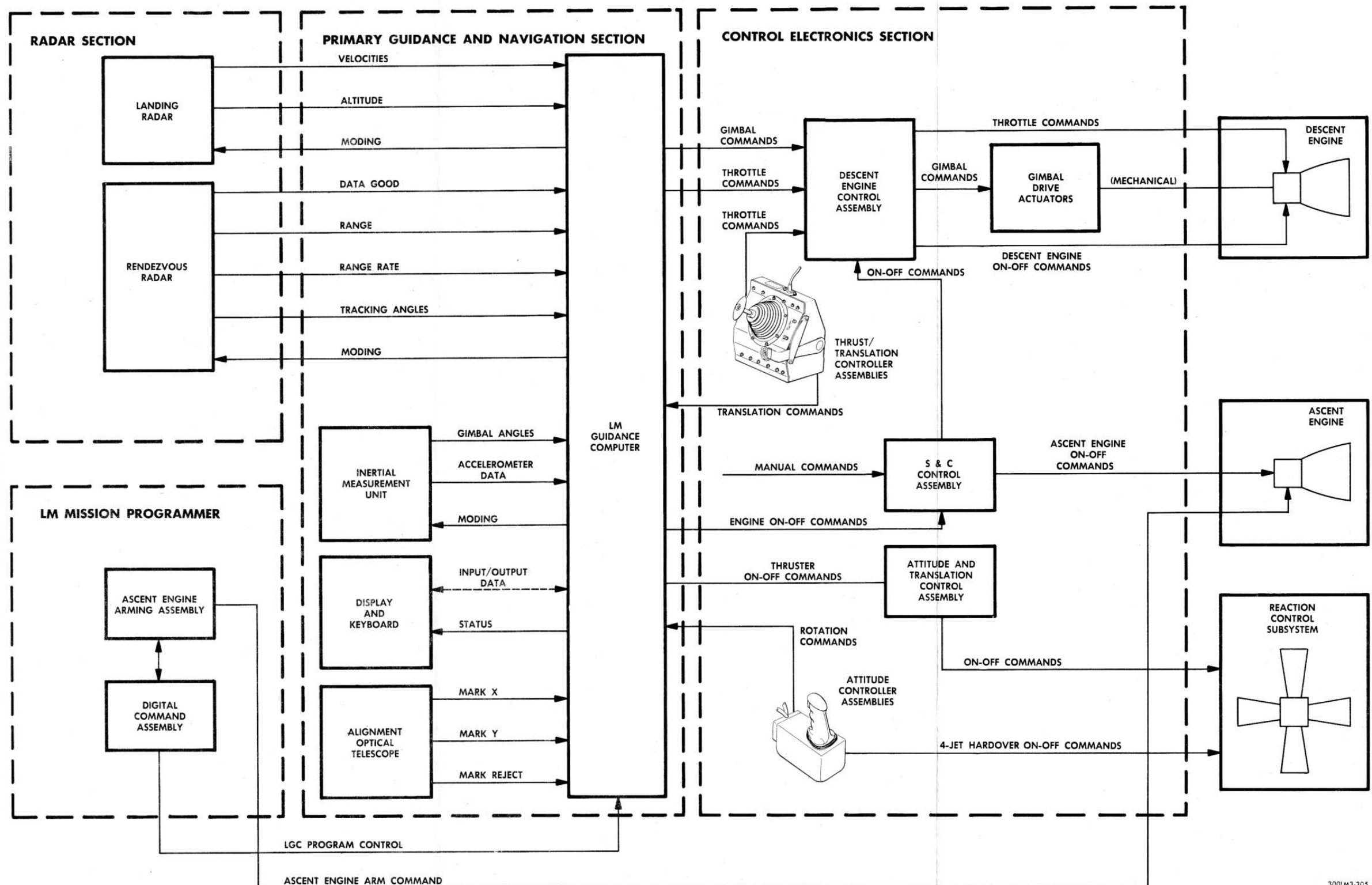
The abort guidance path comprises the AGS, CES, and selected propulsion section. The AGS is a backup system for the PGNS. The term "abort guidance path" is somewhat misleading in that any abort situation is normally under the control of the PGNS; the AGS is used only if the PGNS malfunctions. The AGS performs all inertial navigation and guidance functions necessary to effect a safe orbit or rendezvous with the CSM. The stabilization and control functions are performed by analog computation techniques, in the CES.

The AGS uses a strap-down inertial sensor, rather than the stabilized, gimbaled sensor used in the PGNS's IMU. The abort sensor assembly (ASA) is a strap-down inertial sensor package that measures attitude and acceleration with respect to the LM body axes. The ASA attitude is supplied to the abort electronics assembly (AEA). The AEA is a high-speed, general-purpose digital computer that performs the basic strap-down system computations and the abort guidance and navigation steering control calculations. The data entry and display assembly (DEDA) is a general-purpose input-output device through which the astronaut manually enters data into the AEA and commands various data readouts.

The CES functions as an autopilot when the abort guidance path is selected. It uses inputs from the AGS and from the astronauts to provide the following: on, off, and TTCA throttling commands for the descent engine; gimbal commands for the GDA's to control descent engine trim; on and off commands for the ascent engine; engine sequencer logic to ensure proper arming and staging before engine startup and shutdown; on and off commands for the TCA's for translation and stabilization, and for various maneuvers; jet-select logic to select the proper TCA's for the various maneuvers; and modes of LM control, ranging from fully automatic to manual.

The astronaut uses the TTCA to control throttling of the descent engine and translation maneuvers. The throttle commands, engine on and off commands from the S&C control assemblies, and trim commands from the ATCA are applied to the DECA. The DECA applies the throttle commands to the descent engine, the engine on and off commands to the descent engine latching devices, and the trim commands to the GDA's. The S&C control assemblies receive engine on and off commands for the descent and ascent engines from the AEA. As in the primary guidance path, the S&C control assemblies route descent engine on and off commands to the DECA and apply ascent engine on and off commands directly to the ascent engine.

The abort guidance path operates in the automatic mode or the attitude-hold mode. In the automatic mode, navigation and guidance functions are controlled by the AGS; stabilization and control functions, by the CES. In the attitude-hold mode, the astronaut uses his ACA to control LM attitude. The ACA generates attitude rate, pulse, direct, and hardover commands. The attitude rate and pulse commands, AEA error signals, rate-gyro assembly (RGA) rate-damping signals, and TTCA translation commands are applied to the ATCA. The ATCA processes these inputs to generate TCA on and off commands.



300LM3-305

Figure 2-3. Primary Guidance Path - Simplified Block Diagram

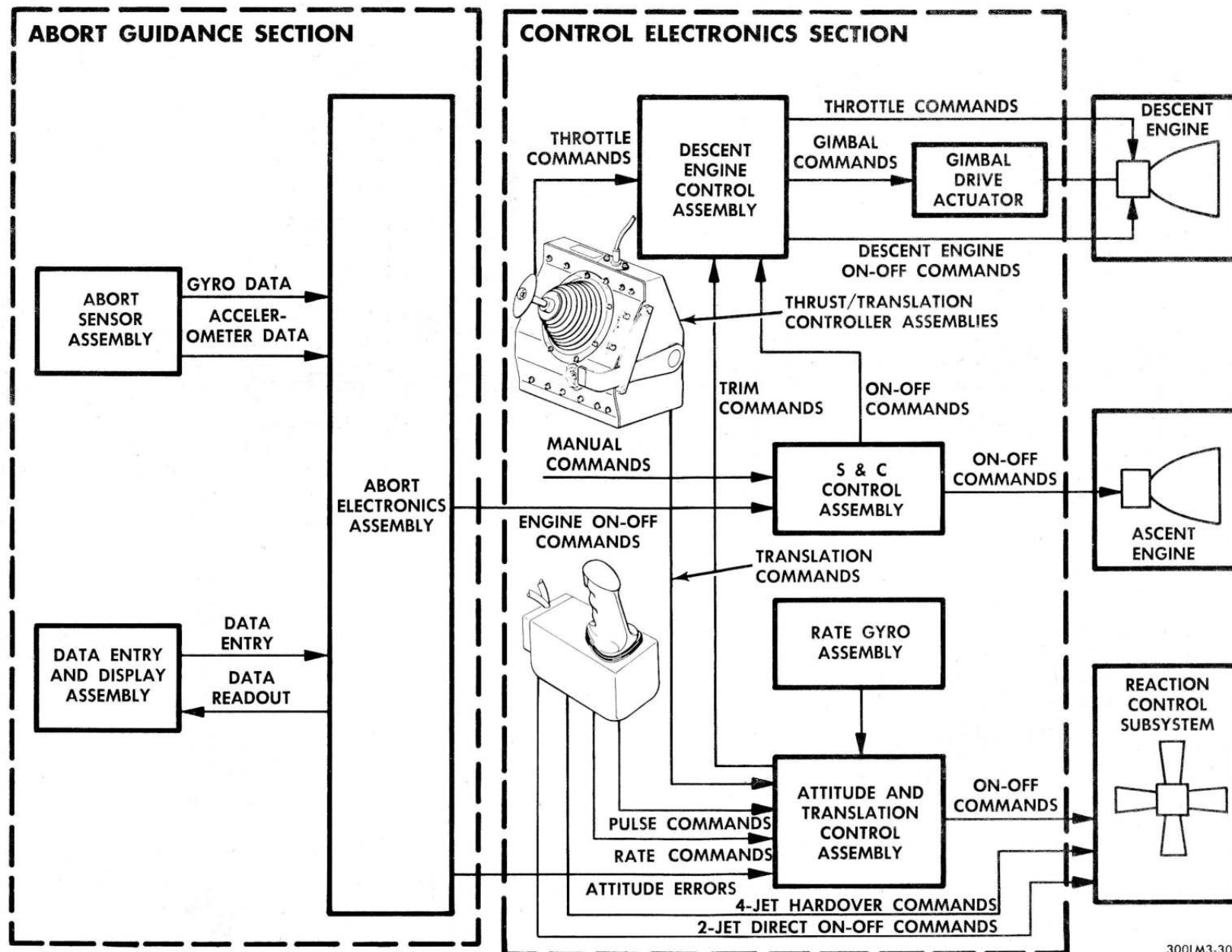


Figure 2-4. Abort Guidance Path - Simplified Block Diagram

300LM3-304

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

In the attitude-hold mode, pulse and direct submodes are available for each axis. The pulse submode is an open-loop attitude control mode in which the ACA is used to make small attitude changes in the selected axis. The direct submode is an open-loop attitude control mode in which pairs of TCA's are directly controlled by the ACA. The astronaut can also control vehicle attitude in any axis by moving the ACA to the hard-over position. In addition, the astronaut can override translation control in the +X-axis with the +X TRANSL pushbutton (panel 5). Pressing the +X TRANSL pushbutton fires all four +X-axis TCA's.

2.2.2.3 LM Vehicle and Primary Guidance and Navigation Section Axes. (See figure 2-5.)

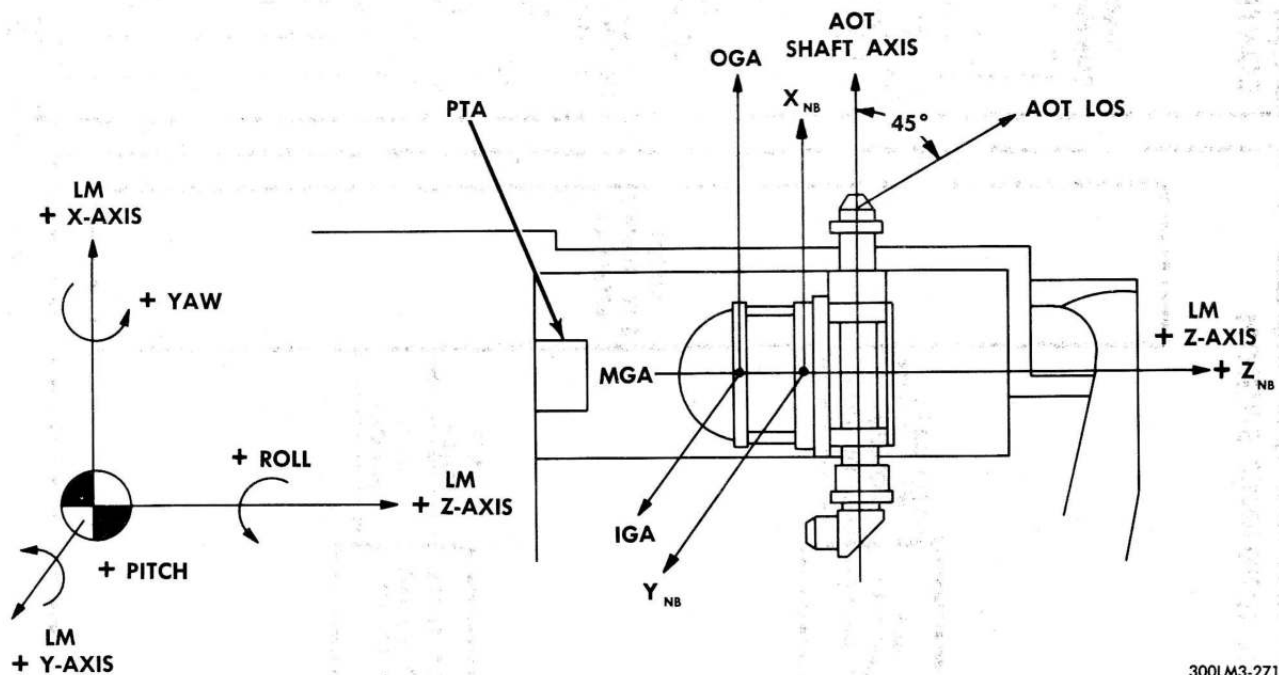
Several sets of axes are associated with the LM and the PGNS. Each set is a three-axis, right-hand, orthogonal coordinate system. Figure 2-5 shows the relationships of various sets of axes when the IMU gimbal angles are zero.

2.2.2.3.1 LM Vehicle Axes.

The X-axis positive direction is through the overhead hatch; the Z-axis positive direction is through the forward hatch. The Y-axis is perpendicular to the X-Z plane.

2.2.2.3.2 Navigation Base Axes.

The navigation base is mounted to the LM structure so that a coordinate system is formed by its mounting points. The Y_{NB} axis is parallel to the vehicle Y-axis. The X_{NB} axis is parallel to the vehicle X-axis. The Z_{NB} axis is perpendicular to the X_{NB} - Y_{NB} plane and parallel to the vehicle Z-axis.



300LM3-271

Figure 2-5. LM Vehicle and Primary Guidance and Navigation Section Axes

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

2.2.2.3.3 IMU Axes.

The IMU axes are defined by the three gimbal axes. These axes are designated as the outer gimbal axis (OGA), middle gimbal axis (MGA), and the inner gimbal axis (IGA). The gimbal axes are defined when the gimbal angles are zero degrees; they are as follows: The OGA is parallel to the X-axis, the MGA is parallel to the Z-axis, and the IGA is parallel to the Y-axis. The axes of the IMU stable member are parallel to the vehicle axes and the gimbal axes when the gimbal angles are zero degrees.

2.2.2.3.4 Alignment Optical Telescope Axes.

The AOT is mounted to the navigation base so that the AOT shaft axis is parallel to the X-axis. The telescope LOS is approximately 45° above the vehicle Y-Z plane. The LOS can be positioned to six azimuth detents located at 60° increments from the vehicle +Z-axis.

2.2.2.3.5 Radar Antenna Axes.

The LR and RR antenna axes are described in paragraph 2.2.3.3.

2.2.3 MAJOR COMPONENT/FUNCTIONAL DESCRIPTION.

2.2.3.1 Primary Guidance and Navigation Section. (See figure 2-6.)

The PGNS provides data-measuring and data-processing capabilities and control functions necessary to accomplish descent, ascent, and rendezvous and docking with the CSM. The PGNS performs inertial guidance, navigation, and flight control.

Inertial guidance is accomplished with accelerometers mounted on a gyroscopically stabilized, gimbal-mounted platform, and a central data-processing device (the LGC). The inertial guidance system senses acceleration and attitude changes instantaneously and provides incremental velocity and attitude information to the LGC for generation of attitude-change and thrust commands.

Navigation is accomplished with data derived from star sightings. These data, obtained with the AOT, are used to establish an inertial reference. The crew optical alignment sight (COAS) is used as a backup navigational device for the AOT. (Refer to subsection 2.11.) The navigation performed by the PGNS is dependent upon the software capability of the LGC and data obtained from other portions of the PGNS and other LM subsystems. As an aid to navigation, the RR tracks a transponder on the CSM. The radar interfaces with the LGC and the PGNS inertial subsection, for automatic positioning and data transfer.

The PGNS has sensing and monitoring devices for determining LM position, velocity, and attitude; it provides output signals necessary for control or correction of LM motion. During rendezvous and docking the PGNS uses inertial, radar tracking, and manual inputs to provide rotation and translation commands.

The PGNS consists of a navigation base, the IMU, AOT, a power and servo assembly (PSA), pulse torque assembly (PTA), a signal conditioner (SC), the LGC, coupling data units (CDU), a display and keyboard (DSKY), and various other displays and controls. (See figure 2-2.) The navigation base, mounted to the structure above the astronaut heads, is used as a holding fixture for the IMU and AOT. The IMU and AOT are attached, and precisely aligned to, the navigation base. The LGC and CDU's are mounted on cold plates located on the upper portion of the aft equipment bay. The PSA and SC, also mounted on cold plates, are located below the LGC and CDU's. The PTA is mounted, on a cold plate, to the rear wall of the IMU compartment. The DSKY is on panel 4 in the cabin.

GUIDANCE, NAVIGATION, AND CONTROL SUBSYSTEM

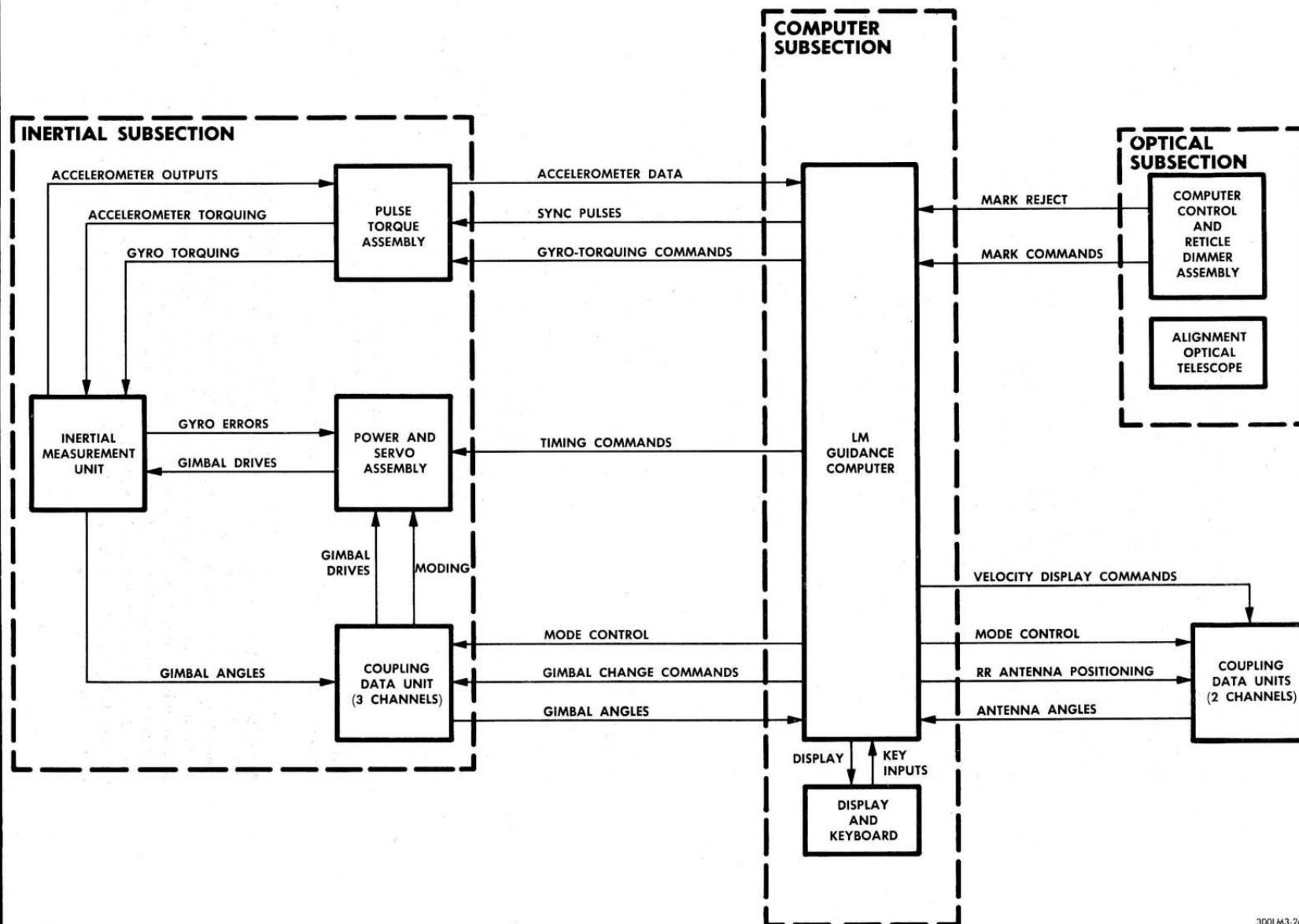


Figure 2-6. Primary Guidance and Navigation Section - Block Diagram

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Functionally, the PGNS is divided into three major subsections: inertial, optical, and computer. The subsections individually, or in combination, perform the following functions:

- Establish an inertial reference which is used for measurements and computations
- Enable IMU alignment through the LGC by entering optical sighting data through the DSKY
- Enable calculation of LM position and velocity by inertial techniques
- Enable LM and CSM rendezvous by radar tracking and inertial techniques
- Generate attitude-control and thrust commands to maintain the vehicle on a satisfactory trajectory
- Control throttling and gimbal trim of the descent engine
- Display pertinent flight data related to guidance status.

The inertial subsection (ISS) performs the following major functions:

- Measures LM attitude
- Senses LM acceleration due to thrust
- Assists in data conversion for display or telemetry transmission.

The optical subsection (OSS) performs the following major functions:

- Provides a means of aligning the inertial reference on the lunar surface
- Provides measurements for establishing the inertial reference in flight.

The computer subsection (CSS) performs the following major functions:

- Aligns the IMU
- Solves the guidance and navigation problems for all mission phases
- Provides control information to the PGNS and to other subsystems
- Displays pertinent information to the astronauts and MSFN when requested
- Provides a means by which the astronauts can directly communicate with the LGC
- Provides on-off control of the RCS thrusters and the ascent and descent engines
- Provides gimbaling and throttling control of the descent engine
- Provides the timing for the PGNS and other LM subsystems
- Monitors its own operation and certain other subsystem operations
- Positions the RR antenna.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

ISS operation can be initiated automatically by the LGC or by the astronaut, using computer keyboard entries to command the LGC to select the various operating modes. The status or mode of operation can be displayed on the DSKY as determined by computer program. The IMU furnishes the inertial reference; it consists of a stable member with three degrees of freedom, stabilized by three integrating gyros. The stable member must be aligned with respect to the reference coordinate system each time the ISS is powered-up. During flight this alignment is accomplished by optical sighting of celestial objects.

Once the ISS is energized and aligned to an inertial reference, LM rotation is about the gimbaled stable member, which remains fixed in space. Resolvers, mounted on the gimbal axes, act as angle-sensing devices and measure LM attitude with respect to the stable member. These angular measurements are displayed to the astronaut by the flight director attitude indicator (FDAI) and angular changes of the inertial reference are sent to the LGC.

Desired LM attitude is calculated in the LGC and compared with the actual gimbal angles. A difference between the actual and calculated angles results in generation of attitude error signals, by the ISS channels of the CDU, which are sent to the FDAI for display. These error signals are used by the digital autopilot program in the LGC to activate RCS thrusters for LM attitude correction. Attitude error is displayed by the FDAI error needles. LM acceleration due to thrusting is sensed by three pendulous integrating accelerometers, which are mounted on the stable member with their input axes orthogonal. The resultant signals (velocity changes) from the accelerometer loops are supplied to the LGC, which calculates the total LM velocity.

The OSS is used to determine the position of the LM, using a catalog of stars stored in the LGC and celestial measurements made by an astronaut. The identity of celestial objects is determined before earth launch.

The OSS consists of the AOT, which is a unity-power instrument with a 60° field of view and the computer control reticle dimmer assembly. The AOT can be set to six positions; it has a manually rotated reticle with a visual angular display. (Refer to paragraph 2.2.3.1.2.)

The CSS consists of the LGC and the DSKY. This subsection is used to perform powered flight, tracking, and rendezvous computations and data handling. The LGC is a general-purpose digital computer that uses a core memory and parallel operation. Programs and routines are stored in the LGC to provide control and solve flight equations. Mission programs must be selected manually.

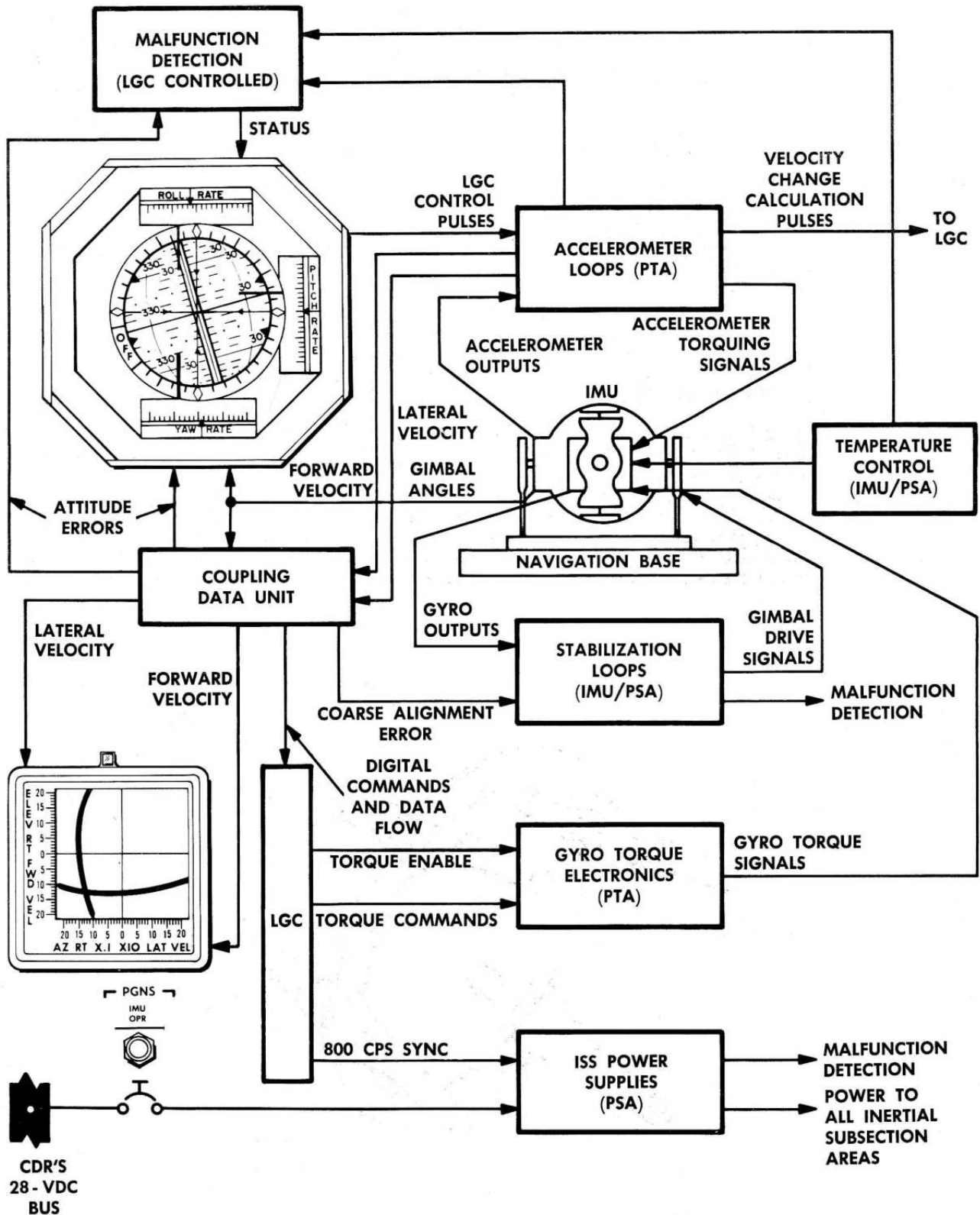
Using information from navigation fixes, the LGC computes deviations from the required course and calculates the necessary corrective attitude and thrust commands. The velocity corrections are measured by the ISS and controlled by the computer subsection. Velocity corrections are not made continuously; they are initiated at pre-determined checkpoints. This reduces fuel consumption, because the engines are used only when a significant velocity correction is required.

The PGNS has two primary modes of operation: automatic and manual. In the automatic mode, the PGNS generates the commands required to effect thrust vector control and/or stabilization control. In the manual mode, the PGNS implements the commands in response to astronaut inputs from the ACA's and TTCA's.

2.2.3.1.1 Inertial Subsection. (See figure 2-7.)

The ISS comprises the navigation base, IMU, CDU's, PTA, PSA, and the SC.

The ISS maintains a platform (stable member) fixed with respect to a preselected inertial reference frame, senses acceleration along the coordinate system defined by the stable member orientation, and provides the LGC with incremental velocity data and the attitude of the stable member with respect to the LM.



300LM3-272

Figure 2-7. Inertial Subsection - Functional Diagram

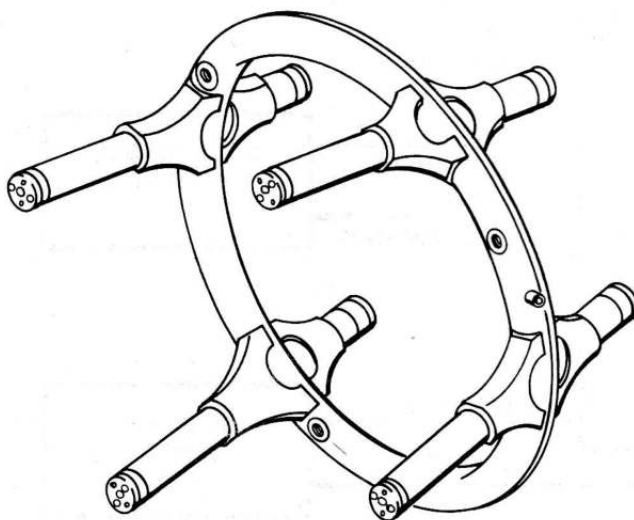
LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

The stable member must be realigned during flight because the stable member may deviate from its alignment, due to gyro drift. Also, a new stable member orientation may be desired by the crew. The alignment orientation may be that of the CSM or that defined by the thrusting programs within the LGC. Sighting of two stars is required for in-flight fine alignment. The stable member is aligned after the LGC processes sighting data that has been combined with the known IMU angles and supplies gyro-torquing signals to the IMU. The ISS modes of operation are initiated automatically by the LGC.

The ISS measures acceleration along the axes of the stable member coordinate system and supplies incremental velocity data to the LGC. The LGC calculates the LM present position and velocity by integrating the components of velocity due to gravitational field accelerations and velocity due to thrust with the last known position and velocity.

The ISS also generates signals that are used to control LM attitude. Gimbal-mounted resolvers measure the orientation of the stable member with respect to the LM axes. This angular displacement is fed to the LGC and displayed to the astronaut. The astronaut or the LGC can command changes in angular displacement by controlling the firing of the RCS thrusters.

Navigation Base. (See figure 2-8.) The navigation base is a lightweight mount that supports, in critical alignment, the IMU, ASA and AOT. The navigation base is constructed of 1-inch-diameter, aluminum-alloy tubing; it weighs approximately 3 pounds. It consists of a center ring with four legs that extend from either side. The IMU is mounted to the ends of one side of the four legs. The AOT and the abort sensor assembly are mounted to the opposite ends of the legs. The navigation base is bolted to the LM structure above the astronauts' head, with three mounting pads on the center ring. An electrical grounding strap is attached to the center ring and to the LM structure.



300LM3-334

Figure 2-8. Navigation Base - Pictorial Diagram

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Inertial Measurement Unit. (See figure 2-9.) The IMU is the primary inertial sensing device of the LM. It is a three-degree-of-freedom, gyroscopically stabilized device whose primary functions are:

- Maintaining an orthogonal, inertially referenced coordinate system for LM attitude control and measurement
- Maintaining three accelerometers in the reference coordinate system for accurate measurement of velocity changes.

The IMU uses three Apollo 25-inertial reference integrating gyros (IRIG's) to sense changes in stable member orientation, and three 16-pulse integrating pendulums (PIP's) to sense velocity changes. The 25-IRIG's are fluid- and magnetically-suspended, single-degree-of-freedom gyros with 2.5-inch-diameter case. The 16-PIP's are fluid- and magnetically-suspended, pendulum-type devices with a 1.6-inch-diameter case. When fixed in its associated electronics loop, the 16-PIP becomes an integrating accelerometer.

The IMU gimbals consist of an outer gimbal mounted to the case, a middle gimbal mounted to the outer gimbal, and an inner gimbal (stable member) mounted to the middle gimbal. All three gimbals are spherical, have 360 degrees of freedom, and are positioned by torque motors. The complete IMU weighs approximately 42 pounds.

Inner Gimbal Assembly. (See figure 2-9.) The inner gimbal (stable member) is free to rotate 360° about the inner axis. The stable member is machined from a solid block of cold-pressed and sintered beryllium; holes for mounting the IRIG's, PIP's, and the associated electronics are bored in the block. The stable member inputs and outputs are routed through a 40-contact slipring on each end of the inner gimbal axis (IGA). Angular data are transmitted by multispeed transmitter resolvers (1X and 16X), which supply 800-cps signals to the CDU's. A gyro error resolver, mounted on the negative end of the IGA, is used in the stabilization loop to transform gyro error into gimbal axis error. A d-c torque motor, mounted on the positive end of the axis, is used in the stabilization loop to position the stable member.

Middle Gimbal Assembly. (See figure 2-9.) The middle gimbal is suspended by two intergimbal assemblies inside the outer gimbal. It supports the inner gimbal. Each intergimbal assembly provides 360 degrees of freedom. Each intergimbal assembly contains a duplex pair ball bearing (one fixed; one floated) and a 40-contact slipring for routing electrical inputs and outputs. A multispeed transmitter resolver, mounted on the negative end of the middle gimbal axis (MGA), transmits angular data. A d-c torque motor is mounted on the opposite end of the axis.

Outer Gimbal Assembly. The outer gimbal configuration is similar to the middle gimbal (figure 2-9); it is suspended inside the supporting case by two intergimbal assemblies. Each intergimbal assembly provides 360 degrees of freedom for the outer gimbal axis (OGA). Each intergimbal assembly contains a duplex pair ball bearing (one fixed, one floated) and a 50-contact slipring for routing electrical inputs and outputs. A multispeed transmitter resolver (1X and 16X) is mounted on the negative end of the OGA; a d-c torque motor, on the opposite end of the axis. Two thermostatically controlled axial-flow blowers mounted in the outer gimbal walls move air from the vicinity of the middle gimbal to the walls of the case, where heat is carried away by the water-glycol solution circulating through the passages in the case.

IMU Case. The IMU case is a spherical enclosure, which supports the inner, middle, and outer gimbals. The outside diameter of the case is approximately 12.5 inches. The walls of the case contain coolant passages through which a water-glycol solution is circulated to dissipate heat generated by inertial components and electronic modules. Two quick-disconnect fittings connect the coolant passages to the LM primary heat transport coolant loop. (The case is surrounded by insulating material to prevent condensation of moisture on the coolant passages before launch.)

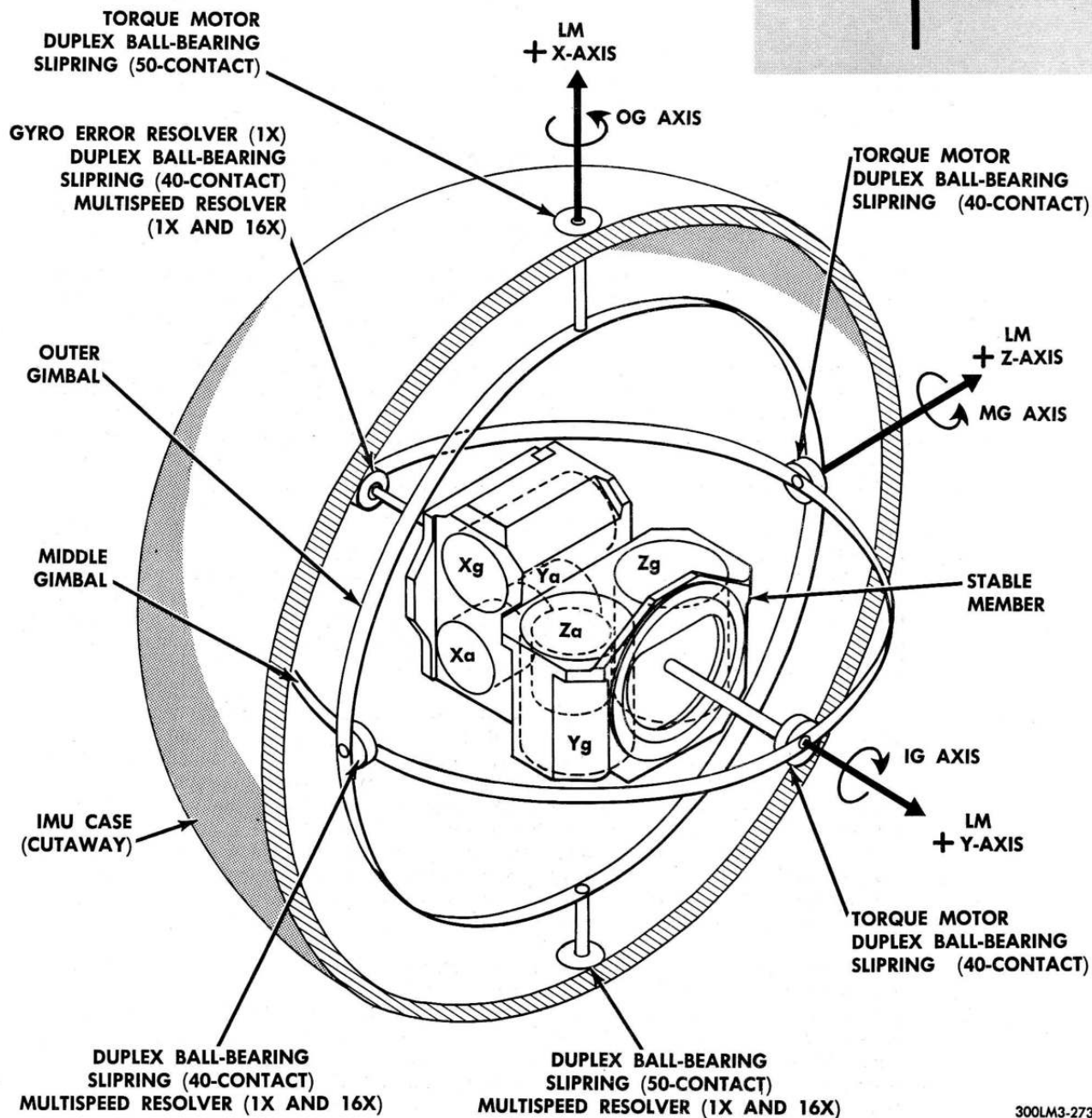
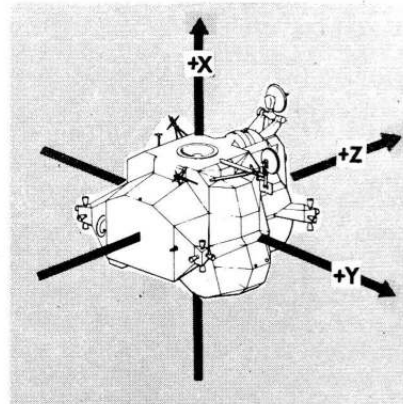
LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Note:

$X_g = X \text{ IRIG}; X_a = X \text{ PIP}$

$Y_g = Y \text{ IRIG}; Y_a = Y \text{ PIP}$

$Z_g = Z \text{ IRIG}; Z_a = Z \text{ PIP}$



300LM3-273

Figure 2-9. IMU Gimbal Assembly - Pictorial Diagram

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

IMU Temperature Control Assembly. (See figure 2-10.) The IMU temperature control assembly maintains the temperature of the three IRIG's and three 16-PIP's within required limits during IMU standby and operating modes. The assembly supplies and removes heat, as required, to maintain IMU heat balance with minimum power consumption. Heat is removed by convection, conduction, and radiation. The natural convection, used during the IMU standby mode, is changed to blower-controlled forced convection during IMU operating modes. Forced convection between the middle gimbal and the water-glycol-cooled gimbal case is shown in figure 2-11. By sealing the IMU, internal air pressure is maintained at 1 atmosphere to provide the required natural and forced convection. The temperature control assembly consists of a temperature control circuit, a blower control circuit, and a temperature alarm circuit.

The temperature control circuit applies the required nominal heat ($+130^{\circ}\pm 4^{\circ}\text{F}$) to the inertial components. This circuit includes six IRIG end-mount heaters, three PIP end-mount heaters, a temperature control thermostat assembly mounted on the stable member, two stable member heaters, an anticipator heater, and a temperature control module that turns the heaters on and off, as necessary. There are three additional PIP end-mount heaters; these are not controlled by the control module, but operate continuously when 28-volt, 800-cps IRIG power is applied. Power for the other heaters is 28 volts dc.

The blower control circuit removes heat, as required, to maintain heat balance. This circuit includes a blower control thermostat assembly mounted on the stable member, two axial blowers mounted on the outer gimbal, and a blower control module that turns the blower on and off, as necessary. The blowers are turned off when the temperature exceeds $+139^{\circ}\pm 0.2^{\circ}\text{F}$; they do not operate during the IMU standby mode.

The temperature alarm circuit monitors the temperature control assembly. The alarm circuit contains an alarm thermostat for high-temperature sensing ($>+134^{\circ}\pm 0.2^{\circ}\text{F}$), an alarm thermostat for low-temperature sensing ($<+126^{\circ}\pm 0.2^{\circ}\text{F}$), and a temperature alarm module that provides a discrete to the LGC during normal-temperature operation ($+126^{\circ}$ to $+134^{\circ}\text{F} \pm 0.2^{\circ}\text{F}$). When an out-of-limit temperature occurs ($+126^{\circ}\text{F} > \text{temp} > +134^{\circ}\text{F}$), the TEMP light on the DSKY and the PGNS caution light (panel 2) go on.

IMU Failure-Detection Assembly. (See figure 2-12.) The IMU failure-detection circuits monitor IMU temperature, PIPA counts, 800-cps 5% power supplies, 3,200-cps power supply, inner gimbal servo error, middle gimbal servo error, and outer gimbal servo error. When a malfunction occurs, the failure-detection circuits provide a failure signal to the LGC. The LGC processes the failure signal and routes it through the DSKY to the appropriate caution and warning indicators on panels 1 and 2 or the condition indicators on the DSKY. The signals monitored for IMU failure detection and the indicator lighted by specific failures are shown in figure 2-12.

Coupling Data Units. The CDU's convert and transfer angular information between major assemblies of the GN&CS. The five CDU's used are considered part of the PGNS, even though two of them process RR data. The five CDU's are, as follows:

- One for the RR shaft axis
- One for the RR trunnion axis
- One for each of the three gimbals.

The two CDU's used with the RR antenna provide interfaces between the antenna and the LGC. The LGC calculates digital antenna position commands before acquisition of the CSM. These signals are converted into analog form by the CDU's and applied to the antenna drive mechanism to aim the antenna toward the CSM. Tracking-angle information is converted to digital form by the CDU's and applied to the LGC.

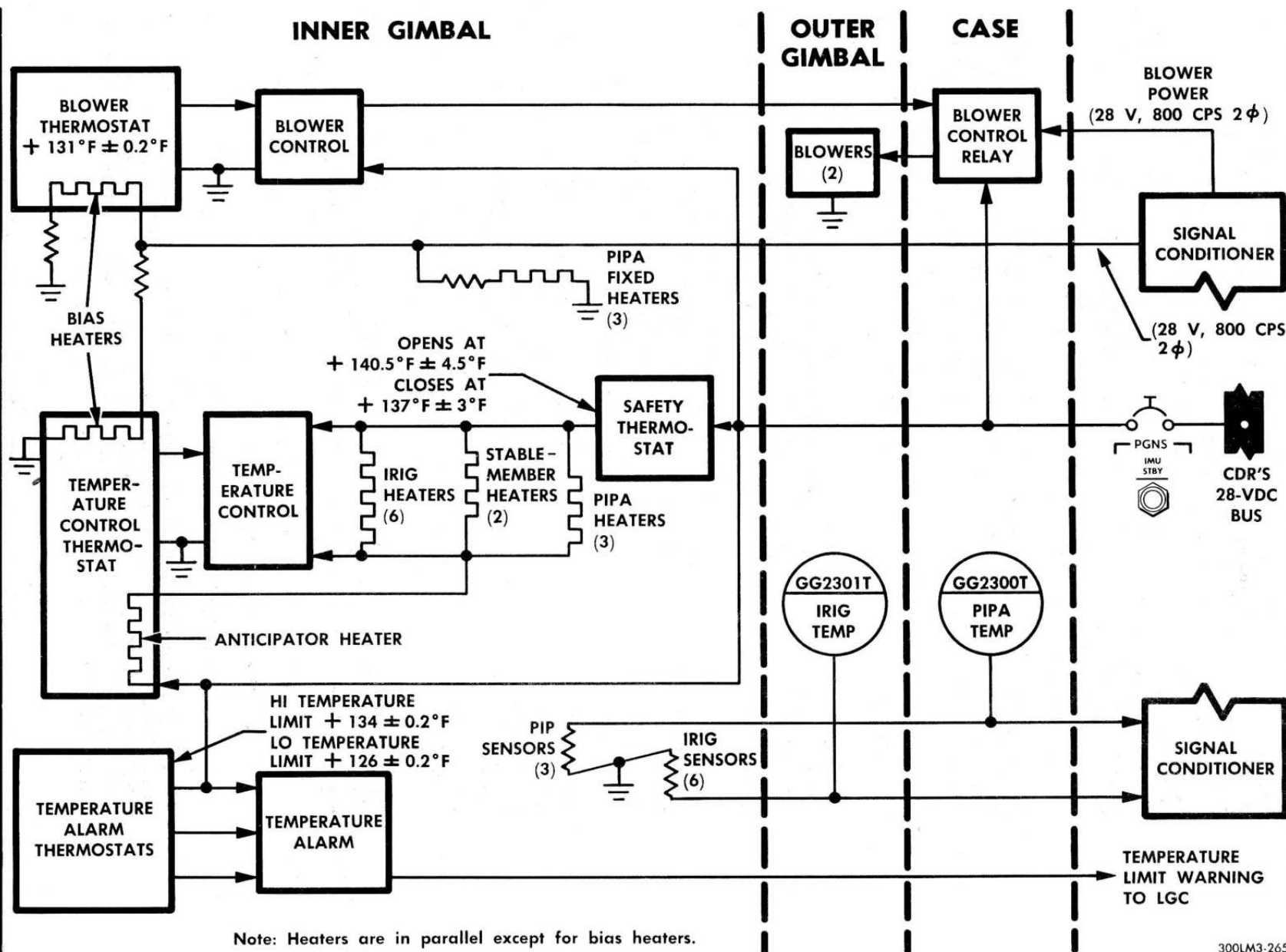
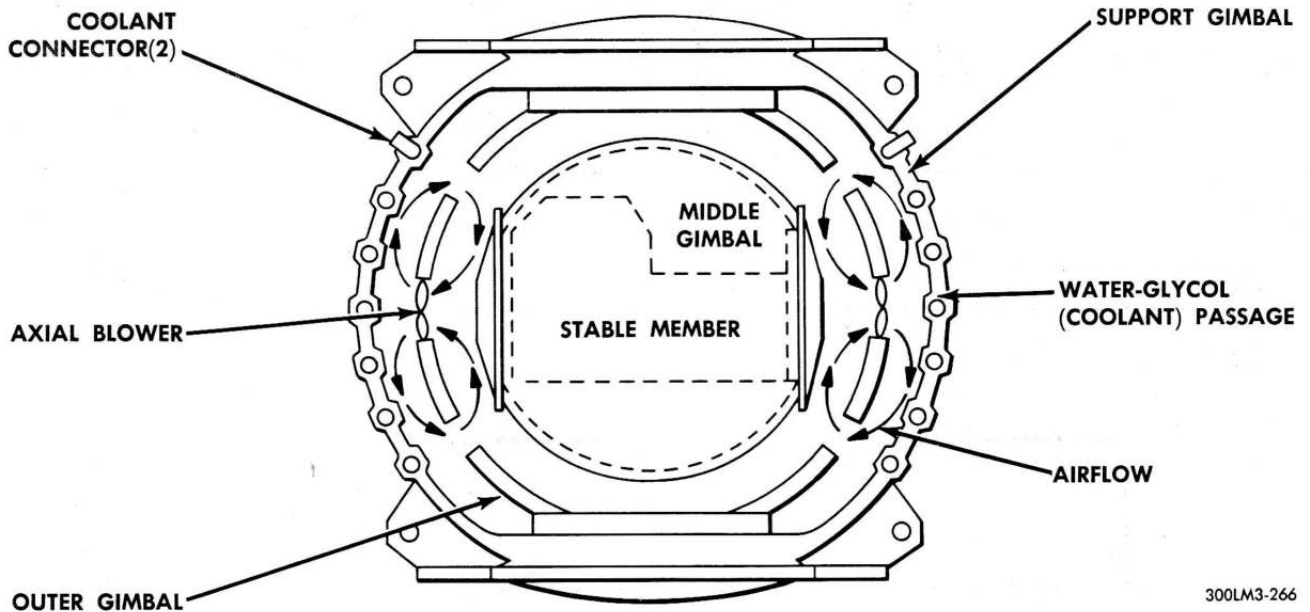


Figure 2-10. IMU Temperature Control

300LM3-265



300LM3-266

Figure 2-11. IMU - Forced Convection Cooling

The three CDU's used with the IMU provide interfaces between the IMU and the LGC, and between the LGC and the AGS. Each IMU gimbal angle transmitter resolver provides its CDU with analog gimbal-angle signals that represent LM attitude. The CDU converts these signals to digital form and applies them to the LGC. The LGC uses these signals to calculate necessary attitude or translation commands and routes the commands through the CES to the proper TCA. The CDU converts the steering-error signals to 800-cps analog signals and applies them to the FDAI. IMU coarse- and fine-alignment commands generated by the LGC are coupled to the IMU through the CDU's.

The CDU's are electronic devices that perform four functions, as follows:

- Analog-to-digital conversion
- Digital-to-analog conversion
- Moding
- Failure detection.

Each CDU is a sealed container, which encloses 34 modules of 10 types. The 10 types of modules make up five almost identical loops: one each for the inner, middle, and outer gimbals and one each for the RR gimbals. Several CDU modules are shared by the five loops.

Analog-to-Digital Conversion. (See figure 2-13.) Analog signals are received by the CDU from the IMU or the RR 1X or 16X resolvers. The magnitude of these signals is indicative of the degree of angular displacement of the resolver; the phase is indicative of the direction of angular displacement.

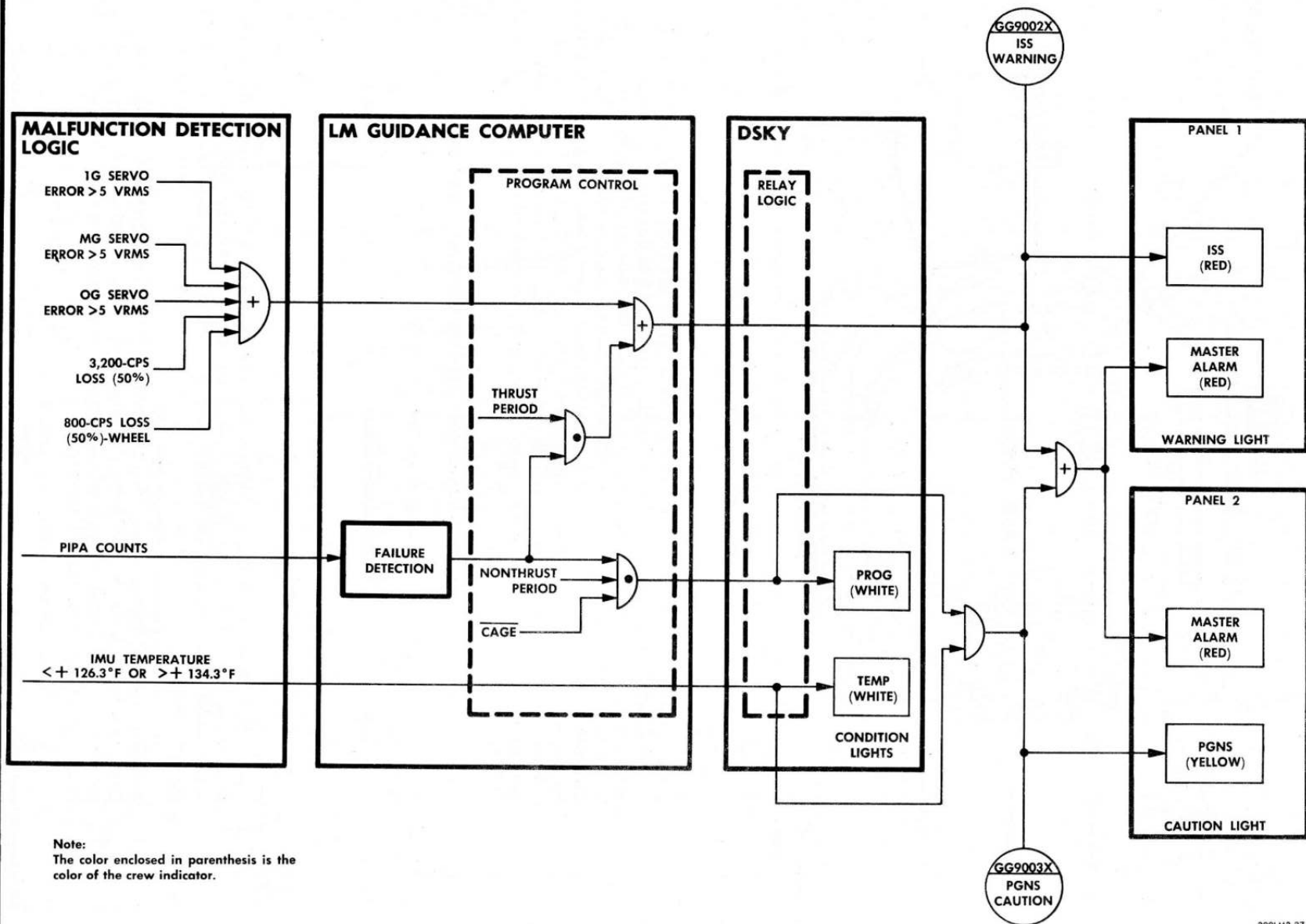


Figure 2-12. IMU Failure-Detection Logic

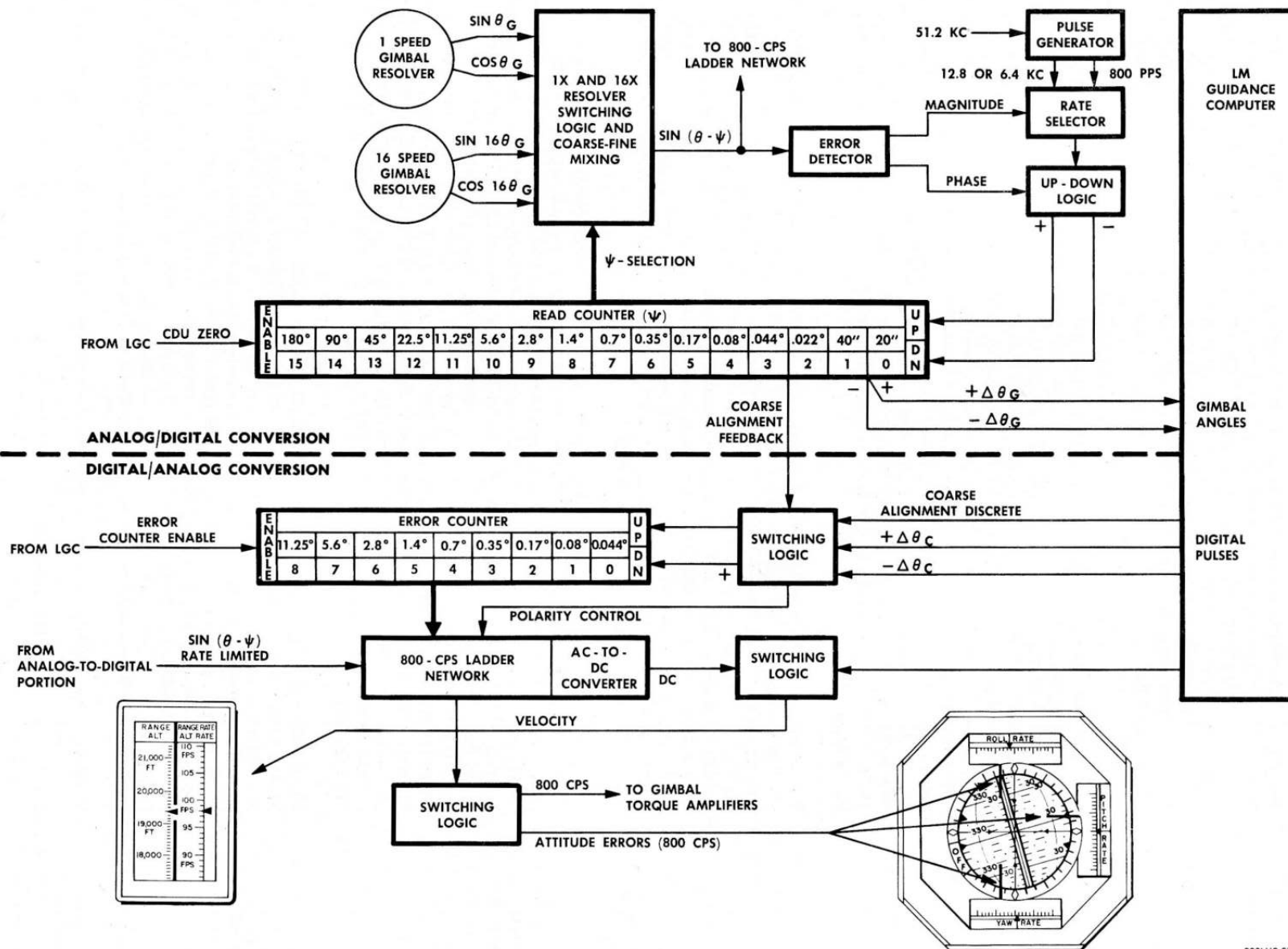


Figure 2-13. CDU Digital-to-Analog and Analog-to-Digital Conversion Breakdown

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

The inputs are phase shifted and attenuated by the switching logic and coarse-fine mixing block. The signals are used as an input to an error detector circuit. The error detector monitors the phase and amplitude of the 800-cps error output of the mixing and attenuation circuit. The phase of the signal determines whether the digital signal to be generated is positive or negative. The amplitude of the signal determines whether the digital pulses, equivalent to 20 arc seconds of gimbal displacement are generated at 800 pps or 12.8 kpps. The digital pulse train is the input to a 16-bit binary read counter.

The read counter, with binary stages designated as 2^0 to 2^{15} , counts the pulse train generated by the rate select and up-down logic circuitry. The 2^0 or least significant bit output is transmitted to the LGC as a gimbal angle change ($\Delta \theta_c$) equivalent to 40 arc seconds. This is the only information pertaining to gimbal angles or angle changes transmitted from the CDU to the LGC. During the ISS coarse-alignment mode of operation, a $\Delta \theta_g$ of 160 arc seconds per pulse is transmitted from the 2^2 output stage to the error counter of the CDU. The two stages (2^0 and 2^2) and the remainder of the read counter permit accumulation of the gimbal angle, with the least significant bit equivalent to 20 arc seconds of gimbal angle and the most significant bit (2^{15}) equivalent to 180° of gimbal displacement. The read counter can accumulate a total gimbal angle of $359^\circ 59' 40''$. The contents of the read counter are not accessible for readout or display at any time.

The primary function of the read counter is to provide the incremental ψ angles to be used in the coarse-fine mixing and switching logic for the mechanization of the trigonometric identity $\sin(\theta - \psi)$. When the read counter has accumulated value ψ equal to the angle θ , the input to the error detector is nulled and the read counter does not receive additional input pulses until a change in gimbal angle occurs. During certain ISS modes of operation, the read counter receives a reset pulse that sets the counter to zero. This command is generally given when the system is energized to permit the gimbals and the read counter to come into agreement with each other before using the gimbal angle information stored in the computer.

Digital-to-Analog Conversion. (See figure 2-13.) The error counter, a nine-bit (2^0 to 2^8) counter, is used primarily in the conversion of digital data to its analog equivalent. With only one exception, coarse alignment, the error counter is operated solely from LGC input data. Each pulse into the error counter, whether from the LGC or from the read counter is equivalent to 160 arc seconds of gimbal angle displacement or attitude error. The counter must be enabled by an error counter enable discrete from the LGC. When attitude error is to be displayed, the counter accumulates the pulse train from the LGC and maintains that value until the LGC either counts the value down or removes the error counter enable discrete. In the coarse-alignment mode of operation, the read counter, as it accumulates increasing gimbal angles due to a coarse repositioning of the gimbal, can cause the contents of the error counter to decrease toward zero.

When the binary stages of the error counter are switched, switches in the 800-cps ladder network of the digital-to-analog converter are opened or closed. As the ladder switches are closed, an 800-cps analog signal, whose amplitude is proportional to the contents of the error counter and whose phase is determined by a positive or negative value stored in the error counter, is generated in the digital-to-analog converter. If the LGC moding control has selected a coarse-alignment or attitude error display mode, the 800-cps signal is used without conversion to dc. If the error counter contents are indicative of an LGC-calculated forward and lateral velocity signal, the 800-cps, 0 or π phase signal is converted from ac to dc for use as a display drive signal.

Moding. The moding section of the CDU receives the following discretes from the LGC:

- ISS CDU zero
- ISS error counter enable

- RR CDU zero
- RR error counter enable
- ISS coarse alignment
- Display inertial data (DID).

The DID command is routed to the LGC and the CDU moding section by setting the MODE SEL switch (panel 1) to PGNS. The LGC discretes are buffered and processed by the moding section to the proper logic levels and timing for use in other sections of the CDU. The CDU zero discrete, besides being used in the CDU, is sent to the AGS to initialize the PGNS angle input registers and start accumulation of PGNS alignment signals.

Failure Detection. (See figure 2-14.) Failure-detection circuits monitor CDU circuitry for malfunctions. The failure-detection circuits monitor ISS CDU performance and RR CDU performance; they operate identically for both. Upon detection of an out-of-tolerance condition, an ISS CDU failure or RR CDU failure discrete is issued to the LGC. The LGC then issues a failure discrete to the caution and warning electronics for display.

Pulse Torque Assembly. The PTA consists of a group of modular electronic assemblies used in the pulsing circuits of the gyros and accelerometers. The PTA is mounted close to the IMU to avoid line loss in low-level signals. (See figure 2-2 and paragraph 2.2.1.)

Power and Servo Assembly. The PSA provides a central mounting point for the PGNS amplifiers, modular electronic components, and power supplies. The PSA is on the cabin bulkhead behind the astronauts. (See figure 2-2 and paragraph 2.2.) It consists of 15 subassemblies mounted to a header assembly. Connectors and harnesses are integral to the header assembly. A thin cover plate, mounted on the PSA, hermetically seals the assembly. During flight, this permits pressurization of the PSA to remain at 15 psi. Connectors at the PSA permit measuring signals at various test points.

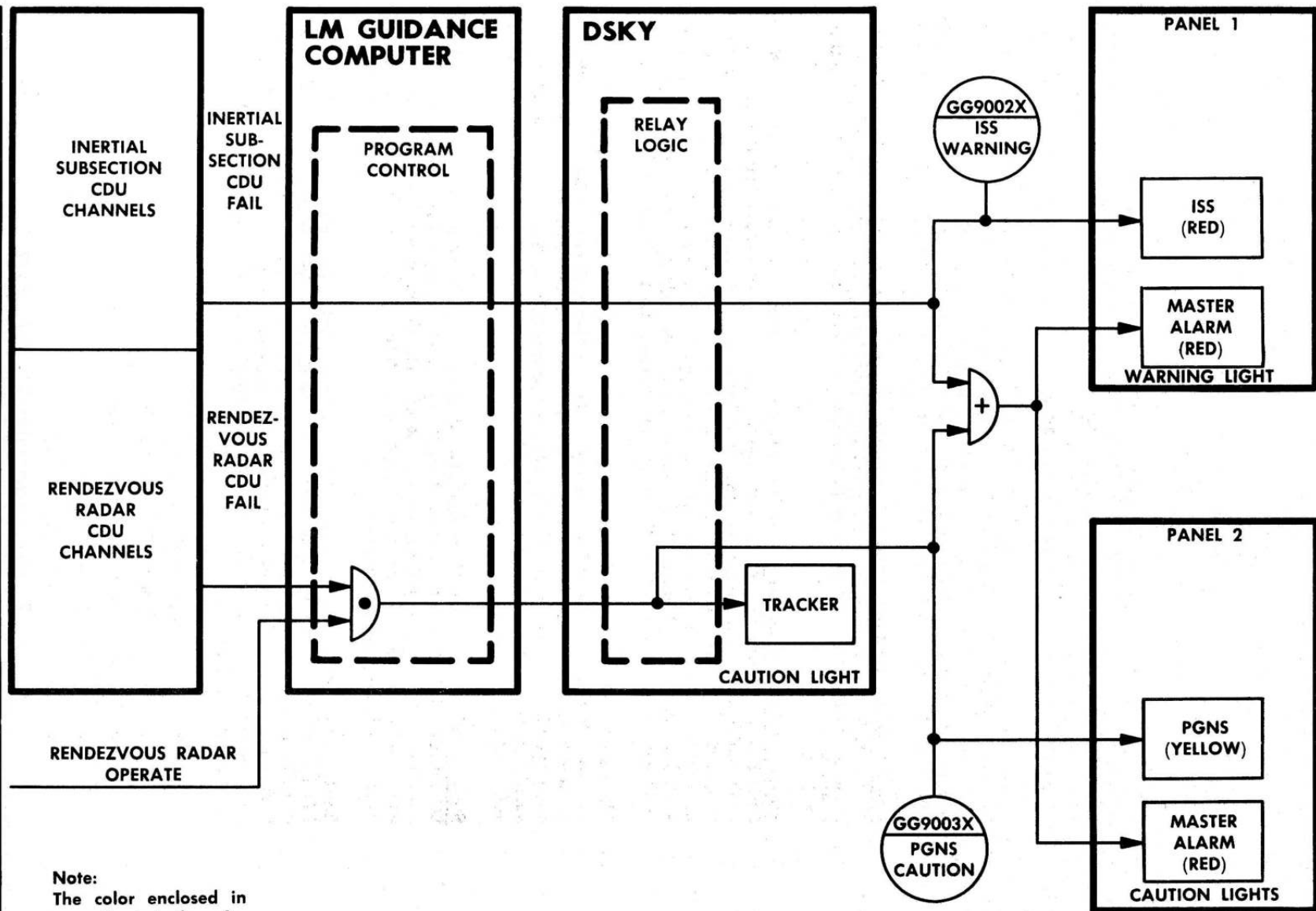
The PSA consists of the following subassemblies: three gimbal servo-amplifiers, one amplifier module and one filter module for the 3,200-cps power supply, three amplifiers and one filter module for the 800-cps 1% and 5% power supplies, one -28-volt d-c power supply, one power supply filter for prime 28-volt d-c power, one power supply for the signal conditioner, and three subassemblies for load-compensating relays and auxiliary functions.

Signal Conditioner. The SC provides an interface between the PGNS and the IS. The SC converts PGNS signals to levels acceptable for telemetry transmission and provides isolation between the signal source and the IS. The SC receives various PGNS signals and conditions them to a common voltage range (0 to 5 volts dc) and to an impedance range that is suitable for telemetry.

Inertial Power Supplies. (See figure 2-15.) Input power for the ISS is taken from the LM 28-volt dc bus supplied from the EPS. The nominal input voltage is 28.3 ± 2.5 volts d-c with transient limits between 24.0 and 31.8 volts dc. In addition to the 28-volt d-c input from the EPS, the power supplies require clock pulses from the LGC. These clock pulses are of various frequencies, as shown in figure 2-15. The ISS power supplies are as follows:

- Pulse torque power supply
- 28-volt, 800-cps 1% power supply
- 28-volt, 800-cps 5% power supply
- -28-volt d-c power supply
- 28-volt, 3,200-cps power supply.

300LM3-276



Note:
 The color enclosed in parenthesis is the color of the crew indicator.

Figure 2-14. CDU Failure Detection Logic

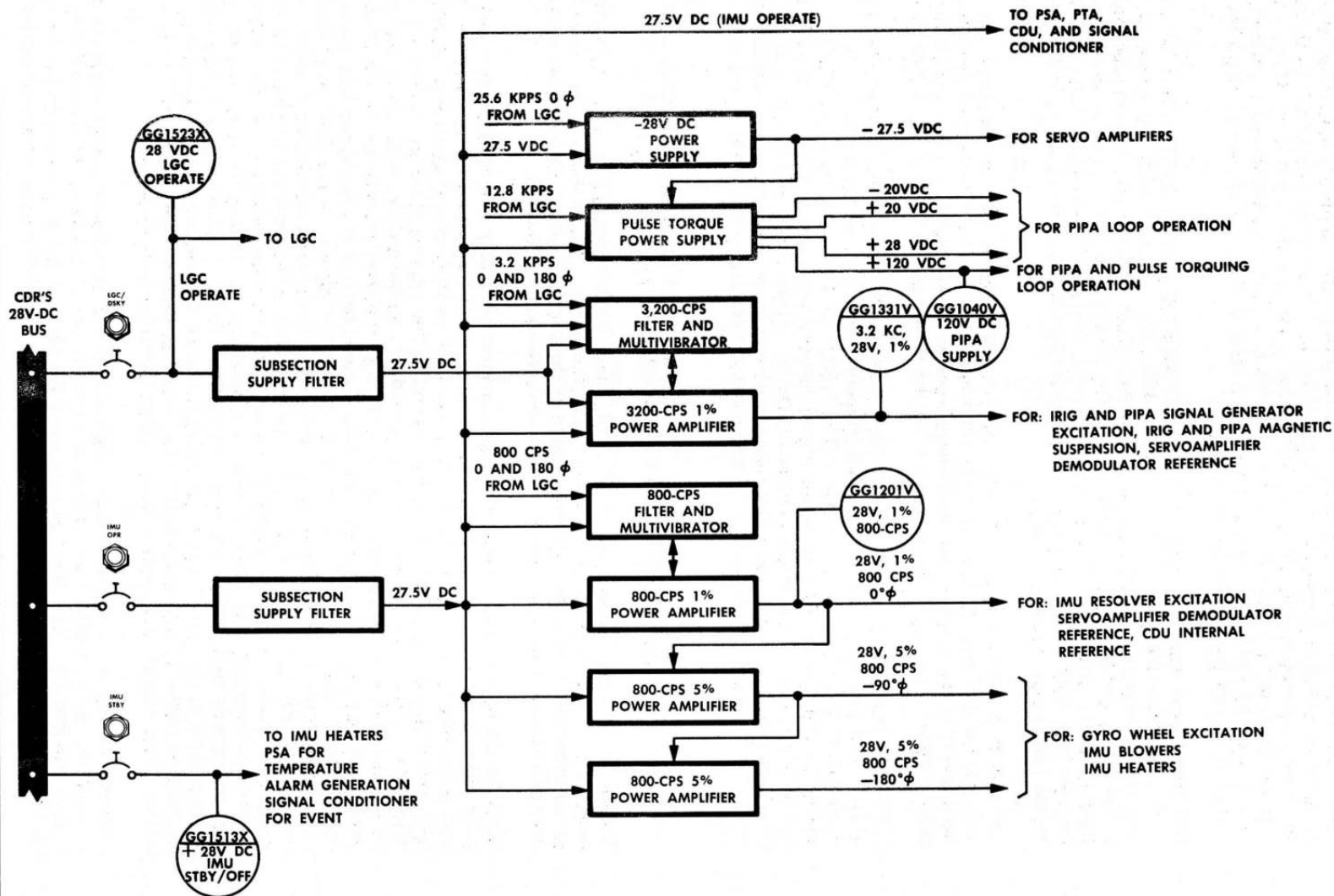


Figure 2-15. Inertial Subsection Power Distribution - Block Diagram

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Pulse Torque Power Supply. The pulse torque power supply provides +28-volt d-c to the three binary current switches and three d-c differential amplifiers in the PIPA loops and to the binary current switch and d-c differential amplifier in the fine-alignment electronics associated with the stabilization loops. This supply also provides three individual +28-volt d-c inputs to the PIPA loop, a +20-volt d-c input to the three a-c differential amplifier and interrogator modules and their associated binary current switches in the PIPA loop, and a -20-volt d-c input to the a-c differential amplifier and interrogator module in the PIPA loop.

800-CPS Power Supplies. The 800-cps power supplies provide the ISS with 1% 0°, 5% -90°, and 5% -180° power. The 28-volt, 800-cps, 1% power supply provides the IMU resolver excitation, stabilization amplifier demodulator reference, a reference signal to the FDAI, and a reference to the CDU. The 1% amplifier output is also used as an input to the 5% amplifier. The 28-volt, 800-cps, 5% power supply amplifiers provide the -90° and -180° excitation power for the gyro wheels, the IMU blowers, PIPA fixed heater power and bias heater power.

-28-Volt D-C Power Supply. The -28-volt d-c power supply provides negative d-c inputs to the d-c amplifiers used in the ISS loops. The -28-volt d-c supply provides input power to the three gimbal servoamplifiers in the stabilization loops and to the pulse torque power supply to generate -20 volts dc for use in the accelerometer loops.

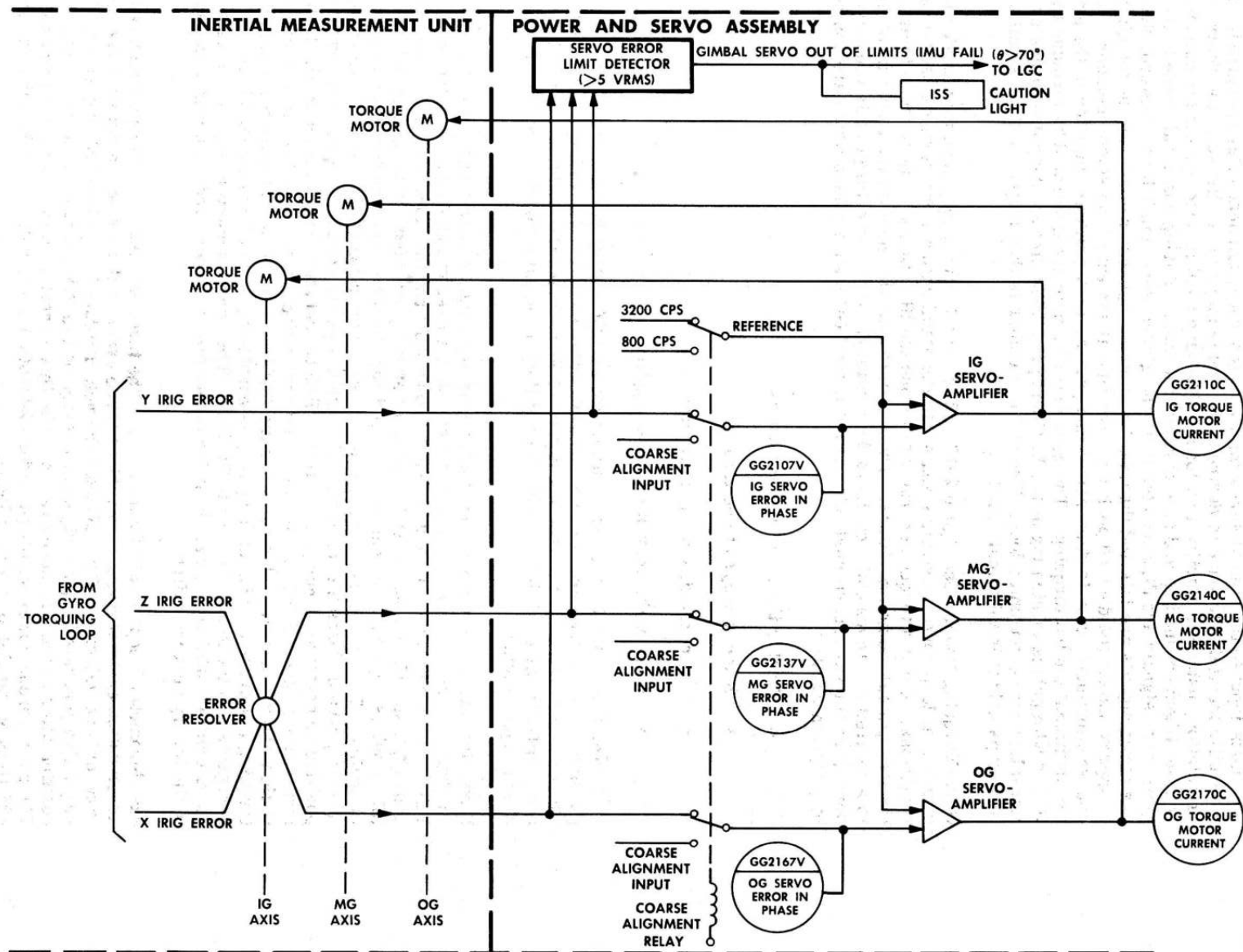
3,200-CPS Power Supply. The 3,200-cps power supply provides the IMU with 28-volt power, which is then reduced through a transformer to 2- and 4-volt levels. The transformer is on the stable member. The 3,200-cps 1% power supply provides excitation voltages (2 and 4 volts) for signal ducosyn signal-generator excitation and for magnetic suspension winding excitation for the torque and signal ducosyns of the IRIG's and PIPA's. The 3,200-cps output is also used as a reference for the demodulator of the gimbal servoamplifier in all modes of operation, except the coarse-alignment mode.

Inertial Subsection Functional Loops. The ISS functional loops consist of three stabilization loops, a gyro-torquing loop, and three accelerometer loops.

Stabilization Loops. (See figure 2-16.) The three stabilization loops maintain the stable member rotationally fixed with respect to inertial space. The stable member is used as the reference to maintain the orientation of the accelerometers with respect to the inertial frame of reference and as an attitude reference for the LM.

When the stabilization loops hold the stable member inertially referenced, any movement of the stable member is sensed by one or more of the three IRIG's. (For the location of the IRIG's, see figure 2-7.) This results in an IRIG-signal-generator, 3,200-cps, error signal output, which is proportional to the rotation of the gyro about its input axis. This error signal is then amplified by a preamplifier, which is an integral part of the IRIG assembly. The Y-gyro error signal passes directly to the associated gimbal servoamplifier through the normally closed contacts of the coarse-alignment relay. The X-gyro error signal and the Z-gyro error signal are resolved about the IGA by the gyro error resolver before being introduced to the associated gimbal servoamplifiers. The servoamplifier current output is fed to the appropriate gimbal torque motor to restore the stable member to its original reference position. As the stable member is returned to its original reference position, the movement sensed by the IRIG is opposite in direction but equal in magnitude to the disturbance input, and results in precession of the float. Due to precession, the float returns to its null position. Because no output is then present from the signal generator, the loop is nulled and no further drive signals are applied until another disturbance is introduced.

Resolution of the X- and Z-gyro error signals is required because motion about the MGA or the OGA, with the stable member at some angle other than zero, is sensed by the X-gyro and Z-gyro. The resolver then sums the components of gyro error that lie along the MGA or OGA and directs the gyro errors to the applicable gimbal servoamplifier.



300LM3-278

Figure 2-16. Stabilization Loops - Functional Diagram

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

When the stabilization loops are initially energized, the stable member is referenced to the LM axes (zero) by driving the gimbals with an error signal inserted at the coarse-alignment input to the gimbal servoamplifiers (coarse-alignment relay energized). If a specific inertial reference is desired, the stable member is aligned to the desired orientation, using the stabilization loops. The alignment is accomplished in two steps: coarse-alignment moding and fine-alignment moding. During coarse alignment, the gyro error signals are disconnected from the gimbal servoamplifiers. Instead, 800-cps error signals are injected through the coarse-alignment relay to torque the gimbals to approximately the desired position. For fine alignment of the stable member, the coarse-alignment relay is deenergized and gyro error signals are injected in the loops for additional gimbal torquing. The gyro error signals are generated by torquing the IRIG's with pulses originating at the LGC and processed through the pulse torque or fine-alignment electronics loop. The stable member is then aligned and the stabilization loops hold it in this final position.

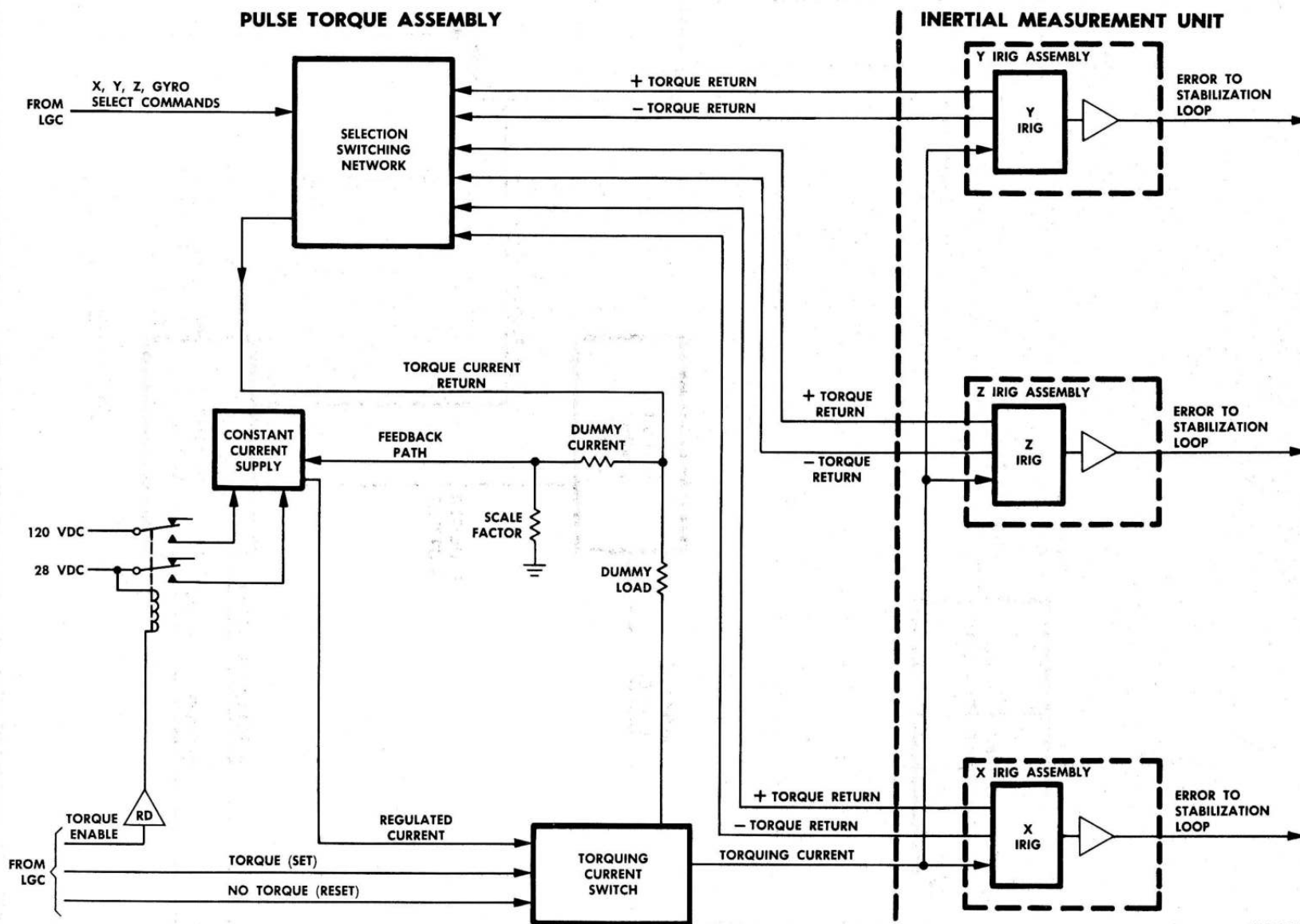
Gyro-Torquing Loop. (See figure 2-17.) The gyro-torquing loop permits introduction of external loop control driving signals into the stabilization loops during closed-loop conditions. Using a torque generator to torque the IRIG floats, it is possible to drive the IMU gimbals to new positions. This permits fine alignment of the stable member to a desired reference with considerable accuracy. When gyro torquing is required during the fine-alignment mode of operation, the LGC issues pulses which are controlled by program 52 that:

- Enable the torquing electronics
- Select the gyro to be torqued
- Select the direction of torquing
- Control the amount of torque applied.

The three IRIG's are torqued sequentially by the LGC during fine alignment; it is possible for all three gyros to be controlled through one set of torquing electronics. The torquing electronics consists of a gyro calibration module, a binary current switch, a d-c differential amplifier and precision voltage reference module, and a pulse torque power supply module.

Basically, the gyro-torquing loop operates by applying a constant current to the torque windings in the IRIG. When torque pulses and gyro select pulses are initiated by the LGC, a constant direct current is applied to an IRIG and the float is torqued a specific amount; a specific amount of IMU gimbal rotation is provided. The number of torque (SET) pulses applied to the current switch determines how long the torquing current is applied. The gyro select pulses enable a switching network (in the gyro calibration module), which closes a current path through a specific winding in a specific gyro for positive or negative torquing of the float. Before and after actual torquing, the LGC issues no-torque (RESET) pulses to the current switch, which enables constant current to flow along a dummy path external to the IRIG's. This reduces transients when actual torquing is initiated. The torquing loop is enabled by an LGC command, which energizes a relay to apply power to the loop. The constant-current supply consists of the d-c differential amplifier, the pulse torque power supply, and a current regulator in the binary current switch.

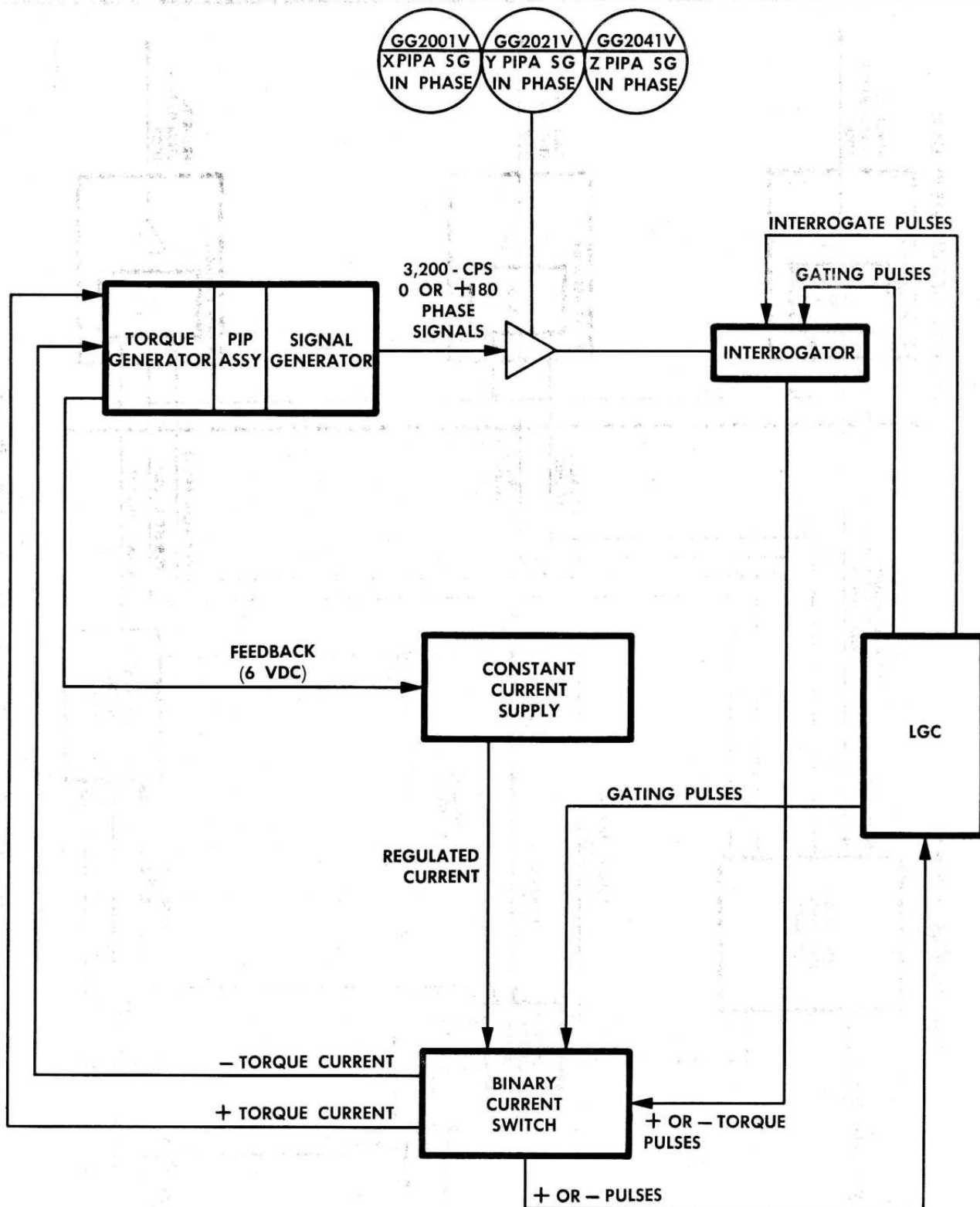
Accelerometer Loops. (See figure 2-18.) The three accelerometer loops measure the acceleration of the stable member along three orthogonal axes and integrate these data to determine velocity. The LGC uses the velocity data to compute LM trajectory. The loops also generate torquing signals for torquing the PIP pendulums back to a null position after sensing an acceleration. The three accelerometer loops are identical. The pulse torque power supply provides +20 volts dc, -20 volts dc, +120 volts dc, and +28 volts dc regulated to all the loops.



300LM3-279

Figure 2-17. Gyro Torquing Loop - Functional Diagram

LMA790-3-LM 3
 APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA



300LM3-280

Figure 2-18. Accelerometer Loop - Functional Diagram

GUIDANCE, NAVIGATION, AND CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

The PIP signal generator outputs are two 3,200-cps error signals, which are of opposite phase and proportional to the rotation of the pendulum about its output axis. These error signals are amplified by the preamplifier and, then, routed to the a-c differential amplifier. There the two signals are summed; the resultant is amplified and, then, phase split. The two resulting signals are of opposite phase; they are fed to the interrogator circuitry, which determines the direction of pendulum movement and generates positive or negative commands indicative of the direction of movement. The interrogate and switching pulses from the LGC are used to generate the positive or negative torque pulses to the binary current switch.

The binary current switch uses the interrogator outputs to generate torquing current (to torque the pendulums back to null) and pulses that represent velocity changes. The velocity pulses are generated by providing data pulses from the LGC such that the velocity outputs are positive or negative increments of velocity. The torquing current is generated in a manner similar to that used in the gyro-torquing loop. The constant-current supply consists of a d-c differential amplifier and precision voltage reference and a current regulator. Constant current is supplied to the binary current switch. A positive or negative input command turns on the positive or negative current switch, routing a positive or negative torque signal to the torque windings in the PIP. The torquing current to the PIP torque generator is fed through a load-balancing network in the calibration module. This ensures that for a given amount of torquing current an equal amount of torque is developed in the positive or negative direction.

When the accelerometer loops operate, a certain amount of PIP torquing occurs at all times, even during periods of no acceleration. This torquing continuously moves the pendulums an equal amount in the positive and negative directions; as a result, an equal amount of positive or negative velocity pulses are sent to the LGC. When an acceleration is sensed, more of one type of pulse is generated. This unbalance produces either positive or negative ΔV pulses, which are routed to the LGC PIPA counter to be accumulated as LM velocity changes.

Modes of Operation. The ISS modes of operation are listed and defined in table 2-1. Except for the IMU cage and inertial reference modes, the modes are controlled by the CDU as commanded by the LGC. The IMU cage mode is initiated when the IMU CAGE switch (panel 1) is set to ON. The inertial reference mode is entered automatically whenever the ISS is not in another mode. The CDU logic receives the following discrete commands:

- ISS CDU zero
- ISS error counter enable
- Coarse-align enable
- RR CDU zero
- RR error counter enable
- Display inertial data (DID) (program controlled).

The ISS CDU zero, ISS error counter enable, and ISS coarse-align enable discretely control three identical channels in the ISS portion of the CDU. The RR CDU zero, RR error counter enable, and DID discretely control the RR azimuth and elevation channels in the RR portion of the CDU. All discretely, except RR CDU zero, are used for moding operations. In addition to the LGC-CDU discretely, the LGC issues a torque enable command to the gyro torque loop for initiation of the fine-alignment mode.

Table 2-1. Inertial Subsection - Modes of Operation

ISS Mode	Purpose	LGC Discretes Issued						Switch Action Discretes to LGC		
		ISS CDU Zero	ISS Error Counter Enable	Coarse- Align Enable	RR Error Counter Enable	Gyro Torque Enable	Display Inertial Data	Close PGNS: IMU OPR cb	IMU CAGE sw - ON	Display Request (MODE SEL sw - PGNS)
ISS turn-on	Initializes ISS	X		X				X		
Coarse alignment	Rapidly drives IMU gimbals to desired position, with limited accuracy		X	X						
Fine alignment	Accurately positions stable member at pre-determined attitude					X				
Attitude error display	Permits LGC-calculated attitude errors (roll, pitch, and yaw) to be displayed to astronauts		X							
Display inertial data	Permits LGC-calculated forward and lateral velocities to be displayed to astronauts				X		X			X
IMU cage	Sets IMU gimbals to their zero position								X	
Gimbal lock	Provides astronauts with indications of approach of gimbal lock and loss of inertial reference due to gimbal lock			X						
Inertial reference	Maintains reference coordinate system upon which guidance and navigation calculations can be based									

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

IMU Turn-On Mode. (See figure 2-19.) The IMU turn-on mode initializes ISS operation by driving the IMU gimbals to zero and clearing and inhibiting the CDU read counters and error counters. The IMU turn-on mode (program controlled; see program 05, table 2-8) is initiated by applying IMU operate power to the ISS. The LGC issues the two discretes required for this mode: CDU zero and coarse align. The LGC also issues the turn-on delay complete discrete to the ISS after 90 seconds.

When IMU power is applied to the ISS, the LGC receives an ISS power-on discrete and a turn-on delay request. The LGC responds to the turn-on delay request by issuing the CDU zero and coarse-align enable discretes to the CDU. To prevent PIPA torquing for 90 seconds during the IMU turn-on mode, an inhibit signal is applied to the pulse torque power supply. The CDU zero discrete clears and inhibits the read counters. The error counters are cleared and inhibited. The ISS power (28 volts dc) is applied directly to the coarse-alignment relay and, through the deenergized contacts of the turn-on control relay, to energize the cage relay. A ground is provided through the energized contacts of the cage relay to the coil of the coarse-alignment relay, energizing the coarse-alignment relay. The energized contacts of the coarse-alignment relay switch the gimbal servo-amplifier reference from 3,200 cps to 800 cps and close the IMU cage loop through the energized contacts of the cage relay.

The coarse-alignment relay is held energized by the CDU coarse-align discrete and the energized contacts of the cage relay. The IMU gimbals drive to the zero reference position, using the sine output of the 1X gimbal resolvers ($\sin \theta$).

After 90 seconds, the LGC issues the ISS turn-on delay complete discrete, which energizes the turn-on control relay. The turn-on control relay locks up through its own energized contacts. Energizing the turn-on control relay removes the turn-on delay request and deenergizes the cage relay, removing the $\sin \theta$ signal. Energizing the turn-on control relay also removes the pulse torque power supply inhibit signal. The 90-second delay permits the gyro wheels to reach their operating speed before the stabilization loops close. The pulse torque power supply inhibit signal prevents accelerometer torquing during the 90-second delay.

After the 90-second delay, the LGC program removes the CDU zero and coarse-align enable discretes, allowing the ISS to go to the inertial reference mode (coarse-alignment relay deenergized), or it can remove the CDU zero discrete and provide an error counter enable discrete while maintaining the coarse-align enable discrete. The latter combination of discretes defines the coarse-alignment mode of operation.

Coarse-Alignment Mode. (See figure 2-20.) The coarse-alignment mode enables the LGC to align the IMU rapidly to a desired position, with limited accuracy. In this mode, the LGC issues two discretes to the CDU: coarse-align enable and ISS error counter enable.

The coarse-align enable discrete is routed through the CDU, where it provides a ground path to the coarse-alignment relay, energizing the relay. The energized relay opens the gyro preamplifier output, replaces the normal 3,200-cps reference with an 800-cps reference, and routes the 800-cps coarse-alignment output from the CDU digital-to-analog converter to the gimbal servoamplifier. This drives the gimbal until the coarse-alignment signal is zero volts rms. The coarse-align enable discrete and error counter enable discrete are also accepted by the CDU logic as moding commands, enabling the error counter and permitting transfer of $\Delta \theta_g$ angles from the read counter to the error counter.

After the logic circuitry in the CDU has been set up to accept commands from the LGC, the LGC begins transmitting positive or negative $\Delta \theta_c$ pulse trains at 3,200 pps. These pulses, each equivalent to a gimbal angle change of 160 arc seconds, are accumulated in the error counter. The first $\Delta \theta_c$ pulse determines the direction in which the error counter is to count and provides a digital-to-analog converter polarity control to the digital-to-analog converter. The polarity control provides an in-phase or an out-of-phase analog reference. An 800-cps analog signal, whose amplitude is dependent on

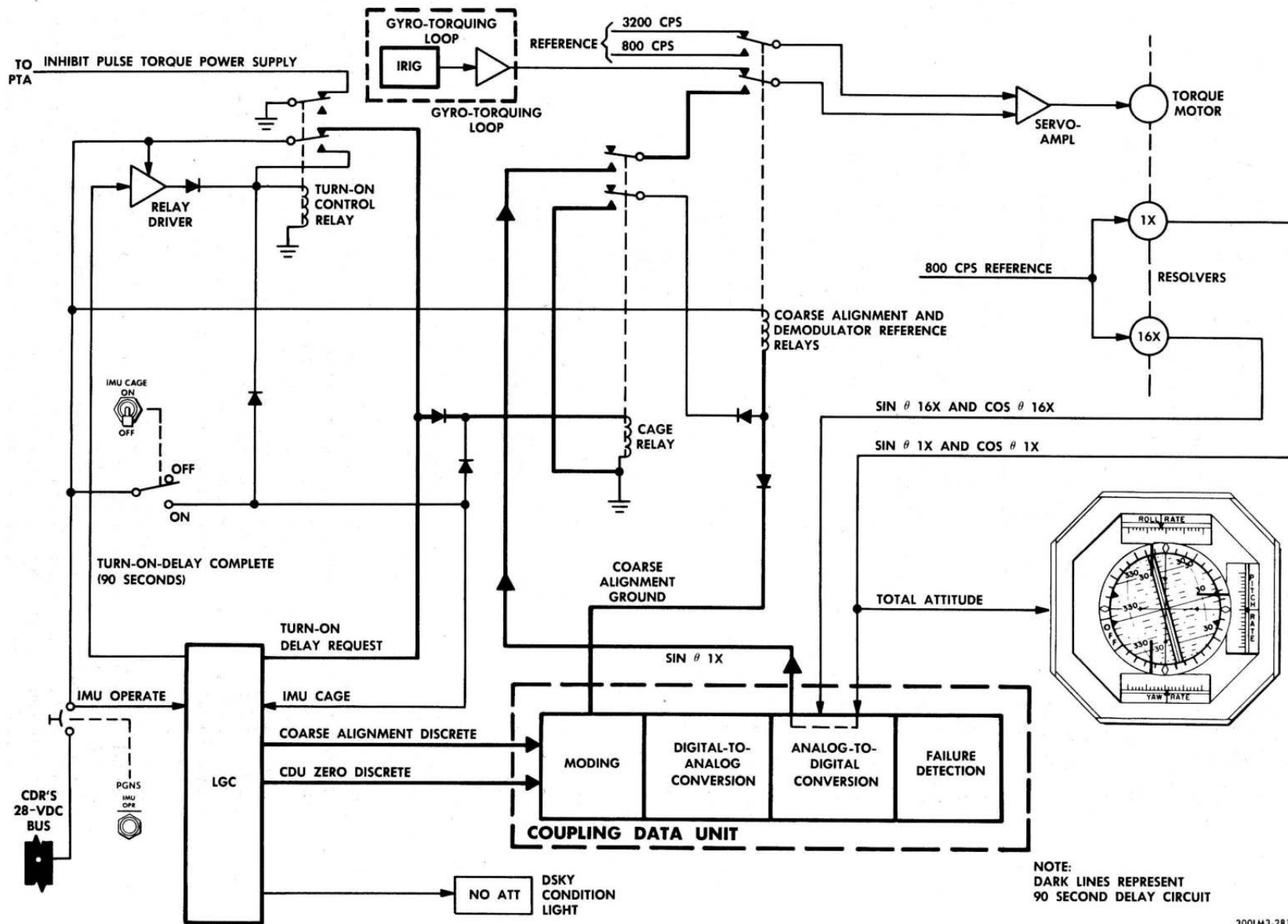
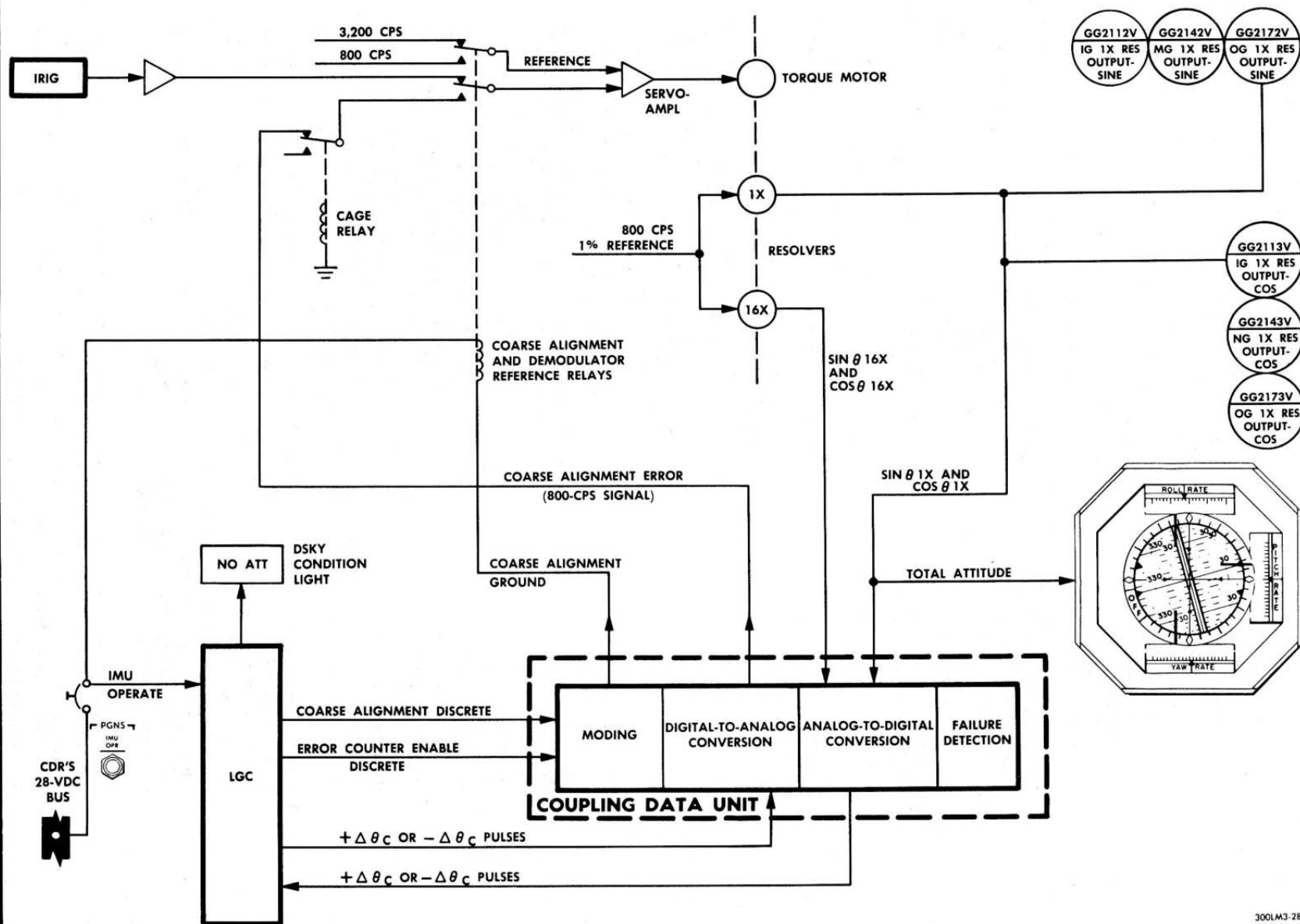


Figure 2-19. IMU Turn-On and Gage Modes - Functional Diagram

GUIDANCE, NAVIGATION, AND CONTROL SUBSYSTEM


 LMA790-3-LM 3
 APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

300LM3-282

Figure 2-20. Coarse Align Mode - Functional Diagram

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

the error counter content and the polarity of the input command ($\Delta \theta_c$), is then generated. This signal is the 800-cps coarse-alignment output from the digital-to-analog section; it is routed to the gimbal servoamplifier, causing the gimbal to drive in the direction commanded by the LGC.

The changing gimbal angles are detected by the error-detection circuits in the CDU. These detected errors permit a pulse train, at 6,400 pps, to increase the read counter. The increasing read counter nulls the sine and cosine voltage inputs from the IMU 1X and 16X resolvers into the error detector circuits.

As the read counter is being incremented, one output of the counter, representing an increase in gimbal angle of 40 arc seconds per pulse, is routed to the LGC. Another output of the counter, representing 160 arc seconds per pulse, is recognized in the CDU logic as an incremental value to be entered into the error counter in a direction opposite to that of the LGC-commanded $\Delta \theta$. If $\Delta \theta$ is positive, the error counter counts up and the $\Delta \theta_g$ from the read counter decreases the counter. For each counter pulse into the error counter the total content decreases, thereby decreasing the digital-to-analog converter output and, therefore, the rate of drive. When the number of digital feedback pulses equals the LGC-commanded number of pulses, the error counter is empty and the digital-to-analog converter output should be zero.

The rate of drive of the gimbals during coarse alignment is limited to a maximum of 35° per second. This is due to degenerative feedback provided within the CDU mechanization.

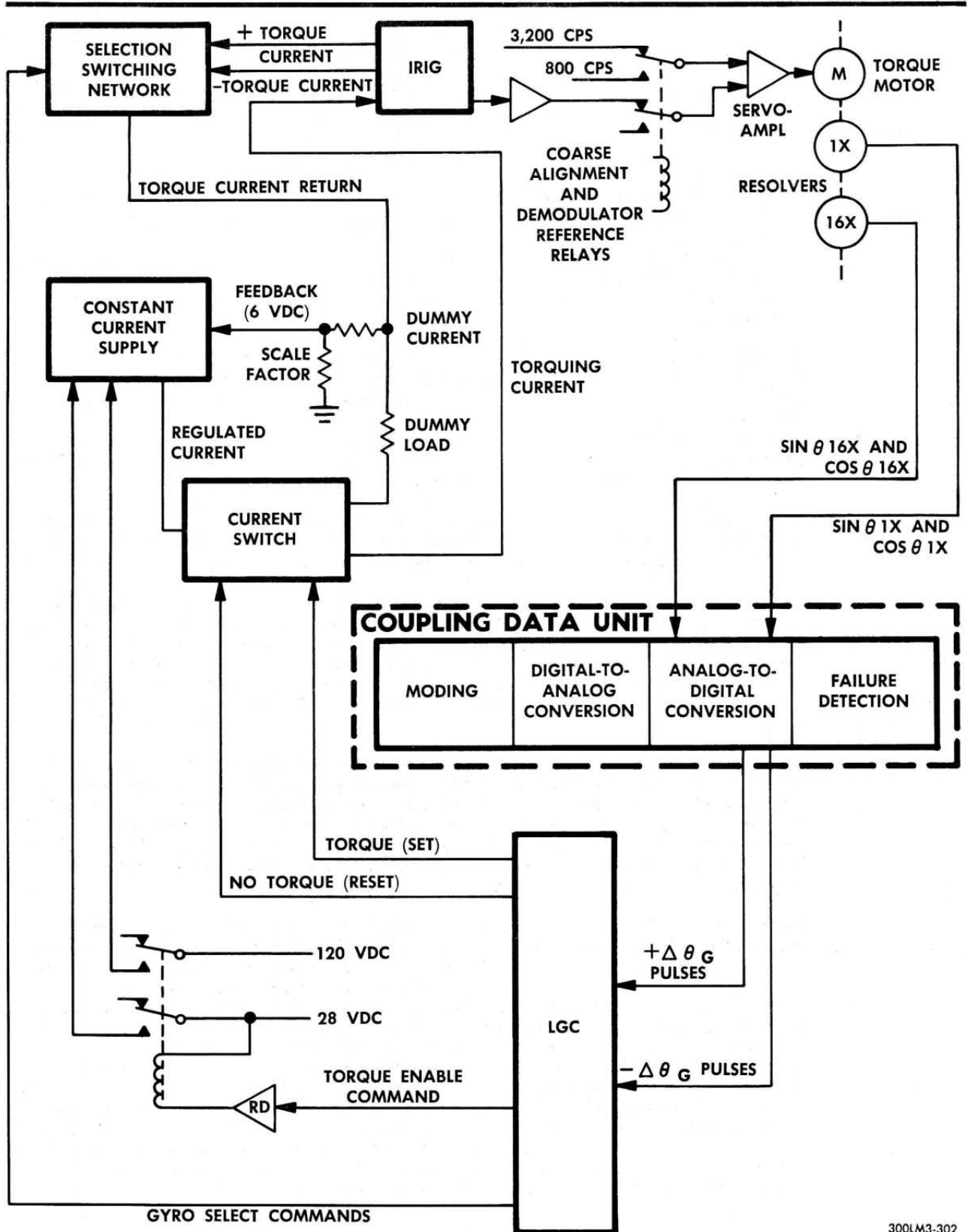
Fine-Alignment Mode. (See figure 2-21.) The fine-alignment mode allows the LGC to accurately position the IMU to a predetermined gimbal angle, within 40 arc seconds. The LGC does not issue any discretes to the CDU during this mode of operation; therefore, the read counter circuitry repeats the changing gimbal angles exactly as was done in the coarse-alignment mode. The LGC keeps track of the gimbal angle to within 40 arc seconds.

The commanding signals for the fine-alignment mode are issued to the time-shared fine-alignment or pulse torque electronics. The LGC first issues a torque enable discrete, which applies 28 and 120 volts dc to the binary current switch and a differential amplifier, and precision voltage reference circuit, allowing the circuit to become operative. The current switch is reset by the no-torque pulses, allowing a dummy current, which is equal to the torquing current, to flow. This allows the current to settle to a constant value before it is used for gyro torquing. A gyro is then selected (gyro select pulses) for either (positive or negative) torquing current. After the discretes have been issued, the LGC sends torque (SET) pulses or fine-alignment commands to the set side of the current switch. The pulse allows the selected torquing current (positive or negative) to flow through the gyro windings, causing the float to move. The resulting signal generator output causes the stable member to be driven through an angle equal to the commanded angle. The LGC receives inputs from the CDU read counter indicating a change in gimbal angle of 40 arc seconds per pulse.

The number of torquing pulses sent from the LGC to the torquing electronics is computed on the basis of gimbal angle at an instant of time and a desired alignment angle. The difference is converted into the number of pulses necessary to drive the gimbal through the difference angle. Each pulse sent is equivalent to 0.615 arc second of gimbal displacement. The required number of fine-alignment pulses is computed only once; it is not recomputed on the basis of gimbal angle after the desired number of pulses have been sent. Fine-alignment loop operation is open-loop as far as the LGC is concerned; the $\Delta \theta_g$ pulses are not used for feedback.

The fine-alignment pulses generated by the LGC are issued in bursts at a bit rate of 3,200 pps. The fine-alignment electronics permits the torquing current to be on in the direction chosen by LGC logic, for the duration of the pulse burst. When the LGC is not issuing fine-alignment pulses or the gyro floats are not being torqued, the stable member can be considered inertially referenced.

LMA790-3-LM 3
 APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA



300LM3-302

Figure 2-21. Fine Align Mode - Functional Diagram

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Attitude Error Display Mode. (See figure 2-22.) The attitude error display mode permits the LGC to display attitude errors, in analog form, to the astronaut. In this mode, a CDU error counter enable discrete is generated by the LGC; the LGC is informed of the gimbal angle and any changes to it by the read counter and the analog-to-digital converter associated with it. The read counter output is routed through logic to the LGC. The LGC is then aware of the current LM attitude.

The digital autopilot program has a computed desired attitude associated with current time and LM position. The difference between the desired and actual values is attitude error. The attitude error is converted to $\Delta\theta_c$ pulses (each equivalent to 160 arc seconds of error), which are fed to the error counter at a rate of 3,200 pps. The error counter is incremented to contain the number of pulses commanded. The contents of the error counter are converted to an 800-cps error signal by the digital-to-analog converter. The phase of the digital-to-analog converter output depends on whether the input command is a positive or negative $\Delta\theta$.

The 800-cps attitude errors, with a maximum amplitude of 5 volts rms, 0 or π phase, are displayed by the FDAI attitude error needles. Digital feedback from the read counter to the error counter is disabled during this mode of operation; only the LGC-generated $\Delta\theta$ commands increase or decrease the error counter. Total LM attitude can also be displayed on the FDAI. This information is taken from the gimbal angle 1X resolver sine and cosine windings. Pitch, yaw, and roll can be displayed from the inner, outer, and middle gimbals, respectively.

Display Inertial Data Mode. (See figure 2-23.) The DID mode is program controlled. This mode is initiated by setting the MODE SEL switch to PGNS. This arms the DID relay in the CDU and provides an input discrete to the LGC, requesting the DID program.

The LGC, upon recognition of the input discrete, issues a DID discrete to the CDU. This energizes the same DID relay, completing the interface between the CDU digital-to-analog converter and the X-pointer indicator. The LGC also issues a RR error counter enable discrete and an ISS error counter enable discrete to the CDU. This enables all five CDU error counters of which three ISS error counters are used for attitude error display; and two RR error counters, for forward and lateral velocity display.

Attitude error is displayed in the same manner as in the attitude error display mode. The ISS read counters repeat the gimbal angle changes and provide $\Delta\theta_g$ commands to the LGC, which then determines the attitude error. The attitude error is converted to a pulse train, which increases the CDU ISS error counters. The contents of the counters are converted to analog signals, which are fed to the FDAI for display. The read counter input to the error counter is inhibited, allowing the error counters to be increased or decreased only by the LGC.

For forward and lateral velocity display, the LGC receives positive and negative pulses from the ISS accelerometer loops and velocity data from the LR. On the basis of calculations derived from this information, the LGC increments the CDU RR error counters with $\Delta\theta_c$ commands, which are proportional to LM forward and lateral velocity. The contents of the error counters are converted to analog signals in the digital-to-analog conversion section. The resulting positive or negative d-c voltages are routed through the energized DID relay, the MODE SEL switch, and to the cabin displays. The CDU RR error counters operate independently of the read counter circuitry; therefore, the condition of the RR is immaterial for this operation. The CDU RR analog-to-digital sections are not affected by this mode, but may be used for RR antenna position readout, if required. Altitude or altitude rate is also displayed during this mode. The LGC calculates the altitude/altitude rate and sends this data directly to the ALT and RATE indicators via the MODE SEL switch and the RNG/ALT MON switch (panel 1). Altitude data from the LR are supplied to the LGC to aid in this calculation.

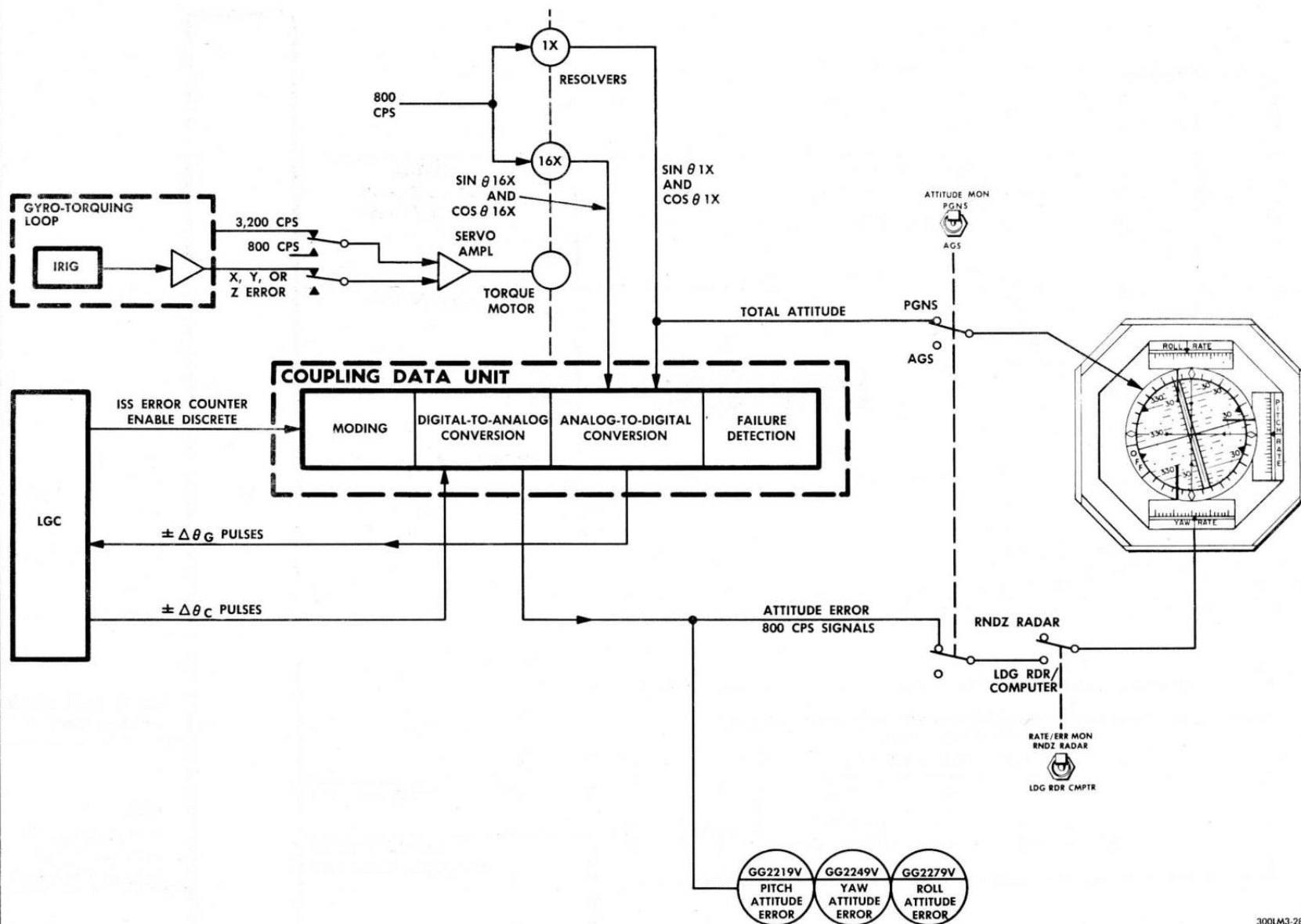


Figure 2-22. Attitude Error Display Mode - Functional Diagram



Figure 2-23. Display Inertial Data Mode - Functional Diagram

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

IMU Cage Mode. (See figure 2-19.) The IMU cage mode is an emergency mode that enables the astronauts to recover a tumbling IMU by setting the gimbals to zero, and to establish an inertial reference. This mode can also be used to establish an inertial reference when the LGC is not activated. The IMU cage mode is initiated by holding the IMU CAGE switch to ON for sufficient time (5 seconds maximum) to allow the IMU gimbals to settle at the zero position. The IMU gimbal zeroing can be observed on the FDAI. If the mode is commanded to recover a tumbling IMU after the IMU turn-on mode is completed or to establish an inertial reference with the CSS in standby or off, holding the IMU CAGE switch to ON drives the IMU gimbals to zero. When the switch is released, the ISS enters the inertial reference mode.

Holding the IMU CAGE switch to ON energizes the cage and coarse-alignment relays, which apply the $\sin \theta$ signals to the gimbal servoamplifiers, and sends an IMU cage discrete to the LGC. Releasing the switch deenergizes the cage and coarse-alignment relays. When the coarse-alignment relay is deenergized, the stabilization loops are closed. The LGC, upon receiving the IMU cage discrete, discontinues issuing discretetes.

The IMU cage mode should not be used indiscriminately. The mode is intended only as an emergency recover function for a tumbling IMU. During the IMU cage mode, the IMU gimbal rates are sufficient to drive the gyros into their rotational and radial stops due to the lack of CDU rate limiting.

Gimbal Lock Mode. (See figure 2-24.) The gimbal lock mode provides the astronauts with an indication of a large middle gimbal angle and disables the stabilization loop when gimbal lock occurs. An indication is also provided to notify the astronauts that the inertial reference has been lost. When the magnitude of the middle gimbal angle exceeds $+70^\circ$ or -70° , the LGC turns on the GIMBAL LOCK condition light on the DSKY. The light goes off as soon as the middle gimbal angle is less than $+70^\circ$ or -70° . If the magnitude of the middle gimbal angle increases to $+85^\circ$ or -85° , the LGC turns on the NO ATT condition light on the DSKY, indicating that the inertial reference is lost, and issues the coarse-alignment discrete to the CDU, which opens the stabilization loop and allows the stable member to be referenced to the LM. The astronauts can leave this mode by requesting the coarse-alignment mode via a DSKY entry.

Inertial Reference Mode. (See figure 2-25.) Inertial reference is considered a mode of ISS operation during any period after IMU turn-on is completed and the stabilization loops are closed (coarse-alignment relay deenergized) without any gyro-torquing occurring. The IRIG's hold the stable member inertially referenced, and the reference can be displayed on the FDAI from the gimbal angle 1X resolver sine and cosine outputs. The ISS is considered to be in the inertial reference mode of operation during any period after IMU turn-on is completed during which the ISS is not in any other of its modes. The CDU read counters continuously monitor gimbal angle changes due to LM motion and indicate to the LGC the changing angles. The error counters and the digital-to-analog converter are not used in this mode.

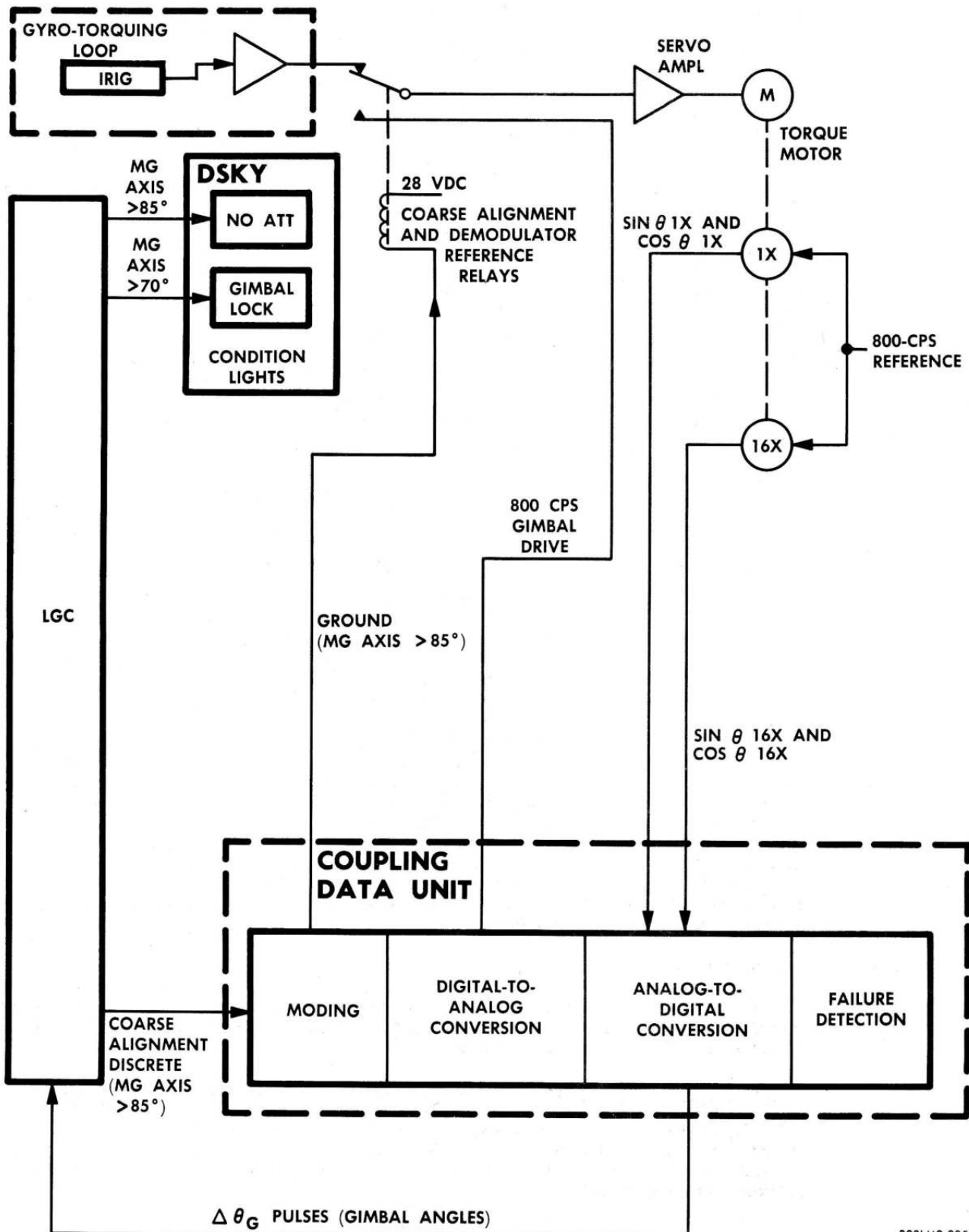
2.2.3.1.2

Optical Subsection.

The OSS comprises the AOT and the computer control and reticle dimmer assembly. The OSS provides an accurate method of establishing an inertial reference with respect to celestial bodies, for in-flight operations.

Alignment Optical Telescope. (See figure 2-26.) The AOT, mounted on the navigation base to provide a mechanical alignment and a common reference between the AOT and IMU, is a unity-power periscope-type device with a 60° conical field of view. It is operated manually by the astronauts. The AOT has a movable shaft axis (parallel to the LM X-axis in the X-Z plane) and a line-of-sight axis (approximately 45° from the X-axis in the X-Z plane).

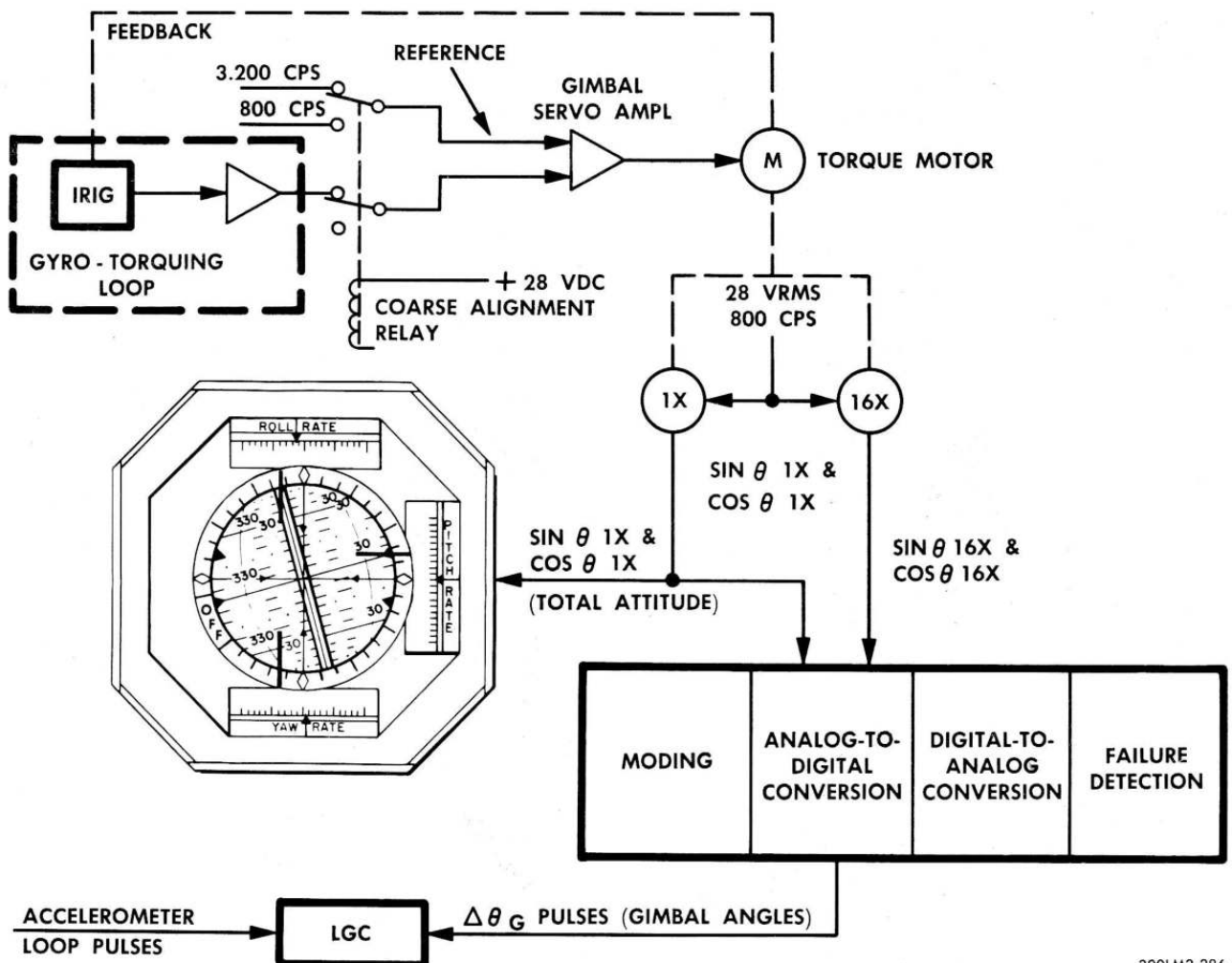
LMA790-3-LM 3
 APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA



300LM3-285

Figure 2-24. Gimbal Lock Mode - Functional Diagram

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

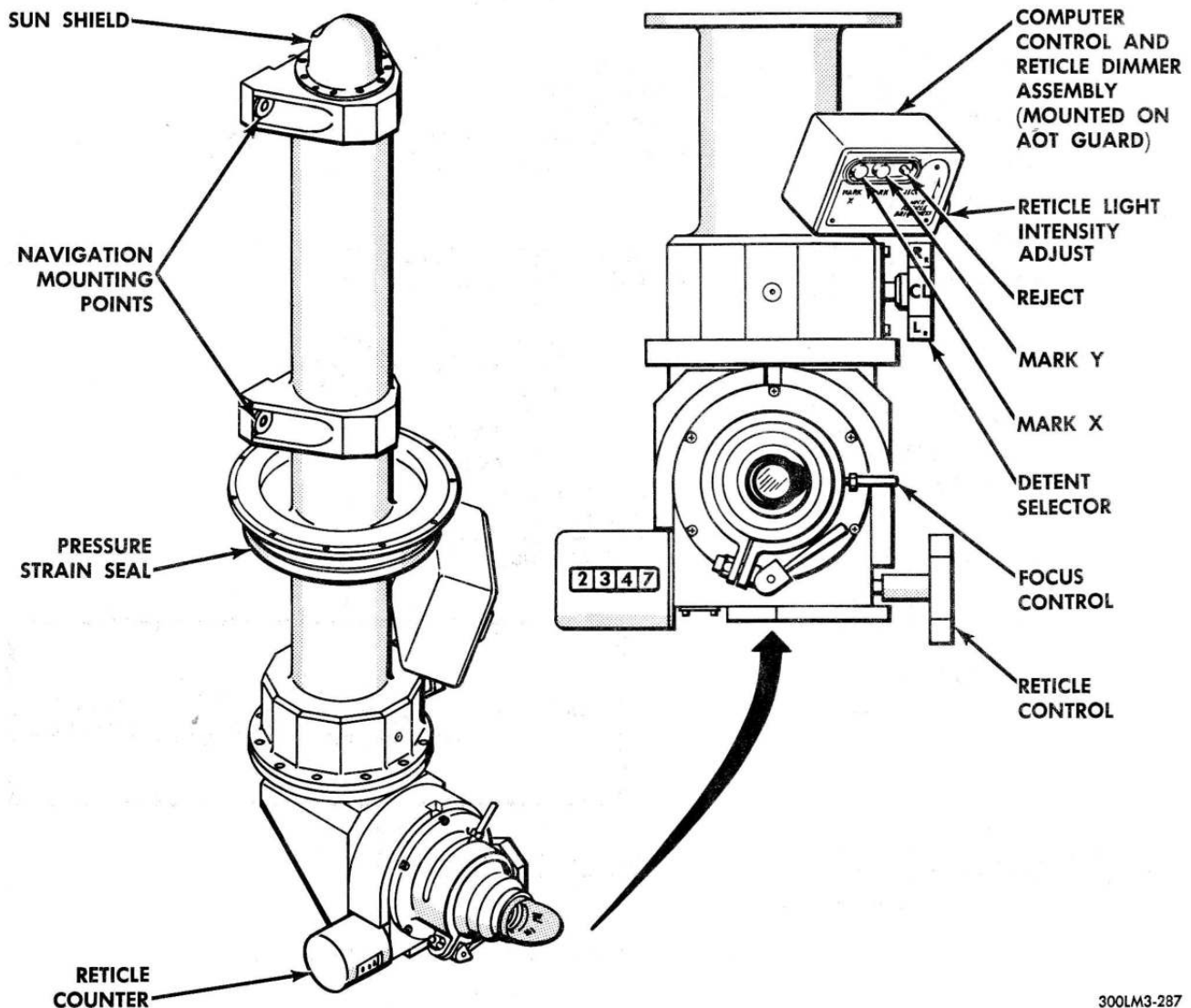


300LM3-286

Figure 2-25. Inertial Reference Mode - Functional Diagram

The AOT line of sight (LOS) is fixed in elevation and movable in azimuth to six detent positions. These detent positions are selected manually by turning a detent selector knob on the AOT; they are located at 60° intervals. (See figure 2-27.) Three positions (forward, left, and right), can be used for star sightings. The forward (F), or zero detent position, places the LOS in the X-Z plane, looking forward and up as one would look from inside the LM. The right (R) position places the LOS 60° to the right of the X-Z plane; the left (L) position, 60° to the left of the X-Z plane. Each of these positions maintains the LOS at 45° from the LM +X-axis. The remaining three detent positions reverse the prism on top of the AOT so that the frontal plane is protected by a shield. These positions are right-rear, closed (CL), and left-rear. The CL position (180° from the F position) is the stowage position. The other two positions have minimal use.

The AOT is essentially an L-shaped device approximately 36 inches long. It consists of the perpendicular intersection of two cylinders each of which is a major assembly, the upper section and the eyepiece. Structural components, such as housing and mounts, are machined from beryllium; spacers and similar parts are made of aluminum. A pressure strain seal is used to seal the LM cabin from space environment.

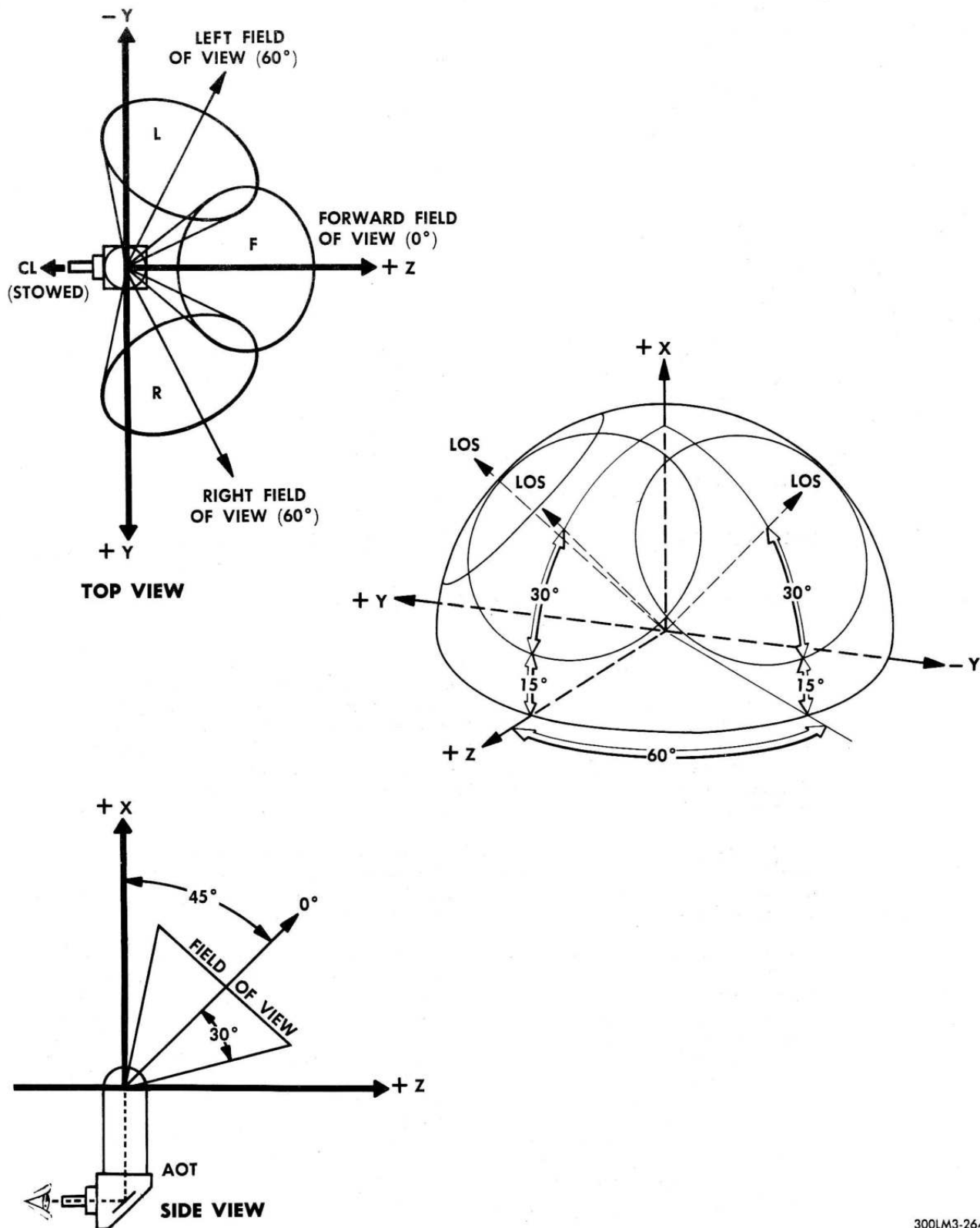


300LM3-287

Figure 2-26. Alignment Optical Telescope

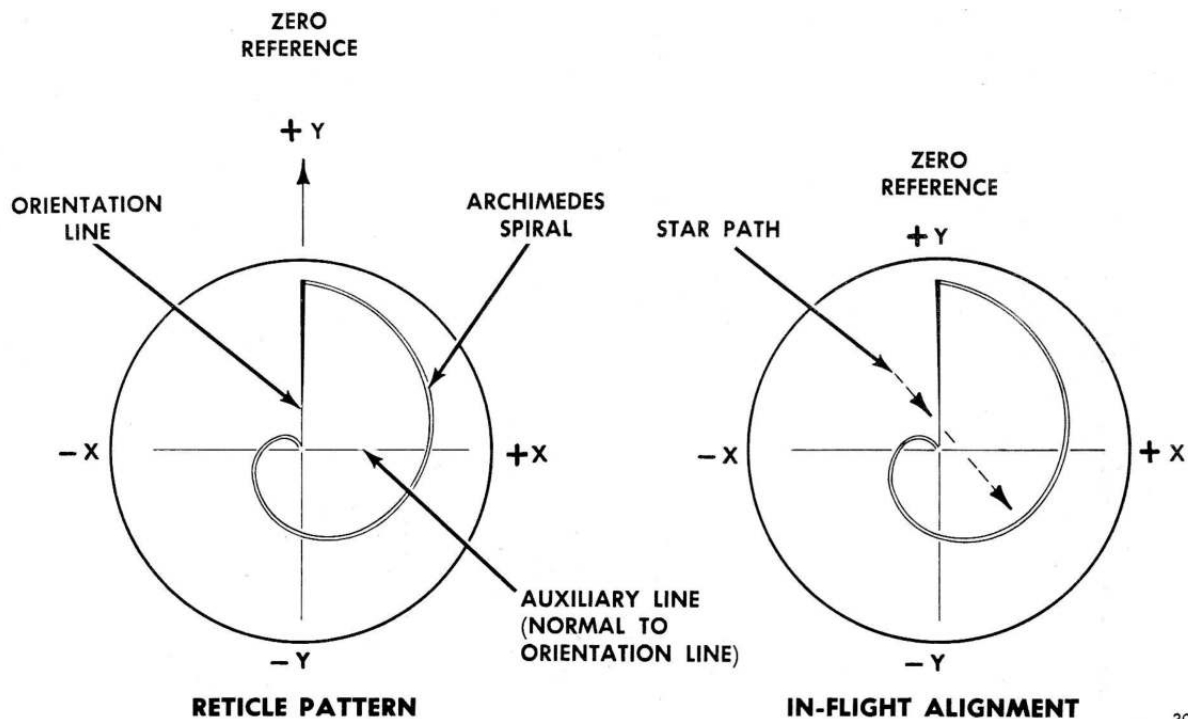
The reticle control enables manual rotation of the reticle for use in future lunar surface alignments. A counter, on the left side of the AOT, provides angular readout of reticle rotation. The counter reads in degrees to within $\pm 0.02^\circ$ or ± 72 seconds. The maximum reading is 359.98° ; then the counter returns to 0° . Interpolation is possible to within $\pm 0.01^\circ$.

The AOT reticle pattern consists of crosshairs and a superimposed Archimedes spiral. (See figure 2-28.) The vertical crosshair, an orientation line designated the Y-line, is parallel to the LM X-axis when the reticle is at the 0° reference position. The horizontal crosshair, an auxiliary line designated the X-line, is perpendicular to the orientation line. The one-turn spiral is superimposed from the center of the field of view to the top of the vertical crosshair. During use, the reticle is edge illuminated by red reticle lamps to provide color discrimination between stars and a faulty reticle pattern.



300LM3-264

Figure 2-27. Alignment Optical Telescope Articulation



300LM3-267

Figure 2-28. Alignment Optical Telescope - Reticle Pattern

Computer Control and Reticle Dimmer Assembly. The computer control and reticle dimmer assembly is mounted on the AOT guard. A thumbwheel on this control box enables the astronauts to adjust the brightness of the AOT reticle light when taking a star sighting. The MARK X and MARK Y pushbuttons, also on this assembly, are used by the astronauts to send discrete signals to the LGC when making star sightings for an IMU in-flight alignment. A REJECT pushbutton is used if an invalid mark discrete has been sent to the LGC. The assembly routes heater power to the AOT and supplies reticle lamp power.

Optical Subsection Operation. The OSS is used for manual star sightings, which are necessary for accurate determination of the inertial orientation of the IMU stable member. These star sightings are required during certain periods while the LM is in flight. There are two methods for using the OSS.

In-Flight Sightings. (See figure 2-28.) For in-flight sightings, the AOT may be placed in any of the three usable detent positions. However, when the LM is attached to the CSM, only the F position is used. For in-flight operation, the CSS and the ISS are turned on, the AOT counter is zeroed, a detent position is selected, and the LM is maneuvered to obtain a selected star in the AOT field of view, near the center. The specific detent position code and selected star code are entered into the LGC via the DSKY. The LM is then maneuvered so that the star image crosses the reticle crosshairs. When the star image is coincident with the Y-line, the astronaut presses the MARK-Y pushbutton; when it is coincident with the X-line, he presses the MARK-X pushbutton. The astronaut may do this in either order and, if desired, he may erase the latest mark by pressing the REJECT pushbutton. When a MARK pushbutton is pressed, a discrete is sent to the LGC. The LGC then records the time of mark and the IMU gimbal angles at the instant of the mark.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Crossing of a reticle line by the star image defines a plane containing the star. Crossing of the other reticle line defines another plane containing the same star. The intersection of these planes forms a line that defines the direction of the star. To define the inertial orientation of the stable member, sightings on at least two stars are required. Each star sighting requires the same procedure. Multiple reticle crossings and their corresponding marks can be made on either or both stars to improve the accuracy of the sightings. Upon completion of the second star sighting, the LGC calculates the orientation of the stable member with respect to a predefined reference coordinate system.

Lunar Surface Sighting. Because the LM-3 mission is an earth-orbital flight, OSS operation on the lunar surface is not discussed.

2.2.3.1.3

Computer Subsection.

The CSS is the control and processing center of the PGNS. It comprises the LGC and the DSKY.

LM Guidance Computer. (See figure 2-29.) The LGC is a core memory, digital computer with two types of memory: fixed and erasable. The fixed memory permanently stores navigation tables, trajectory parameters, programs, and constants. The erasable memory stores intermediate information.

The LGC processes data and issues discrete control signals for the PGNS and the other subsystems. It is a control computer with many of the features of a general-purpose computer. As a control computer, the LGC aligns the IMU stable member and provides RR antenna drive commands to the RR channels of the CDU's. The LGC provides control commands to the RR, LR, ascent engine, descent engine, RCS thrusters, and LM displays. As a general-purpose computer, the LGC solves guidance problems required for the mission. In addition, the LGC monitors the operation of the PGNS and other subsystems.

The main functions of the LGC are implemented through the execution of programs stored in memory. Programs are written in a machine language called basic instructions. A basic instruction can be an instruction word or a data word. All words for the LGC are 16 bits long.

In memory, data words contain a parity bit, fourteen magnitude bits, and a sign bit. A binary 1 in the sign bit indicates a negative number; a binary 0, a positive number. Instruction words contain a 12-bit address code and a 3-bit order code. Normally, the address code represents the location of a word in memory or the central processor. The order code represents an operation to be performed on the data whose location is represented by the address code. Parity bits are included only in words that are stored in memory. They are used as a means of ensuring that information is transferred correctly from memory. Odd parity is used; all words correctly transferred from memory contain an odd number of 1's. If words to be transferred into memory contain an even number of 1's, another 1 is added as a parity bit.

The LGC stores data pertinent to the ascent and descent flight profiles that the LM must assume to complete its mission. These data (position, velocity, and trajectory information) are used by the LGC to solve flight equations. The results of various equations can be used to determine the required magnitude and direction of thrust required. The LGC establishes corrections to be made. The LM engines are turned on at the correct time, and steering signals are controlled by the LGC to orient the LM to a new trajectory, if required. The ISS senses acceleration and supplies velocity changes to the LGC for calculating total velocity. Drive signals are supplied from the LGC to the CDU's and stabilization gyros in the ISS to align the gimbal angles in the IMU. IMU position signals are supplied to the LGC to indicate changes in IMU gimbal angles. The LGC provides drive signals to the RR for antenna positioning and receives, from the RR channels of the CDU's, antenna angle information. This information is used in the LGC

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

in the antenna-positioning calculations. Star-sighting information is loaded manually into the LGC via the DSKY. This information is used in the LGC to determine IMU alignment commands.

The LGC contains a timer, sequence generator, central processor, memory, priority control, input-output interfaces, and an alarm-detection network.

Timer. The timer provides synchronization or timing pulses to ensure a logical flow of data within the LGC and provides synchronization pulses to the other PGNS subsections for power-supply frequency stabilization and other control functions. Other LM subsystems receive timing signals for control and synchronization purposes. The LM central timing equipment is synchronized to the LGC timer.

Sequence Generator. The sequence generator directs execution of machine instructions, by generating control pulses that logically sequence data throughout the LGC. The control pulses are formed by combining the order code of an instruction word with synchronization pulses from the timer.

Central Processor. The central processor performs all arithmetic operations required of the LGC, buffers all information coming from and going to memory, checks for correct parity on all words coming from memory, and generates a parity bit for all words written into memory.

Memory. Memory provides the storage capability for the LGC; it is divided into two sections: erasable memory and fixed memory. Erasable memory can be written into or read from; its readout is destructive. Fixed memory cannot be written into; its readout is nondestructive.

Priority Control. The priority control establishes a processing priority for operations that must be performed by the LGC. Priority control consists of counter priority control and interrupt priority control. Counter priority control initiates updating of counters in erasable memory. Interrupt priority control transfers control of the LGC to one of several interrupt subroutines stored in fixed memory.

Input-Output Interfaces. The input interface receives signals from the PGNS and the other subsystems. These signals are conditioned and isolated by the input interface before they are routed into the LGC logic circuitry. The output interface conditions and isolates the LGC output signals before routing them to the appropriate CSS block, PGNS, or subsystem. The input and output circuits of the LGC also include storage and gating devices, which are referred to as input-output channels.

Alarm-Detection Network. The alarm-detection network monitors LGC operation. If an LGC failure is discovered, a failure signal is routed to the DSKY for display. An LGC power failure is also displayed by the LGC warning light (panel 1).

Display and Keyboard. The DSKY provides a two-way communications link between the astronauts and the LGC. Through this communications link, the following functions can be performed:

- Loading of data into the LGC
- Display of data from the LGC and data loaded into the LGC
- Monitoring of data in the LGC
- Display of the LGC modes of operation
- Requests, by the LGC, for the astronauts to perform actions.

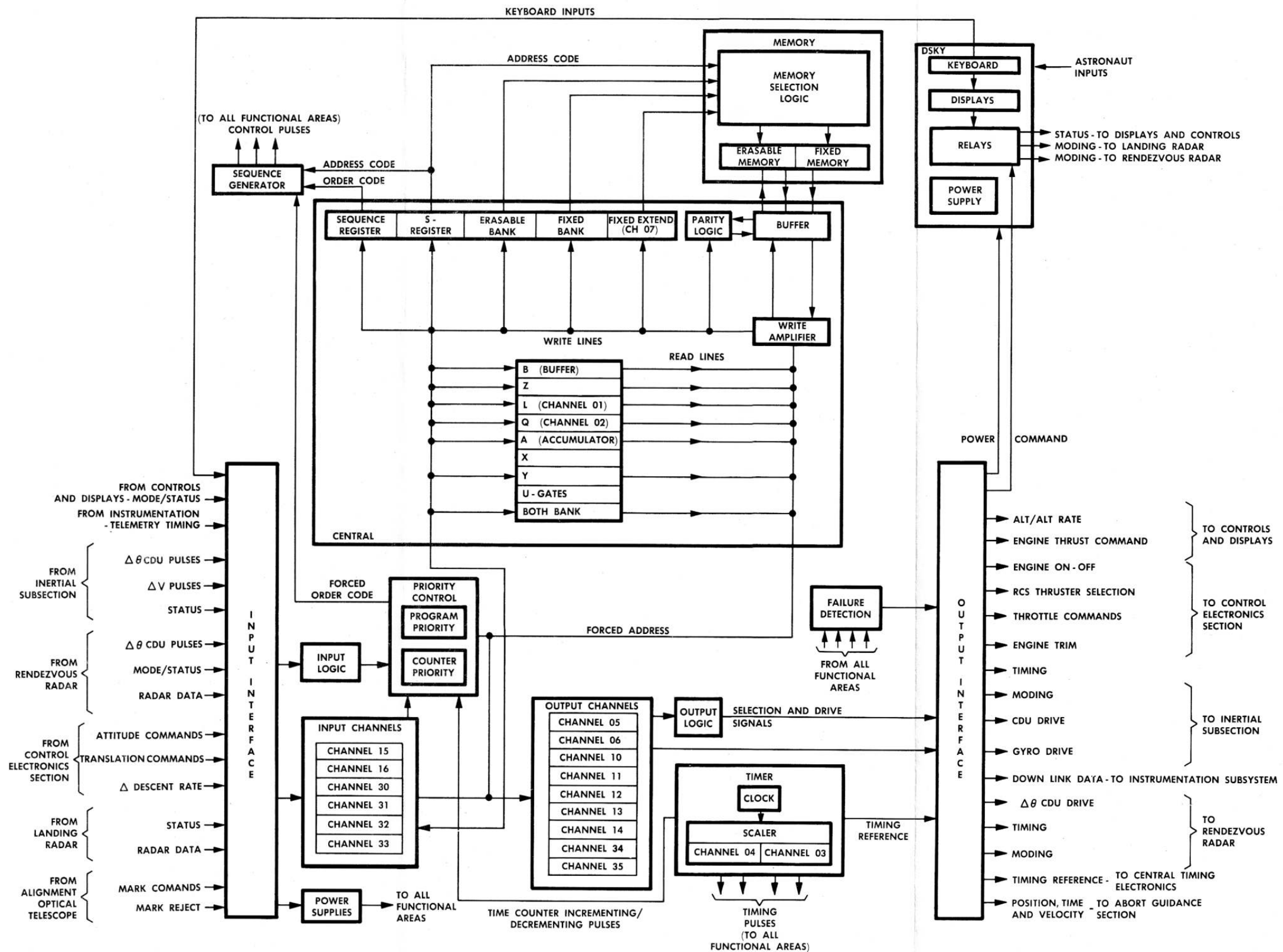


Figure 2-29. LM Guidance Computer - Functional Flow Diagram

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

The DSKY consists of a keyboard, display panel, condition indicators, a power supply, and a relay package. The keyboard enables the astronauts to insert data into the LGC and to initiate LGC operations. Through the keyboard, the astronauts can also control ISS moding. The DSKY display panel provides visual indications of data being loaded into the LGC, LGC condition, and LGC program. The display panel also provides the LGC with a means of displaying or requesting data. The condition indicators display PGNS status and malfunctions. The controls and displays associated with the DSKY are discussed in section 3.

Keyboard. The DSKY keyboard is used to manually insert or read out LGC data. The keyboard consists of 10 numerical pushbuttons (0 to 9), two sign pushbuttons (+ and -), and seven instruction pushbuttons (ENTR, CLR, VERB, NOUN, RSET, STBY, and KEY REL). All the pushbuttons, except the STBY pushbutton, have five-bit codes associated with them; they convey information to the LGC. The STBY pushbutton is hard wired into the LGC power supplies.

Displays and Indicators. There are two types of displays on the DSKY: control displays and data displays. Each display can display any decimal character or remain blank. The indicators on the DSKY are referred to as condition lights; they represent various PGNS operating conditions. Each control display (VERB, NOUN, and PROG) can display two decimal characters or remain blank. The VERB and NOUN displays can also flash. The data displays are three separate registers, referred to as R1, R2, and R3. Each register can display as many as five decimal characters, with or without a plus or minus sign, or remain blank. Each of the 11 condition lights on the DSKY is labeled with the PGNS condition it represents; it goes on if that condition occurs. The condition lights and the conditions they represent are described in Section 3.

Power Supply. The DSKY power supply receives +28 and +14 volts dc and an 800-pps sync signal from the LGC. The power supply develops 275-volt, 800-cps power. The output provides power for the DSKY electroluminescent displays.

Manual Operation of DSKY. The operator of the DSKY can communicate with the LGC by pressing a sequence of pushbuttons on the DSKY keyboard. Except for the STBY pushbutton, each pushbutton pressed inserts a five-bit code into the LGC. The LGC responds by returning a code, which controls the display on the display panel, to the DSKY or by initiating an operation by the central processor. The LGC can also initiate a display of information or request the operator for some action, through the processing of its program.

The basic language of communication between the operator and the DSKY consists of the verb and noun codes. The verb code (table 2-2) indicates what action is to be taken (operation). The noun code (table 2-3) indicates to what this action is applied (operand). Verb and noun codes may be originated by manual operation or by internal LGC sequence. Each verb or noun code contains two numerals. The standard procedure for manual operation involves pressing a sequence of seven pushbuttons:

VERB V₁ V₂ NOUN N₁ N₂ ENTR

Pressing the VERB pushbutton blanks the VERB lights on the display panel and clears the verb code register within the LGC. The next two pushbuttons (0 to 9) pressed provide the verb code (V₁ and V₂). Each numeral of the code is displayed by the VERB lights as the pushbutton is pressed. NOUN pushbutton operates the same as the verb pushbutton, for the NOUN lights and noun code register. Pressing the ENTR pushbutton causes the performance of the operation called for by the verb-noun combination displayed by the lights. It is not necessary to follow any order in punching in the verb or noun code. It can be done in reverse order, and a previously entered verb or noun may be used without repunching it.

The operation called for by the verb-noun combination is not started until the ENTR pushbutton is pressed. If an error in the verb code or the noun code is noticed before the ENTR pushbutton is pressed, correction is made by pressing the VERB or NOUN

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

pushbutton and repunching the erroneous code, without changing the other one. Only when the operator has verified that the desired verb and noun codes are displayed by the lights, should he press the ENTR pushbutton. An example of the sequence in which the pushbuttons are pressed is as follows: VERB, 1, 6, NOUN, 2, 1, ENTR. Pressing the ENTR pushbutton advises the LGC that it should perform the operation called for by the verb and noun codes. An alternative sequence would be: NOUN, 2, 1, VERB, 1, 6, ENTR. When the VERB pushbutton is pressed, the two VERB displays are blanked. As the digits of the VERB code are punched in, they are displayed in the VERB displays. The NOUN display operates in the same manner.

A noun code can refer to a group of LGC erasable registers, a group of counter registers, or it may serve merely as a label. A label noun does not refer to a particular LGC register; it conveys information by its noun code number only. The group of registers to which a noun code refers may be a group of one, two, or three members. These members are generally referred to as 1-, 2-, or 3-component nouns. The component is understood to be a component member of the register group to which the noun refers. The machine addresses for the registers to which a noun refers are stored in the LGC in noun tables.

A single noun code refers to a group of 1-, 2-, or 3-component members. The verb code determines which component member of the noun group is processed. For instance, there are five different load verbs. Verb 21 is required for loading the first component of whatever noun is used therewith; verb 22 loads the second component of the noun; verb 23, the third component; verb 24, the first and second component; and verb 25, all three components. A similar component format is used for the display and monitor verbs.

When the decimal display verb is used, all the component members of the noun being used are scaled as appropriate, converted to decimal, and displayed in the data display registers.

Decimal data are identified by a plus or minus sign preceding the five digits. If a decimal format is used for loading data of any component members of a multicomponent load verb, it must be used for all components of the verb. Mixing of decimal and octal data for different components of the same load verb is not permissible. If data are mixed, the operator error alarm is initiated.

Monitor verbs display data approximately every second. Once a monitor verb is executed, the data on the display panel continues to be updated until the monitor is turned off by V33E (proceed/proceed without data), V34E (terminate), and internal program initiation of the keyboard and display system program, or by a fresh start of the LGC. V33E is the abbreviation for the sequence of depressions (VERB, 3, 3, ENTR) that instructs the LGC to stop updating the monitor (display registers).

Monitor action is suspended (but not ended) by pressing any key, except reset (RSET). This turns on the KEY REL light immediately. Monitor action continues after the keyboard and display system is released. Thus it is possible to suspend a monitor while the operator loads some data, or requests another display, and to return to the original monitor when his intervention is concluded.

After any use of the DSKY, the numerals (verb, noun and data words) remain visible until the next use of the DSKY. If a particular use of the DSKY involves fewer than three data words, the data display registers (R1, R2, R3) not used remain unchanged, unless blanked by deliberate program action.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-2. DSKY Verb List

Verb Code	Function	Remarks
00	Not in use	
01	Display in R1 (in octal form) first component of:	
02	Display in R1 (in octal form) second component of:	
03	Display in R1 (in octal form) third component of:	
04	Display in R1 and R2 (in octal form) first and second components of:	
05	Display in R1, R2, and R3 (in octal form) first, second, and third components of:	
06	Display (in decimal form) all components of:	This verb performs decimal display of data. The scale factors, types of scale factor routines, and component information are stored in the LGC for each noun.
07	Display double precision decimal in R1 and R2.	This verb performs a double precision decimal display of data without scale factoring. It performs a 10-character fractional decimal conversion of two consecutive erasable registers, using R1 and R2. (The sign is placed in the R1 sign position; the R2 sign position is blank.) It cannot be used with mixed nouns. Its intended use is primarily with machine address to be specified nouns. If this verb is used with nouns that inherently are not double precision, the display is meaningless.
08	Not in use	
09	Not in use	
10	Not in use	
11	Monitor on R1 (in octal form) first component of:	The monitor verbs (11 through 17) allow other keyboard activity. It is ended by VERB 34 (terminate). Monitor action is turned off, but not ended, by any keyboard action except error reset; it begins again when key release is initiated.
12	Monitor on R1 (in octal form) second component of:	
13	Monitor on R1 (in octal form) third component of:	
14	Monitor on R1 and R2 (in octal form) first and second component of:	
15	Monitor on R1, R2 and R3 (in octal form) first, second, and third component of:	

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-2. DSKY Verb List (cont)

Verb Code	Function	Remarks
16	Monitor (in decimal form) all components of:	
17	Monitor double precision decimal on R1 and R2.	
18	Not in use	
19	Not in use	
20	Not in use	
21	Load first component into R1.	Verbs 21 through 25 perform data loading. Decimal quantities are preceded by a plus or minus sign. Octal quantities do not have a sign.
22	Load second component into R2.	
23	Load third component into R3.	
24	Load first and second component into R1 and R2.	
25	Load first, second, and third component into R1, R2, and R3.	
26	Not in use	
27	Display fixed memory.	This verb is included to permit displaying the contents of fixed memory in any bank. Its use is intended for checking program ropes and the bank position of program ropes.
28	Not in use	
29	Not in use	
30	Request executive.	This verb enters request to executive routine for any machine address with priority. This verb is used with the "specify machine address" noun. The verb assumes that noun 26 has been preloaded. The end-of-job subroutine is performed after the request is entered. The displays are also released.
31	Request waitlist.	This verb enters request to waitlist routine for any machine address with any delay. The verb is used with the "specify machine address" noun. The verb assumes that noun 26 has been preloaded. The end-of-job subroutine is performed after the request is entered. The displays are also released.
32	Recycle program.	
33	Proceed without DSKY inputs.	This verb informs the routine in progress, requesting data to be loaded, that the astronaut will not load new data, and that the LGC should continue the routine, using previously entered data. The choice of whether to continue is left to the specific routine.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-2. DSKY Verb List (cont)

Verb Code	Function	Remarks
34	Terminate function.	This verb informs the routine in progress, to load data, that astronaut will not load new data and that the routine should be terminated. Final decision regarding what action should be taken is left to the requesting routine. If monitoring action is chosen, the routine is terminated.
35	Test lights.	The "test lights" routine checks all the DSKY lamps. After 5 seconds, the lamps are returned to their initial condition.
36	Request fresh start.	This verb initializes the program control software and keyboard and display system program.
37	Change program (major mode) to:	This verb changes the LGC program. This is accomplished by keying VERB, 37, ENTR, the new program number, and ENTR. The new program number is in the NOUN display until the ENTR pushbutton is pressed. At that time, the program number appears in the PROG display.
38	Not in use	
39	Not in use	
EXTENDED VERBS (40 through 99)		
40	Zero CDU's.	Must be used with noun 20, 40, or 70 only
41	Coarse-align CDU's.	Must be used with noun 20, 40, or 70 only
42	Fine-align IMU.	Call programs that perform indicated PGNS procedure
43	Load IMU attitude error.	Call programs that perform indicated PGNS procedure
44	Pulse torque gyros.	
45	Not in use	
46	Establish primary guidance control.	
47	Initialize AGS.	
48	Load digital autopilot data (routine 03).	
49	Start automatic attitude maneuver.	
50	Please perform.	<p>This verb is used only by internal routines that wish the operator to perform a certain task. It should never be keyed in by the operator. It is usually used with noun 25 (checklist). The coded number for the checklist item to be performed is displayed in register R1 by the requesting routine.</p> <p>Once the operator has performed the requested action, he should press the ENTR pushbutton to indicate that the checklist item has been performed. If he does not wish to perform the requested action, the operator should key in verb 33 (proceed/proceed without data.)</p>

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-2. DSKY Verb List (cont)

Verb Code	Function	Remarks
51	Not in use	Verbs 52, 53, and 54 are used only by the internal routines of the LGC. These verbs are not entered by the astronaut. They are displayed to the astronaut along with noun 70 (star numbers).
52	Mark X-reticle.	
53	Mark Y-reticle.	
54	Mark X-reticle or Y-reticle.	
55	Increment LGC time (decimal).	
56	Terminate tracking (P20 or P25).	
57	Not in use	
58	Not in use	
59	Not in use	
60	Set LM digital autopilot (DAP).	
61	Command LR to position No. 2.	
62	Sample radar once per second.	
63	Not in use	
64	Start LM flight control test.	
65	Not in use	
66	Not in use	
67	Not in use	
68	Not in use	
69	Not in use	
70	Update lift-off time.	
71	Universal update-block address	
72	Universal update-single address	
73	Update LGC time (octal).	
74	Initialize erasable dump via down-link.	
75	Not in use	
76	Minimum impulse command mode	
77	Rate command and attitude hold mode	

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-2. DSKY Verb List (cont)

Verb Code	Function	Remarks
78	Not in use	
79	Not in use	
80	Update LM state vector.	
81	Update CSM state vector.	
82	Request orbit parameter display (routine 30).	
83	Request rendezvous parameter display (routine 31).	
84	Start target ΔV (routine 32).	
85	Not in use	
86	Not in use	
87	Not in use	
88	Not in use	
89	Not in use	
90	Not in use	
91	Compute Banksum	Check the sum of the fixed memory bank as a cursory check on the validity of the memory.
92	Start IMU performance tests.	
93	Not in use	
94	Not in use	
95	Not in use	
96	Not in use	
97	Not in use	
98	Not in use	
99	Not in use	

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-3. DSKY Noun List

Noun Code	Description	Register No.	Scale and Format*	Unit
	<p>*Scale and format indicates the manner in which data will be displayed.</p> <p>X - integer (0 to 9)</p> <p>O - Zero</p> <p>B - Blank window</p> <p>. - Implied position of decimal point (not displayed)</p>			
00	Not in use			
01	Specify machine address (fractional).	1, 2, and 3	. X X X X X	fractions
02	Specify machine address (whole).	1, 2, and 3	X X X X X .	integers
03	Specify machine address (degree).	1, 2, and 3	X X X . X X	degrees
04	Spare			
05	Angular error/difference	1	X X . X X X	degree
06	Option code	1	Octal only	
		2	Octal only	
07	Change of program (used with verb 50)	1	X X X X X .	N/A
08	Alarm data	1, 2, and/ or 3	Octal only	
09	Alarm codes	1, 2, and/ or 3	Octal only	
10	Channel to be specified	1	Octal only	
11	Not in use			
12	Not in use			
13	Not in use			
14	Inbit message	1, 2, and 3	Octal only	
15	Increment address	1	Octal only	
16	Not in use			
17	Not in use			
18	Not in use			

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-3. DSKY Noun List (cont)

Noun Code	Description	Register No.	Scale and Format*	Unit
19	Enable trim (used with verb 50 only) (retains noun 94 displays)			
	Yaw	1	X X X . X X	degrees
	Pitch	2	X X X . X X	degrees
	Roll	3	X X X . X X	degrees
20	Inertial CDU angles			
	Yaw	1	X X X . X X	degrees
	Pitch	2	X X X . X X	degrees
	Roll	3	X X X . X X	degrees
21	PIPA's			
	X	1	X X X X X .	pulses
	Y	2	X X X X X .	pulses
	Z	3	X X X X X .	pulses
22	New inertial CDU angles			
	Yaw	1	X X X . X X	degrees
	Pitch	2	X X X . X X	degrees
	Roll	3	X X X . X X	degrees
23	Δ inertial CDU angles			
	Yaw	1	X X X . X X	degrees
	Pitch	2	X X X . X X	degrees
	Roll	3	X X X . X X	degrees
24	Δ time for LGC clock			
		1	0 0 X X X .	hours
		2	0 0 0 X X .	minutes
		3	0 X X . X X	seconds
25	Checklist (used with verb 50) (Refer to table 2-4.)	1, 2, and 3	X X X X X .	N/A
26	Priority/delay, address	1, 2, and 3	Octal only	N/A
	*See note at beginning of table			

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-3. DSKY Noun List (cont)

Noun Code	Description	Register No.	Scale and Format*	Unit
27	Self-test switch (on-off)	1	X X X X X .	N/A
28	Rotational hand controller angle rates	1, 2, and 3	X X X X X .	° /sec
29	Forward velocity	1	X X X X X .	fps
	Lateral velocity	2	X X X X X .	fps
30	T_{ig} of CSI (GETI)	1	0 0 X X X .	hours
		2	0 0 0 X X .	minutes
		3	0 X X . X X	seconds
31	T_{ig} of CDH (GETI)	1	0 0 X X X .	hours
		2	0 0 0 X X .	minutes
		3	0 X X . X X	seconds
32	Time to perigee	1	0 0 X X X .	hours
		2	0 0 0 X X .	minutes
		3	0 X X . X X	seconds
33	Time of ignition (T_{ig})	1	0 0 X X X .	hours
		2	0 0 0 X X .	minutes
		3	0 X X . X X	seconds
34	Time of event	1	0 0 X X X .	hours
		2	0 0 0 X X .	minutes
		3	0 X X . X X	seconds
35	Time-to-go to event	1	0 0 X X X .	hours
		2	0 0 0 X X .	minutes
		3	0 X X . X X	seconds
36	Time of LGC clock	1	0 0 X X X .	hours
		2	0 0 0 X X .	minutes
		3	0 X X . X X	seconds
*See note at beginning of table				

GUIDANCE, NAVIGATION, AND CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-3. DSKY Noun List (cont)

Noun Code	Description	Register No.	Scale and Format*	Unit
37	GETI of TPI	1	0 0 X X X .	hours
		2	0 0 0 X X .	minutes
		3	0 X X . X X	seconds
38	GETI of MID	1	0 0 X X X .	hours
		2	0 0 0 X X .	minutes
		3	0 X X . X X	seconds
39	Δ time to transfer	1	0 0 X X X .	hours
		2	0 0 0 X X .	minutes
		3	0 X X . X X	seconds
40	Time from ignition or cutoff	1	X X B X X	min, sec
	VG	2	X X X X . X	fps
	ΔV_M (accumulated)	3	X X X X . X	fps
41	Target azimuth	1	X X X . X X	degrees
	Target elevation	2	X X . X X X	degrees
	Target identifier	3	0 0 0 0 X	N/A
42	Apogee (Ha)	1	X X X X . X	nm
	Perigee (Hp)	2	X X X X . X	nm
	ΔV (required)	3	X X X X . X	fps
43	Latitude (+North)	1	X X X . X X	degrees
	Longitude (+East)	2	X X X . X X	degrees
	Altitude	3	X X X X . X	nm
44	Apogee	1	X X X X . X	nm
	Perigee	2	X X X X . X	nm
	TFF	3	X X B X X	min, sec
45	Marks	1	X X X X X .	N/A
	TFI of next burn	2	X X B X X	min, sec
*See note at beginning of table				

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-3. DSKY Noun List (cont)

Noun Code	Description	Register No.	Scale and Format*	Unit
45 (cont)	MGA	3	X X X . X X	degrees
46	Autopilot configuration	1 and 2	Octal only	
47	LM weight	1	X X X X X .	pounds
	CSM weight	2	X X X X X .	pounds
48	Pitch trim (gimbal)	1	X X X . X X	degrees
	Roll trim (gimbal)	2	X X X . X X	degrees
49	ΔR	1	X X X X . X	nm
	ΔV	2	X X X X . X	fps
50	VI	1	X X X X X .	fps
	TF GETI	2	X X B X X	min, sec
	ΔV_M	3	X X X X . X	fps
51	Pitch angle	1	X X . X X X	degrees
	Yaw angle	2	X X . X X X	degrees
52	LPD angle	1	X X X X . X	degrees
	H	2	X X X X . X	fps
	H	3	X X X X X .	feet
53	Range	1	X X X X . X	nm
	Range rate	2	X X X X . X	fps
	Phi	3	X X X . X X	degrees
54	Range	1	X X X X . X	nm
	Range rate	2	X X X X . X	fps
	Theta	3	X X X . X X	degrees
55	CDH apsis	1	X X X X X .	degrees
	Elevation	2	X X X . X X	nm
	Post-CDH altitude	3	X X X X . X	fps
*See note at beginning of table				

GUIDANCE, NAVIGATION, AND CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-3. DSKY Noun List (cont)

Noun Code	Description	Register No.	Scale and Format*	Unit
56	ΔV CSI	1	X X X X . X	fps
57	ΔV CDH	1	X X X X . X	fps
	Altitude (CDH)	2	X X X X . X	nm
	Δ altitude (CDH)	3	X X X X . X	nm
58	ΔV (TPI)	1	X X X X . X	fps
	Perigee (TPI)	2	X X X X . X	nm
	ΔV (TPF)	3	X X X X . X	fps
59	ΔV (MID)	1	X X X X . X	fps
	TFI (MID)	2	X X B X X	min, sec
	ΔV (TPF)	2	X X X X . X	fps
60	Not in use			
61	Not in use			
62	VI	1	X X X X X .	fps
	H	2	X X X X . X	fps
	H	3	X X X X X .	feet
63	Not in use			
64	Not in use			
65	Sampled LGC time (fetched in interrupt)	1	0 0 X X X .	hours
		2	0 0 0 X X .	minutes
		3	0 X X . X X	seconds
66	Not in use			
67	Not in use			
68	Not in use			
69	Not in use			
70	Star code	A, B blank	1	Octal only
	Landmark data	C AOT detent code	2	Octal only
	Horizon data	D, E star code	3	Octal only
*See note at beginning of table				

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-3. DSKY Noun List (cont)

Noun Code	Description	Register No.	Scale and Format*	Unit
71	AOT rotation angles	1, 2, and 3	X X X . X X	degrees
72	RR trunnion angle	1	X X X . X X	degrees
	RR shaft angle	2	X X X . X X	degrees
73	New RR trunnion angle	1	X X X . X X	degrees
	New RR shaft angle	2	X X X . X X	degrees
74	LR altitude	1	X X X X X .	feet
	LR time	2	X X X . X X	seconds
75	LR Vx	1	X X X X X .	fps
	LR time	2	X X X . X X	seconds
76	LR Vy	1	X X X X X .	fps
	LR time	2	X X X . X X	seconds
77	LR Vz	1	X X X X X .	fps
	LR time	2	X X X . X X	seconds
78	RR range	1	X X X X B .	feet
	RR trunnion angle	2	X X X . X X	degrees
	RR shaft angle	3	X X X . X X	degrees
79	RR range rate	1	X X X X X .	fps
	RR trunnion angle	2	X X X . X X	degrees
	RR shaft angle	3	X X X . X X	degrees
80	Data indicator	1	X X X X X .	N/A
	Omega	2	X X X . X X	degrees
81	Not in use			
82	ΔV_x (LV)	1	X X X X . X	fps
	ΔV_y (LV)	2	X X X X . X	fps
	ΔV_z (LV)	3	X X X X . X	fps
*See note at beginning of table				

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-3. DSKY Noun List (cont)

Noun Code	Description	Register No.	Scale and Format*	Unit
83	ΔV_x (IMU)	1	X X X X . X	fps
	ΔV_y (IMU)	2	X X X X . X	fps
	ΔV_z (IMU)	3	X X X X . X	fps
84	ΔV_x (CSM)	1	X X X X . X	fps
	ΔV_y (CSM)	2	X X X X . X	fps
	ΔV_z (CSM)	3	X X X X . X	fps
85	V_{Gx} (body)	1	X X X X . X	fps
	V_{Gy} (body)	2	X X X X . X	fps
	V_{Gz} (body)	3	X X X X . X	fps
86	V_{Gx} (LV)	1	X X X X . X	fps
	V_{Gy} (LV)	2	X X X X . X	fps
	V_{Gz} (LV)	3	X X X X . X	fps
87	Not in use			
88	Not in use			
89	Not in use			
90	Not in use			
91	Not in use			
92	Not in use			
93	Δ gyro angles			
	X	1	X X . X X X	degrees
	Y	2	X X . X X X	degrees
	Z	3	X X . X X X	degrees
94	FDAI angles			
	X	1	X X X . X X	degrees
	Y	2	X X X . X X	degrees
	Z	3	X X X . X X	degrees
*See note at beginning of table				

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-3. DSKY Noun List (cont)

Noun Code	Description	Register No.	Scale and Format*	Unit
95	Initial altitude	1	X X X X X .	feet
	Final altitude	2	X X X X X .	feet
	Altitude rate	3	X X X X X .	fps
96	Not in use			
97	System test inputs	1	X X X X X .	N/A
		2	. X X X X X	N/A
		3	X X X X X .	N/A
98	System test results	1	X X X X X .	N/A
		2	. X X X X X	N/A
		3	X X X X X .	N/A
99	Engine enable (used with verb 50 only) (retains noun 40 displays)			
		1	X X B X X	min, sec
		2	X X X X . X	fps
		3	X X X X . X	fps

*See note at beginning of table

"Machine address to be specified" nouns allow any machine address to be used. When the ENTR pushbutton is pressed the verb-noun combination senses a noun of this type, and the flash is immediately turned on. The verb code is left unchanged. The operator loads the desired five-octal-character complete machine address. It is displayed in R3 as it is punched in. If an error is made in loading the address, the clear (CLR) pushbutton may be used to remove it. Pressing the ENTR pushbutton causes continuation in executing the verb.

Data Loading. Some verb-noun codes require additional data to be keyed in. If additional data are required after the ENTR pushbutton is pressed, following the keying of the verb-noun codes, the VERB and NOUN displays flash on and off at a 1.5-cps rate. These displays continue to flash until all of the information associated with the verb-noun code is keyed in.

Numerical data are considered decimal if the five-numeral data word is preceded by a plus sign or a minus sign; if no sign is supplied, it is considered octal. The + and - pushbuttons are accepted by the LGC only when they precede the first numeral of the data word; they are ignored at any other time. Decimal data must be loaded in full five-numeral words (no zeros may be suppressed); octal data may be loaded with high-order zeros suppressed. If decimal format is used for any component of a multicomponent

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

load verb, it must be used for all components of that verb. Mixing of octal and decimal data for different components of the same load verb is not permissible. (If such data are mixed, the operator error alarm is initiated.) The ENTR pushbutton must be pressed after each data word. This tells the program in progress that the numerical word entered is complete.

After the ENTR pushbutton is pressed, the VERB and NOUN displays stop flashing and remain on, displaying the entered verb-noun combination. As the various pushbuttons are pressed (while entering the data), the digits are displayed in positions of one of the display registers corresponding to the order in which they were entered. As the data is entered, it is temporarily stored in intermediate buffers. It is not placed into its final destination as a specified address noun code until the final ENTR pushbutton is pressed.

If an attempt is made to enter more than five numerals in sequence, the sixth and subsequent numerals are rejected. If the 8 or 9 pushbutton is pressed during octal load (as identified by lack of a sign entry), it is rejected and the operator error (OPR ERR) condition light goes on.

In multicomponent load situations, the appropriate single component load verbs are flashed one at a time. The LGC always instructs the operator through a loading sequence. The operator (or the internal program) initiates the sequence by selecting VERB, 25 (load 3 components of), (any noun will do), ENTR. The verb code is changed to 21 (load first component of) and the flash is turned on. Verb 21 continues to be flashed as the first data word is being loaded. When the ENTR pushbutton is pressed, the verb code is changed to 22 (load second component). Flashing continues while the second data word is loaded. When the ENTR pushbutton is pressed, the verb code is changed to 23 (load third component); the flash continues while the third data word is loaded. When the ENTR pushbutton is pressed, the flash is turned off and all three data words are placed in the locations specified by the noun.

Correcting Erroneous Data. The CLR pushbutton is used during data loading to remove errors in R1, R2, or R3. This allows the astronaut to begin loading again. Use of the CLR pushbutton does not affect the PROG, NOUN, or VERB displays.

To correct errors for single-component load verbs, the CLR pushbutton clears the register being loaded, provided that the CLR pushbutton is pressed before the ENTR pushbutton. Once the ENTR pushbutton is pressed, the CLR pushbutton has no effect. After the ENTR pushbutton has been pressed, the only way to correct an error for a single component is to begin to load again.

To correct errors for second and third component load verbs, the CLR pushbutton is used. The first pressing of the CLR pushbutton clears the register being loaded. Consecutive pressing clears the register above the register being loaded, until R1 is cleared.

Program Selection. Verb 37 is used to change the program. Keying VERB, 37, and ENTR blanks the NOUN display; the verb code flashes. The two-digit program code is then loaded. For verification purposes, the program code is displayed as it is loaded, in the NOUN display register. When the ENTR pushbutton is pressed, the flashing stops, the new program to be entered is requested, and a new program code is displayed in the PROG display.

Release of Keyboard and Display System. The keyboard and display system program can be used by internal LGC programs. However, any operator keyboard action (except reset) makes the keyboard and display system program unavailable (busy) to internal routines. The operator has control of the keyboard and display system until he wishes to release it. Thus, he is assured that data he wishes to observe will not be replaced by internally initiated data displays. In general, it is recommended that the operator release the keyboard and display system for internal use when he has temporarily finished with it. This is done by pressing the KEY REL pushbutton.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

If an internal program attempts to use the keyboard and display system, but finds that the operator has used it and not yet released it, the KEY REL light goes on. When the operator finds it convenient, he should press the KEY REL pushbutton to allow the internal program to use the keyboard and display panel.

Operator Error. The OPR ERR condition light goes on when the operator presses pushbuttons improperly. The light goes on when an undefined verb or noun is entered or when a verb that is defined and a noun that is defined is entered, but the combination of verb and noun is illegal. Both of these errors do not require any further operator action. The following operator errors also do not require further action:

- The component number of the verb exceeds the number of the components in the noun.
- The octal display and monitor verbs are used with a "decimal only" noun.
- The decimal display and monitor verbs are used with mixed nouns.
- The decimal display and monitor verbs are used with an "octal only" noun.
- A no-load verb is used with a noun that is not a no-load noun. (Nouns that have a split minute/second scale for any component are no-load nouns.)
- An input code other than those that are defined is received from the keyboard.
- The contents of the register exceed its limit.

When improper data are entered for a defined verb-noun combination that requires loading of additional data, the OPR ERR condition light goes on. The error is detected when the final entry of the loading sequence is accomplished. When the light goes on, recycling back to the beginning of the loading sequence is required. Only the data must be entered again, not the verb-noun combination. Other errors that cause the OPR ERR condition light to go on, and require recycling, are as follows:

- The address entered for a "machine address to be specified" noun is not octal.
- Octal and decimal data are mixed in multicomponent load verbs. (All data words loaded for a given noun must be all octal or all decimal.)
- Octal data are loaded a "decimal only" noun.
- Decimal data are loaded an "octal only" noun.
- Decimal data that have been loaded numerically exceed the maximum permitted by the scale factor associated with the appropriate component of the noun.
- Negative decimal data are loaded, using the Y-optics scale.
- For displays of time, the three data words are not loaded for hours, minutes, and seconds scale.
- When loading with the hours, minutes, seconds scale, the minutes exceed 59, the seconds exceed 59.99, and the total exceeds 745 hours 39 minutes 14.55 seconds
- Two numerals are not supplied for the program code under verb 37.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

DSKY Operation Under LGC Control. The principles of DSKY operation by the internal LGC sequences are the same as those described for manual operation of the DSKY. The DSKY operations, as instructed by the internal LGC sequences are of the following categories: display, loading, please perform, and please mark.

The display operation is used to display data to the operator. Data computed by the mission program can be displayed by using various display verbs. The loading operation requests that the operator load data. The please-perform operation requests an action by the operator who then notifies the LGC that he has complied. The please-mark operation requests that the operator press the MARK pushbutton on the AOT for an optics sighting.

LGC-initiated verb-noun combinations are displayed as static or flashing displays. A static display identifies data displayed only for operator information; no operator response is required. If the displayed verb-noun combination flashes, appropriate operator response is required, as dictated by the verb-noun combination. In this case, the internal sequence is interrupted until the operator responds appropriately; then the flashing stops and the internal sequence is resumed. A flashing verb-noun display must receive only one of the proper responses; otherwise the internal sequence that instructed the display may not be resumed.

Display. The appropriate operator response to a flashing display (verb-noun combination) is as follows:

- Correct the data and perform the appropriate load-verb sequence. Upon pressing the ENTR pushbutton, the internal sequence proceeds normally.
- Recycle by keying VERB, 32, ENTR. This returns the program to a previous location.
- Proceed or proceed without data by keying VERB, 33, ENTR. This indicates acceptance of the displayed data and a desire for the internal sequence to continue normally.
- Terminate by keying VERB, 34, ENTR.

Data Loading. When data are to be loaded, the VERB and NOUN displays flash. The flashing occurs whether data loading is initiated by LGC or by the operator. The appropriate register (R1, R2, or R3) is blanked in anticipation of data loading. Data are loaded as five-numeral words; they are displayed numeral-by-numeral in one of the registers as loaded.

The appropriate response to an internally initiated verb-noun combination for loading is as follows:

- Load the desired data. After the final entry, the internal sequence proceeds normally.
- Proceed or proceed without data by keying VERB, 33, ENTR.
- Terminate by keying VERB, 34, ENTR.

Please Perform. The operator must respond to a "please perform" request. With this request, the verb-noun combination flashes and the internal sequence is interrupted. The "please perform" verb (50) is usually used with the "checklist" noun (25) and an appropriate checklist code number (table 2-4) in R1. The appropriate response is as follows:

- Press the ENTR pushbutton to indicate that the requested action has been performed. (The internal sequence continues normally.) Proceed without data by keying VERB, 33, ENTR. The operator chooses not to perform

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

the requested action, but desires the internal sequence to continue with the previous data.

- Terminate by keying VERB, 34, ENTR.

The "please perform" verb is also used with the "change of program" noun and "engine-on enable" noun. Its use in these cases is subject to the LGC program in process.

Please Mark. The "please mark" verbs are flashed when the LGC is prepared to accept optical-sighting data from the AOT.

Table 2-4. Checklist Reference Codes Used With Verb 50, Noun 25

Code	Action To Be Taken
00011	Key in auto optics positioning option.
00012	Key in target data.
00013	Switch OSS to LGC control.
00014	Key in fine-alignment option.
00015	Perform star acquisition.
00016	Key in terminate mark option.
00017	Perform additional star sightings.
00025	Perform backup star sightings (program 53 or 54).
00026	Terminate backup star sightings (program 53 or 54).
00031	Key in engine on option.
00035	Perform LGC thrusting preparation.
00036	Perform thrust termination.
00037	Trim finished; terminate routine R63.
00060	Switch ISS to on.
00061	Switch IMU power down.
00062	Switch LGC power down.
00200	Key in zero AEA clock option.
00201	Switch RR mode to automatic.
00202	Key in sighting check option.
00203	Set GUID CONT switch (panel 1) to PGNS, MODE CONTROL switch (panel 3) to AUTO, and THR CONT switch (panel 1) to AUTO.
00204	Key in enable gimbal trim option (enable, off).

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-4. Checklist Reference Codes Used With Verb 50, Noun 25 (cont)

Code	Action To Be Taken
00205	Perform manual acquisition of RR.
00400	Switch Service module propulsion subsystem ready to on.
00401	Switch LM control to guidance and navigation.

Table 2-5. DSKY Option Codes (V50 N06)

Option Code (Displayed in R1)	Data To Be Loaded in R2
00001	Specify state vector to be updated. 1 = LM, 2 = CSM
00002	Specify acquisition mode. 1 = automatic, 2 = manual
00003	Specify GETI or elevation angle input. 1 = GETI, 2 = elevation angle
00004	Specify translation axis. 1 = +X, 2 = -X, 3 = +Y, 4 = -Y, 5 = +Z, 6 = -Z
00005	Specify IMU orientation. 1 = preferred, 2 = nominal, 3 = REFSMMAT

Table 2-6. DSKY Alarm Codes

Code	Description
00107	More than seven mark pairs
00110	No mark since last mark reject
00111	Mark missing
00112	Mark not being accepted
00113	No inbits
00114	Mark made, but not desired
00115	OSS torque request with switch not at LGC
00116	OSS switch altered before 15-second zero time elapsed
00117	OSS torque request with OSS not available
00120	OSS torque request with OSS not zeroed
00205	Preferred orientation selected, but not specified
00206	Zero encode not allowed with coarse align or gimbal lock

GUIDANCE, NAVIGATION, AND CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-6. DSKY Alarm Codes (cont)

Code	Description
00207	ISS turn-on request not present for 90 seconds
00210	IMU not operating
00211	Coarse align error
00212	PIPA fail, but PIPA not in use
00213	IMU not operating with turn-on request
00214	Program using IMU when turned off
00215	Orientation not specified
00216	Bad PIPA reading
00217	Bad return from stall routines
00401	Desired gimbal angles yield gimbal lock
00404	Target out of view
00405	Two stars not available
00406	Rendezvous navigation not operating
00407	Target out of view
00420	Third call to orbital integration
00421	W-matrix overflow
00501	Radar antenna out of limits
00503	Radar antenna designate fail
00510	Radar auto discrete not present
00514	Radar goes out of automatic mode while being used
00515	RR CDU fail discrete present
00525	$\Delta\theta > 3^\circ$
00526	Range > 400 nm
00600	Imaginary roots on first iteration
00601	Perigee altitude (CSI)
00602	Perigee altitude (CDH)
00603	CSI to CDH time
00604	CDH to TPI time

GUIDANCE, NAVIGATION, AND CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-6. DSKY Alarm Codes (cont)

Code	Description
00605	Number of iterations exceeds loop maximum.
00606	ΔV exceeds maximum.
00607	Hyperbolic velocity
00610	Computed CDH time > input TPI time
00611	No GETI for given elevation angle
00700	ΔR or ΔV exceeds threshold.
01102	LGC self-test error
01103	Unused CCS branch executed
01104	Delay routine busy
01105	Downlink too fast
01106	Uplink too fast
01107	Phase table failure. Assume erasable memory destroyed.
01110	Restart with no active phase
01111	Restart with active phase
01201	Executive overflow; no vacant areas
01202	Executive overflow; no core sets
01203	Waitlist overflow; too many tasks
01206	Second job attempts to go to sleep via DSKY program
01207	No vacant areas for mark
01210	Two programs using device at same time
01211	Illegal interrupt of extended verb
01301	ARCSIN - ARCCOS input angle too large. Abort.
01302	SQRT called with negative argument. Abort.
01401	TESTIDX too large in integrated test. End test.
01402	Illegal quantity loaded in jet or engine task erasable
01403	Illegal quantity loaded in Service module propulsion sub-system or Saturn steering task
01404	Integrated test; please perform task 401, 402, or 403 failed. End test.
01405	Inertial CDU's busy during Saturn steering test. End test.

GUIDANCE, NAVIGATION, AND CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-6. DSKY Alarm Codes (cont)

Code	Description
01406	Thrust misalign >90°
01407	VG increasing
01411	Radar out of limits or IRIG scale factor test alarm
01412	Bad pulse torque of gyros X-CDU out of limits
01413	Bad pulse torque of gyros Y-CDU out of limits
01414	Bad pulse torque of gyros Z-CDU out of limits
01426	IMU unsatisfactory
01427	IMU reversed
01501	DSKY alarm during internal use. Abort.
01502	Illegal flashing display
01520	V37 request not permitted at this time
01550	V46 inoperative when TVC DAP is on
01600	Overflow and drift test
01601	Bad IMU torque; abort
01602	Bad optics during verification
01703	<45 seconds to ignition
01704	PGNS automatic mode not selected
01705	DAP flag hold not set to -1
01706	Stage verify discrete does not agree with N46
01707	Checklist reference code 00203 not performed (Refer to table 2-4.)

Table 2-7. Star Codes

Code	Star	Visual Magnification	Right Ascension		Declination	
			Hr	Min	Deg	Min
1	Alpha Andromedae (Alpheratz)	2.1	0	06	+28	53
2	Beta CETI (Diphda)	2.2	0	42	-18	11
3	Gamma Cassiopeiae (NAVI)	2.2	0	54	+60	27
4	Alpha Eridani (Achernar)	0.6	1	36	-57	25

GUIDANCE, NAVIGATION, AND CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-7. Star Codes (cont)

Code	Star	Visual Magnification	Right Ascension		Declination	
			Hr	Min	Deg	Min
5	Alpha Ursae Minoris (Polaris)	2.1	1	58	+89	06
6	Theta Eridani (Acamar)	3.4	2	57	-40	26
7	Alpha CETI (Menkar)	2.8	3	00	+03	56
10	Alpha Persei (Mirfak)	1.9	3	22	+49	44
11	Alpha Tauri (Aldebaran)	1.1	4	34	+16	26
12	Beta Orionis (Rigel)	0.3	5	12	-08	15
13	Alpha Aurigae (Capella)	0.2	5	13	+45	57
14	Alpha Carinae (Candpus)	-0.9	6	23	-52	40
15	Alpha Canis Majoris (Sirius)	-1.6	6	44	-16	40
16	Alpha Canis Minoris (Procydn)	0.5	7	37	+05	19
17	Gamma Velorum (Regor)	1.9	8	08	-47	14
20	Iota Ursae Majoris (Dnoces)	3.1	8	50	+48	30
21	Alpha Hydrae (Alphard)	2.2	9	26	-08	30
22	Alpha Leonis (Regulus)	1.3	10	06	+12	09
23	Beta Leonis (Denebola)	2.2	11	47	+14	46
24	Gamma Corvi (Gienah)	2.6	12	13	-17	20
25	Alpha Crucis (Acrux)	1.6	12	24	-62	49
26	Alpha Virginis (Spica)	1.2	13	23	-10	58
27	Eta Ursae Majoris (Alkaid)	1.9	13	46	+49	30
30	Theta Centauri (Menkent)	2.3	14	04	-36	11
31	Alpha Bootis (Arcturus)	0.2	14	14	+19	22
32	Alpha Coronae Borealis (Alphecca)	2.3	15	33	+26	50
33	Alpha Scorpii (Antares)	1.2	16	27	-26	21
34	Alpha Trianguli Austr. (Atria)	1.9	16	43	-68	56
35	Alpha Ophiuchi (Rasa/hague)	2.1	17	33	+12	35
36	Alpha Lyrae (Vega)	0.1	18	36	+38	45
37	Sigma Sagittarii (Nunki)	2.1	18	53	-26	20

GUIDANCE, NAVIGATION, AND CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-7. Star Codes (cont)

Code	Star	Visual Magnification	Right Ascension		Declination	
			Hr	Min	Deg	Min
40	Alpha Aquilae (Altair)	0.9	19	49	+08	46
41	Beta Capricorni (Dabih)	3.2	20	19	-14	54
42	Alpha Pavonis (Peacock)	2.1	20	23	-56	51
43	Alpha Cygni (Deneb)	1.3	20	40	+45	09
44	Episilon Pegasi (Enif)	2.5	21	42	+09	42
45	Alpha Piscis Austr. (Formalhaut)	1.3	22	56	-29	49

2.2.3.1.4 Primary Guidance and Navigation Section Operation Modes.

The PGNS is considered to be in an operational mode upon initiation of a program by the astronauts or MSFN. When operating under one of the various programs (table 2-8), the LGC automatically computes required mission parameters, commands the PGNS and the other sections and subsystems, and displays pertinent data to the astronaut and MSFN (via downlink). For operational compatibility, the astronauts and/or MSFN can initiate, modify, or interrupt the automatic program sequences. The programs are initiated manually by the astronaut or by MSFN and, in certain cases, by a previous program.

The LGC is preprogrammed to display a mode number or program number on the DSKY in response to initiation of a program. This display remains on until the sequence of events for the specific mission phase, as dictated by the program, is completed.

2.2.3.1.5 Primary Guidance and Navigation Section Routines.

The PGNS routines (table 2-9) are used by most LGC programs, to perform the required input and output functions. Through these routines, the LGC can command various guidance modes, display and accept information from the DSKY and radar, provide for telemetry inputs and outputs, control the positions of the RR antenna and the IMU stable member, and remain cognizant of the PGNS and LM subsystem operations.

2.2.3.1.6 General Operation of the Primary Guidance and Navigation Section. (See figure 2-30.)

This discussion of PGNS operation is limited to astronaut interface with the PGNS, because PGNS operation is dependent on the LGC program in progress and on the mission phase. The astronaut can perform optical sightings, monitor subsystem performance, load data, select mode of operation, and, with the aid of the PGNS, manually control the LM. The program to be performed by the LGC is selected by the astronaut or initiated internally by the LGC.

The primary displays and controls of the PGNS comprise the DSKY, the attitude and translation controllers, and portions of the astronauts' panels. The DSKY enables the astronaut to communicate with the LGC and perform a variety of tasks such as testing the LGC, entering voice link data, and commanding IMU mode switching. The controllers permit manual changes or computer-aided manual changes in attitude or translation.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-8. LGC Programs

Program No.	Title	Mission Phase	Primary Purpose
00	LGC idle	Service	Maintains LGC in condition of readiness (after PGNS startup) in circumstances where no PGNS control or major computational operations are required
05	PGNS startup	Service	Transfers ISS and CSS from standby condition to operate condition Permits manual loading of LM/CSM state vector components (position, velocity, time) into LGC
06	PGNS power-down	Service	Transfers ISS and CSS from operate condition to standby condition
20	Rendezvous navigation	Coast	Controls RR and LM for acquisition of CSM Performs navigational computation (state vector update), using RR-provided data
21	Ground track determination	Coast	Calculates ground track information and displays latitude, longitude, and altitude to astronaut at specified time
25	Preferred tracking attitude	Coast	Calculates attitude for LM, to permit CSM to track LM beacon Automatically maneuvers LM to preferred tracking attitude
27	LGC update	Coast	Inserts information into LGC via digital uplink from MSFN, or manually via DSKY
30	External ΔV	Prethrusting	To calculate and display, to astronaut, initial conditions required for execution of PGNS-controlled thrusting maneuver Enables astronaut to insert targeting parameters used in computation of initial conditions
32	Coelliptic sequence initiation (CSI)	Prethrusting	To calculate and display required parameters associated with all coelliptic rendezvous flight plan maneuvers, but primarily those parameters associated with CSI maneuver Enables astronaut to insert maneuver data into LGC, for these calculations
33	Constant delta altitude (CDH)	Prethrusting	To calculate and display required parameters primarily for CDH maneuver but, also, for all other coelliptic rendezvous flight plan maneuvers, except CSI Enables astronaut to insert maneuver data into LGC, for these calculations
34	Transfer phase initiation (TPI)	Prethrusting	To calculate and display initial conditions required for LM execution of TPI maneuver Enables astronaut to insert maneuver data into LGC, for these calculations

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-8. LGC Programs (cont)

Program No.	Title	Mission Phase	Primary Purpose
35	Transfer phase midcourse (TPM)	Prethrusting	To calculate and display required parameters for LM execution of possible midcourse correction during transfer phase of LM active rendezvous To calculate and display information to enable astronauts to prepare for entry into final rendezvous phase
40	Descent propulsion section (DPS) thrust control	Thrusting	To calculate preferred IMU orientation and preferred LM attitude for LM DPS thrust maneuver To automatically maneuver LM to preferred attitude and control LM through termination of thrusting maneuver
41	Reaction Control Subsystem thrust control	Thrusting	Same as for program No. 40, but for RCS thrust maneuver To provide rapid trimming of residual steering errors left at DPS or APS cutoff
42	Ascent propulsion section (APS) thrust control	Thrusting	Same as for program No. 40, but for thrust maneuvers using ascent engine
47	Thrust monitor	Thrusting	To monitor LM acceleration during thrust maneuver that is not controlled by PGNS and display resulting change in inertial velocity
51	IMU orientation determination	Alignment	To determine inertial orientation of IMU stable member with respect to celestial coordinates, for guidance and navigation computations
52	IMU realign	Alignment	To align IMU stable member to specific inertial orientation, as selected by astronaut, from previously established inertial orientation
72	CSM-CSI targeting	Prethrusting	To calculate and display required parameters associated with all coelliptic rendezvous flight plan maneuvers, for CSM execution of the maneuvers
73	CSM-CDH targeting	Prethrusting	To calculate and display required parameters associated with all coelliptic rendezvous flight plan maneuvers, except CSI, for CSM execution of the maneuvers
74	CSM-TPI targeting	Prethrusting	To calculate and display required initial conditions for active CSM transfer phase initiation maneuver
75	CSM-TPM targeting	Prethrusting	To calculate and display required initial conditions for active CSM midcourse correction during transfer phase of rendezvous

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-9. Primary Guidance and Navigation Section Routines

Routine No.	Title
00	Final automatic request terminated
02	IMU status check
03	DAP data loading (verb 48)
04	RR/LR self-test
12	LR data read
21	RR designate
22	RR data read
23	RR manual acquisition
24	RR search
25	RR monitor
30	Orbit parameter display (verb 82)
31	Rendezvous parameter display (verb 83)
32	Target ΔV (verb 84)
33	LGC - Command module computer clock synchronization
36	Out-of-plane rendezvous display
47	AGS initialization
50	Coarse alignment
51	In-flight fine alignment
52	Auto optics positioning
53	Sighting mark
54	Sighting data test
55	Gyro torquing
60	Attitude maneuver
61	Preferred tracking attitude
62	Crew-defined maneuver
63	Rendezvous final attitude

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

The PGNS flight data that are displayed to assist the astronaut during various phases of the LM-3 mission are: total LM attitude, attitude errors, altitude and altitude rate, forward and lateral velocities, and percentage of descent engine thrust commanded by the LGC.

Total attitude is generated from the IMU gimbal angles. With the ATTITUDE MON switch (panel 1) set to PGNS, the IMU gimbal angles are routed to the GASTA. The GASTA transforms the gimbal angles into signals of the proper configuration of total attitude. (Refer to paragraph 2.2.3.4.) The total attitude signals are applied to the FDAI sphere for direct astronaut readout. The FDAI also displays roll, pitch, and yaw rates and errors. The FDAI rate indicators monitor the rate of change of angular position. When the RATE/ERR MON switch (panel 1) is set to LDG RDR/CMPTR, the FDAI error indicators indicate the deviation between the programmed and actual attitude. The FDAI rate indicators are fed from the CES rate gyros; the pitch, yaw, and roll attitude errors are supplied from the LGC via the CDU's.

The astronauts can select the LGC, PGNS, or AGS as the source for the altitude and altitude-rate parameters. When the MODE SEL switch is set to PGNS, the LGC calculates altitude and altitude rate, but issues signals for display of either altitude or altitude rate. Altitude and altitude rate are not displayed simultaneously. These signals are routed through the RNG/ALT MON switch (panel 1) to the ALT and ALT RATE indicators (panel 1).

Forward and lateral velocities are displayed on the X-pointer indicator (panels 1 and 2). The indicator receives velocity signals from the LGC via the CDU when the MODE SEL switch is set to PGNS. The LGC calculates the velocities from its stored information and from information received from the LR. The LGC feeds the calculated data to the CDU for digital-to-analog conversion before display. The X-POINTER SCALE switch (panel 3) selects the scale of the indicator. The type of velocity and the scale selected are indicated by illuminated placarding on the borders of the X-pointer indicator.

The amount of descent engine throttling, as commanded by the LGC, is routed to the CES. The CES sends this command to the THRUST indicator and to the descent engine. The THRUST indicator also displays the amount of thrust sensed at the engine thrust chamber, so that a comparison can be made.

PGNS vehicle control includes interfacing for reaction control (attitude and translation) and for propulsion control (descent and ascent engine thrust). The PGNS interfaces directly with the CES for reaction control and propulsion control. Commands from the LGC are routed through the CES to the RCS thrusters and to the ascent and descent engine for proper flight control.

2.2.3.2 Abort Guidance Section. (See figure 2-31.)

The AGS provides backup guidance and navigation for LM 3, from any point during the mission. The AGS serves as backup for the PGNS; normally the AGS will be used to control the LM only in the event of a PGNS malfunction. A portion of the LM-3 mission will be under AGS control, to contribute to the verification of the AGS before the lunar flight. During a mission abort or AGS control, the AGS performs the guidance computations and steering required to place the LM in a coelliptic flight plan (direct intercept trajectory with the CSM or a parking orbit). Rendezvous from the abort point can be accomplished automatically under AGS control or manually by the astronaut, based on data displayed from the AGS.

The AGS uses a strapped-down inertial guidance technique, unlike the conventional gimbaled-platform technique used in the PGNS. The basic differences between these two techniques is the method used to determine the direction of sensed acceleration.

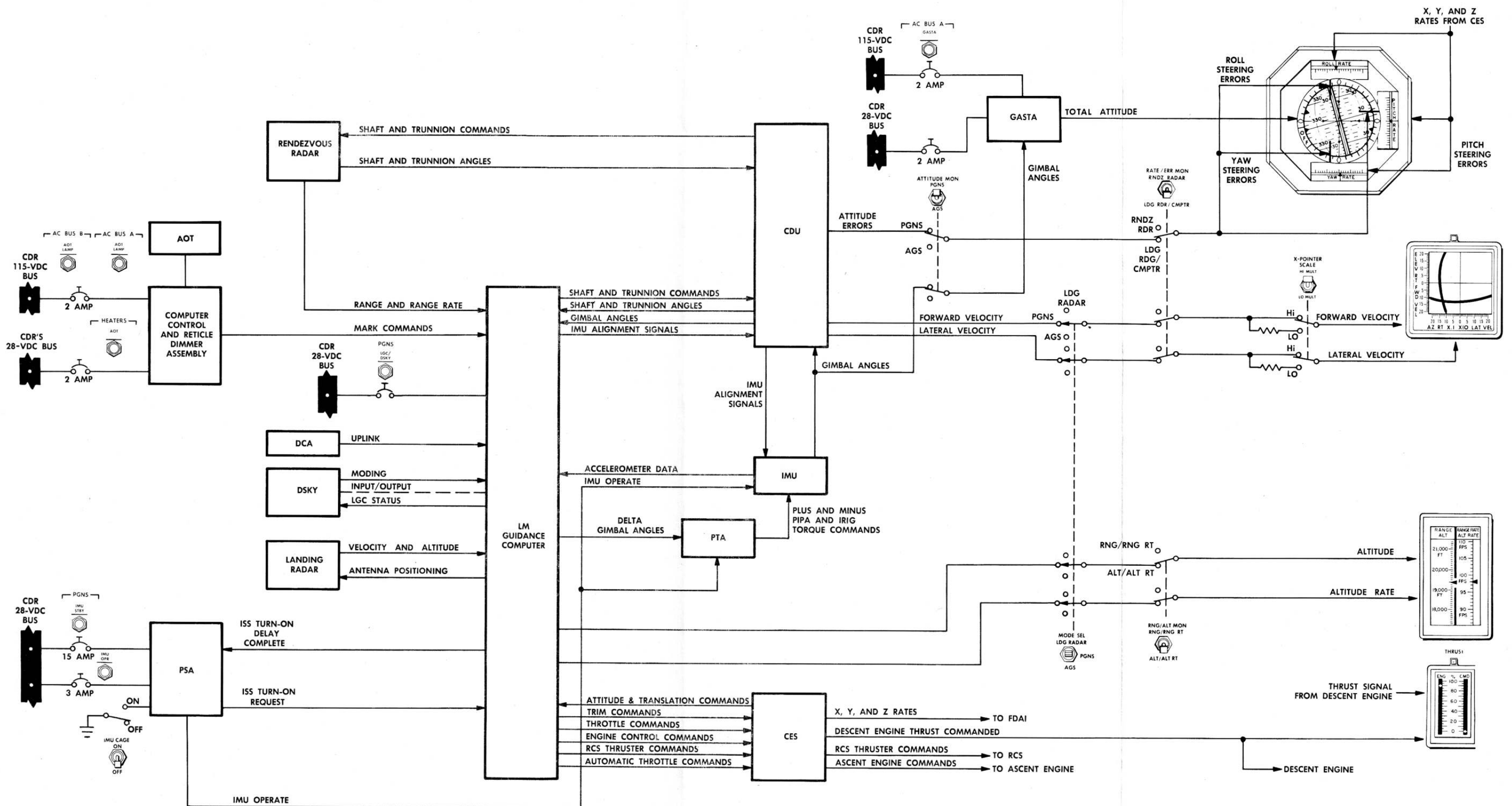


Figure 2-30. Primary Guidance and Navigation Section - Functional Flow Diagram

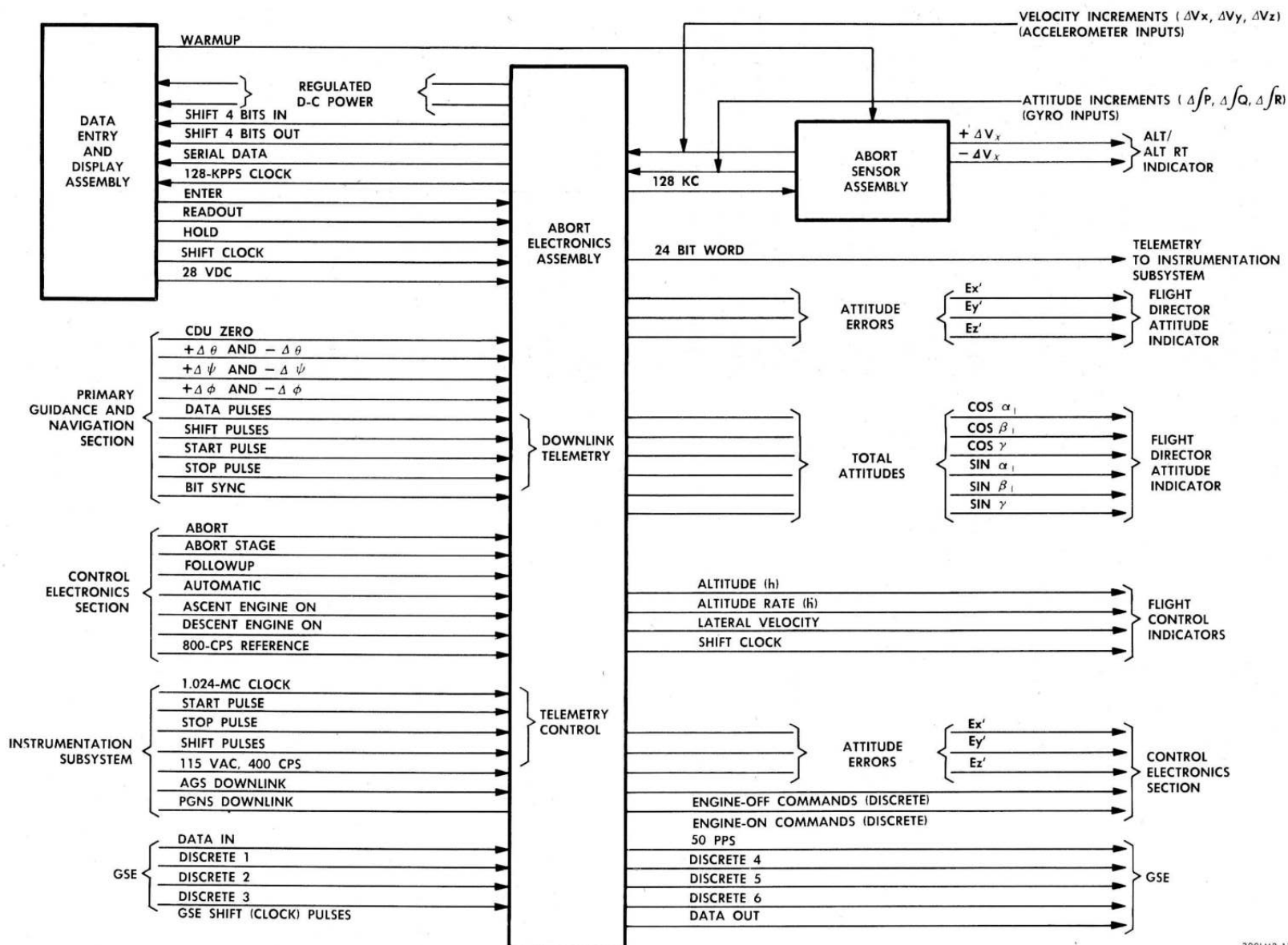


Figure 2-31. Abort Guidance Section - Block Diagram

300LM3-179

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

In the conventional configuration, sensors are mounted on a platform that is positioned by gyroscopic control. In the strapped-down configuration, the sensors are fixed and referenced to the LM body axes; the orientation of the sensors is computed from outputs of gyroscopes also directly mounted and fixed to the LM body axes. A digital computer, in the strapped-down configuration, replaces the gimbaling structure of the conventional configuration in determining inertially referenced acceleration.

The AGS maintains an inertial attitude reference that relates the LM orthogonal axes to an inertial reference frame through either IMU alignment, lunar alignment, or body-axis alignment. During IMU alignment, the AGS accepts the attitude reference of the PGNS. During lunar alignment, the AGS accepts the attitude reference from the lunar gravity vertical and azimuth angle stored in the AEA memory. When body-axis alignment is used, the AGS sets the inertial reference frame equal to the LM orthogonal axes.

The AGS interfaces with the CES, PGNS, IS, and the associated controls and displays. The AGS input and output signal characteristics are listed in tables 2-10 and 2-11, respectively. If a mission abort occurs, the CES functions as an autopilot. The CES uses the AGS input signals and manual control signals. During prelaunch activities the AGS interfaces with ground support equipment, which stores the AEA input data during this time and provides a functional checkout of all subsystems. PGNS interfacing includes the Euler angles for alignment and downlink data initialization.

The AGS comprises the AEA, and DEDA. The ASA is a strapped-down inertial sensor package; it senses incremental attitude changes and incremental velocity changes along the LM axes and routes these data to the AEA. The AEA is a general-purpose digital computer that performs the basic strapped-down calculations for control of abort guidance, navigation, and steering. The DEDA, an abbreviated version of the DSKY, permits manual entry of data into the AEA and displays data that are stored in the AEA.

Table 2-10. Abort Guidance Section - Input Signal Characteristics

Nomenclature	Routing	Signal Description	Remarks
1,024-pps clock	ISS to AEA	Digital pulse train for AGS internal timing	± 2 -pps accuracy
AGS telemetry stop pulse	ISS to AEA	50-pps signal; indicates completion of telemetry shift for one digital word	
AGS telemetry shift pulses	ISS to AEA	51.2 kpps (burst of 24 pulses, 50 times per second); shifts telemetry data out of AEA	
800-cps reference	CES to AEA	Sinusoidal excitation for digital-to-analog converters in AGS	± 0.5 vrms and $\pm 1\%$ frequency accuracy
Automatic	CES to AEA	Discrete used to put AEA in automatic submode	Definitions: 1 - Ground 0 - Open circuit
Abort	CES to AEA	Discrete, indicating an abort but that staging has not occurred	Definitions: 1 - Ground 0 - Open circuit

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-10. Abort Guidance Section - Input Signal Characteristics (cont)

Nomenclature	Routing	Signal Description	Remarks
Followup	CES to AEA	Discrete used to put AEA in followup submode	Definitions: 1 - Ground 0 - Open circuit
Abort stage	CES to AEA	Discrete, indicating abort and that staging is initiated	Definitions: 1 - Ground 0 - Open circuit
PGNS alignment signals: - $\Delta\theta$, + $\Delta\theta$, - $\Delta\psi$ + $\Delta\psi$, - $\Delta\phi$, + $\Delta\phi$	PGNS to AEA	Digital pulse train (6.4 kpps maximum), denoting negative and positive angular increments of the three PGNS gimbal angles (θ , ϕ , ψ)	The gimbal angles are used during IMU alignment, to define the inertial reference frame.
CDU zero	PGNS to AEA	51.2-kpps pulse train, used to reset PGNS angle input registers	Definition On - Application for 300 milliseconds (minimum)
PGNS telemetry downlink stop	PGNS to AEA	50-pps signal, indicating termination of PGNS telemetry downlink shift operation	
PGNS telemetry bit-synchronizing pulse	PGNS to AEA	51.2-kpps pulse train, used to shift in PGNS telemetry downlink data	Burst of 40 pulses with period of 20 milliseconds each
PGNS telemetry downlink data pulses	PGNS to AEA	51.2-kpps signal, comprising 40-bit words; used to initialize AGS navigation	Burst of 40 pulses with period of 20 milliseconds each
Descent engine on	CES to AEA	Discrete, indicating state of descent engine	Definitions: 1 - Ground, engine on 0 - Open circuit, engine off
Ascent engine on	CES to AEA	Discrete, indicating state of ascent engine	Definitions: 1 - Ground, engine on 0 - Open circuit, engine off

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-11. Abort Guidance Section - Output Signal Characteristics

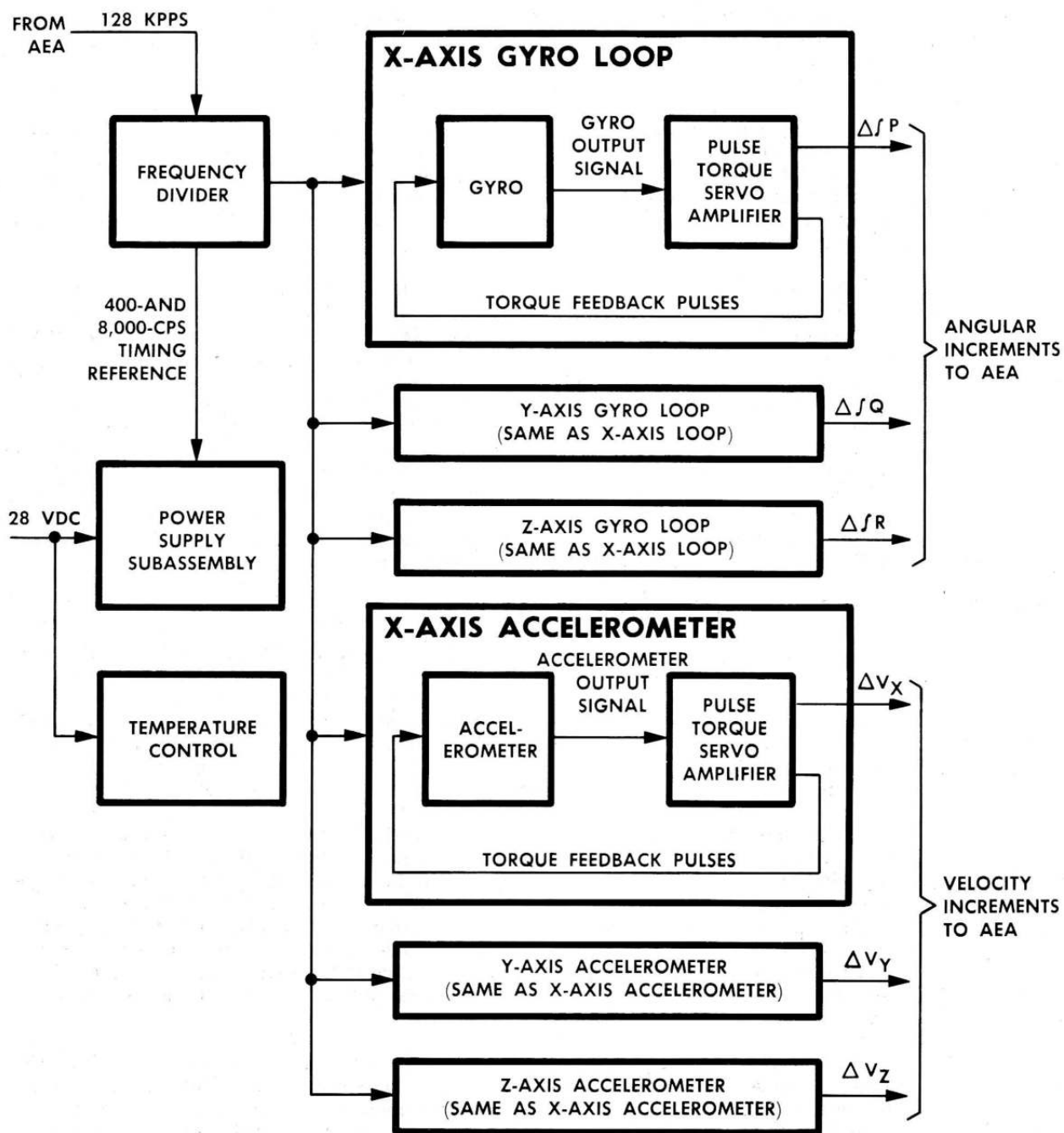
Nomenclature	Routing	Signal Description	Remarks
Total attitude signals: sine α , cosine α , sine β , cosine β , sine γ , cosine γ	AEA to FDAI	0- to 15-vrms, 400-cps, sinusoidal signals for total attitude display	Scale factor: 30 millivolts per step Computation rate: 25 times per second
Altitude signal (h)	AEA to displays	64-kpps signal with word frequency of five times per second, used for altitude display	Resolution: 2.3 feet per bit (15-bit word)
Altitude rate signal (h)	AEA to displays	64-kpps signal with word frequency of five times per second, used for altitude rate display	Resolution: least significant bit 0.5 foot per second (14 bits plus sign)
Lateral velocity (Vy)	AEA to displays	-5 to +5 vdc, dynamic range -200 to +200 feet per second	Resolution: 25 mv fps
Shift pulses for h, h, and Vy	AEA to displays	64 kpps	
Attitude error signals: E _X , E _Y , E _Z	AEA to CES and display	0- to 3-vrms, 800-cps, sinusoidal, body-referenced, altitude error signals for steering and display	Resolution: 300 millivolts per degree $\pm 5\%$ with -70° to $+78^\circ$ range
Engine commands: on and off	AEA to CES	Commands issued when AGS requires engine on (28 \pm 11 volts) or engine off (0 \pm 2 volts)	
AGS telemetry data pulses	AEA to IS	51.2-kpps (maximum) telemetry word; burst of 24 pulses 50 times per second	

2.2.3.2.1 Abort Sensor Assembly. (See figure 2-32.)

The ASA contains three floated, pulse-rebalanced, single-degree-of-freedom, rate-integrating gyroscopes and three pendulous reference accelerometers in a strapped-down configuration. These six sensors are housed in a beryllium block, which is mounted on the navigation base. The sensors are aligned with the three LM reference axes. The assembly also includes pulse torque servoamplifiers (one associated with each sensor), temperature control amplifiers, and a power supply.

The ASA senses LM angular displacements and velocity increments and generates output pulses to update the AEA. Electromagnetic torquers balance the gyroscopic input torque; the average current in the torquers corresponds to angular rate. The pulses (time-modulated increments of current) are equivalent to angular increments and are used to indicate vehicle attitude changes sensed by the gyroscope. These signals are used by the AEA in the same manner that torque commands would balance gimbaled gyros.

Current generated in the accelerometer produces torque that opposes the torque caused by the force of acceleration on a pendulous mass. The average current is



300LM3-262

Figure 2-32. Abort Sensor Assembly - Block Diagram

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

proportional to the acceleration, and pulses are generated in the accelerometers for use by the computer in measuring velocity increments.

The output of each gyro and accelerometer is applied to a pulse torque servoamplifier. The pulse torque servoamplifiers use quantized time-modulated feedback to torque-balance their associated gyro or accelerometer. The servoamplifiers consist of an amplifier, a quantizer bridge and driver, and a current regulator.

The strapped-down inertial guidance system has the advantage of substantial size and weight reduction over the more conventional gimbaled inertial guidance system, but has the disadvantage of error buildup over sustained periods of operation. The calibration method uses the PGNS as a reference to determine the drift-compensation parameters for the ASA gyros. These parameters are stored in the AEA and used to correct calculations based on the gyro inputs.

The accuracy of the ASA inertial data outputs is temperature-dependent. The ASA temperature control subassembly maintains the internal ASA temperature at +120° F, with external temperatures between -65° and +185° F. Two temperature control circuits are used, one each for fast warmup and fine temperature control. During fast warmup, ASA temperature can be raised from 0° F to approximately +116° F in 40 minutes. The ASA must warm up for at least 30 minutes (standby mode - AGS STATUS switch on panel 6 set to STANDBY) before operation. The fast warmup circuitry consists of a thermal sensor, which detects the internal ASA temperature and provides a proportional d-c analog to heater driver electronics that maintain the required heater power constant. The constant heater power requirement permits a uniform temperature rise within the ASA. The fine temperature control circuit controls the temperature after ASA temperature reaches +116° F. The fine temperature control circuit can raise the temperature 4° F and maintain this operating temperature within 0.2° F.

2.2.3.2.2

Abort Electronics Assembly. (See figure 2-33.)

The AEA is a general-purpose, high-speed, 4,096-word digital computer that performs the basic strapped-down guidance system calculations and the abort guidance and navigation steering calculations. The computer uses a fractional two's complement, parallel arithmetic section and parallel data transfer. Instructions consist of 18 bits: a 5-bit order code, an index bit, and a 12-bit operand address. Data words for the computer consist of a sign and 17 magnitude bits. The AEA has three software computational sections: stabilization and alignment, navigation, and guidance.

The stabilization and alignment computational section performs stabilization and alignment computations, on generation of mode signals by the DEDA. These mode signals (attitude hold, rendezvous, acquisition, IMU alignment, lunar align, and body-axis align) determine the operation of the stabilization and alignment computational section in conjunction with the navigation and guidance computational sections. Body-referenced steering error signals and total attitude sine and cosine signals are used to control the FDAI. Direction cosine data are routed to the navigation computational section, where they are used in computing lateral velocity and inertial acceleration data.

The navigation computational section uses accelerometer inputs received from the ASA, via AEA input logic circuits, to calculate the position and velocity of the LM in the inertial reference frame. The navigation computational section supplies total velocity, altitude, and altitude rate data in earth-centered coordinates, and lateral velocity data in the LM reference frame, to the output logic circuits. Velocity data are routed to the DEDA, altitude and altitude rate data are routed to the RANGE, RANGE RATE, ALT, and ALT RATE indicators (panel 1), and lateral velocity data are routed to the X-Pointer indicators (panels 1 and 2). Velocity and position data are routed to the guidance computational section, for computing LM orbital parameters.

The guidance computational section provides trajectory computation and selection, steering computation, and midcourse-correction computation. This computational

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

section receives data relating to the CSM state vector and the LM state vector from the LGC via the AGS input selector logic. Body-referenced steering errors are received from the stabilization and alignment computational section, for trajectory computation. The LM abort guidance problem (coelliptic flight plan) consists of determining a trajectory that either intercepts the CSM directly in its orbit or places the LM in a parking orbit until rendezvous maneuvers can be executed. On determining the abort trajectory, the AEA performs steering computations to provide engine on and off commands and attitude commands, which place the LM in the desired trajectory and effect LM-CSM rendezvous. Midcourse-correction computations are initiated during the coast phase of the abort trajectory. These computations weigh the most recent LM and CSM position and velocity data heavier than previous data, and discount random disturbances; the computations are not dependent on data spacing. Outputs of the guidance computational section, via the output select logic circuits, include the engine on and off signals to the CES, and velocity to be gained (selectable by DEDA readout).

The AEA consists of a memory subassembly, arithmetic and control logic subassemblies (central computer), an input-output subassembly, and a power supply.

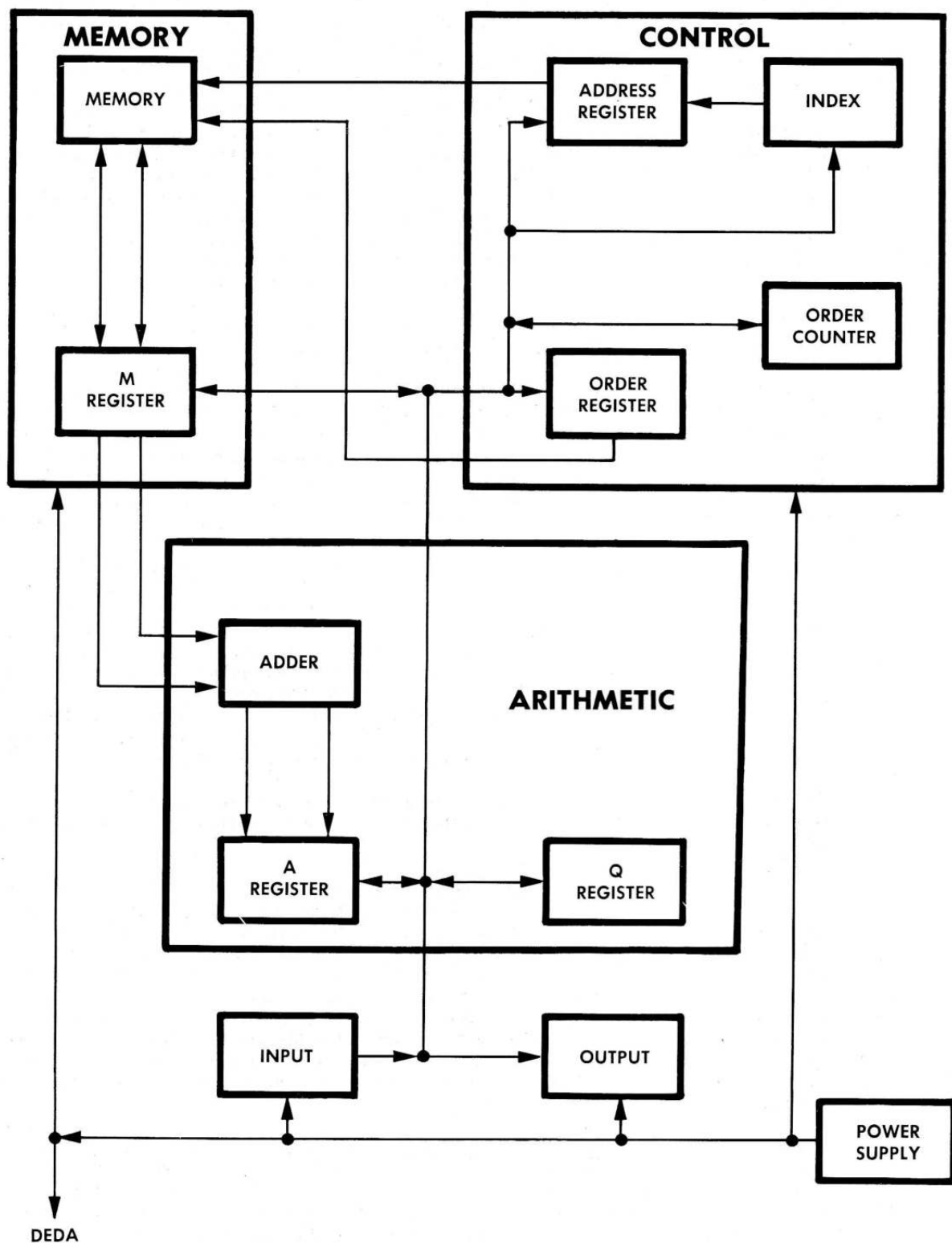
Memory. The AEA memory is a coincident-current, parallel, random-access, ferrite-core memory with a capacity of 4,096 words (18 bits each). The cores are arranged in square planes; each core is subjected to X- and Y-coordinate selection. There is one plane for each bit in the word; the arrangement consists of 64 rows and 64 columns. The number of words in the memory is equal to the number of cores in a bit plane. An address to the computer is specified by an X-coordinate and a Y-coordinate; it refers to the core at that location in all 18-bit planes.

The memory core stack is divided into two sections: scratchpad memory (2,048 words) and permanent memory (2,048 words). The scratchpad memory stores replaceable instructions and data. Temporary results may be stored in the scratchpad memory and may be updated as necessary. Checkout routines may be loaded during checkout and subsequently discarded. Each core in the scratchpad memory is threaded by an X-selection winding, a Y-selection winding, a sense winding, and an inhibit winding. The permanent memory stores instructions and constants that are not modified during operation of the permanent-memory section. Using a permanent memory prevents inadvertent loss of information. In the permanent memory, the inhibit winding is omitted and the X-selection winding passes only through cores that represent zeros.

The cycle time of the memory is 5 microseconds. The addresses of the scratchpad storage locations are 0 through 3777g; the addresses of the permanent storage locations, 4000g through 7777g.

Memory Register. The memory register (M-register) is an 18-bit register, which is loaded from the memory cores. The register holds data that are to be transferred between the central computer and the memory, by the data bus. The data bus is a collection of gates through which data (up to 18 bits in parallel) may transfer from one register to another. Data transferred from the memory are held by the M-register as they are placed on the data bus. During this time, data transfer is a read-and-restore operation. Data transferred to the memory from the central computer are held by the M-register as they are written into the memory. The M-register holds the multiplicand during multiplication, the divisor during division, the addend during addition, and the subtrahend during subtraction. The accumulator is loaded by clearing it and then adding the contents of the M-register to the accumulator.

Arithmetic and Control Logic Subassemblies. The arithmetic and control logic subassemblies (central computer) comprise an address register, index register, order counter, order register, adder, accumulator, and a multiplier - quotient register (Q-register). The registers are interconnected by a parallel data bus. Central-computer operations are executed by appropriately timed transfer of information between these registers, between the memory and the M-register, and between the accumulator and input-output registers. The adder, M-register, Q-register, and accumulator form the basis for execution of arithmetic operations.



300LM3-261

Figure 2-33. Abort Electronics Assembly - Block Diagram

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Address Register. The address register is a 12-bit register that is loaded under LGC control, from the least significant 12 bits of the data bus. The address register holds the address of the memory location to which access is requested.

Index Register. The index register is a three-bit counter that is used for operand-address modification. When an indexed instruction is executed, the effective operand address is computed by a logical OR operation between the index register and the three least significant bits of the operand address. When a transfer and text index instruction is executed, the index register is decreased by one if the counter is greater than zero, and the next instruction is taken from the location specified by the address field of the transfer and text index instruction. If the index register is zero, the counter is not decreased, and the next instruction is taken in sequence. The index register is loaded under program control, from the least significant three bits of the data bus.

Order Counter. The order counter consists of a program counter and a cycle counter. The program counter is a 12-bit counter, which is loaded from the least significant 12 bits of the data bus by execution of a transfer instruction. The program counter holds and generates instruction addresses in sequence. The cycle counter is a five-bit counter that controls shift instructions and certain long orders.

Order Register. The order register is a five-bit register that is loaded under central-computer control, from the five most significant bits of the data bus. The order register holds the five-bit order code during its execution.

Adder. The arithmetic section is designed around an 18-bit, 3-microsecond parallel adder. Two 18-bit registers (the accumulator and the M-register) furnish the inputs to the adder. The sum generated by the adder is loaded into the accumulator. Shifting is implemented by displacing the sum generated by the adder one bit right or left when loading it into the accumulator.

Accumulator. The accumulator (A-register) is an 18-bit register; it communicates, in parallel, with the adder and the data bus. The accumulator also communicates serially with the Q-register for shifting operations, such as multiplication, division, and double-length shifts. The accumulator holds the results of most arithmetic operations; it is used to communicate with the input or output registers.

Multiplier-Quotient Register. The multiplier-quotient register (Q-register) is an 18-bit register that communicates, in parallel, with the data bus and, serially, with the accumulator. The Q-register holds the least significant half of the double-length product after multiplication, and initially holds the least significant half of the double-length dividend for division. After division, it holds the unrounded quotient. For double-length shifting operations, the Q-register is logically attached to the low-order end of the accumulator. After execution of a transfer and set Q-instruction, the Q-register holds a transfer instruction with an address field set to one greater than the location of the transfer and set Q-register instruction.

Input-Output Subassembly. There are four basic types of registers in the input-output subassembly: integrator, ripple counter, shift, and static. These registers operate independently of the central computer, except when they are accessed during execution of an input or output instruction. All transfers of data between the central computer and the input-output registers are in parallel. The PGNS Euler angles are accumulated in three 15-bit integrator registers. The integrator registers shift 15 bit positions at 512 kc upon receipt of each input pulse, serially adding or subtracting one from the previous count. The integrator registers are set to zero by an external signal. ASA gyro and accelerometer pulses are accumulated in six 11-bit counters (in the AEA), which are set to zero by the central computer. A 4-bit DEDA register, an 18-bit input telemetry register, a 24-bit output telemetry register, and a 15-bit output register time-shared for altitude and altitude rate are all used as shift registers. The remaining registers (digital-to-analog converter registers and discrete input and output registers) are static registers. The discrete output register is modified by setting or resetting specific bits within the register with specific output instructions.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

2.2.3.2.3

Data Entry and Display Assembly.

The DEDA is used to control the AGS modes of operation manually, to insert data manually into the AEA, and to command the contents of the accessible AEA memory to be displayed on numeric readouts. Only 512 of the 4,096 words stored in the AEA memory are DEDA accessible. The DEDA consists of a keyboard, logic circuits, electroluminescent displays, and driving circuits. The controls and indicators associated with the DEDA are listed in section 3.

Data input to the AEA, via the DEDA, consists of nine-character code. The first three characters form the address entry, in octal form; the fourth is the sign (+ or -); and the remaining five characters represent the data, in decimal or octal form. DEDA inputs to the AEA are listed in table 2-12. Before entering data, all nine characters must have been entered into the AEA. When requesting a readout, three numerical pushbuttons (0 through 9) are used. This three-digit code represents the address and is displayed on the upper portion of the readout. The selected information from the AEA memory is displayed on the lower portion of the readout. Table 2-13 contains the DEDA-accessible outputs.

Table 2-12. Data Entry and Display Assembly - Inputs

Address	Code	Definition	Range	Quantization	Remarks
047		Sine of landing azimuth angle	N/A		
053		Cosine of landing azimuth angle	N/A		
231		Launch site radial distance from center of earth	33,554,000 feet	10^3	
232		Orbit insertion targeted injection altitude	33,554,000 feet	10^3	
233		Vertical pitch steering altitude threshold	33,554,000 feet	10^3	
240		LM initial position, X-component	$\pm 33,554,000$ feet	10^3	
241		LM initial position, Y-component	$\pm 33,554,000$ feet	10^3	
242		LM initial position, Z-component	$\pm 33,554,000$ feet	10^3	
244		CSM initial position, X-component	$\pm 33,554,000$ feet	10^3	
245		CSM initial position, Y-component	$\pm 33,554,000$ feet	10^3	
246		CSM initial position, Z-component	$\pm 33,554,000$ feet	10^3	
254		LM epoch time (AGS referenced)	4,369 minutes	0.1	

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-12. Data Entry and Display Assembly - Inputs (cont)

Address	Code	Definition	Range	Quantization	Remarks
260		LM initial velocity, X-component	$\pm 32,767$ fps	1	
261		LM initial velocity, Y-component	$\pm 32,767$ fps	1	
262		LM initial velocity, Z-component	$\pm 32,767$ fps	1	
264		CSM initial velocity, X-component	$\pm 32,767$ fps	1	
265		CSM initial velocity, Y-component	$\pm 32,767$ fps	1	
266		CSM initial velocity, Z-component	$\pm 32,767$ fps	1	
272		CSM epoch time (AGS referenced)	4,369 minutes	0.1	
275		Desired absolute time of CSI maneuver	4,369 minutes	0.1	
277		Desired fixed absolute time of TPI, or mid- course maneuvers	4,369 minutes	0.1	
301		Desired TPI time for CSI computation	4,369 minutes	0.1	
302		Desired LOS angle be- tween LM and CSM at TPI time, for CSI com- putation	20° to 75°	0.01	
306		Desired yaw angle (about +X-axis) to main- tain S-band communica- tions	$\pm 30^\circ$	0.01	
310		Rendezvous offset time	136 minutes	0.01	
311		Desired LM transfer time for direct inter- cept transfer routine	136 minutes	0.01	
315		Δt time increment from present time to TPI or to CDH	136 minutes	0.01	
316		Radar range		0.01 nm	
377		Absolute time	4,369 minutes	0.1	

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-12. Data Entry and Display Assembly - Inputs (cont)

Address	Code	Definition	Range	Quantization	Remarks
400	+00000	Attitude hold function	Nondecimal input	N/A	Program automatically sets attitude hold function upon AGS engine cutoff, completion of IMU alignment, or completion of calibration.
400	+10000	Guidance steering function	Nondecimal input	N/A	Program automatically sets guidance steering function upon receipt of abort stage signal.
400	+20000	Acquisition function	Nondecimal input	N/A	
400	+30000	IMU alignment function	Nondecimal input	N/A	
400	+40000	Lunar alignment function	Nondecimal input	N/A	
400	+50000	Body-axis alignment function	Nondecimal input	N/A	
400	+60000	In-flight calibration function	Nondecimal input	N/A	
400	+70000	Accelerometer calibration only	Nondecimal input	N/A	
407	+10000	Freezes external ΔV reference into inertial reference frame	N/A	N/A	Program automatically sets this function upon detection of ullage.
410	+00000	Orbit insertion	N/A	N/A	
410	+10000	Coelliptic sequence initiate	N/A	N/A	
410	+20000	Constant Δh	N/A	N/A	
410	+30000	Direct transfer time increment $T\Delta$ constant (TPI search)	N/A	N/A	
410	+40000	Direct transfer fixed time of ignition (TPI execute)	N/A	N/A	

GUIDANCE, NAVIGATION, AND CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-12. Data Entry and Display Assembly - Inputs (cont)

Address	Code	Definition	Range	Quantization	Remarks
410	+50000	External ΔV	N/A	N/A	Program automatically sets code +00000 upon AGS engine cut-off.
411	+00000	DPS or RCS burn	N/A	N/A	
411	+10000	APS burn	N/A	N/A	
412	+00000	Reset error indicator or reinitiate testing.	N/A	N/A	
412	+10000	Test successfully completed	N/A	N/A	
412	+30000	Logic test failure	N/A	N/A	
412	+40000	Memory test failure	N/A	N/A	
412	+70000	Logic and memory test failures	N/A	N/A	DEDA entry causes data to be stored.
413	+00000	Normal position	N/A	N/A	
413	+10000	Store lunar azimuth and reset lunar surface flag.	N/A	N/A	Content of address 413 is only reset by computer power turn-on sequence.
414	+00000	Navigation initialization complete	N/A	N/A	Reset to zero within 2 seconds by radar filter equations.
414	+10000	Initialize LM and CSM via downlink.	N/A	N/A	
414	+20000	Initialize LM via DEDA.	N/A	N/A	
414	+30000	Initialize CSM via DEDA.	N/A	N/A	
415	+00000	Program reset. Normal value of store Z-axis direction cosines command	N/A	N/A	
416	+00000	CDH at first crossing of LM orbit line of apsides	N/A	N/A	
416	+10000	CDH at second crossing of LM orbit line of apsides	N/A	N/A	

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-12. Data Entry and Display Assembly - Inputs (cont)

Address	Code	Definition	Range	Quantization	Remarks
417	+00000	Select CDH at apsidal crossing.	N/A	N/A	
417	+10000	Select CDH at CSI 180° or 360° per address 416.	N/A	N/A	
450		Component of external ΔV in horizontal direction parallel to CSM orbit plane	$\pm 32,767$ fps	1 fps	Plus display indicates VG in posigrade direction.
451		Component of external ΔV in horizontal direction perpendicular to CSM orbit plane	$\pm 32,767$ fps	1 fps	Plus display indicates VG opposite to LM angular momentum vector.
452		Component of external ΔV in radial direction	$\pm 32,767$ fps	1 fps	Plus display indicates VG toward earth.
455	+00000	Altitude-rate scaling for lunar orbits	N/A	N/A	
455	+10000	Change altitude rate scaling for earth orbits.	N/A	N/A	
503		Radar range rate	$\pm 32,767$ fps	1 fps	
504		Vertical pitch steering altitude-rate threshold	$\pm 32,767$ fps	1 fps	
505		Targeted radial rate at orbit insertion	$\pm 32,767$ fps	1 fps	
506		Orbit insertion targeted injection horizontal velocity	$\pm 32,767$ fps	1 fps	
540		X-axis accelerometer bias	N/A	N/A	
541		Y-axis accelerometer bias	N/A	N/A	
542		Z-axis accelerometer bias	N/A	N/A	
544		X-gyro drift compensation constant	-	0.01°/hr	
545		Y-gyro drift compensation constant	-	0.01°/hr	

GUIDANCE, NAVIGATION, AND CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-12. Data Entry and Display Assembly - Inputs (cont)

Address	Code	Definition	Range	Quantization	Remarks
546		Z-gyro drift compensation constant	-	0.01°/hr	
547		Lunar align azimuth correction	N/A	N/A	

DEDA Operation. DEDA operation is initiated by pressing the CLR pushbutton. This enables data entry with the numerical pushbuttons (0 through 9). As each numerical pushbutton is pressed, its code is placed in a register for display in the order in which the pushbuttons are pressed. When the appropriate number of characters is entered, the ENTR or READOUT pushbutton can be pressed without generating an operator error.

The following paragraphs contain the operating procedures for the DEDA, using the front panel pushbuttons and electroluminescent readouts. Before performing these procedures, the appropriate cabin switches must be set to the on position; the AC BUS B: AGS (panel 11); STAB/CONT: AEA, and ASA circuit breakers (panel 16) must be closed; and the AGS STATUS switch (panel 6) must be set from STANDBY to OPERATE.

Data Insertion. The sequence of operations for inserting data into the AEA via the DEDA is as follows:

- Press and release CLR pushbutton.

This operation clears the DEDA and blanks all lighted characters. The CLR pushbutton must always be pressed before any DEDA entry.
- Press and release three consecutive numerical pushbuttons.

This operation identifies the address of the AEA memory word location into which the data are to be inserted.
- Press and release pushbutton that corresponds to sign (+ or -) of data to be inserted.
- Press and release desired five consecutive numerical pushbuttons that correspond to the numerical value of data to be inserted (decimal or octal, as appropriate for entry). Refer to table 2-12 for DEDA inputs (addresses).
- Verify entry by comparing electroluminescent display with desired address and desired numerical value.
- Press and release ENTR pushbutton.

At this time, the word is entered into the AEA and the address and data displays are blanked.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-13. Data Entry and Display Assembly - Accessible Data

Address	Quantization	Range (Nominal)	Description	Symbol
172	0.1	+1380 to -1380 nm	Perigee altitude of predicted LM transfer trajectory	q_1
211	10^3	33,554,000 ft	Out-of-CSM-orbit plane displacement in orbit insertion	y
217	10^3	$(5 \times 10^4 \text{ ft})$	Initial p perturbation	
223	10^3	$(4 \times 10^6 \text{ fps})$	Constant in linear expression for \dot{r}_f as a function of r_f	
230	10^3	$(5 \times 10^5 \text{ ft})$	(Δp) limiter	
274	0.1	(4,369 min)	Best predicted time from CDH to TPI	T_{co}
275	0.1	TBS	Desired AGS time of CSI maneuver	t_{igA}
276	0.1	(4,369 min)	Predicted absolute time of CDH maneuver	
301	0.1	(4,369 min)	Nominal AGS time of TPI maneuver	
303	0.01	360°	Predicted LOS angle at TPI time	θ_{LOS}
305	0.01	360°	CSI iteration error in LM/CSM relative central angle	C_0
307	0.01	+90° to -90°	Angle between local horizon and LM Z-axis	ζ
311	0.01	TBS	Time from TPI to rendezvous	
312	0.01	TBS	Time-to-go until CSI maneuver	T_I
314	0.01	TBS	Time to rendezvous	T_r
315	0.01	TBS	Time-to-go until CDH maneuver in CSI mode	T_{Δ}
317	0.1	1380 nm	Range from LM to CSM	R
321	1	+32,767 to -32,767 fps	Range rate	\dot{R}
330	10^3	32,554,000 ft	LM altitude	h
331	1	+32,767 to -32,767 fps	LM altitude rate	\dot{h}
337	10^3		LM altitude	h
340	10^3	+33,554,000 to -33,554,000 ft	X-component of LM position	Y_x
341	10^3	+33,554,000 to -33,554,000 ft	Y-component of LM position	Y_y
342	10^3	+33,554,000 to -33,554,000 ft	Z-component of LM position	Y_z

GUIDANCE, NAVIGATION, AND CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-13. Data Entry and Display Assembly - Accessible Data (cont)

Address	Quantization	Range (Nominal)	Description	Symbol
343	0.1	+1380 to -1380 nm	Perigee altitude of present LM trajectory	q
344	10^3	+33,554,000 to -33,554,000 ft	X-component of CSM position	Y_{cx}
345	10^3	+33,554,000 to -33,554,000 ft	Y-component of CSM position	Y_{cy}
346	10^3	+33,554,000 to -33,554,000 ft	Z-component of CSM position	Y_{cz}
347	10^3	+33,554,000 to -33,554,000 ft	Predicted orbit insertion burnout altitude	r_f
360	1	+32,767 to -32,767 fps	X-component of LM velocity	V_x
361	1	+32,767 to -32,767 fps	Y-component of LM velocity	V_y
362	1	+32,767 to -32,767 fps	Z-component of LM velocity	V_z
364	1	+32,767 to -32,767 fps	X-component of CSM velocity	V_{cx}
365	1	+32,767 to -32,767 fps	Y-component of CSM velocity	V_{cy}
366	1	+32,767 to -32,767 fps	Z-component of CSM velocity	V_{cz}
367	1	+32,767 to -32,767 fps	LM altitude rate	
370	1	(32,767 fps)	Magnitude of LM velocity to be gained	V_G
371	1	(32,767 fps)	ΔV for CDH maneuver	V_{po}
373	0.01	(136 min)	Coast time from CSI to CDH	T_{AO}
377	0.1	4,369 min	Absolute time	t
405	10^3	33,554,000 ft	Differential altitude in coelliptic orbit	Δy_o
406	10^3	33,554,000 ft	Predicted value of out-of-CSM-orbit position	y_f
423	1	33,554,000 fps	Desired final value of altitude rate	\dot{r}_f
433	1	+32,767 to -32,767 fps	Magnitude of LM velocity	V
440	1	+32,767 to -32,767 fps	Range rate between LM and CSM (negative display = LM closing on CSM)	

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-13. Data Entry and Display Assembly - Accessible Data (cont)

Address	Quantization	Range (Nominal)	Description	Symbol
441	1	+32,767 to -32,767 fps	LM velocity normal to CSM orbit plane	V_y
454	1	(+25 fps)	V_G threshold on engine cutoff computations	
456	1	(+1,000 fps)	Set value of V_G	
463	1	(+32,767 fps)	Radial velocity at CSI	\dot{r}_5
464	1	+32,767 to -32,767 fps	Minus descent stage capability plus ΔV expended	V_{dx}
473	1	(-1,833 fps)	Descent stage ΔV bias	
477	1	(+32,767 fps)	Total direct transfer velocity to rendezvous	V_T
500	1	+32,767 to -32,767 fps	X-axis component of velocity to be gained to engine shutdown	ΔV_{gx}
501	1	+32,767 to -32,767 fps	Y-axis component of velocity to be gained to engine shutdown	ΔV_{gy}
502	1	+32,767 to -32,767 fps	Z-axis component of velocity to be gained to engine shutdown	ΔV_{gz}
507	1	+32,767 to -32,767 fps	ΔV for CSI maneuver	V_o
526	1		Set value of V_T	
527	1		Upper limit on r_f	
534	1		Compensation and scale factor constant for X-axis accelerometer	
535	1		Compensation and scale factor constant for Y-axis accelerometer	
536	1		Compensation and scale factor constant for Z-axis accelerometer	
537	1		Compensation constant for X-gyro spin axis mass unbalance drift	
540	1		Compensation constant for X-axis accelerom- eter bias	
541	1		Compensation constant for Y-axis accelerom- eter bias	
542	1		Compensation constant for Z-axis accelerom- eter bias	
544	0.01	+10 to -10°/hr (0°/hr)	X-gyro drift compensation constant	

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-13. Data Entry and Display Assembly - Accessible Data (cont)

Address	Quantization	Range (Nominal)	Description	Symbol
545	0.01	+10 to -10°/hr (0°/hr)	Y-gyro drift compensation constant	
546	0.01	+10 to -10°/hr (0°/hr)	Z-gyro drift compensation constant	
550	octal	(-16 radians)	Compensation constant for attitude-rate scale factor error of X-gyro	
551	octal	TBS	Compensation constant for attitude-rate scale factor error of Y-gyro	
552	octal	TBS	Compensation constant for attitude-rate scale factor error of Z-gyro	
555	octal	(0.002 ft/sec ³)	Limit on \ddot{r}_d	
556	octal	(-0.005 ft/sec ³)	Lower limit on \ddot{r}_d	
564	octal	(0.125 fps)	Lower limit on Δ_6	
565	octal	(10 fps)	Initial value and limit of Δ_6	
566	octal	(0 radians)	Cant angle of engine in pitch plane	
574	N/A	N/A	Descent section staging flag	
602	octal	TBS	Cant angle of engine in yaw plane	
604	N/A	N/A	Lunar surface flag (positive if in flight)	
611	1	-	Predicted value of altitude rate	
612	N/A	N/A	Staging sequence counter	
616	octal	(3)	Number of 2-second cycles for voltage test delay	
617	octal	(150)	Gyro calibration time duration	
620	octal	(5)	Controls iterations of p-iterator	
621	octal	(15 sec/cycle)	Accelerometer calibration time	
622	octal	(25)	Staging times (1 count per 40 milliseconds) to maintain attitude hold momentarily after staging	
624	octal	(0.1)	Constant in altitude and altitude-rate 200-millisecond readout	
625	octal	TBS	FDAI computation singularity	
626	octal		X-axis alignment gain constant	
627	octal		Lunar alignment constant	

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-13. Data Entry and Display Assembly - Accessible Data (cont)

Address	Quantization	Range (Nominal)	Description	Symbol
630	octal		Lunar alignment constant	
631	octal		Lunar alignment stop, error criterion	
632	octal		Calibration gain constant	
633	octal		Calibration gain constant	
634	octal		Navigation sensed velocity threshold	
635	octal		Accelerometer calibration gain constant	
636	octal		Gravitational constant	
637	octal		Reciprocal of gravitational constant	
641	octal		Filter velocity uncertainty term	
642	octal		Coefficient in linear expression for r_f as a function of r_f	
643	octal		Coefficient in evaluation of cost	
644	octal		Factor to decrease Δ_6	
645	octal		Factor to increase Δ_6	
646	octal		Constant error term in radar filter	
647	octal		Velocity-to-be-gained threshold	
651	octal		Initial position error variance	
652	octal		Initial velocity error variance	
653	octal		Radar error model constant	
654	octal		Factor in T_B computation	
655	octal		Factor in T_B computation	
657	octal		Ascent engine cutoff impulse compensation	
660	octal		Lower limit on a_T	
661	octal		Ullage threshold	
666	octal		Limit on body attitude errors	
673	octal		Product of lunar rotation rate and 20-milli- second compute cycle period	

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Data Readout. The sequence of operations for reading the contents of an AEA memory cell is as follows:

- Press and release CLR pushbutton.

This operation initializes the DEDA and blanks all lighted characters. The CLR pushbutton must always be pressed before any readout.

- Press and release three consecutive numerical pushbuttons.

This operation identifies the address of the AEA memory core location from which data is to be extracted. The address is in octal form; it must not exceed the number 704. If a number larger than 704 is entered into the address, the DEDA readout will be extinguished when the READOUT pushbutton is pressed. Refer to table 2-13 for data that are DEDA accessible from the AEA.

- Verify entry by comparing electroluminescent address with desired address.
- Press and release READOUT pushbutton.

After the READOUT pushbutton has been pressed, the displayed quantity and its address are updated twice per second. The astronaut can hold a value on the display by pressing the HOLD pushbutton. This value is held on the display until the READOUT pushbutton is pressed (at which time the displayed quantity is updated twice per second) or until the CLR pushbutton is pressed (at which time the DEDA is initialized for the next command and the displays are blanked).

Data Verification. Verification that data are being properly transferred between the DEDA and AEA is obtained as follows:

- Press and release CLR pushbutton.
- Enter readout address 412 by pressing and releasing 3 pushbutton three times in succession and then pressing and releasing READOUT pushbutton.
- Read and interrogate output display.
- Clear address 412 by pressing and releasing CLR pushbutton.
- Enter +0 into address 412 by pressing and releasing pushbuttons in following order:
4, 1, 2, +, 0, 0, 0, 0, 0, and ENTR.
- Read out address 412 by pressing and releasing 3 pushbutton three times in succession and then pressing and releasing READOUT pushbutton.
- Examine readout of address 412.

Readout of +10000 indicates that AGS has passed self-test and is ready for further flight operation. Readout of +30000 indicates that AGS has failed logic portion of self-test; readout of +40000, that AGS has failed memory portion of self-test; and readout of +70000, that AGS has failed logic and memory portions of self-test. Readout of +00000 indicates that self-test procedure has not been performed properly and that the first five steps should be repeated.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Decimal Point Location. There is no decimal point indication on the DEDA. To use the AGS correctly, the astronauts must have knowledge of the quantization of the decimal quantity being entered or read out. This information is given in table 2-13.

Operator Error. The OPR ERR light on the DEDA display panel goes on if the operator makes any of the following errors.

- Nine pushbuttons are not pressed and the ENTR pushbutton is pressed.
- Three pushbuttons are not pressed and the READOUT pushbutton is pressed.
- The READOUT pushbutton is pressed after more than three digits have been entered.
- More than nine pushbuttons have been pressed since the last pressing of the CLR pushbutton.
- The 8 or 9 pushbutton is pressed while loading the address portion of the word.
- The + or - pushbutton is not pressed in the fourth position of the nine-digit word.
- The + or - pushbutton is pressed in other than the fourth position.
- A quantity is being read out and the ENTR pushbutton is pressed.

The following operator errors do not cause the OPR ERR light to go on.

- If a number greater than 704 is entered into the address portion of the display along with other numbers to be entered, the DEDA exhibits an odd display when the ENTR pushbutton is pressed. The numbers shift and several entry slots are blanked.
- If a number greater than 704 is entered into the address portion of the DEDA and the READOUT pushbutton pressed, the DEDA is blanked.
- If an octal quantity is entered with a digital greater than 7 or of a number greater than its allowable range is entered via the DEDA, a computer-processing error results. If the address is read out, the display is different than what was entered.

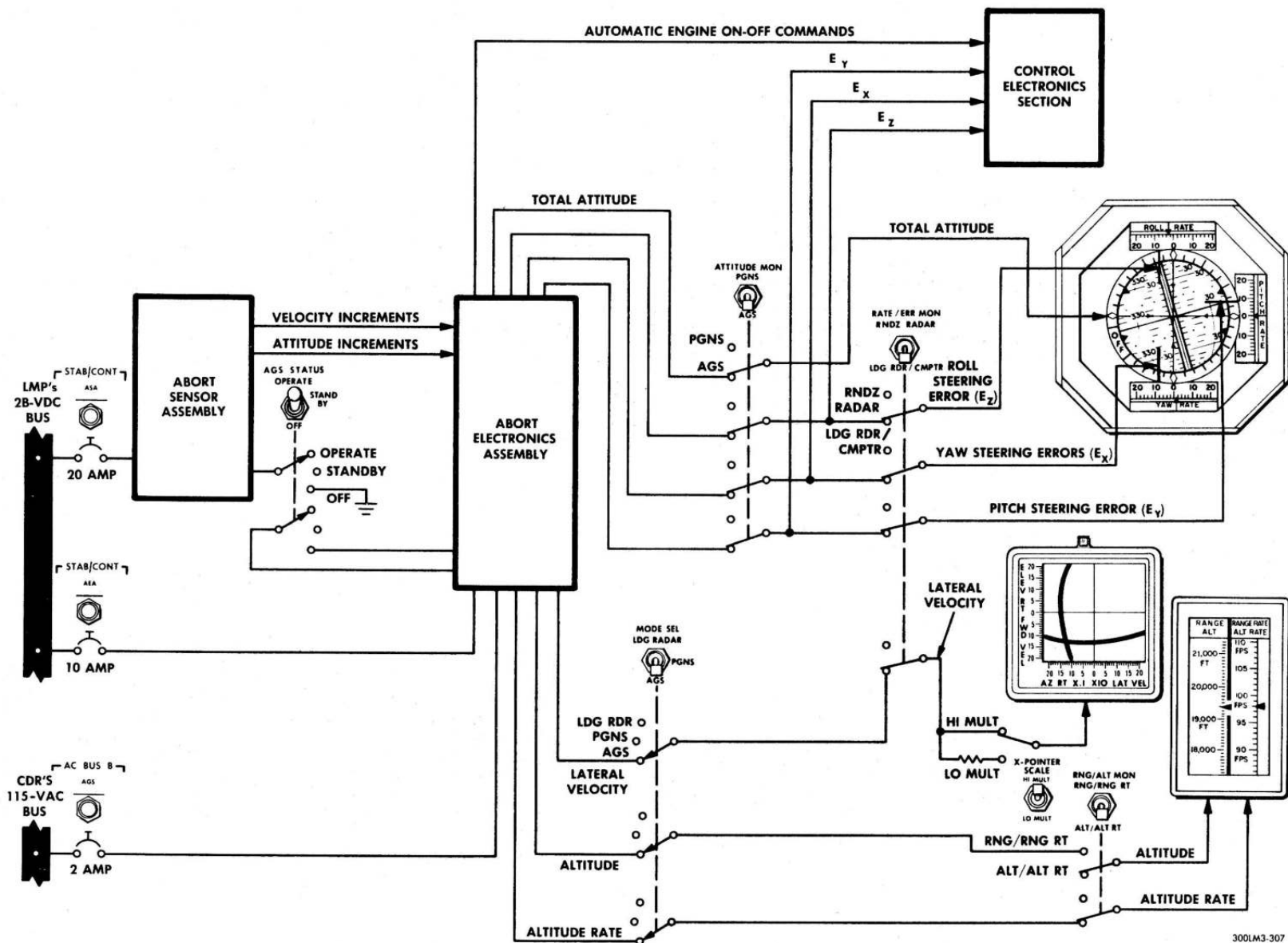
Address values greater than 704, used for program instructions, cannot be entered into the DEDA. If such entries are attempted, the symptoms described in the preceding paragraph occur. Normal operation is restored by pressing the CLR pushbutton.

2.2.3.2.4

General Operation of Abort Guidance Section.

Control of the LM by the AGS depends on the settings of various cabin switches (figure 2-34) and on DEDA entries. In addition, attitude control, using the RCS, must be under guidance steering direction (ROLL, PITCH, and YAW switches on panel 3 set to MODE CONT).

For the AGS to effect guidance steering (not merely attitude hold) and engine control, the GUID CONT switch (panel 1) must be set to AGS and the MODE CONTROL selector switch (panel 3) must be set to AUTO. For nominal DPS operation, the ENG ARM switch (panel 1) is set to DES and the engine START pushbutton (panel 5) is pressed. For abort DPS operation, the ABORT pushbutton (panel 1) is pressed to arm the descent engine. Ascent engine operation is similar to descent engine operation, except that the ENG ARM switch is set to ASC. For APS operation in abort situations, with



300LM3-307

Figure 2-34. Abort Guidance Section - Functional Flow Diagram

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

the descent stage attached, the ABORT STAGE pushbutton (panel 1) is pressed to arm the ascent engine. If the ABORT or ABORT STAGE pushbutton is not pressed, AGS control is limited to attitude hold.

The MODE SEL, ATTITUDE MON, and RATE/ERR MON switches (panels 1 and 2) are used to monitor AGS maneuvers. When these switches are set as indicated in figure 2-34, the FDAI's, X-pointer indicators, and the ALT and ALT RATE indicators display the information required to monitor AGS operations.

The AGS STATUS switch provides power to the AGS when the AC BUS B: AGS circuit breaker (panel 11) and the STAB/CONT: ASA and AEA circuit breakers (panel 16) are closed. With the AGS STATUS switch set to OFF, closing the ASA circuit breaker causes the ASA to be in a temperature-controlled condition. Closing the AEA circuit breaker causes power to be applied to the AEA. Closing the AGS circuit breaker applies 115-volt (rms), 400-cps power to the AGS power supply.

Initial conditions for AGS operation require that the AGS STATUS switch be set to STANDBY, then to OPERATE. The time between closing the circuit breakers and setting the AGS STATUS switch to OPERATE should be 40 minutes; for at least the last 25 minutes, the switch should be set to STANDBY. Degraded performance is available after 10 minutes in the standby mode. When the AGS STATUS switch is set to OFF, the AEA has no functional capability. After 20 seconds in the standby mode, the AEA can accept the CDU zero signal and integrate the PGNS Euler angle changes. Complete AEA capability is afforded when the switch is set to OPERATE. In the operate mode, the AEA enters a core-priming routine that ensures that the memory is magnetized properly.

AGS operations are performed mainly through two DEDA addresses: 400 and 410. (Refer to table 2-12.) Address 400 is the AGS submode selector; address 410, the guidance routine selector. The selected routine is computed every 2 seconds, regardless of the submode selected. The AGS does not respond to orient the LM in accordance with the routine selected, unless the guidance steering submode (DEDA entry 400 + 10000) has been selected.

When the LM is under full AGS control, the engine-on signal cannot be generated unless the guidance steering submode is selected. The engine-on signal is generated automatically after ullage has been sensed for three (DEDA accessible constant) consecutive computer cycles (2 seconds per cycle). The AGS recognizes ullage to have occurred when the average acceleration in the +X-direction exceeds 0.1 fps^2 . (The average acceleration is DEDA accessible.) The ASA (containing the accelerometers) is located ahead of the center of gravity (in the +X-direction). Therefore, LM rotations cause sensed accelerations in the -X-direction. For this reason, LM rotations cannot cause the AGS to sense that ullage has occurred.

When the LM is not under full AGS control (neither the ABORT nor ABORT STAGE pushbutton has been pressed, or the MODE CONTROL selector switch is not set to AUTO, or the GUID CONT switch is not set to AGS), the AGS issues engine commands (on or off) that duplicate actual engine operation.

Under full AGS control, the ascent or descent engine is commanded off automatically when the velocity to be gained in the +X-direction is less than the nominal ascent engine thrust decay velocity and if the total velocity to be gained is less than a prescribed threshold (a DEDA accessible constant currently set at 100 fps). This dual check maintains the engine on if an abort occurs during powered flight with the LM incorrectly oriented for the abort maneuver and the velocity to be gained large (greater than the 100-fps threshold).

When the velocity to be gained (LM under full AGS control) is less than 15 fps and the sensed thrust acceleration level in the +X-direction is greater than 0.1 fps^2 , the desired thrust direction is fixed in inertial space (a form of attitude hold). If this were not done, the LM desired attitude might go through an undesirably wide excursion in an

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

attempt to achieve perfect velocity cutoff conditions. Large attitude variations near the end of a maneuver are undesirable. The velocity cutoff errors incurred by fixing the desired attitude before engine cutoff are small. After the maneuver is completed, small cutoff errors can be removed (if desired) by the axis-by-axis velocity trim capability of the AGS.

The LM descent stage is staged (when the AGS is in control) by pressing the ABORT STAGE pushbutton. The staging sequence begins only when engine-on commands are issued. During a thrusting maneuver, the staging sequence begins immediately upon pressing the ABORT STAGE pushbutton (assuming that all panel controls that transfer control of the LM to the AGS have been set properly). The AGS senses sufficient average thrust acceleration throughout the staging maneuver to maintain ullage. When the AGS receives verification from the CES that the ascent engine is on, the AGS enters the attitude hold submode automatically. After a prescribed interval, between zero and 10 seconds (DEDA-controlled, presently set at 1 second), the AGS enters the normal guidance steering submode automatically.

When the PGNS controls the LM (GUID CONT switch set to PGNS), the AGS is in the followup mode. Manual control of the LM by the astronauts (MODE CONTROL switch set to ATT HOLD, attitude controller out of detent) also causes the followup signal to be routed to the AGS. In the followup mode, the AGS follows the PGNS by routing engine commands (on or off) in accordance with ascent or descent engine operation and provides zero attitude control error signals. The AGS provides attitude error signals (corresponding to the AEA guidance solutions) for FDAI display when the PGNS is in control, the MODE CONTROL selector switch is set to AUTO, the ATTITUDE MON switch is set to AGS, and the RATE/ERR MON switch is set to LDG RDR/CMPTR.

The selected modes (with their submodes) and the selected routines are discussed in detail in paragraphs 2.2.3.2.5 and 2.2.3.2.6, respectively.

2.2.3.2.5

Abort Guidance Section - Modes of Operation.

The AGS modes of operation are inertial reference, alignment, attitude reference, and initialization. These modes are selected by DEDA operation after the ASA has warmed up for 30 minutes, the AGS STATUS switch is set to OPERATE, and the STAB/CONT: AEA circuit breaker is closed.

Inertial Reference Mode. When the AGS is in the inertial reference mode, it provides attitude error information and engine commands (on and off), which are used for vehicle stabilization and/or for directing vehicle abort. The inertial reference mode is always in one of the following submodes:

- Followup
- Guidance steering
- Attitude hold
- CSM acquisition.

Followup Submode. In the inertial reference mode, with the followup signal present, the AGS is in the followup submode. In the followup submode, the AGS can perform the following functions:

- Maintain an inertial reference frame and provide total attitude signals for display
- Maintain the attitude error signals to the CES at zero (If automatic and followup discretes are present, error signals are computed.)

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

- Use accelerometer inputs from the ASA to calculate LM current position and velocity in the inertial reference frame
- Solve the LM abort guidance problem, using a specific guidance scheme
- Accept initializing information from the PGNS downlink or the DEDA
- Command the engine on if the ascent engine-on signal or the descent engine-on signal is present, and command the engine off otherwise.

Guidance Steering Submode. The guidance steering submode is entered by keying address 400 and the value +10000 on the DEDA. Guidance steering orients the LM so that its thrust vector points in the desired direction for achieving the objective of the selected guidance routine. The LM X-axis orientation also depends upon which engine is used. The RCS engines are assumed to thrust along the LM body axes. If the descent engine is used, the thrust vector is assumed to be along the +X-axis. If the ascent engine is used, the thrust vector is displaced from the +X-axis by an amount equal to the nominal cant of the ascent engine.

Because of thrust alignment errors, the actual thrust does not lie exactly along the nominal direction. Small velocity errors at engine cutoff may result. The cutoff errors are sensed by the AGS. If desired, velocity errors sensed at cutoff can be removed through axis-by-axis thrusting (ΔV residual removal).

When the ascent engine is used, the equations that compensate for the canted engine are used. This is accomplished via the DEDA. The address 411 and the value +10000 are entered. This is done before active AGS guidance steering, to achieve desired orientation of the thrust axis. When the ascent engine is ignited, the canted thrust direction is selected by the AEA, regardless of the value of the address 411 entry.

The AEA correction for the canted engine is adjusted by two octal constants, one for pitch and one for roll. The constants are preprogrammed into the AEA, but are DEDA accessible so that they can be changed during the mission. The pitch constant is entered with the address 566. The value of the constant is entered in octal radians; it should be positive if the canted engine causes a thrust acceleration component along the +Z-axis. Similarly, the roll component is entered in octal radians via DEDA address 602. The sign of the value entered should be positive if the cant of the engine causes a thrust acceleration component along the +Y-axis.

The AGS aligns the LM thrust vector along the desired thrust vector. The LM Z-axis is normally driven parallel to the CSM orbit plane. If the +X-axis points ahead of the local vertical, the Z-axis lies below the local horizontal. If the +X-axis is behind the local vertical, the Z-axis lies above the local horizontal. If the X-axis is vertically upward, the Z-axis is pointed horizontally forward. If the X-axis is pointed vertically downward, the Z-axis is directed horizontally opposite to the direction of motion.

The desired +Z-axis orientation is a continuous function of X-axis orientation. The gain in E_x decreases toward zero as the +X-axis approaches a perpendicular orientation with respect to the CSM orbit plane. When the +X-axis is perpendicular to the CSM orbit plane, $E_x = 0$ for any orientation of the +Z-axis.

A DEDA-accessible constant (306) has been made available to cause the LM to assume a desired yaw orientation about the X-axis to maintain S-band communications. The effect of this is to cause the Z-axis no longer to be oriented parallel to the CSM orbit plane (except when the X-axis is perpendicular to the CSM orbit plane). DEDA input 306 is quantized at 0.01 in decimal degrees; it should not exceed +30° to -30°. Values of this constant other than zero should be avoided when the velocity-to-be-gained vector is primarily in the cross-plane direction. In general, this situation should arise only in the direct transfer routine. It could occur, however, during the orbit insertion routine if the abort occurred on a laterally perturbed trajectory late in powered ascent, with the velocity-to-be-gained vector primarily in the cross-plane direction. The

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

effect of this situation, coupled with a constant whose value is not zero, could be a continuous rotation about the X-axis at a rate of 5° per second.

AGS steering orientation, before engine ignition, falls into two categories:

- CSI, CDH, External ΔV

Before initiation of these maneuvers, the desired attitude of the LM is established in the local horizontal coordinate system.

- Direct Transfer (TPI and Midcourse)

If the AGS is in a direct transfer guidance routine and guidance steering was selected, the LM will orient itself to the desired attitude in inertial space and stay fixed in inertial space.

The AGS can maintain the LM at any attitude in a local vertical coordinate frame during free flight; this is called orbital rate pitch steering. In particular, the LM can be pitched at the orbital rate to maintain the X-axis along the local horizontal. To accomplish this, the external ΔV guidance routine and the guidance steering submode of operation are used.

The X-axis could also be maintained horizontal by using the CSI guidance routine and guidance steering, because the CSI maneuver is horizontal. This procedure is suitable for use between the orbit insertion phase and the CSI maneuver phase because the desired calculations (CSI) will be performed at the same time. However, if the calculated CSI maneuver is a retrograde maneuver, the +X-axis would point backwards and the Z-axis would be pointed outward along the local vertical and not toward the lunar surface.

The guidance steering submode consists of automatic and semiautomatic steering operations. Semiautomatic steering is accomplished before a maneuver with the AGS operating in one of the guidance steering submodes. The steering commands are computed to orient the LM for the chosen maneuver. When the descent or ascent engine ignites, the AGS is said to be in automatic steering operation. One difference between semiautomatic and automatic steering is that the engine is on during automatic steering. Another difference between semiautomatic and automatic steering is that the ullage condition must be satisfied before automatic steering can be used. The ullage condition is satisfied when the accumulated velocity increments along the LM X-axis exceeds 0.2 fps for each 2-second computer cycle, for three consecutive cycles (total of 6 seconds).

During automatic steering, the AGS provides attitude error output signals and engine commands, which are necessary to guide the LM to a rendezvous with the CSM. During this steering operation, the AGS performs the following functions:

- Maintains an inertial reference frame and provides total attitude signals for display
- Uses accelerometer inputs from the ASA to calculate LM current position and velocity in the inertial reference frame
- Solves the LM abort guidance problem, using a specific guidance scheme.

During semiautomatic steering, the AGS generates attitude error commands (computed and issued every 40 milliseconds) to orient the LM to the desired thrust direction. An engine-on command is generated when this maneuver is completed, provided the engine-on signal is present and the ullage condition is satisfied. In addition, the AGS performs the following functions:

- Maintains an inertial reference frame and provides total attitude signals for display

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

- Uses accelerometer inputs from the ASA to calculate LM current position and velocity in the inertial reference frame
- Solves the LM abort guidance problem, using a specific guidance scheme
- Commands the engine on if the ascent engine-on signal or the descent engine-on signal is present, and commands the engine-off otherwise.

Attitude Hold Submode. The attitude hold submode maintains any selected attitude. The AGS issues steering (attitude error) commands (computed and issued every 40 milliseconds), which cause the LM to maintain (within the deadband selected by the DEAD BAND switch on panel 3) the same inertial attitude that existed when the submode was entered. The attitude hold submode can be entered by setting the MODE CONTROL selector switch to ATT HOLD or by keying address 400 and the value +00000 on the DEDA. If the DEDA is used, the AGS issues the engine-off command when in active control. The descent and ascent engines cannot be used in this submode.

The attitude hold submode is entered in the absence of the other inertial reference submodes and at the following times during a mission abort:

- During staging as signaled by the ABORT STAGE pushbutton and after receipt of the ascent engine-on signal for 1 second
- At liftoff from the lunar surface (subsequent missions) and thereafter for 1 second after receipt of the ascent engine-on signal
- At termination of guidance during an abort or midcourse correction.

During the attitude hold submode, the AGS performs the following functions:

- Maintains an inertial reference frame and provides total attitude signals for display
- Uses accelerometer inputs from the ASA to calculate LM current position and velocity in the inertial reference frame
- Solves the LM abort guidance problem, using a specific guidance scheme
- Accepts initializing information from the PGNS downlink or the DEDA
- Commands the engine on if the ascent engine-on signal or the descent engine-on signal is present, and commands the engine off otherwise.

CSM Acquisition Submode. The CSM acquisition submode is entered by keying the address 400 and the value +20000 on the DEDA. In this submode, the AGS orients the LM Z-axis toward the AGS-computed LOS to the CSM. Normally, this submode is used before taking radar data; descent or ascent engine thrusting cannot be accomplished in this mode. With the Z-axis pointed in the direction of the CSM, the X-axis is oriented parallel to the CSM orbit plane. If the CSM is ahead of the LM, the +X-axis will be above the local LM horizontal plane. If the CSM is behind the LM, the +X-axis will be below the local horizontal plane.

During this submode, the AGS performs the following functions:

- Maintains an inertial reference frame and provides total attitude signals for display
- Uses accelerometer inputs from the ASA to calculate LM current position and velocity in the inertial reference frame

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

- Solves the LM abort guidance problem, using a specific guidance scheme.

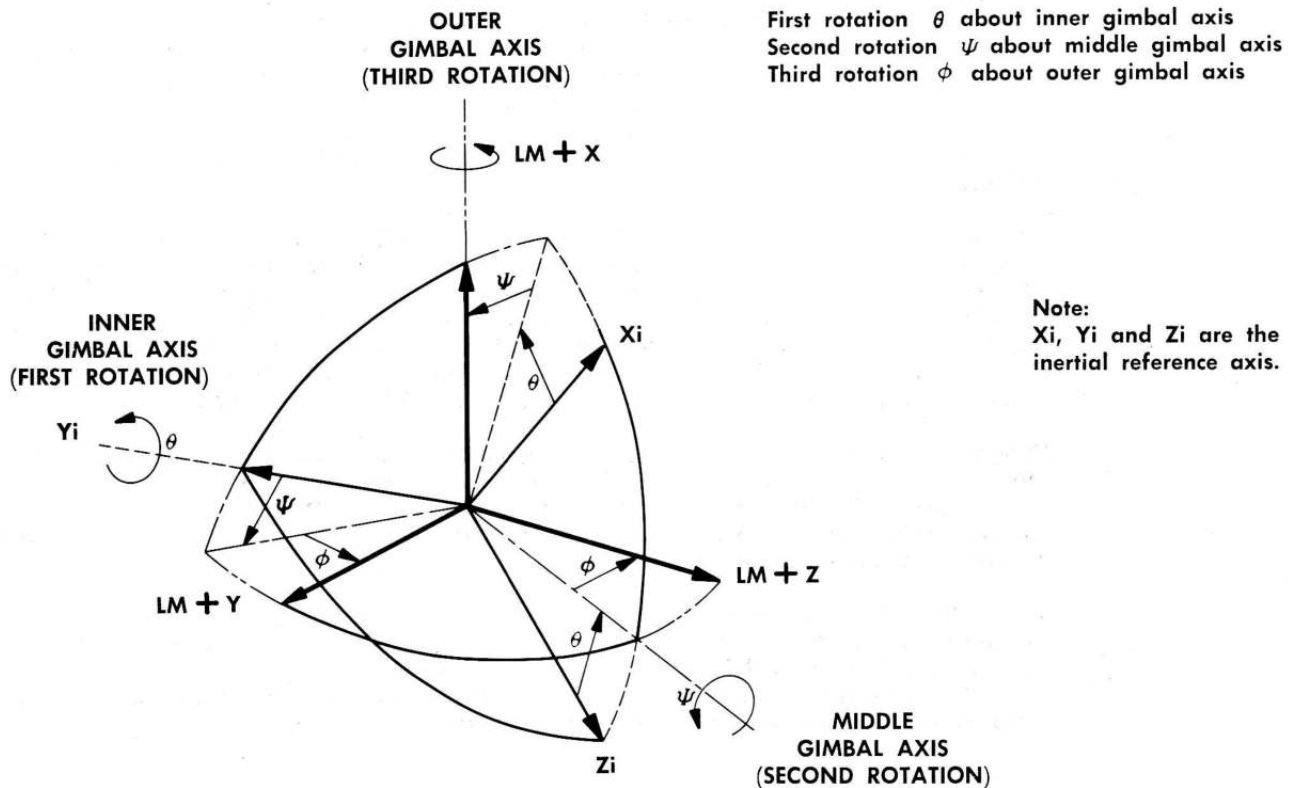
The CSM acquisition submode accommodates updating of AGS navigation computations with rendezvous radar inputs. The radar data consist of range and range rate and a code entered when radar pointing error with respect to the Z-axis is nulled. At least six data points, spaced no more than 4 minutes apart, are used. The radar data are keyed into the AEA via the DEDA.

Alignment Mode. Alignment consists of initializing the AEA to obtain an attitude reference to a desired inertial reference. In response to an alignment submode instruction (a DEDA entry), the inertial reference frame is aligned to a reference frame of the three alignment submodes: IMU alignment, lunar alignment, and body-axis alignment.

The IMU alignment submode aligns the AGS direction cosines to the attitude reference determined by PGNS Euler angles θ , ψ , and ϕ . (See figure 2-35.) The lunar alignment submode uses the local vertical sensed by the Y and Z accelerometers and a previously stored azimuth angle (δ_L), which is updated for lunar stay (subsequent missions) by the correction factor $\Delta\delta$, for an attitude reference frame. The body-axis alignment submode uses current LM attitude as the attitude reference.

The AGS causes the attitude error signals to the CES to be reduced to zero during the alignment mode.

IMU Alignment Submode. The IMU alignment submode is used when AGS alignment is to be accomplished, using PGNS Euler angles. This submode is entered by keying the DEDA (400, +30000, and ENTR); it can only be entered when the PGNS is operative.



300LM3-316

Figure 2-35. Euler Angles

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Lunar Alignment Submode. The AEA is aligned so that the computational inertial reference axes (X_i , Y_i , Z_i) coincide with the axes of a selenocentric coordinate frame with the X-axis along the lunar local vertical (positive outward from the lunar center) and the Z-axis direction conceptually obtained by crossing the unit angular momentum vector of the CSM orbit with a unit vector along the X-axis. Compensated velocity increments from the ASA Y and Z accelerometers are used to determine the local vertical with respect to the instantaneous LM coordinates.

The LM azimuth angle with respect to the CSM orbit plane at lunar touchdown is determined by storing, upon command of the DEDA, the AGS azimuth reference as defined by appropriate elements of the transformation matrix. An azimuth correction angle is subtracted from the stored reference to compensate for the effects of lunar rotation during lunar stay and for any CSM plane changes. The azimuth correction angle ($\Delta \delta$), which updates the inertial Z-axis direction, is inserted via the DEDA (address 547) before lunar alignment. This factor is provided to the astronauts via voice link.

The lunar alignment submode is entered by keying 400, +40000, and ENTR on the DEDA. The astronauts can store the landing azimuth of the touchdown point by keying 413 and +10000 on the DEDA.

Body-Axis Alignment Submode. For the body-axis alignment (orbital alignment) submode, the AGS inertial reference frame is made coincident with the LM axes. Body-axis alignment is achieved by keying 400, +5000, and ENTR on the DEDA. To terminate this submode, the LM Pilot keys 400 and +00000 on the DEDA.

Attitude Reference Mode. The inertial attitude reference is maintained in a 3-by-3 matrix (orthonormal transformation), which relates LM coordinates (X , Y , and Z) to the inertial coordinates (X_i , Y_i , and Z_i). The matrix is not constant; it varies with time as the LM axes rotate about the inertial axes. The incremental changes in the angles between the LM axes and the inertial axes are measured by gyros at 20-millisecond intervals. After compensation for drift and scale factor error, the gyro outputs, incremental changes in angles ($\Delta \gamma_X$, $\Delta \gamma_Y$, $\Delta \gamma_Z$), are used to update the direction cosines at 20-millisecond intervals.

Initialization Mode. The initialization mode consists of two submodes: navigation initialization, and time initialization.

Navigation Initialization Submode. The AGS accepts initialization inputs from the PGNS downlink (automatic) or from the DEDA (manual). Data are accepted when an initialized instruction has been entered through the DEDA during an unpowered flight phase of the mission. Data shall not be inserted during LM powered flight. Initialization is referenced to the AGS absolute time base and the AGS inertial reference frame at the time of initialization. Upon completion of initialization, an initialization-complete indication is generated and may be displayed via the DEDA upon request.

Ephemeris data from the LM and CSM are inputs for initialization. These inputs are initialized automatically via the PGNS downlink by entering 414, +10000, and ENTR on the DEDA. Completion of automatic initialization is indicated by the DEDA address and data indicators being set back automatically to 414 +00000. LM ephemeris data are initialized manually, using the DEDA.

The PGNS downlink data provide LM and CSM position, velocity, and epoch time, which are used to initialize LM navigation and CSM orbit parameters (state vectors). The data are provided in the AGS inertial coordinate frame. The LM and CSM epoch times are in the same time base as the AGS absolute time. The sequence in which the PGNS downlink data are used to initialize the AEA is given in table 2-14.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-14. PGNS Downlink Data Update Sequence

Initialization Sequence	Description	DEDA Address
1	Identification word	414
2	LM X-position, AGS coordinates	240
3	LM Y-position, AGS coordinates	241
4	LM Z-position, AGS coordinates	242
5	LM epoch time (most significant)	254
6	LM X-velocity, AGS coordinates	260
7	LM Y-velocity, AGS coordinates	261
8	LM Z-velocity, AGS coordinates	262
9	LM epoch time (least significant)	254
10	CSM X-position, AGS coordinates	244
11	CSM Y-position, AGS coordinates	245
12	CSM Z-position, AGS coordinates	246
13	CSM epoch time (most significant)	272
14	CSM X-velocity, AGS coordinates	264
15	CSM Y-velocity, AGS coordinates	265
16	CSM Z-velocity, AGS coordinates	266
17	CSM epoch time (least significant)	272

The sequence of the 17 words occurs at a basic rate of 50 words per second. The sequence is not interrupted. The word formats of the 17 downlink words are as follows:

Bit No.	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
ID Word	0	0	0	0	0	0	X	X	X	X	X	X	X	X	X	X	Y	Y
Data Word	1	S	X	X	X	X	X	X	X	X	X	X	X	X	X	X	Y	Y
X = 0 or 1, Y = Not applicable, S = Sign bit (0 or 1).																		

A stop pulse discrete, which is set after a new downlink word has been inserted into the downlink input register, will be available to the program. The stop pulse discrete is reset upon reading the downlink input register. The time interval between stop pulses is 20 milliseconds. The program interrogates the stop pulse discrete twice per 20-millisecond cycle, with at least a 1-millisecond separation. The input register is read only if the stop pulse discrete is set to ensure that the input register is not read while data are being shifted into the input register.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

The three components of LM position are entered by keying address codes 240, 241, and 242, and the value and sign of the data, on the DEDA. The three components of LM velocity are entered by keying address codes 260, 261, and 262, and the value and sign of the data, on the DEDA. The LM epoch time (a multiple of 6 seconds) is entered by keying address code 254 on the DEDA. Keying 414 and +20000 on the DEDA completes initialization. When initialization is completed, the AEA is set back automatically to the attitude hold submode, as indicated by the DEDA display (414 + 00000).

Manual initialization of CSM ephemeris data is identical with that for the LM, except for the address codes. Refer to table 2-13 for the correct code.

Time Initialization Submode. Initialization of AGS absolute time consists of entering an absolute time of zero into memory. This is accomplished by keying 377 on the DEDA. AGS absolute time is not limited to zero, except by procedures.

A time tag, referred to as epoch time, is associated with each state vector. Primary system time, referred to as ground elapsed time (GET) is referenced to the time of lift-off. Therefore, the epoch times are the values of GET at which the state vectors were determined. The LGC clock has a capacity of approximately 2.7 million seconds; the AEA clock, approximately 0.26 million seconds. This disparity requires a procedure for modifying the epoch time transmitted from the LGC to the AEA at initialization. Because the AEA does not require launch time, it is possible to modify epoch time with a subtractive time bias. This bias is the GET at which the AEA clock is started.

The procedure requires entering a verb in the DSKY and establishing an absolute time of zero on the DEDA. At the desired initialization time, the two ENTR pushbuttons are pressed simultaneously. The absolute time in the PGNS at the initialization time becomes the AGS time bias and may be read out in hours, minutes, and seconds via the DSKY. This time bias must then be subtracted from all subsequent times entered into the AGS (if the times are referenced to GET).

2.2.3.2.6 Abort Guidance Section - Guidance Routines.

The AGS program contains the following guidance routines:

- Orbit insertion
- Coelliptic sequence initiation (CSI)
- Constant delta altitude maneuver (CDH)
- Terminal phase initiation (TPI)
- External ΔV .

The routines are selected, using the DEDA. Refer to table 2-15 for the address and function of each guidance routine. Guidance calculations associated with the selected routine are completed every 2 seconds of the submode selected. The LM, however, will not maneuver in accordance with the selected routine unless the AGS has control of the LM and the guidance steering submode is selected.

Before beginning guidance operations, the AGS must be aligned and initialized with LM and CSM ephemeris data. Entry of LM and CSM ephemeris data is required because every guidance routine uses these data in the guidance and steering computation. Navigation data must be updated throughout the mission, using PGNS downlink data, the DEDA, or RR data. Navigation data must also be updated before CSI and TPI maneuvers. Propellant expenditure is highly dependent on the accuracy of these maneuvers.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-15. Abort Guidance Section - Guidance Routines

Address	Routine	Function
410 + 00000	Orbit insertion	Engine and steering commands are generated to drive LM to specified orbit injection conditions.
410 + 10000	CSI maneuver	Engine and steering commands are generated to establish appropriate LM-CSM phasing at TPI time.
410 + 20000	CDH maneuver	Engine and steering commands are generated to drive LM into orbit that is coelliptic with CSM.
410 + 30000	TPI search	AGS evaluates various direct transfer rendezvous solutions. Astronauts select desired solution. Thrusting is not performed with this routine.
410 + 40000	TPI execute	Engine and steering commands are generated to cause LM to be on CSM intercept trajectory.
410 + 50000	External ΔV	Engine and steering commands are generated to perform externally specified thrust maneuver.

Orbit Insertion Routine. The orbit insertion routine provides attitude commands and engine-off commands to obtain predetermined cutoff conditions. These conditions are defined by the following targeting parameters entered into the AEA via the DEDA:

- Insertion altitude; DEDA address 347
- Magnitude of the horizontal component of inertial velocity at burnout; DEDA address 507
- Radial velocity at burnout; DEDA address 423.

The attitude commands provide yaw steering of the LM into the CSM orbit plane by the time the cutoff conditions are attained. The capability of steering out a wedge angle of up to 2° is provided (assuming sufficient ΔV). When the velocity to go to cutoff (ΔV_g) reaches a preselected threshold, updating of the commanded attitude is terminated. The engine is commanded off when ΔV_g reaches the nominal ascent engine tailoff velocity threshold and the total velocity-to-go is less than 100 fps.

Coelliptic Sequence Initiation Routine. Coelliptic rendezvous is initiated by the CSI burn, followed by CDH maneuver. The magnitude of the CSI burn is computed so that, after the CSI and CDH maneuvers, the LM arrives at the desired TPI time with the desired LOS angle to the CSM. The CSI and CDH maneuvers are computed in the AGS X-Z inertial plane. The CSI routine computes the magnitude of the horizontal velocity increment (parallel to the CSM orbit plane) required to satisfy targeting conditions.

One of the targeting conditions for the CSI maneuver is the AGS time of the CSI routine. This entry is made, using DEDA address 275. Time to go until the CSI maneuver can be obtained by reading out address 312 on the DEDA.

After the CSI maneuver has converged to a solution, the time from the CSI to CDH can be obtained by utilizing address 373 on the DEDA. Time until CDH (when less than 136 minutes) can also be obtained by using address 315. Other times available in the CSI routine are listed in table 2-13 (addresses 274, 301, and 377).

Another targeting condition is the angle that the projection of the LM-CSM LOS on the X-Z inertial plane makes with the LM local horizontal at the desired TPI time (positive, measured clockwise from the local horizontal forward of the LM when looking in the direction of the +Y inertial axis).

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

The CDH burn is performed at the time determined by the CSI routine. This time is the predicted time of LM arrival at the first or second crossing of the LM orbit line of apsides, following the CSI burn. A DEDA input (416 + 10000) specifies whether CDH maneuver will be performed at the second crossing. Otherwise, it is assumed that the CDH maneuver will be performed at the first crossing. If the predicted radial rate (\dot{r}_5) is nearly zero at CSI coast, it is possible that the subsequent coast orbit would be circular. Selection of first or second apsidal crossing becomes meaningless for a circular orbit.

The CSI routine is repeated three times every 2 seconds. The routine computes, and makes available for readout via the DEDA, the following parameters:

- CSI iteration error
- Time from CDH to TPI
- Predicted differential altitude in the coelliptic orbit
- Predicted coelliptic burn ΔV magnitude
- Sign and magnitude of predicted horizontal (CSI) ΔV
- Predicted time from CSI to CDH.

The CSI routine provides a real-time commanded attitude. The CSI horizontal ΔV solution is valid at CSI time t_{igA} . When real time (t) becomes greater than t_{igA} , the CSI routine is computed in real time.

Coelliptic Maneuver Routine. The CDH routine computes, in real time, attitude commands and velocity increment required to make the LM and CSM orbits coelliptic. The CDH routine provides commanded attitude such that the horizontal component of vehicle X-axis thrusting is parallel to the CSM orbit plane.

The CDH routine is selected after completion of the CSI burn, by keying 410 and +20000 into the DEDA. When this occurs, targeting is accomplished automatically for the CSI routine, by the CSI computations. The CDH solution is computed for future time, predicted during the CSI routine, until real time exceeds the predicted burn time. The solution is thereafter computed in real time.

If the CDH maneuver does not follow the CSI maneuver, the time to go until the CDH maneuver must be entered as a targeting constant. This is accomplished by keying address 315 on the DEDA. Addresses 274, 301, and 377 are timing quantities available in this mode. (Refer to table 2-13.)

Terminal Phase Initiation Routine. The TPI maneuver begins the direct transfer to rendezvous. There are two direct transfer routines: one, primarily for mission planning (TPI search); the other, for performing the maneuver (TPI execute). The latter routine can also be used for mission planning if desired. In general, the routines are used together, in sequence, to perform the TPI maneuver.

During mission planning, the object is to determine when direct transfer should occur. This determination is based upon achieving the desired LOS angle between the LM and CSM. Once ignition time is determined, the AGS is switched to the alternate direct transfer routine and the maneuver is performed.

This routine is used in the coelliptic rendezvous scheme, following the CDH maneuver. The CSI and CDH maneuvers are performed so that, at the nominal TPI time, the phasing between the LM and CSM is such that the desired LOS angle is achieved.

Because of errors in the AGS (due to sensors, navigation, maneuver execution, etc), the desired LOS is not achieved at exactly the targeted TPI time. To determine when

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

the desired LOS will be achieved and, thus, when to perform the maneuver, a direct transfer search guidance routine is available in the AGS (DEDA entry 410 + 3000). During this routine, the astronauts determine total velocity required to rendezvous, and perform the TPI maneuver based upon achieving a desirable value (TBD) of total velocity. The alternate direct transfer guidance routine (DEDA entry 410 + 40000) is used to actually perform the maneuver.

External ΔV Routine. The external ΔV routine accepts components of a velocity-to-be-gained vector in local vertical coordinates entered via the DEDA. A commanded attitude maintains the LM X-axis toward the resultant of the velocity-to-be-gained vectors in real time, independent of the required burn time. When ullage is sensed, and thereafter until the AEA is switched from the external ΔV , the external ΔV components remain fixed in inertial space. If the external ΔV routine (DEDA entry 410 + 50000) is initiated early or late, the desired orbit at cutoff is not achieved. Large timing errors result in large differences between the actual orbit obtained and the orbit desired.

The AGS can maintain the LM in any attitude in a local vertical coordinate frame during free flight. The LM can be pitched at the orbital rate to maintain the X-axis along the local horizontal, using the external ΔV routine. A fictitious velocity-to-be-gained vector is entered via the DEDA to obtain the desired attitude.

2.2.3.2.7

Abort Guidance Section - Self-Test Routine.

The self-test routine continuously checks that the computer logic and memory are functioning properly. DEDA address 412 is used, in conjunction with the test, to indicate test results to the astronauts and to allow resetting of error indicators. If a readout of address 412 on the DEDA is performed, the following outputs are possible:

- +10000 - Test successfully completed
- +30000 - Logic test failure
- +40000 - Memory test failure
- +70000 - Logic and memory test failure.

An additional output (+00000) permits the astronaut to reinitiate testing and reset the AGS warning light after failure is detected. When a failure is encountered during the test, the output in memory location 412 is displayed and the AGS warning light goes on; future tests are inhibited until testing is reinitiated. The error indicator is reset or testing reinitiated by entering +00000 in address 412. The astronauts need not monitor DEDA address 412 periodically, because the AGS warning light (panel 1) provides a visual indication of an error. However, as part of the AGS turn-on procedure, the DEDA check should be performed as a partial check of AGS warning light and computer operation.

2.2.3.3

Radar Section.

The radar section comprises the RR and LR.

The RR provides LOS range, range rate, and antenna angular rate data to the LGC and range and range rate data to the AEA, via DEDA entry, for a computer-controlled (LGC or AEA) rendezvous of the LM and CSM.

The RR also provides LOS angle, angle rate, range, and range rate data for display in the LM cabin. These data enable the astronauts to effect a safe, manually controlled rendezvous and docking with the CSM. During the descent engine burn phase of the mission, the RR is used to track the orbiting CSM should an abort maneuver be required. RR performance will be evaluated during rendezvous maneuvers of this mission by comparing RR range and range rate tracking data with predetermined tracking values. The derived error signals indicate the degree of accuracy of RR ranging and

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

velocity-change sensing. RR shaft- and trunnion-axis angles and the IMU gimbal angles and telemetered RR tracking error information transmitted to MSFN will also be compared.

The RR is used in conjunction with a transponder in the CSM to acquire and track that vehicle. The transponder operates at X-band frequencies; its horn antenna has 105° by 160° coverage. The RR has three modes of operation: auto track, slew, and LGC. These modes are used to enable automatic tracking, to enable the astronaut to slew the antenna manually, and to enable the LGC to control antenna positioning. The RR antenna is positioned by torquing the antenna-mounted rate gyros through servo-amplifiers.

The LR provides the LGC and the astronauts with LM slant range and velocity data with respect to the lunar surface. The LGC uses these data to calculate control signals for LM rate of descent, hovering at low altitudes, and soft landing on the lunar surface. The LR is activated at approximately 40,000 feet above the lunar surface and left on until touchdown. The PGNS starts to use LR slant range at approximately 25,000 feet; velocity data, at 10,000 feet. (Because the LM-3 mission is an earth-orbital mission, LR performance will only be monitored.)

2.2.3.3.1 Rendezvous Radar. (See figure 2-36.)

The RR, when tracking or locked on to a transponder, is a continuous-wave coherent system, which uses phase-lock techniques in the radar and in the transponder. The radar operates with the LGC and contains all the interface equipment for routing range, range rate, and two antenna angles (shaft and trunnion) into the LGC. RR range and range rate data are also used to update the AEA state vector manually. Range is determined by measuring the time delay between the transmitted signal and the received signal. Range rate is determined by measuring the two-way Doppler shift of the carrier signal received from the transponder. Range and range rate are accepted by the LGC only upon demand. The shaft and trunnion angles are continuously transmitted into registers in the LGC. In addition to the RR outputs to the LGC, shaft and trunnion angles, LOS azimuth and elevation angular rates, and range and range rate are displayed in the cabin. The RR has a range capability from 80 feet to 400 nautical miles and a range rate capability from -4,900 to +4,900 fps.

The RR consists of an antenna assembly and an electronics assembly. The antenna assembly converts VHF signals into phase-modulated microwave signals and propagates them through space. The return signal from the CSM transponder is converted into an IF signal and sent to the electronics assembly. The antenna assembly locks on, and continuously tracks, the source of the return signal. The electronics assembly furnishes crystal-controlled signals, which drive the RR transmitter and provide a reference for processing the return signal. The electronics assembly also supplies servo drive signals for antenna positioning.

The frequency synthesizer develops the frequency (102.425 mc) required for transmission. This frequency is then multiplied to 9832.8 mc (X-band) in a multiplier chain in the antenna assembly and phase modulated by three tones (200 cps, 6.4 kc, and 204.8 kc) generated by a reference generator in the range tracker.

The phase-modulated signal is applied to the antenna. The radiated energy incident upon the CSM transponder is processed so that the tones are removed, the frequency is side stepped, the tones are replaced, and the energy is returned to the RR antenna.

The return energy from the transponder is received by a four-port feedhorn arranged in a monopulse configuration. If the transponder is directly in line with the RR antenna LOS, the return energy is received equally by each of the four-ports of the feedhorn. If the transponder is not directly in line, the four ports receive signals of unequal amplitudes. The RF signal passes through a circulator to a monopulse comparator, which processes the signal to develop required sum and difference signals.

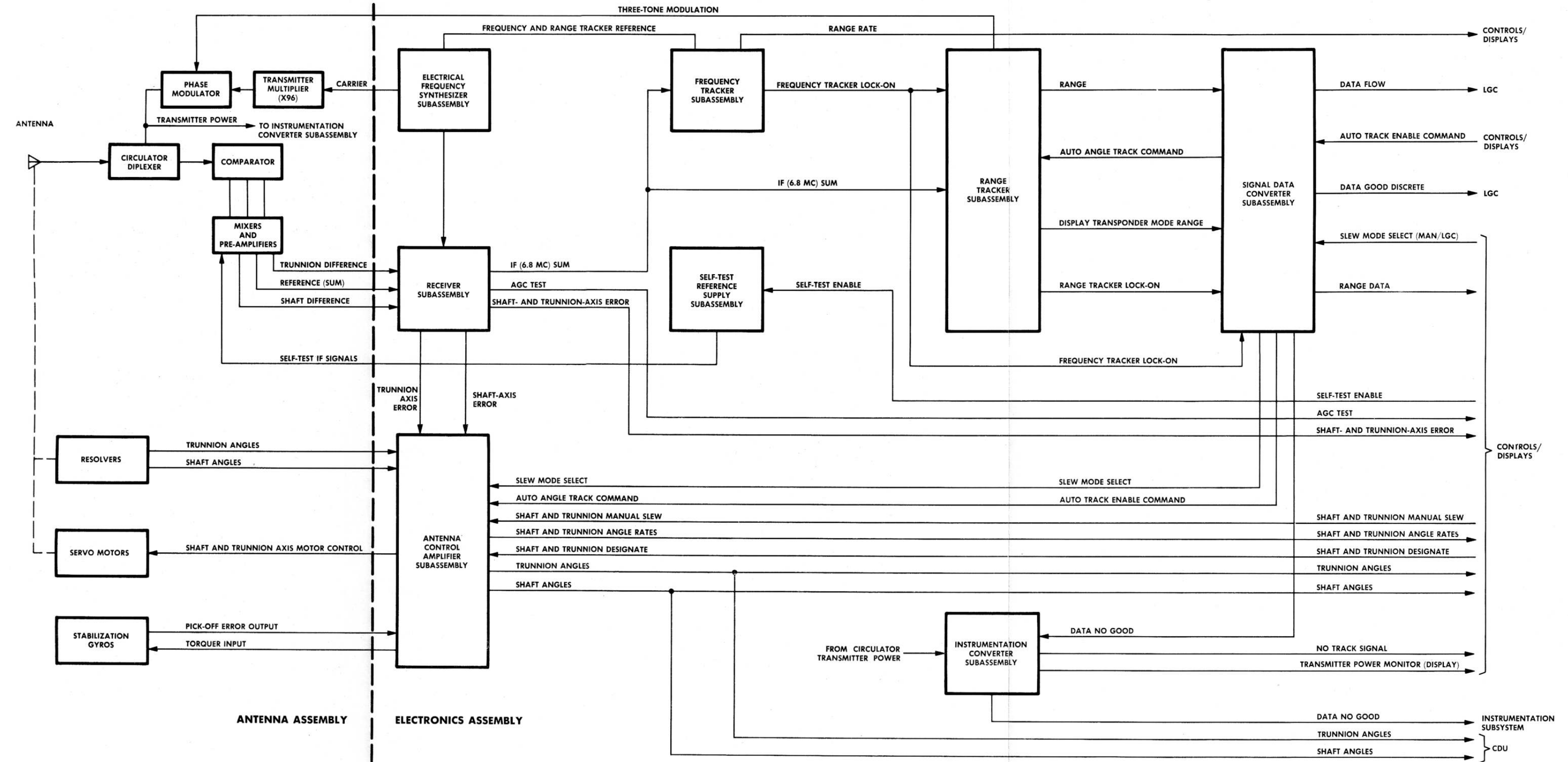


Figure 2-36. Rendezvous Radar - Block Diagram

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

The three comparator RF outputs are fed to mixers in the receiver subassembly, where they are combined with the transmitted frequency to develop three 40.8-mc IF signals.

The preamplifiers of the receiver subassembly contain three channels: trunnion channel, shaft channel, and sum channel (reference). The X-channel input is the difference between the energy received by the vertically adjacent parts of the feedhorn. The Y-channel input is the difference between the energy received by the horizontally adjacent parts of the feedhorn. The sum channel input is the sum of the received energy of all four parts of the feedhorn. The outputs of the preamplifiers are processed by the receiver subassembly, in three separate channels. The sum signals, now 6.8-mc IF signals, are fed to the range tracker subassembly.

The range tracker sequentially compares the phase of the 200-cps, 6.4-kc, and 204.8-kc return modulations with the phase of the reference signal from a reference counter, to provide range information to the signal data converter. Comparison of the phase of the return and reference signals provides unambiguous ranging from 80 feet to 400 nautical miles. The range output is fed to the LGC and to the cabin displays.

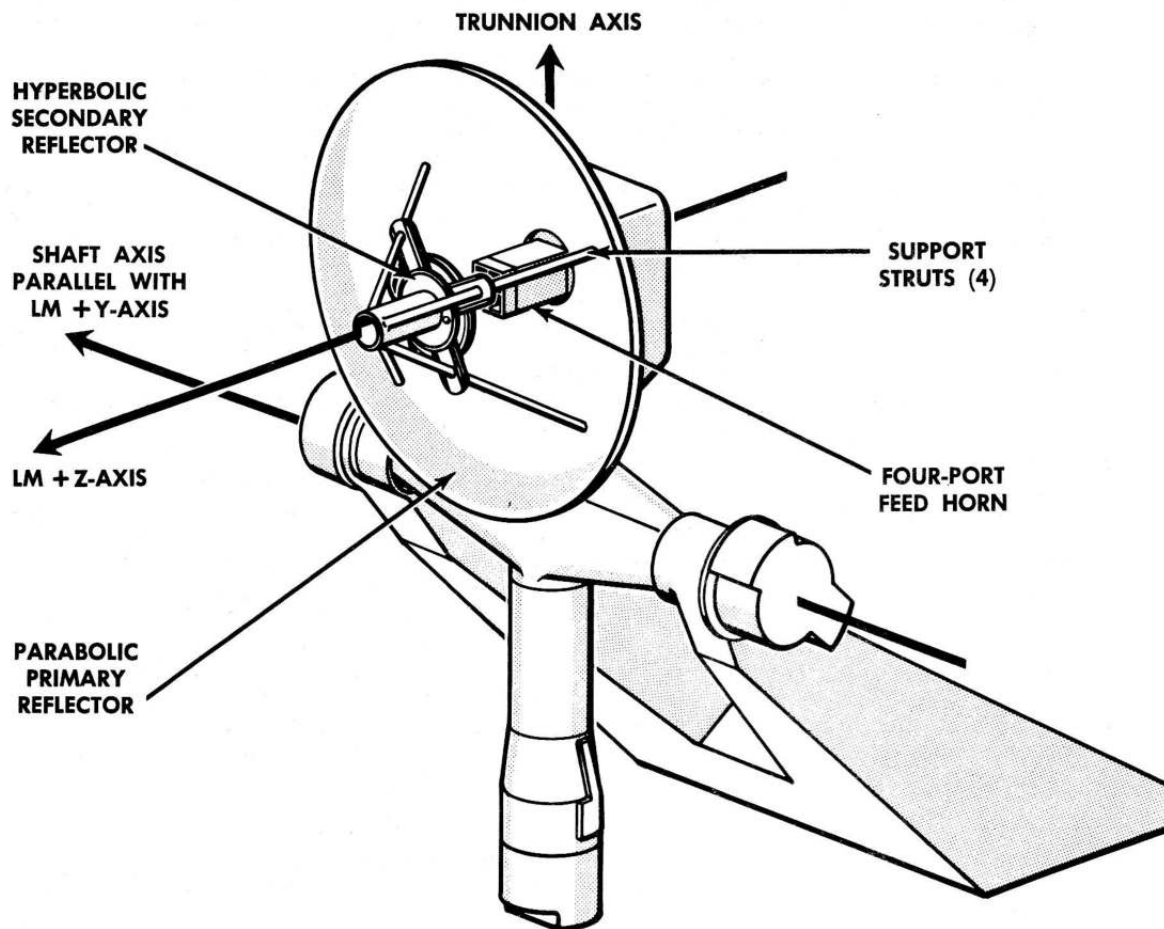
The sum signal output of the receiver subassembly is also fed to the frequency tracker subassembly. The received frequency is not constant; it varies with the range rate between the LM and the CSM. The difference in frequency (Doppler frequency) is a function of the rate of change of range. By measuring the Doppler frequency, the range rate may be determined. A frequency tracker subassembly detects the Doppler frequency by continually comparing the received frequency, after it has been converted to 6.8 mc in the receiver subassembly, with a reference frequency. A voltage-controlled oscillator (VCO) in the frequency tracker subassembly is maintained at the reference frequency plus the Doppler frequency by means of an automatic phase-lock loop. Any change in Doppler frequency results in a corresponding change in VCO frequency. The instantaneous frequency of the VCO is a function of range rate. Range rate data are fed to the LGC and to the cabin displays.

The Doppler frequency component must be eliminated from the ranging and antenna-positioning circuits (the X and Y channels) because it would cause inaccuracies. Therefore, the loop that controls the VCO frequency encompasses part of the receiving circuits. The loop removes the Doppler frequency from the ranging and antenna-positioning circuits, but maintains the VCO at the Doppler frequency plus the reference frequency.

After triple conversion in the receiver, to 1.7 mc, the sum channel signal is compared to the X- and Y-channel signals to obtain drive signals for the antenna. The drive signals eliminate the antenna-pointing error. This automatic antenna-positioning loop keeps the RR antenna LOS directed at the transponder. The antenna-positioning loop, in conjunction with a gyro stabilization loop, compensates for vehicle motion.

The orientation of the antenna, as a result of antenna positioning by the LGC and gyro stabilization, indicates the direction of the transponder with respect to the LM. Resolver outputs, indicating antenna position, are fed to the LGC and to the cabin displays.

Antenna Assembly. (See figure 2-37.) The RR antenna is an amplitude-comparison, monopulse, directional device that provides accurate and unambiguous range and range rate tracking information. The 24-inch-diameter parabolic primary reflector of the radar antenna has a conventional four-port Cassegrainian feedhorn. The radiation from the feedhorn illuminates a 4.65-inch-diameter hyperbolic secondary reflector located to reflect the feedhorn-radiated RF energy back to the primary reflector. Use of the hyperbolic reflector uniformly illuminates the parabolic reflector with RF energy and results in the formation of a narrow direction beam. The antenna operates in the X-band region of the microwave spectrum and possesses an overall power gain of 32 db. The signal radiated from the antenna is circularly polarized to minimize signal losses due to variations in attitude that occur between the LM and CSM. The antenna beam-width is 3.25° to 4.00°.



300LM3-100

Figure 2-37. Rendezvous Radar Antenna Assembly

The antenna pedestal and the base of the antenna assembly are mounted on the external structural members of the LM. The antenna pedestal includes rotating assemblies that contain radar components. The rotating assemblies are balanced about a shaft axis and a trunnion axis. The trunnion axis is perpendicular to, and intersects, the shaft axis. The antenna reflectors and the microwave and RF electronics components are assembled at the top of the trunnion axis. This assembly is counterbalanced by the trunnion-axis rotating components (gyroscopes, resolvers, and drive motors) mounted below the shaft axis. Both groups of components, mounted opposite each other on the trunnion axis, resolve about the shaft axis. This balanced arrangement requires less driving torque and reduces the overall antenna weight. The microwave, radiating, and gimbaling components, and other internally mounted components, have low-frequency flexible cables that connect the outboard antenna components to the inboard electronics assembly. A flexible wrap-up system is used at each rotary bearing joint.

The mechanisms of the RR shaft and trunnion axes contain resolvers, which transmit angular changes to the LGC via a CDU. The LGC uses these data in conjunction with range and range rate to update the state vector. The RR also provides analog information for use by the astronauts in evaluating the rendezvous phase of the mission.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Electronics Assembly. The electronics assembly consists of the following subassemblies: receiver, frequency synthesizer, frequency tracker, self-test, antenna control amplifier, range tracker, signal data converter, and an instrumentation converter.

Receiver Subassembly. The receiver subassembly is an amplitude-comparison, triple-conversion, three-IF-channel unit that provides azimuth and elevation error signals to an antenna servo loop when angle-tracking the target with the radar antenna. The receiver subassembly also functions as an intermediate signal path for received signals, which are then processed before being picked off by the frequency tracker and range tracker. An AGC loop in the receiver subassembly provides a constant signal output to the other subassemblies despite variation in signal input. This ensures that the angle error is a function of the angle error signals, not a function of signal amplitude. The receiver subassembly consists of three channels: sum channel (reference), trunnion-axis difference channel, and shaft-axis difference channel.

The receiver subassembly also contains phase-sensitive detectors for generating angle error signals, an IF distribution amplifier unit for supplying reference channel signals to the range and frequency trackers, and a local oscillator-mixer for generating the second local oscillator signal. The second local oscillator frequency is obtained by heterodyning the frequency tracker VCO output and a reference frequency. This produces a sum frequency that is 6.8 mc lower than the incoming 40.8-mc Doppler-shifted frequency. At the second mixer, the Doppler frequency shift is removed; all subsequent signal processing is accomplished at fixed carrier frequencies.

Frequency Synthesizer Subassembly. The frequency synthesizer subassembly supplies the other RR subassemblies and the antenna assembly with coherent reference frequencies; which provide extreme accuracy and a high degree of stability. Multiplying and dividing circuits, local oscillators, amplifiers, and mixers are used in the frequency synthesizer to provide five output frequencies whose function and destination are listed in table 2-16.

The frequency synthesizer subassembly contains two oscillators. One oscillator operates at 102.425 mc; it provides an input to a chain multiplier in the antenna assembly. The chain multiplier multiplies the input by a factor of 96 to produce the radar transmitter frequency (9832.8 mc). The other oscillator produces a fundamental frequency (1.7 mc). After suitable multiplication and division of this fundamental frequency, the other frequencies required for RR operation are obtained. (The 1.7-mc oscillator is locked in frequency to the 102.425-mc oscillator.)

Frequency Tracker Subassembly. The frequency tracker subassembly is a phase-lock loop that detects, acquires, and phase-tracks the received signal from the receiver subassembly sum channel. In addition, the frequency tracker provides stripped, Doppler, and Doppler sense outputs, and frequency lock-on indication.

The frequency tracker phase-locks a VCO with the return signal. A sweep circuit varies the VCO frequency across the expected Doppler frequency range (-100 to +100 kc). The presence of a carrier signal within the locking range is sensed by a threshold circuit, which stops the sweep and permits the VCO to phase-lock. The phase detector has a 6.8-mc reference signal, supplied by the frequency synthesizer subassembly. An error signal from the receiver subassembly drives the VCO to a frequency, which, when mixed with a 27.2-mc signal at the receiver second IF oscillator, removes the Doppler frequency shift from all signals in the succeeding IF stages and assures passage of the signal through the 1.7-mc filters. The filters have a 1-kc bandwidth.

Self-Test Subassembly. The self-test subassembly is used to perform a quantitative test to verify proper operation of the RR electronics. Information provided as a result of the self-test is range, range rate, and angle error data for a 200-nautical-mile signal. Basically, the self-test subassembly provides a means for inserting, into the antenna assembly, signals that simulate RF inputs to the RR. Range rate information is contained in fixed IF offset of 10 kmc, corresponding to a velocity of 500 fps. Range information is placed on the crystal oscillator frequency by a varactor phase modulator

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-16. Frequency Synthesizer - Output Frequencies

Frequency (mc)	Function	Destination
5.1	Third mixer excitation	Receiver
6.8	Reference signal	Frequency tracker, and range tracker analog processor
7.0125	Doppler bias mixer excitation	Frequency tracker
27.2	Second mixer reference	Receiver
102.425	Transmitter excitation	Antenna assembly, multiplier chain

driven by three-tone phase shifters. Angle error information is simulated by square-wave phase modulation of the difference channel signals, which switches the phase of the difference channels 0° or 180° with respect to the sum channel signal.

The self-test circuits are enabled when the RADAR TEST switch (panel 3) is set to RNDZ. The RANGE and RANGE RATE indicators drive to 200 nm in range and -500 fps in range rate, and the antenna oscillates in both the shaft and trunnion axes.

Antenna Control Amplifier Subassembly. The antenna control amplifier subassembly contains amplifiers for driving the antenna shaft- and trunnion-axis servomotors, amplifiers for driving the gyro torquer coils, and voting logic for selecting redundant gyros in the event of a primary gyro malfunction. The amplifiers, in conjunction with the antenna components and receiver subassembly, form an inner and outer closed loop for each axis. The inner (stabilization) loop maintains the antenna boresight axis fixed in inertial space in the presence of vehicle motion, as sensed by the gyros. The outer (tracking) loop further maintains the antenna boresight on the target, based upon the summation of tracking error signals from the monopulse receiver. In the designate mode, the tracking loop is open and LGC-designated antenna position data, or manual slew data, are accepted by the subassembly. The LGC designates the antenna boresight to the target, and supplies an automatic track enable signal for the RR when within 0.5° of the computed target LOS. The possibility of side-lobe lock-on is made negligible by limiting the antenna boresight displacement from the computed target LOS to within 0.5° before closing the tracking loop. The antenna then continuously tracks the target by maintaining the monopulse receiver angle error signals at null. The antenna may also be slewed manually, at either of two fixed inertial rates. In this case, the enable signal required to close the automatic tracking loop is supplied by setting the RENDEZVOUS RADAR selector switch (panel 3) to SLEW.

The antenna shaft and trunnion are positioned by 32-pole, brushless, permanent-magnet-rotor-type motors. The motors are driven by pulse-width-modulated drive signals applied to their sine and cosine windings. The direction of motor rotation is reversed by reversing the motor winding across the pulse-width-modulated drive voltage.

A gyro voting circuit consisting of performance comparison and logic-switching circuits, automatically detects a malfunctioning gyro and removes it from the control loop. There are two pairs of gyros; one pair at a time is used to stabilize the antenna. Either pair can be used. The voting system determines whether the active pair contains a failed gyro by comparing the output of each of the gyros, three at a time. If a failure or degradation occurs, the redundant pair is switched automatically into the antenna-stabilizing network.

Range Tracker Subassembly. The range tracker subassembly determines the range to the transponder by measuring the relative phase delay between the transmitted signals and the received signals. The transponder reply signal, after undergoing dual

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

frequency conversion in the RR antenna assembly and receiver subassembly, is applied as a 6.8-mc signal to the coherent detector of the range tracker subassembly. This signal is demodulated in the coherent detector, which uses a 6.8-mc quadrature reference. The individual sine-wave signals are extracted from the receiver noise by use of bandpass filters. The range phase delay, proportional to range, is measured independently on each of the three signals in a closed tracking loop, using three locally generated reference square waves each of which has variable phase with respect to the transmitted signals. The phase of the reference square waves is adjusted until the reference square waves have matching phase with respect to each of the received signals. The reference square waves are produced digitally by comparison between a running high-speed counter and a low-speed range counter. The low-speed range counter is driven upward or downward until phase null is achieved in each of three phase detectors by incremental range pulses obtained from a voltage-to-PRF converter. The converter is controlled by weighted integration of the three phase-detector error signals.

Signal Data Converter Subassembly. (See figure 2-38.) The signal data converter subassembly consists of a computer interface board and an input-output amplifier board; it provides the electrical interface between the RR and the LGC for range and range rate data. It also supplies an 18-bit range word for the displays and routes the RR control signals from the control panel. The computer interface board contains a 15-bit binary counter, a 15-bit shift register, two strobe gate generators and associated data transfer logic, and six discrete interface circuits. The input-output amplifier board contains relay drivers, pulse shapers, a signal shaper, and antenna servo control logic. Depending on the control signals from the LGC, the computer and input-output interface board provides either range or range rate data to the LGC.

The LGC requests range data by sending strobe pulses on three lines at a rate of 3,200 pps. One strobe line supplies a continuous train of reset pulses for timing. A burst of 256 pulses is sent on a second strobe line to read the range. After a strobe interval of 80 milliseconds (read time), the LGC sends a burst of readout pulses on a third line to obtain the data. In this operation, the range data are transferred automatically from the range counter to the 15-bit shift register. The range data are transmitted to the LGC in true and complement forms on two separate lines.

The LGC requests range rate data by sending pulses on the reset strobe line and a burst of pulses on the range rate gate strobe line at a rate of 3,200 pps. Both sets of pulses are routed through a gate generator to provide three outputs, as follows:

- Reset pulses to clear the 15-bit binary counter
- Range rate gates to control the duration of the counting period
- Transfer pulses to activate the 15-bit transfer logic.

The range data routed to the LGC have two different scalings. Range low scale factor switching is implemented automatically by the RR at a range of approximately 50.8 nautical miles. For transferring range data to the 15-bit shift register, the RR has an 18-bit accumulator (counter). Only 15 of 18 bits are gated to the shift register, to be sent to the LGC. Range scaling is a factor in determining whether the 15 least significant bits or 15 most significant bits from the counter are gated to the shift register. At ranges greater than 50.8 nautical miles, the most significant bits are transferred. At ranges less than 50.8 nautical miles, the least significant bits are transferred. The RR sends a discrete signal (RR range low scale factor) to inform the LGC that low-scale-factor radar operation is in effect. The low scale factor of the transferred range data is approximately 9.38 feet/bit; the high scale factor, approximately 75.04 feet/bit. RR scale factor switching does not occur during range data transfer.

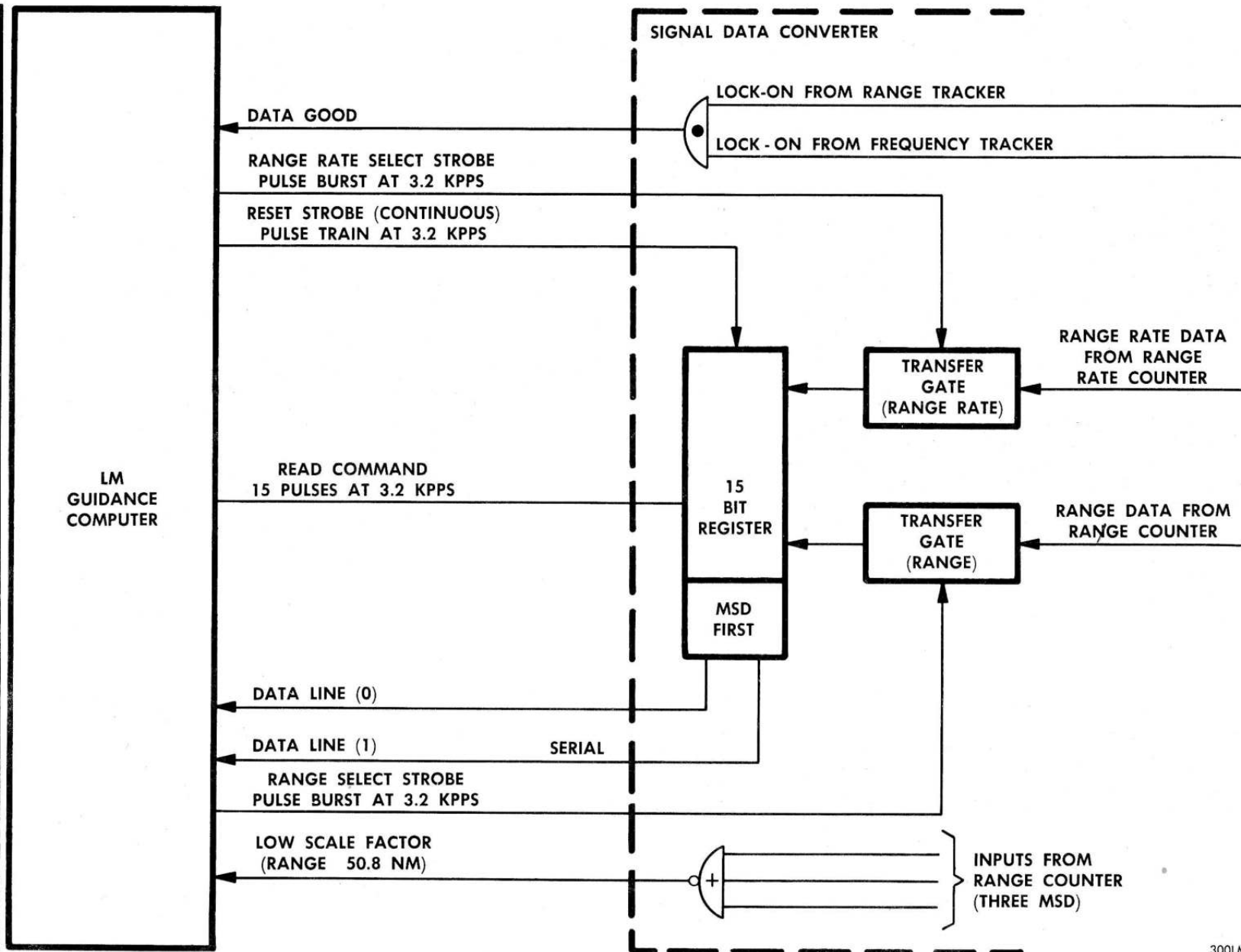


Figure 2-38. Rendezvous Radar Digital Data Transfer - Flow Diagram

Instrumentation Converter Subassembly. The instrumentation converter subassembly provides the following signals, which are obtained as outputs from a power monitor converter and data-no-good/no-track converter:

- Transmitter power output to cabin display (SIGNAL STRENGTH indicator on panel 3)
- Data-no-good signal to telemetry
- No-track signal to cabin display (NO TRACK light on panel 3).

Rendezvous Radar Modes of Operation. The three modes of RR operation are: automatic tracking, slew (manual tracking) and LGC control; there are two modes (No. I and II) of antenna orientation. Antenna orientation modes No. I and II are initiated by the astronaut via a DSKY entry. The relationship between RR antenna radiation coverage and each of the three axes of the LM, for modes No. I and II, is shown in figures 2-39 and 2-40. The limits given in the figures are LGC-programmed limits (limits permitted by the LGC for automatic operation), not the mechanical limits of the antenna. For modes No. I and II, there is a total angular shaft coverage of 225° and trunnion coverage of 110°. In both antenna orientation modes, shaft tracking limits permit the radar beam to cover a band from +40° to +60° above the +Z-axis. The trunnion-axis mechanism permits 70° antenna rotation to either side of the Z-axis at all shaft-axis positions in modes No. I and II, but antenna LOS is limited (-55° to +55°) about the Z-axis. The desired RR mode is selected with the RENDEZVOUS RADAR selector switch.

Automatic Tracking Mode. The automatic tracking mode is selected by setting the RENDEZVOUS RADAR selector switch to AUTO TRACK. This mode enables the RR to track the CSM automatically after it has been acquired; tracking is independent of LGC control. When this mode is selected, tracking is maintained by comparing the received signals from the shaft and trunnion channels with the sum channel signal. The resultant error signals drive the antenna, thus maintaining track.

Slew Mode. The slew (manual tracking) mode is selected by setting the RENDEZVOUS RADAR selector switch to SLEW. This mode enables the astronaut to slew the antenna manually to a position for acquisition of the CSM.

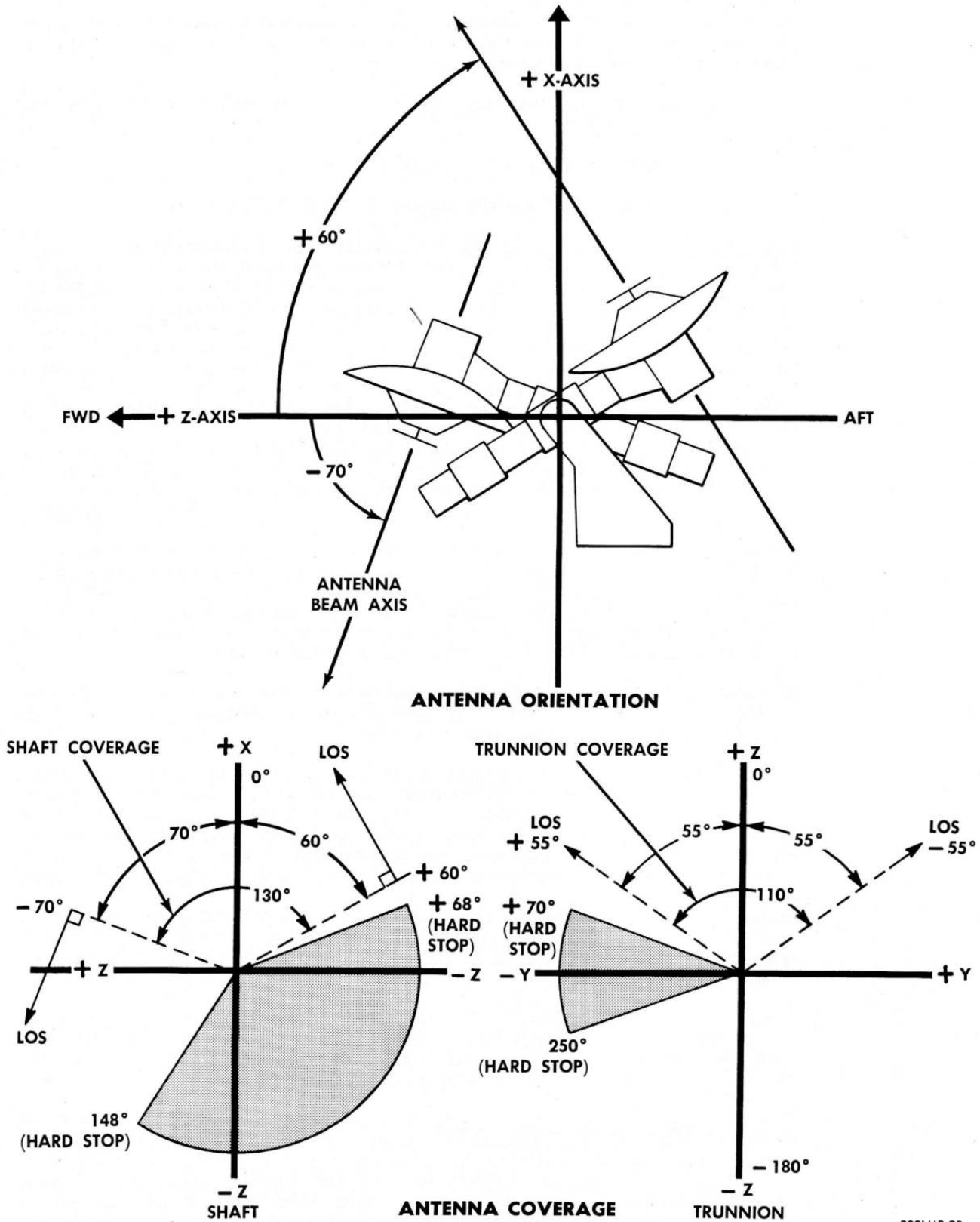
LGC Control Mode. The LGC control mode is selected by setting the RENDEZVOUS RADAR selector switch to LGC. In this mode, the LGC automatically controls positioning of the antenna, initiates automatic tracking once the CSM is acquired, and controls antenna mode changes. When this mode is selected, the RR sends a RR power-on/auto discrete to the LGC. Automatic control of RR search and acquisition operation is provided by the PGNS, which transmits slewing commands to orient the RR antenna.

Antenna Orientation Mode No. I. (See figure 2-39.) This is the downlook mode. It is used during beacon-transponder tracking and rendezvous operations. This mode provides unrestricted antenna radiation coverage from -70° to +60° with reference to the Z-axis.

Antenna Orientation Mode No. II. (See figure 2-40.) This is the overhead mode; it is used during lunar stay. This mode provides unrestricted antenna radiation coverage from +40° to +155° with reference to the Z-axis. In this mode, the antenna is rotated 180° about the trunnion axis to obtain the required shaft coverage.

General Operation of Rendezvous Radar. (See figure 2-41.) The first operation of the RR is angle tracking. The radar antenna is designated at an angle so that its transmitted continuous-wave radiation can be received at the transponder. The shaft and trunnion resolver outputs are routed through the SHFT/TRUN χ switch (panel 1) and the RATE/ERR MON switch to the FDAI error needles. With the RATE/ERR MON switch set to RNDZ RADAR, the shaft angle signals are applied to the pitch error needle;

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA



300LM3-98

Figure 2-39. Rendezvous Radar Antenna Orientation - Mode No. I

LMA790-3-LM 3
 APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

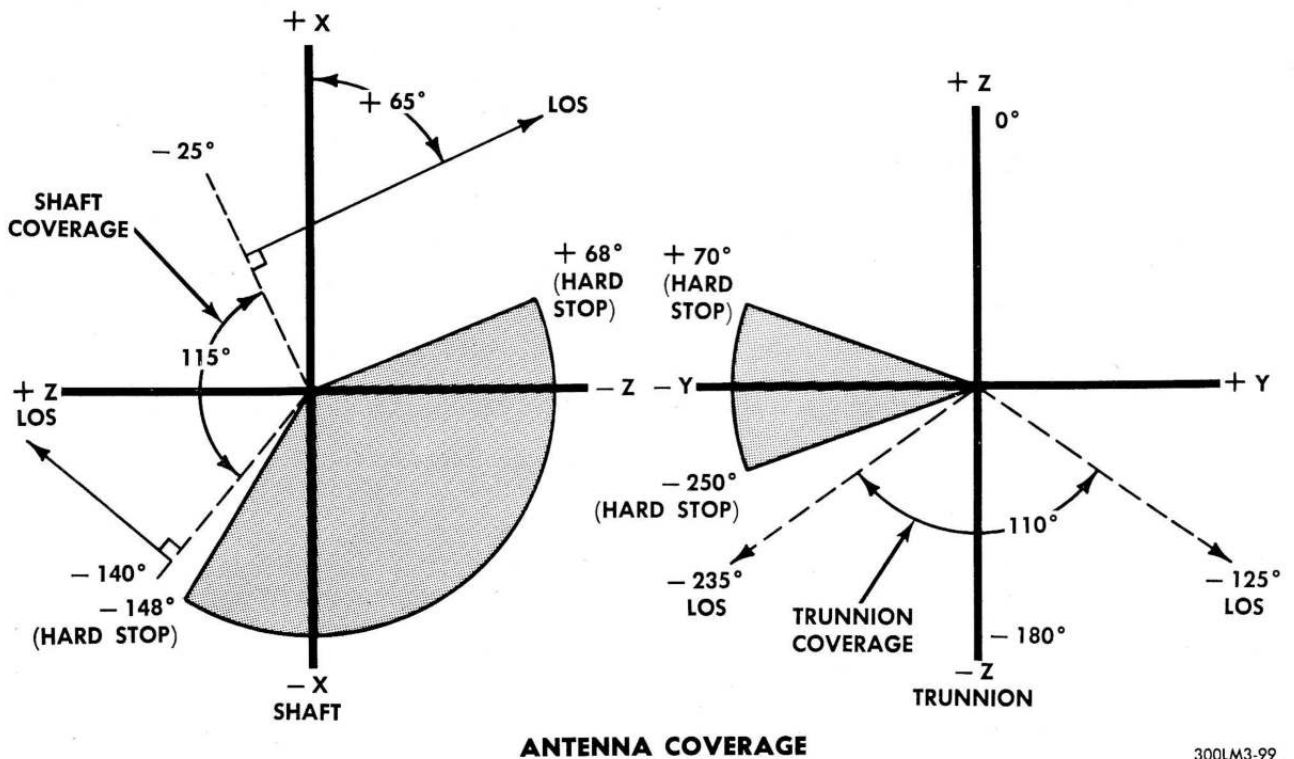
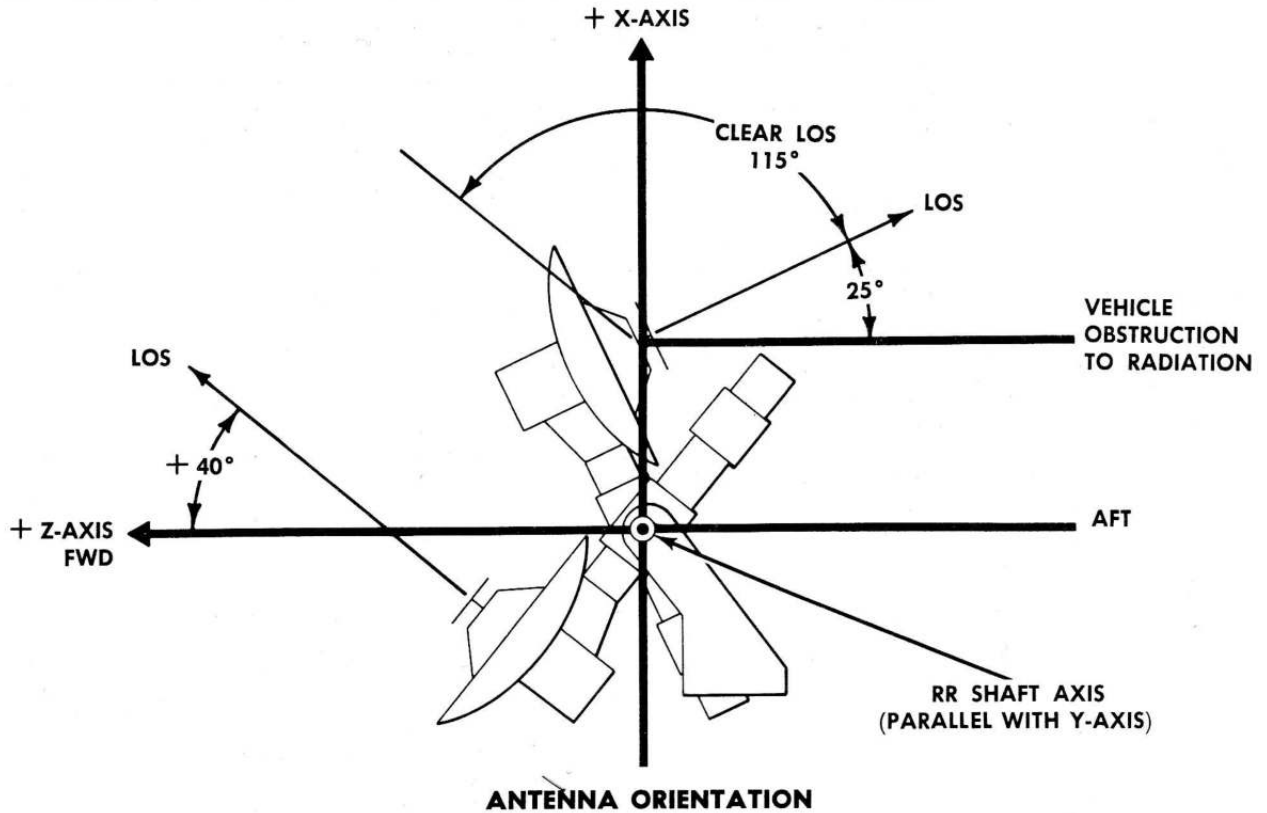


Figure 2-40. Rendezvous Radar Antenna Orientation - Mode No. II

300LM3-99

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

the trunnion angle signals, to the yaw error needle. The SHFT/TRUN χ switch provides the scaling ($\pm 5^\circ$; $\pm 50^\circ$) for the resolver outputs. The shaft and trunnion rates, which correspond to RR LOS elevation and azimuth angular rates, are routed through the SHFT/TRUN χ , X-POINTER SCALE, and RATE/ERR MON switches for display on the X-pointer indicator. When the RATE/ERR MON switch is set to RNDZ RADAR, the ELEV RT and AZ RT placarding on the X-pointer indicator is illuminated. The X.1 or X10 placarding on the X-pointer indicator also is illuminated, depending on the setting of the X-POINTER SCALE switch.

The transponder, which was previously sweeping in frequency, senses this radiation, stops its sweep, and phase-locks to the received radar signal. It then transmits a reply signal whose frequency equals the received signal frequency multiplied by 240/241. (This frequency is sidestepped from the received signal frequency by 40.8 mc.)

When the boresight of the antenna is within 0.5° of the path of the transponder reply signal, the LGC provides an auto track enable signal that initiates the tracking function. This ensures that acquisition cannot occur on a sidelobe. The antenna assembly electronics provides intermediate frequencies that are converted to lower values in the receiver subassembly IF stages. If the RR has been in operation (but has not been under LGC control) and the RENDEZVOUS RADAR selector switch is set to LGC, the PGNS redesignates the antenna and issues the RR auto track enable signal.

The position of the transponder with respect to the RR LOS determines the type of antenna pointing error signal generated. With the RR LOS directly below the transponder, a Y-coordinate (shaft) pointing error signal is generated in the angle error detector. (See figure 2-42.) With the RR LOS on either side of the transponder, an X-coordinate (trunnion) pointing error signal is generated. When fed to the antenna control amplifier subassembly, the d-c error signal causes the antenna servo system to provide tracking compensation and thereby reduces the error. An AGS loop in the receiver subassembly makes the output of the angle error detector dependent on the antenna angle error, rather than on the amplitude of the signal. The output of the angle error detector causes the motors of the antenna trunnion and shaft to position the antenna so that the boresight is always toward the CSM.

When the strength of the received radar signal is at a certain level, the radar issues a data-good discrete to the LGC. The LGC, in turn, issues an auto track enable discrete to the radar electronics. The enable discrete causes the radar to track the target automatically, independent of LGC control; the NO TRACK light goes off. On receipt of the data-good discrete, the LGC commands transfer of range and range rate data from the RR. During automatic tracking, the RR supplies shaft and trunnion angles to the LGC via the CDU analog-to-digital converters. If the target is lost during tracking, the PGNS takes control and positions the antenna in a manner to regain acquisition and automatic tracking.

If the RR loses the target, the NO TRACK light (panel 3) goes on, indicating that the RR is not locked on the CSM. A no-track signal is supplied to the caution and warning electronics assembly, which turns the RNDZ RDR caution light (panel 2) on.

When the RR achieves lock-on, range and range rate data from the electronics assembly are routed through the RNG/ALT MON switch (set to RNG/RNG RT) to the RANGE and RANGE RATE indicators.

If the 6.8-mc IF loop opens, angle tracking stops. The acquisition sweep generator in the frequency tracker begins to sweep and continues sweeping until acquisition is achieved and angle tracking is restored.

When operating in the manual tracking mode (RENDEZVOUS RADAR selector switch set to SLEW), the antenna is positioned manually by the astronaut, using the SLEW and SLEW RATE switches (panel 3). With the SLEW RATE switch set to HI, the astronaut can slew the antenna in the direction designated by the setting of the SLEW switch (UP, DOWN, RIGHT, or LEFT) at a rate of 7° /second until the CSM is acquired.

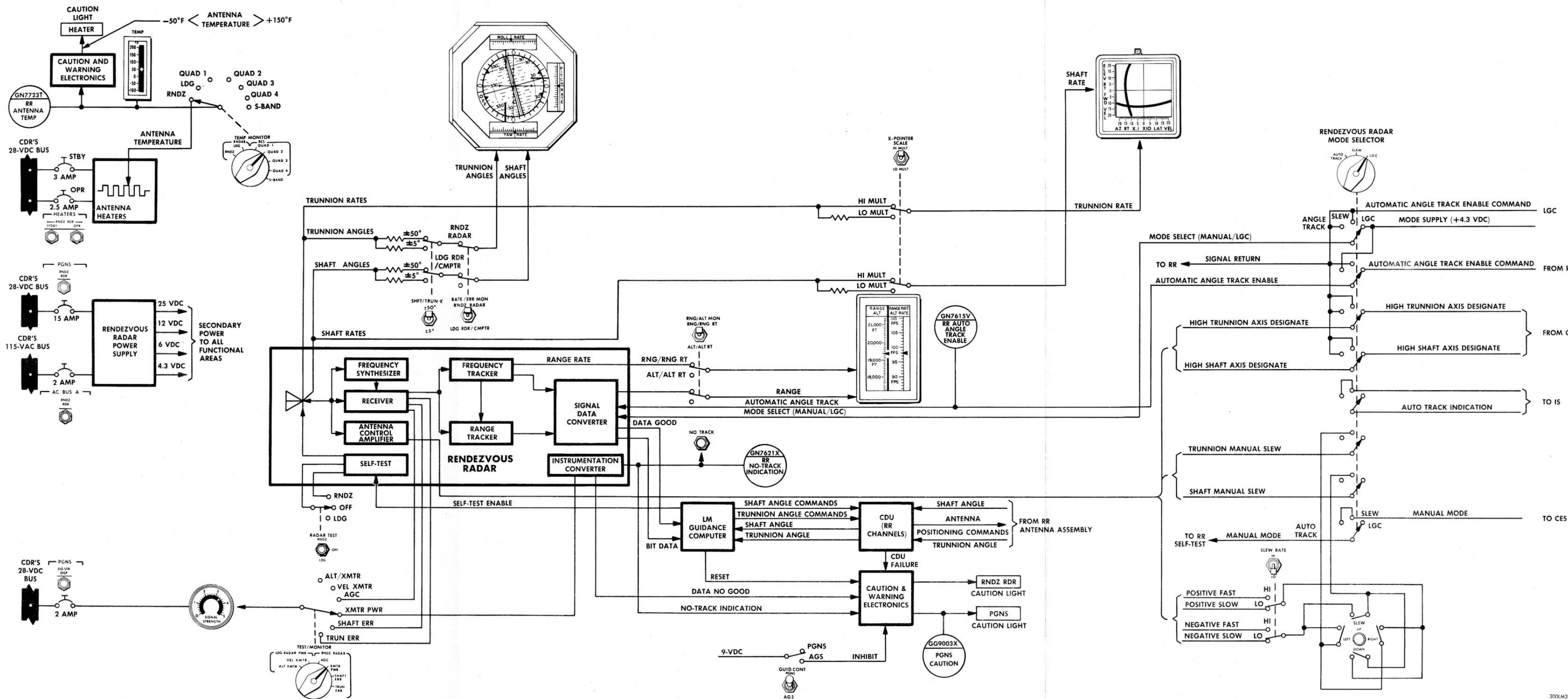


Figure 2-41. Rendezvous Radar - Functional Flow Diagram

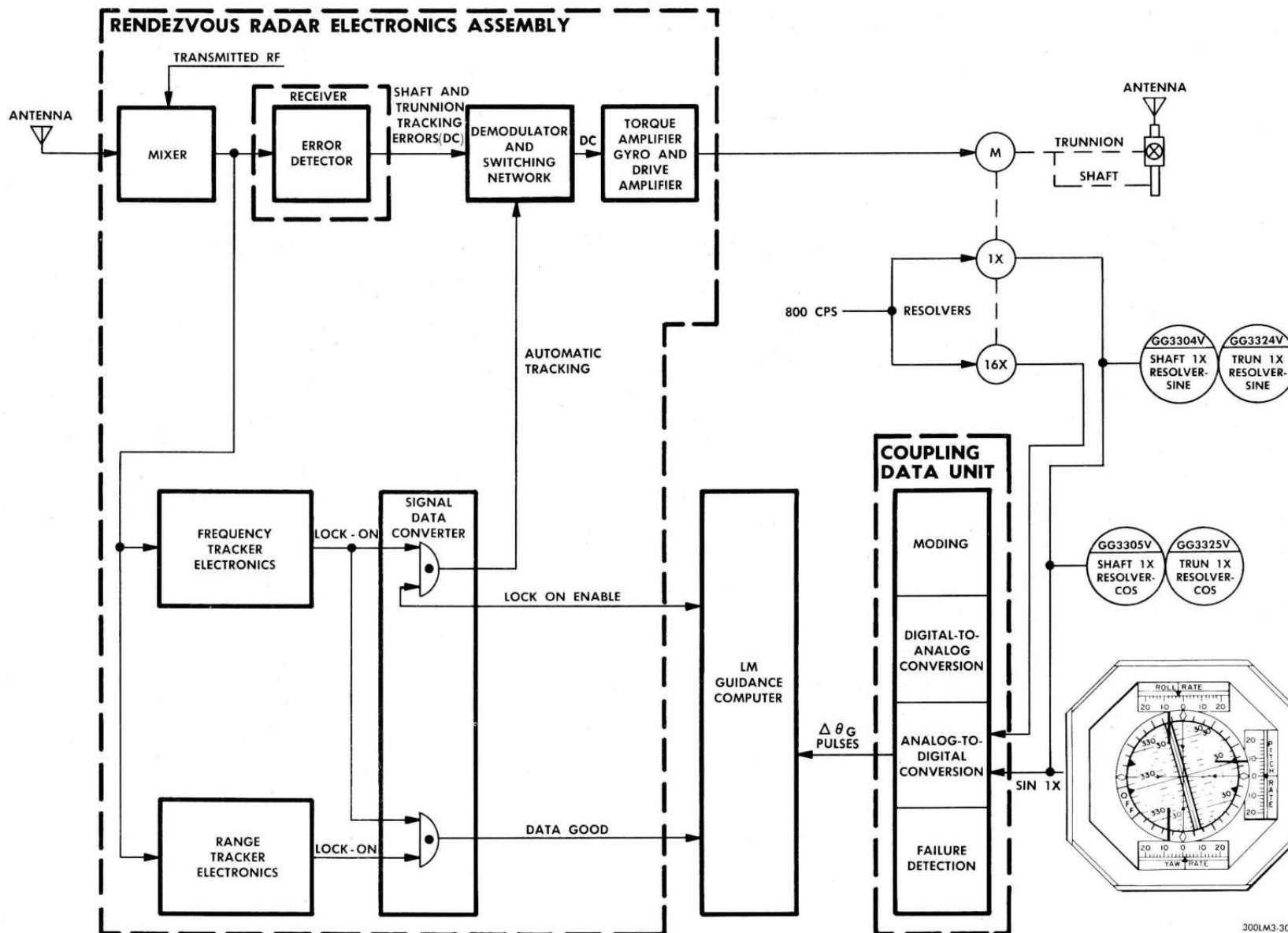


Figure 2-42. Rendezvous Radar Tracking Loop - Functional Diagram

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

The LO position of the SLEW RATE switch permits slewing at a rate of $1.33^\circ/\text{second}$. Once the CSM is acquired, the RR functions in the same manner as in the automatic tracking and LGC control modes.

The manual tracking mode is used for self-testing the RR. With the RADAR TEST switch (panel 3) set to RNDZ, the LGC issues a self-test enable discrete, which enables the astronaut to monitor the RR. Using the TEST/MONITOR switch (panel 3) and the SIGNAL STRENGTH indicator (panel 3), the astronaut can monitor the performance of the AGC loop, transmitter power, and shaft and trunnion error signals.

The astronaut can also monitor the antenna temperature, using the TEMP MONITOR switch and the TEMP indicator on panel 3. If the antenna temperature exceeds the temperature limits (-50° to $+150^\circ$ F), the caution and warning electronics assembly turns the HEATER caution light (panel 2) on.

Antenna Positioning. (See figure 2-43.) When a mode change is required, slewing is commanded by an LGC program to change orientation. Mode change involves a specific combination of alternate shaft and trunnion slewing (single-axis control) to move the antenna to within the tracking limitations of the new mode. Dual-axis control commences after the antenna is at a specific position within the new tracking area, to position the radar beam for acquisition of the target.

The PGNS gains control of the RR antenna when the LGC receives the RR power on/auto discrete. This signal is initiated by setting the RENDEZVOUS RADAR selector switch to LGC. The LGC initializes the control loops by sending the RR-CDU zero discrete to the CDU (RR channels). This discrete clears the read counters in the trunnion and shaft CDU section and inhibits transmission of incrementing pulses from the read counters. The error counters are also cleared and inhibited by a logic circuit within the CDU. The LGC removes the zero discrete to enable the read counters and issues a RR-CDU error counter enable discrete to enable the two counters. The LGC then begins sending pulses representative of positioning angles to the digital-to-analog converters. The resulting analog signal is routed to the radar electronics to position the antenna. The signals are applied to the antenna-mounted gyros, which are torqued, and the resulting error signals are applied to the servomotors via servoamplifiers. Position data are obtained from the 1X and 16X resolver signals. These data are applied to the analog-to-digital converter in the CDU, which converts the data to digital pulses ($\Delta \theta$ pulses) and routes them to the LGC.

In positioning the antenna to the desired LOS, and LGC commands a maximum slew rate of $6.75^\circ/\text{second}$ until the LOS is within 7° of the desired direction. Then the slew rate decreases exponentially to $1.5^\circ/\text{second}$. The slew rate decreases proportionally until acquisition is obtained.

2.2.3.3.2

Landing Radar (See figure 2-44.)

The primary purpose of the LR is to control the LM to effect a safe landing on the lunar surface. During the LM-3 mission, the transmitted signals are not returned to the LR antenna because the mission does not contain a landing phase. The primary mission objective for the LM-3 LR will be to check for stray returns. The reason for the check is that the stray returns may have been generated by reflections from the LM body.

The LM-3 LR contains all the hardware necessary for a functional lunar landing radar. The only differences between the two is that certain internal signal flow has been severed. These changes are shown in figure 2-44 and are denoted by cut lines.

The lunar LR senses the velocity and attitude of the LM relative to the lunar surface by means of a three-beam Doppler velocity sensor and a radar altimeter. Velocities are obtained by measuring the Doppler shift along three beams of microwave energy. Slant range (altitude) is obtained from a single continuous wave of microwave energy. Velocity and range data are processed, and made available to the LGC in

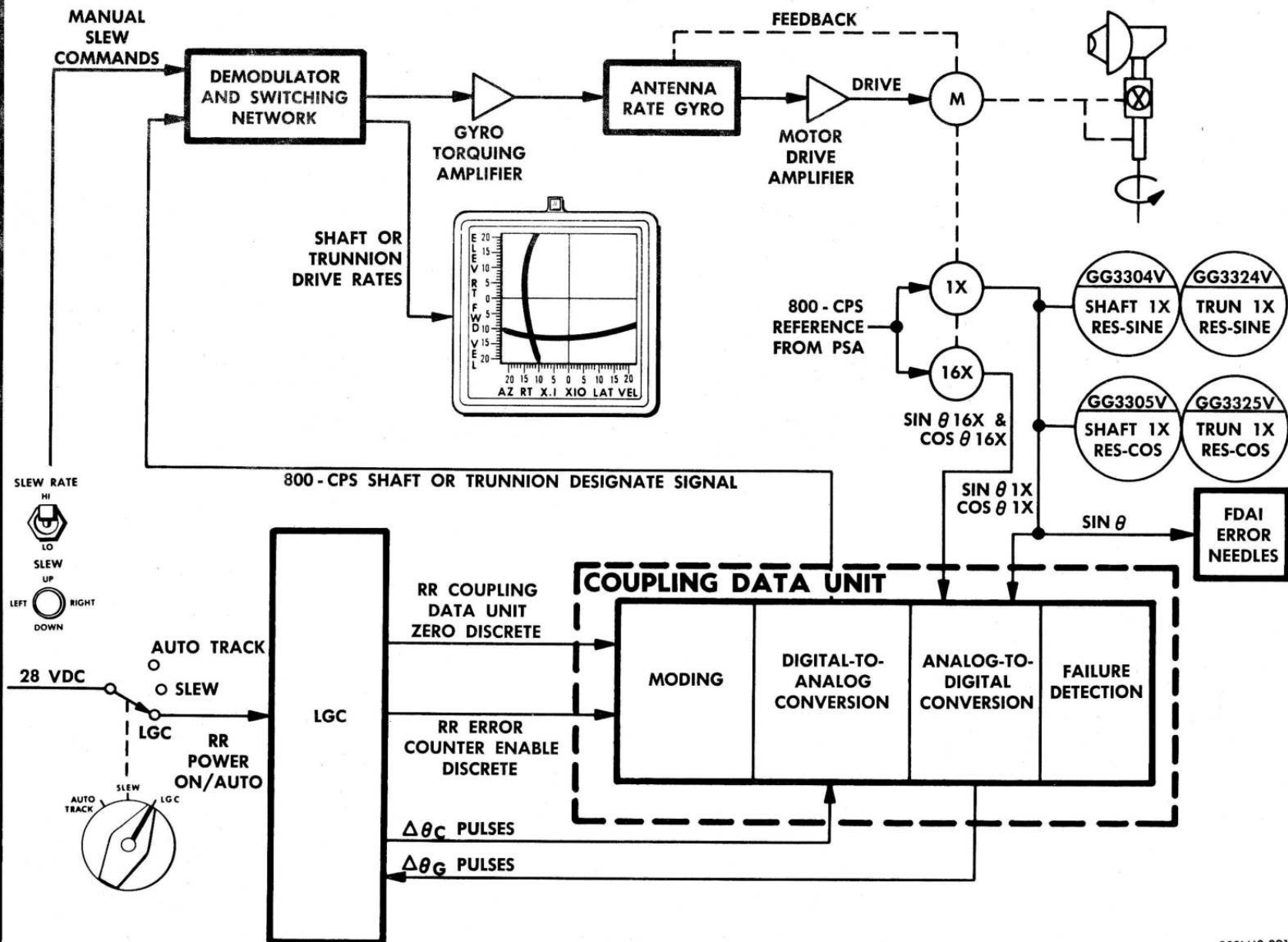


Figure 2-43. Rendezvous Radar Antenna Positioning - Functional Diagram

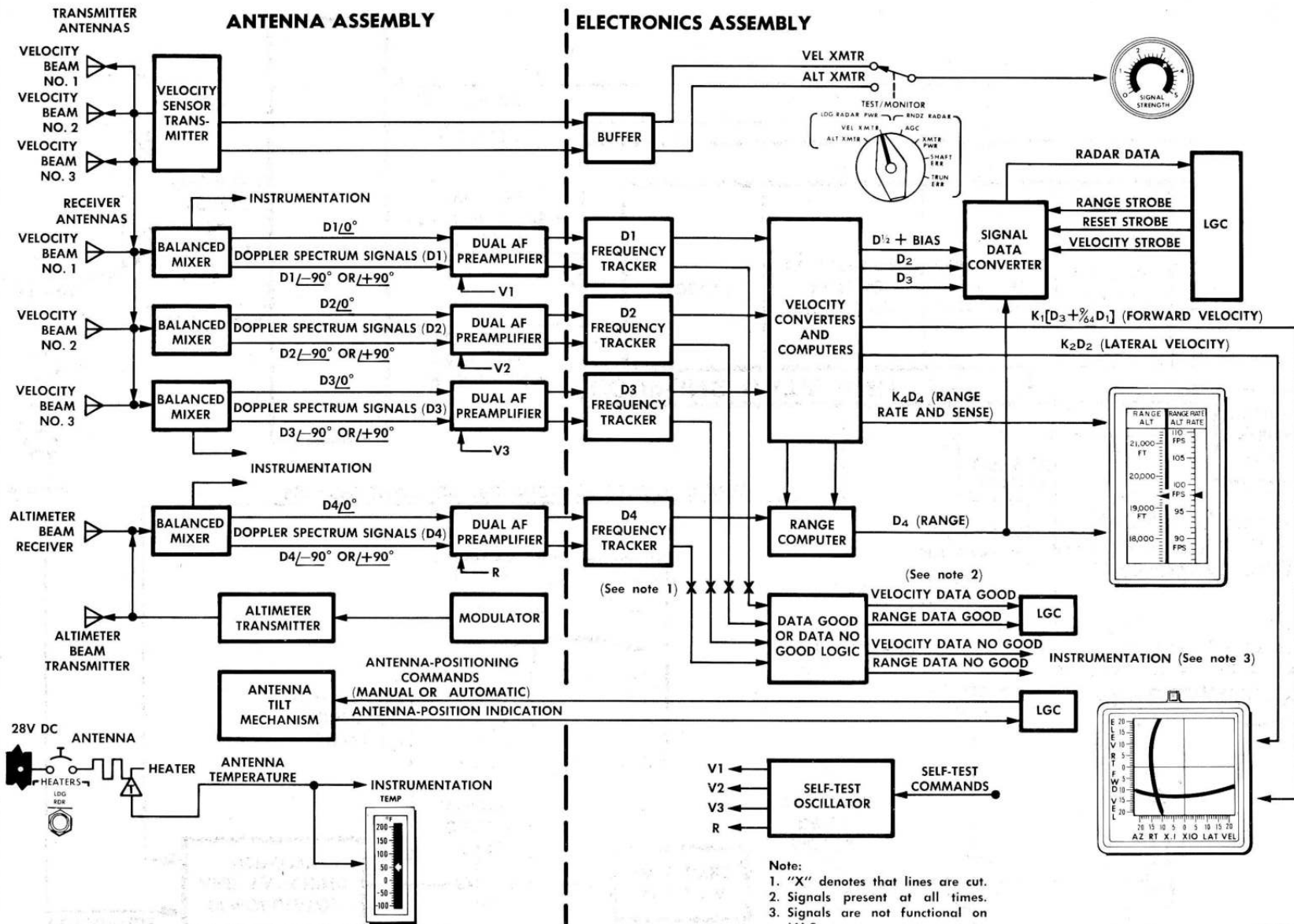


Figure 2-44. Landing Radar - Block Diagram

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

serial binary form and to the LM displays in the form of pulse trains and d-c analog voltages. For the LM-3 mission the stray returns from any of the beams are processed in a similar manner. Pick-off points in the antenna assembly are provided for IS to monitor for the stray returns. The stray returns are then amplified and sent to the IS for telemetry.

The LR, in the descent stage, consists of an antenna assembly and an electronics assembly. The antenna assembly forms, directs, transmits, and receives the four microwave beams. Transmission frequency for the three velocity beams is 10.51 gc; for the altimeter beam, 9.58 gc. The electronics assembly contains the circuitry required for tracking, processing, converting, and scaling the Doppler returns or stray returns.

Antenna Assembly. The antenna assembly consists of two interlaced phase arrays for transmission and four space-duplexed planar arrays for reception. The receiving-array beamwidths are wider than those of the transmitting arrays. Antenna boresighting is not critical. The transmitting arrays form a platform on which four microwave mixers, four dual audio-frequency preamplifiers, two solid-state microwave transmitters, a frequency modulator, and an antenna pedestal tilt mechanism are mounted.

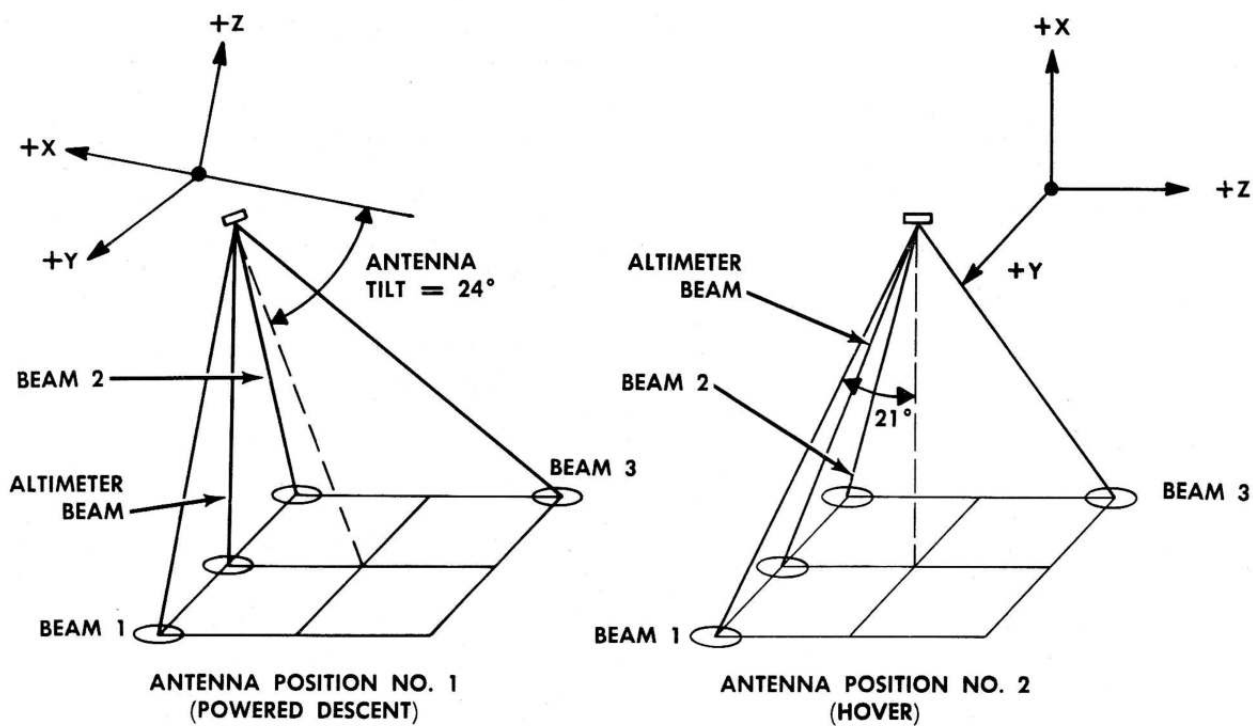
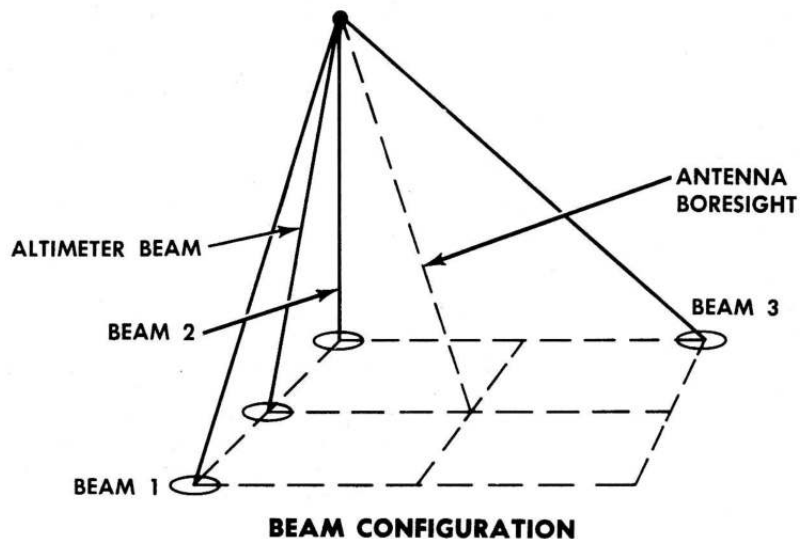
The LR antenna is mounted to the descent stage by means of the antenna pedestal tilt mechanism. The mechanism permits the antenna to be placed in one of two fixed positions. (See figure 2-45.) With the antenna in position No. 1 (powered descent), the range accuracy is optimized at 15,000 feet; the velocity accuracy, between 11,000 and 1,000 feet. With the antenna in position No. 2 (hover), the range accuracy is optimized at 200 feet. For the lunar mission, the LM will be able to hover at 200 feet for 120 seconds. This will permit the astronauts to select, visually, the most desirable landing site. Antenna position No. 1 is the initial position for the antenna in the descent profile. When the LM reaches an altitude of 8,600 feet (high gate), the LGC commands the antenna to position No. 2. The antenna remains in position No. 2 until lunar touchdown.

Balanced Mixers. In the balanced mixers, the received energy is combined with energy from the transmitters to perform an RF-to-AF conversion. To retain the Doppler signal sense, the received signals are routed through signal-splitting devices and through the mixers, which are double-balanced (quadrature pair) mixers. The signal in one channel of the balanced mixers leads or lags the signal in the other channel by 90°, depending on the Doppler sense. The Doppler sense is dependent on whether the velocity is opening or closing. A closing velocity results in a positive Doppler and has a +90° lead signal in the other channel. The balanced mixers produce an AF output.

Dual Audio-Frequency Preamplifiers. The dual AF preamplifiers amplify and process the AF output of the balanced mixers. The preamplifier outputs are routed to the frequency trackers in the electronics assembly. Two stages of amplification (55 and 33 db) are used in the preamplifiers. The output of each preamplifier is sampled by a threshold detector. When the output signal level reaches approximately 6.2 vdc, a solid-state switch is enabled and a low-gain indication signal is routed to the respective frequency tracker. With the switch enabled, the 33-db amplifier is bypassed and the Doppler signal is amplified only by the 55-db amplifier.

Velocity Sensor Transmitter. The velocity sensor transmitter is a continuous-wave-radar velocity transmitter. It operates at 10.51 gc (X-band) in conjunction with an electronically tilted, transmitting, broadside-array antenna. The reflected X-band energy in each beam is frequency shifted in proportion to the relative velocities and beam angles of the LM and the reflecting surfaces. The velocity sensor transmitter has a self-contained, crystal-controlled oscillator.

Altimeter Transmitter. The altimeter transmitter is an FM/CW transmitter, which does not contain an oscillator. The transmitter receives its input, which is a sawtooth signal that is frequency modulated at a repetition rate of 130 cps, from the frequency modulator. The altimeter X-band (9.58 gc) microwave energy is applied to the antenna.



ANTENNA TILT ANGLES

300LM3-180

Figure 2-45. Landing Radar Antenna Beam Configuration

GUIDANCE, NAVIGATION, AND CONTROL SUBSYSTEM

The transmitted energy is continuously sampled, and mixed with any returned energy. The resultant difference of the mixing process (range frequency) is proportional to the sawtooth frequency deviation rate, and is two times the distance to the reflecting surface. In addition to range frequency, there is a frequency component (Doppler) due to relative velocity along the altimeter beam. This Doppler component (D4) is proportional to velocity along the altimeter beam and adds to, or subtracts from, the range frequency, depending on the velocity. A closing velocity results in a positive Doppler signal.

Frequency Modulator. The frequency modulator output is a sawtooth FM signal that is modulated at a repetition rate of 130 cps. The average center frequency of the modulator is 99.8 mc; average output is 14 millivolts. Use of the two FM deviation rates provided depends on the altitude at which the LR is used.

Antenna Pedestal Tilt Mechanism. The antenna pedestal tilt mechanism serves as the electrical and mechanical interface between the antenna assembly and the LM. The mechanism places the antenna in either of two operating positions. The antenna is positioned by a tilt actuator, which is controlled manually by setting the LDG ANT switch (panel 3) to the desired position, or automatically by an LGC command if the LDG ANT switch is set to AUTO.

The tilt actuator is a reversible d-c motor with internal limit switches that remove drive power once the extreme of either position is reached. Travel time of the actuator is approximately 10 seconds. Antenna position is indicated to the LGC by a discrete, which is generated by the closing of a set of switch contacts on the antenna pedestal. The contact closures provide antenna position 1 and position 2 discretes to the LGC, and to the IS for telemetry.

Electronics Assembly. The electronics assembly contains frequency trackers (one for each velocity beam), a range frequency tracker, a velocity converter and computer, a range computer, a signal data converter, and a data-good/no-good logic circuit. The electronics assembly for fully operational LR provides the LGC with digital outputs that correspond to the range along the altitude beam and velocity in relation to LM coordinates. The LR will supply accurate data from 18,000 feet to near lunar touchdown. It has provision for hovering and negative speeds. Self-check devices within the LR enable operational checks of the entire LR without radar returns from the lunar surface. The astronauts can evaluate the LR operational status at any time during the mission.

Velocity Frequency Trackers. The velocity frequency tracker circuits convert the outputs from the antenna assembly AF preamplifiers to discrete frequency components, which are processed by the velocity and range data computers. Doppler sense representative of opening or closing velocity is interpreted and preserved through the frequency trackers, and a tracker lock-on indication is given to the LGC when a signal of proper characteristics and amplitude is acquired (for LM-3 this signal is present for any stray return).

The velocity frequency trackers are divided into three subassemblies, one for each main velocity beam. The three subassemblies, used to track the three Doppler velocity sensor beams, are identical.

Range Frequency Tracker. The range frequency tracker operates in a manner similar to that of the velocity frequency trackers. Preamplifier output, which is the sum of the range signal and the Doppler signal associated with this signal, is applied to the range frequency tracker, where it is processed. The main difference between operation of the velocity frequency tracker and the range frequency tracker is that the range frequency tracker contains a gate that is used to disable the tracking loop. The range frequency tracker produces two outputs: a tracker lock signal, and a range signal, which is routed to the range computer.

Velocity Converter and Computer. The velocity converter contains three identical Doppler-processing circuits (D1, D2, and D3 converters). These circuits synchronize

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

the signals and multiply the Doppler frequency by four; indicate Doppler sense; and, based on Doppler sense, provide an output to the velocity computer. In addition to the D1, D2, and D3 converters, the velocity converter contains a velocity sensor bandwidth control circuit. This circuit is basically a frequency comparator, used to switch each velocity frequency tracker to its narrow band-pass mode when its output frequency is less than 1.47 kc and to switch all the velocity frequency trackers to the narrow band-pass mode when the altitude is less than 2,500 feet.

The velocity computer normally converts the beam Doppler products into antenna velocity coordinate outputs (V_{xa} , V_{ya} , and V_{za}) and applies them to coordinate computers. There are three coordinate computers, one associated with each coordinate. The outputs of these computers are d-c voltages that are directly proportional to the measured velocity; they drive the velocity displays (X-pointer and RANGE RATE indicators). During the LM-3 mission, the velocity computer converts the stray returns into analog voltages proportional to the stray returns.

Range Computer. The range computer is to calculate the range of the LR and remove the Doppler effect of the altimeter beam. The Doppler effect is removed by an adder-subtractor circuit in the computer. The velocity-compensated range signal is then routed to a frequency comparator and to a pulse shaper and gating circuit. The output of the range computer is routed to the signal data converter and to the RANGE indicator.

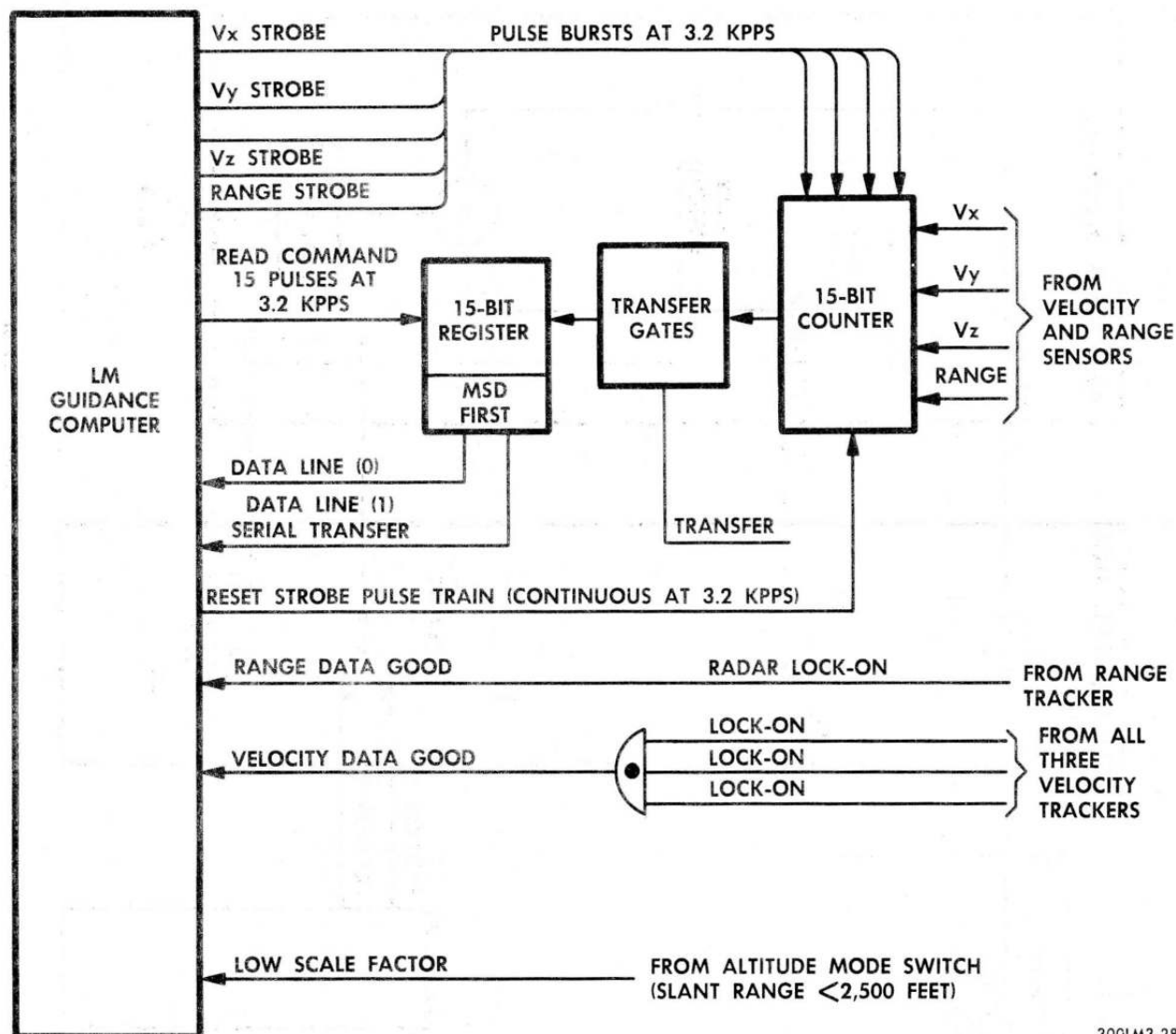
Signal Data Converter. The basic function of the signal data converter is to convert the LR outputs to the 15-bit format required by the LGC. To accomplish this, the signal data converter uses a 15-bit counter, transfer gates, and a 15-bit shift register. (See figure 2-46.) The LGC provides the timing signals that sequentially select the PRF input to be counted, determine the counting time, and provide the data readout command required to shift out the contents of the shift register. Before the LGC issues transfer commands, range (altitude) data-good and velocity data-good discretes must be received from the radar. During the LM-3 mission these two discretes are present as soon as the LR is turned on. Upon receipt of these discretes, the LGC issues strobe pulses, alternately, to the 15-bit accumulator or counter in the signal data converter. This permits stray return data to accumulate in the counter, depending upon which strobe line is used. The data are then transferred to the 15-bit shift register by an internal timing pulse. The LGC initiates a readout command, consisting of a train of 15 pulses, to the shift register. Each bit in the shift register is then transferred to the LGC input registers over the 0 data line or the 1 data line.

The 15-bit data word is shifted out, most significant digit (MSD) first. The two data lines permit a parity check of the transfer (serial) functions to be made by the LGC, because both lines (1 or 0) are not simultaneously high or low.

Landing Radar Modes of Operation. The LR modes of operation concern orienting the LR antenna to either of its two positions. The positions are shown in figure 2-47. Antenna orientation is determined by the setting of the LDG ANT switch. (See figure 2-48.)

With the LDG ANT switch set to LGC, a motor drive signal is routed to an actuator motor upon command from the LGC. This position command is initiated by an LGC program when the pitch of the LM is such that the LM is in a vertical descent or hovering configuration. The position command only changes the antenna from position No. 1 to position No. 2. The antenna must initially be in position No. 1 for the LGC to have an active part in antenna positioning. Either position, however, can be commanded manually via the LDG ANT switch. The motor drive signal is applied to a reversible motor, which moves a piston-type actuator to move the antenna. When the antenna reaches the commanded position, a limit switch opens and cuts off the motor drive signal. Any movement of the antenna, out of position, closes the limit switch, driving the antenna back. There are three limit switches on the antenna assembly: two are used in the motor drive lines; the other one, for position indication. Position indications (position No. 1 or position No. 2) are sent to the LGC. These discretes

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA



300LM3-288

Figure 2-46. Landing Radar Digital Data Transfer - Functional Diagram

are used in the LGC for transformation of radar data into inertial coordinates, which are used in guidance computations.

General Operation of Landing Radar. (See figure 2-48.) Because the LM-3 mission is an earth-orbital mission, the LR parameters will only be monitored. Operating power will be applied to the LR, and all critical voltages and temperatures will be monitored. The LR contains self-test circuits that permit operational checks of the LR without radar returns from external objects or the lunar surface. This self-checking capability will be initiated during this mission.

The HEATERS: LDG RDR circuit breaker (panel 11) is closed at the launch pad and left closed for the duration of the mission. Activation of the LR heater provides the necessary heating for survival of the LR antenna components.

300LM3-290

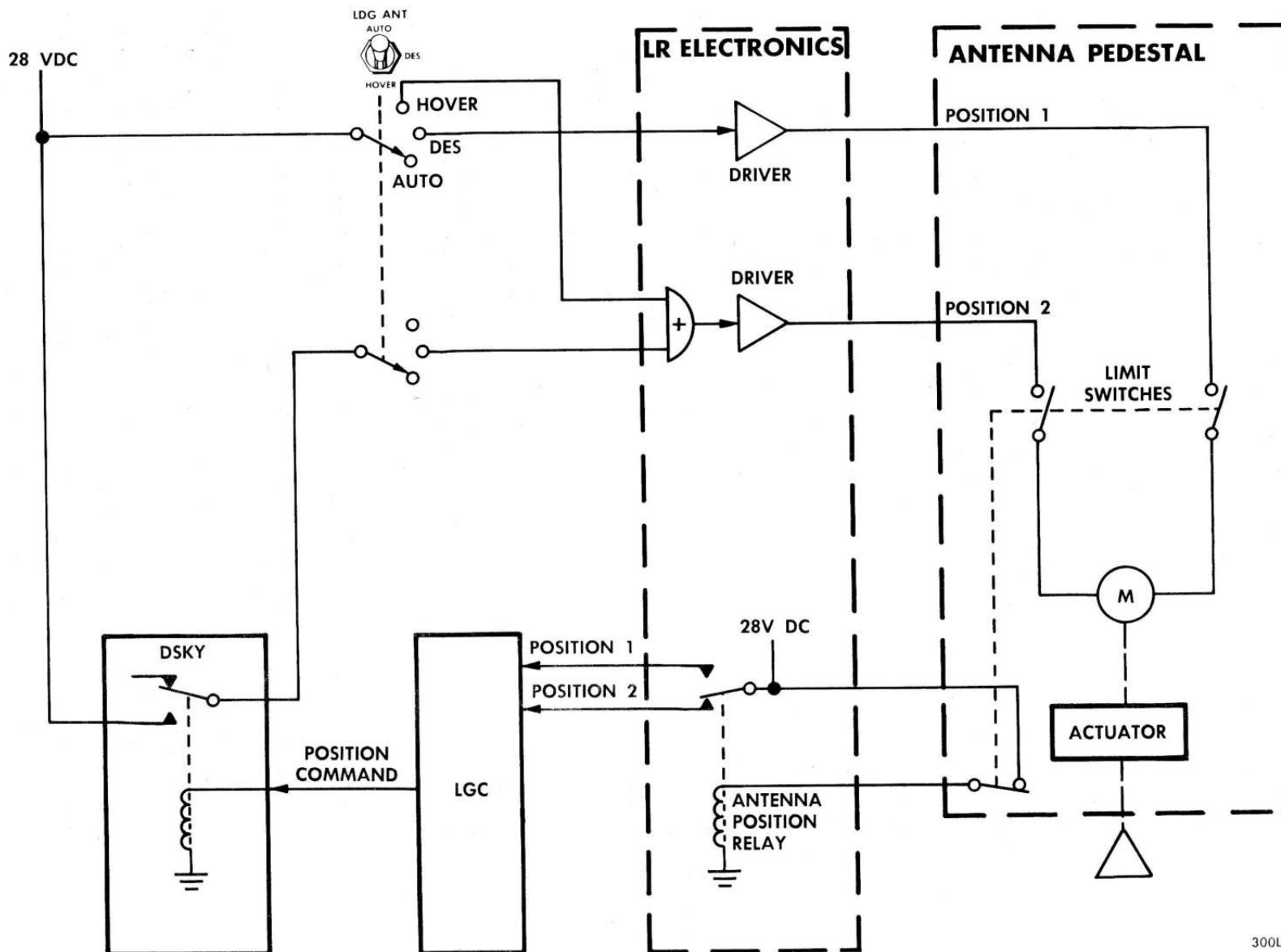


Figure 2-47. Landing Radar Antenna Positioning - Functional Diagram

Figure 2-48. Landing Radar - Functional Flow Diagram

The LR is first turned on and a self-check performed for 5 minutes during LM checkout before LM separation from the CSM. The self-check is accomplished by first activating the LR by closing the PGNS: LDG RDR circuit breaker (panel 11); then, after a 1- to 2-minute warmup period, setting the RADAR TEST switch to LDG. This provides a contact closure, to the radar, which is used as a bit-activate command that permits generation of internal self-test signals. These self-test signals represent simulated known Doppler returns, which, after processing through the radar, are made available to the LGC, and to the cabin displays for monitoring. An additional self-check is performed by setting the TEST MONITOR switch to VEL XMTR and monitoring the SIGNAL STRENGTH indicator (panel 3) for an output reading from the transmitter. The procedures for checking the LR after separation are covered in volume II of Apollo Operations Handbook, LMA790-3-LM 3.

The X-pointer and ALT and ALT RATE indicators indicate the LR operational velocity and slant range (altitude). The X-pointer indicator's display the LM forward and lateral velocities. These data, generated in the velocity computers of the LR electronics assembly, are displayed when the MODE SEL switch is set to LDG RADAR and the RATE/ERR MON switch is set to LDG RDR/CMPTR. The altitude and altitude rate generated in the velocity and range computers, respectively, are displayed when the MODE SEL switch is set to PGNS, and the RNG/ALT MON switch is set to ALT/ALT RT.

The LDG ANT switch enables the astronaut to command the LR antenna to one of its two positions. A detailed discussion of the use of this switch is presented in the discussion of the LR modes of operation. The LR antenna temperature can be monitored, using the TEMP MONITOR switch and the TEMP indicator (panel 3). If the antenna temperature exceeds the temperature limits (-20° to +110° F), the caution and warning electronics assembly turns the HEATER caution light on.

2.2.3.4 Control Electronics Section. (See figure 2-49.)

The CES processes attitude and translation signals when operating in the primary guidance mode or the abort guidance mode.

When operating in the primary guidance mode, the CES performs the following functions:

- Converts RCS commands to the required electrical power to operate the RCS solenoid valves
- Accepts discrete (on and off) descent engine gimbal commands and, upon receipt of an on command, causes the descent engine to move about its gimbal axes
- Accepts LGC and manual engine on and off commands and routes them to the MPS to fire or stop the descent or ascent engine
- Accepts LGC and manual thrust commands to throttle the descent engine 10% to 92.5% of its range
- Provides manual attitude and translation commands to the LGC.

When operating in the abort guidance mode, the CES performs the following functions:

- Accepts attitude error signals from the AGS, or manual attitude rate commands from the ACA's and rate-damping signals from the RGA, and fires the RCS TCA's to achieve attitude control
- Accepts manual translation commands and fires the TCA's to accelerate the LM in the desired direction

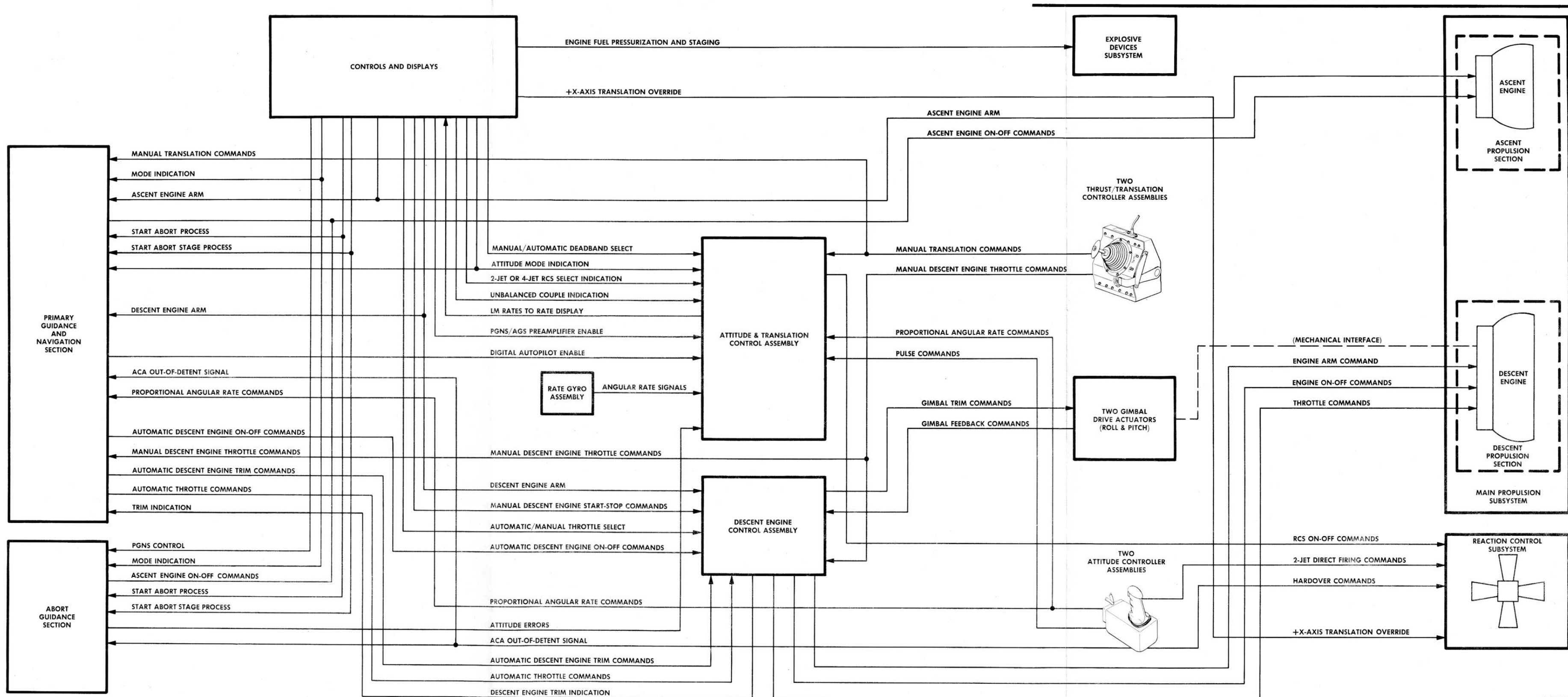


Figure 2-49. Control Electronics Section - Block Diagram

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

- Automatically gimbals descent engine for trim control
- Accepts AGS and manual engine on and off commands and routes them to the descent or ascent engine
- Accepts manual throttle commands to control descent engine thrust.

The CES comprises two ACA's, two TTCA's, five electronic assemblies and an 800-cps synchronization loop. An ACA and a TTCA are provided in the LM cabin, for each astronaut; they are right- and left-hand controls, respectively. The four electronic assemblies include the ATCA, RGA, DECA, and two GDA's. Although they are not major assemblies, the S&C control assemblies and the gimbal angle sequencing transformation assembly (GASTA) of the CES are discussed in paragraphs 2.2.3.4.8 and 2.2.3.4.9, to provide comprehensive coverage of the CES.

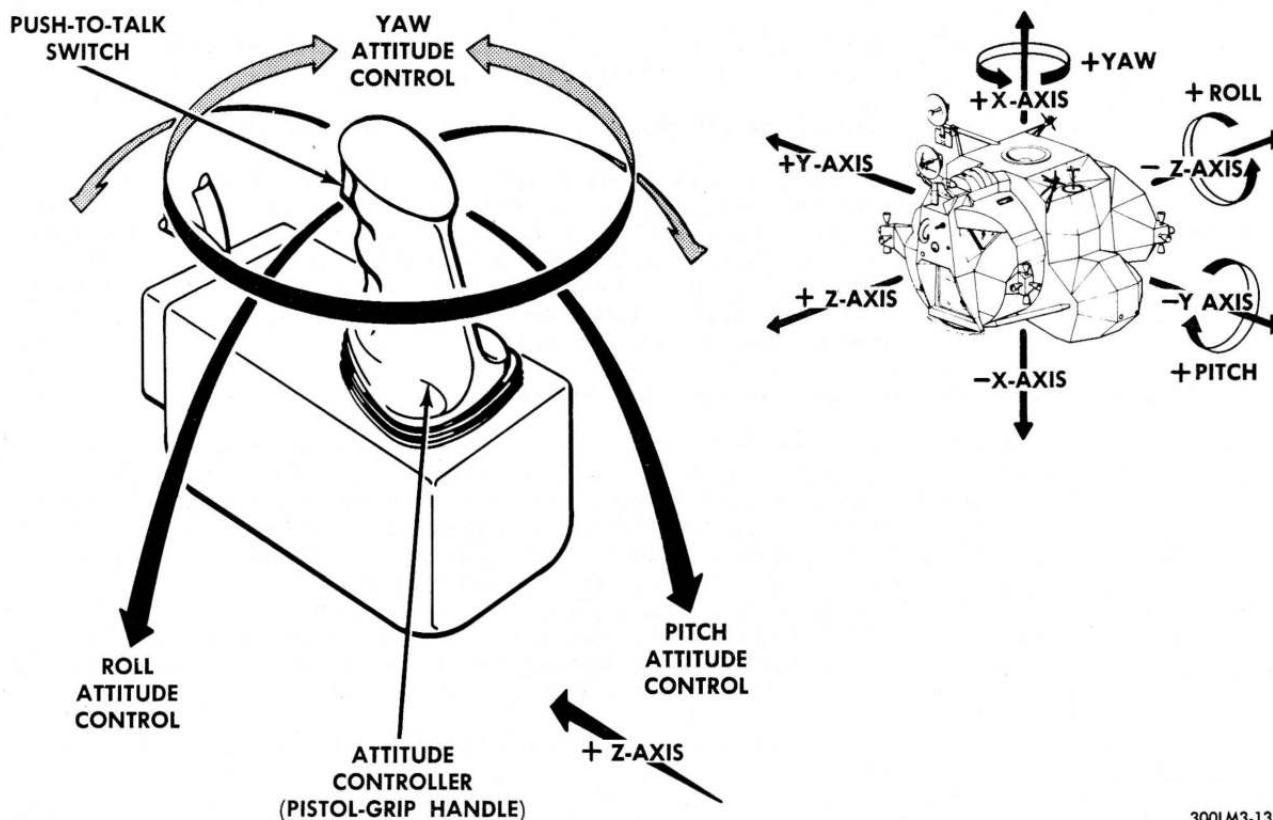
2.2.3.4.1 Attitude Controller Assemblies. (See figure 2-50.)

The ACA's are three-axis, pistol-grip controllers. Either astronaut can command attitude changes, using his ACA. The ACA is installed with its longitudinal axis approximately parallel to the LM X-axis so that vehicle rotations correspond to astronaut hand movement when operating the ACA. Clockwise or counterclockwise rotation of the ACA about its longitudinal axis commands yaw left or yaw right, respectively. Forward or aft movement of the controller commands vehicle pitch down or up, respectively. Left or right movement of the controller commands roll left or right, respectively. The ACA is used for closed-loop proportional rate commands in the attitude hold mode and open-loop acceleration commands in the pulse, direct, and hard-over modes. The ACA performs the following functions:

- Supplies attitude rate commands proportional to ACA displacement, to the LGC
- Supplies an out-of-detent discrete to the LGC and a followup discrete for the AEA, when the PGNS is in control, each time the ACA is out of the neutral position
- Supplies a followup discrete to the AEA, when the AGS is in control and operating in the attitude hold mode, each time the ACA is out of the neutral position. The followup discrete is present at all times.
- Provides a switch for the push-to-talk function, required for communications.

On subsequent missions, the ACA's will also be used in an incremental landing point designator (LPD) mode, which is available to the astronauts during the final approach phase. In this mode, the angular error between the designated landing site and the desired landing site is nulled by repetitive manipulation of an ACA. LPD signals from the ACA are directed to the LGC, which issues commands to incrementally move the designated landing site along the Y-axis and Z-axis.

For ACA proportional control, a 28-volt, 800-cps signal is applied to the primary coil of each of three proportional transducers. The secondary voltage of each transducer (one each for roll, pitch, and yaw axes) is proportional to ACA displacement about its input axis. (See figure 2-51.) When ACA displacement exceeds 0.5° , two sets of switch contacts close. One set of contacts sends an out-of-detent discrete to the LGC and a followup discrete to the AEA. The other set of contacts sends a proportional secondary voltage to the LGC or the ATCA. The output voltages are 0.28 volt degree of displacement (1° to 11°). Positive rotation commands generate in-phase voltage; negative commands, 180° out-of-phase voltage.



300LM3-131

Figure 2-50. Attitude Controller Assembly

During attitude control (ROLL, PITCH, or YAW switch on panel 3 set to MODE CONT) when the minimum pulse mode is selected via the DSKY and the PGNS is in control, the LGC common applied to the plus and minus switches of the ACA is returned to the LGC when the ACA is displaced more than 2.5°. When the AGS is in control and the pulse mode is selected for a given axis (ROLL, PITCH, or YAW switch set to PULSE), positive or negative d-c voltages are applied to the plus and minus switches of the ACA. When the ACA is displaced 2.5° or more from neutral, a positive or negative d-c voltage is applied to the ATCA. A positive voltage commands a positive acceleration (pulsed) about the selected axis; a negative voltage commands negative acceleration. With the ROLL, PITCH, or YAW switch set to DIRECT, 28 volts dc is applied to two RCS secondary solenoids when the ACA is displaced more than 2.5°.

In any attitude control operation, if the ACA is moved 12° or more in any axis (hardover mode), the ACA activates four TCA's via the secondary coils. With the MODE CONTROL selector switch set to ATT HOLD and the ROLL, PITCH, and YAW switches (one or more) set to MODE CONT, the ACA can command LM attitude about the selected axis or about as many as three axes simultaneously.

2.2.3.4.2 Thrust/Translation Controller Assemblies. (See figure 2-52.)

Either astronaut's TTCA can be used for manual control of LM translation or descent engine thrust, depending on the setting of the THROTTLE-JETS select lever. The THROTTLE position is selected for translation control, using the descent engine and the TCA's; JETS, for translation control, using only the TCA's.

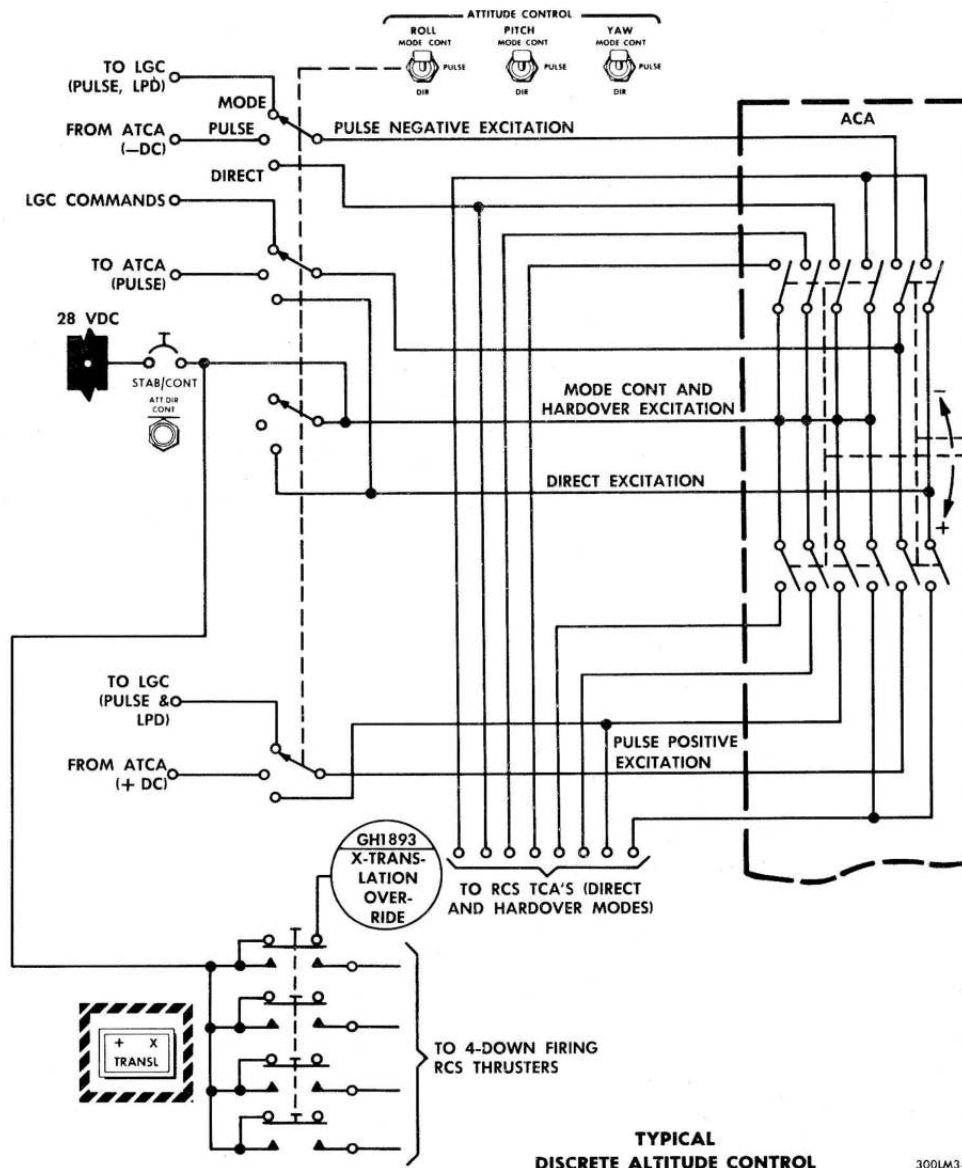
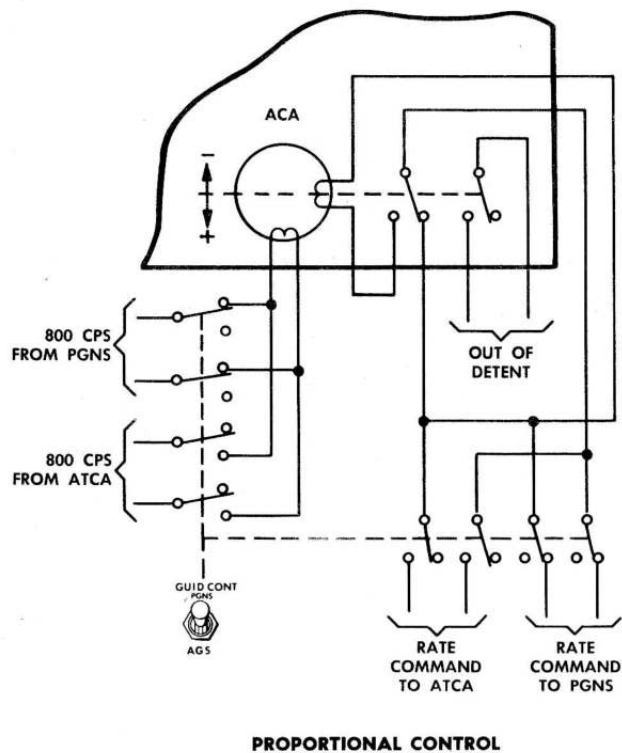


Figure 2-51. Attitude Controller Assembly - Functional Diagrams

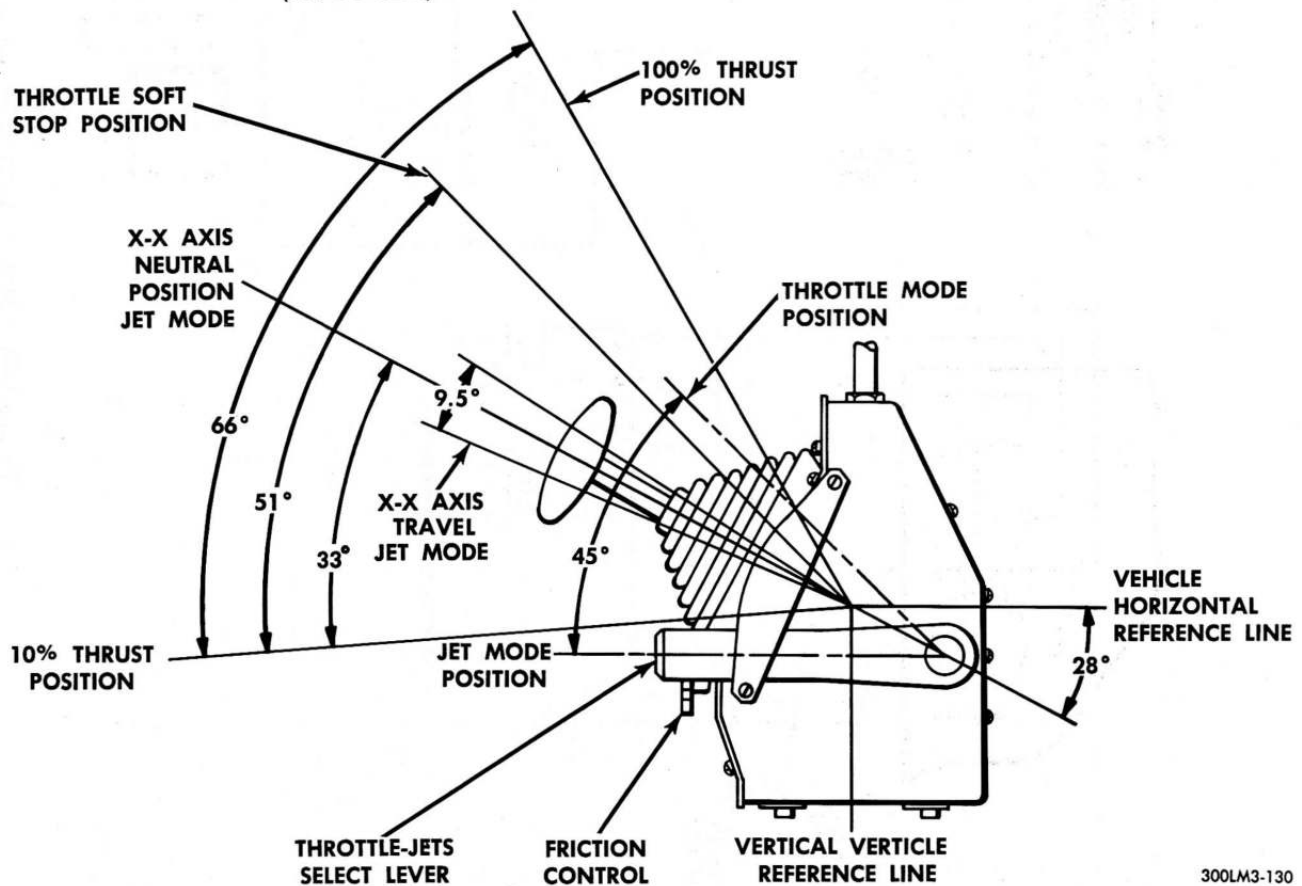
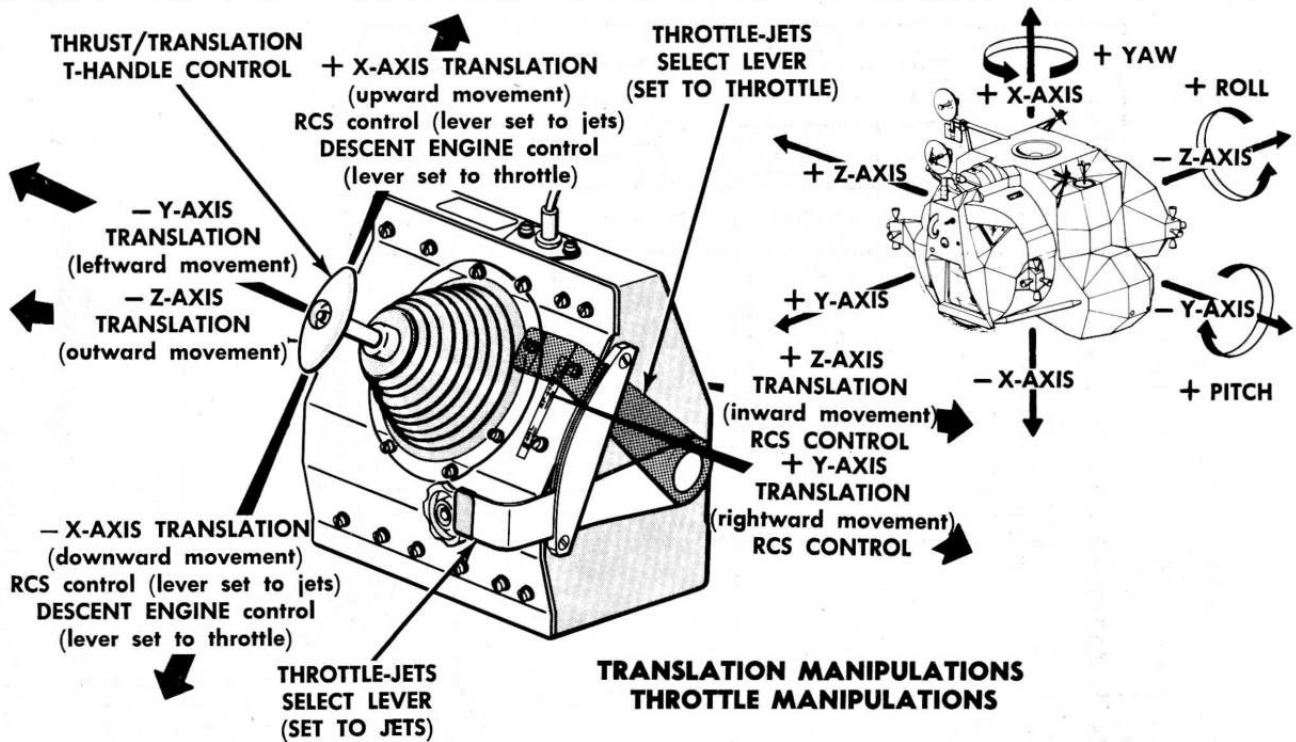


Figure 2-52. Thrust/Translation Controller Assembly

300LM3-130

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Due to the TTCA's mounting position, LM translations correspond approximately to astronaut hand movement when operating the TTCA. Operating the TTCA to the left or right commands translation along the Y-axis. Operating the TTCA forward or aft commands translation along the Z-axis. Operating the TTCA up or down commands translation along the X-axis when the THROTTLE-JETS select lever is set to JETS. When the select lever is set to THROTTLE, up or down operation of the TTCA increases or decreases, respectively, the magnitude of descent engine thrust. Regardless of the select lever position selected, the TTCA can command translation along the Y-axis and Z-axis.

A pair of detent switches and a pair of limit switches are located about each TTCA axis; a nonlinear potentiometer is located along the longitudinal axis. (See figure 2-53.) The detent switches provide a discrete to the LGC when the astronaut operates the TTCA 0.25 inch out of its neutral (detent) position. The discrete commands the LGC to issue translation change commands in accordance with the TTCA motion. The limit switches are used when the AGS is controlling the vehicle; they issue on and off translation commands directly to the RCS jet logic and driver circuitry. The nonlinear potentiometer provides an electrical output, which is proportional to TTCA displacement, when the THROTTLE-JETS select lever is set to THROTTLE. These signals are routed to the DECA to command proportional control of thrust (magnitude). The nonlinear characteristic provides increased servo characteristics.

2.2.3.4.3 Attitude and Translation Control Assembly. (See figure 2-54.)

The ATCA processes signals from the ACA, TTCA, and RGA in the CES and from the PGNS and AGS. The ATCA provides control of LM translation and rotation in all three axes, using the TCA's. Automatic and manual control are available in the primary guidance and abort guidance modes.

The ATCA performs the following functions in the primary guidance mode:

- Under automatic attitude hold control, conditions the TCA commands from the LGC to the TCA's
- Supplies regulated 800-cps power to the RGA, FDAI, and AGS
- Supplies regulated d-c power to the DECA, ACA, TTCA, and S&C control assemblies
- Supplies externally generated pulses to the jet solenoid drivers during the digital autopilot (DAP) mode.

The ATCA performs the following functions in the abort guidance mode:

- Accepts as inputs 800-cps attitude error signals, command rate signals, and rate gyro signals
- Sums, amplifies, limits, demodulates, and deadbands engine command signals to produce vehicle rotation
- Combines vehicle rotation and translation commands in logic networks
- Determines, by combination of rotation and translation commands, the appropriate pulse ratio modulator and jet solenoid to be energized. Proper TCA selection provides the desired rotation and translation.
- Supplies external open-loop rotation commands directly to the logic networks (direct mode)
- Provides trim signals to the DECA

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

- Provides d-c voltages to the DECA, ACA, TTCA, and the control panel
- Provides synchronized three-phase, 800-cps power to the RGA and single-phase, 800-cps power to the ACA, TTCA, and RGA.

In the primary guidance mode, only the primary preamplifiers are enabled by the GUID CONT switch. The circuits in the ATCA remain fully active when used with the PGNS, but automatic and manual steering and translation commands from the jet selection logic are inhibited. Regulated d-c power and the synchronized 800-cps power are still supplied from the ATCA. In this mode, the ATCA amplifies the TCA command signals from the LGC, provides vehicle rotation rates to the FDAI, and provides driving-power amplification for RCS jet solenoid actuation. In the abort guidance mode, only the abort preamplifiers are enabled and TCA signals from the pulse ratio modulators are amplified; the signals drive the RCS primary solenoids. The BAL CPL switch (panel 1) must be set to ON to enable all 16 abort preamplifiers. If the BAL CPL switch is set to OFF, the four abort preamplifiers that control the upward-firing TCA's (A1U, B2U, A3U, and B4U) are disabled.

In the abort guidance mode, pitch, roll, and yaw signals are processed in three similar channels. Attitude error signals from the AGS are applied to the ATCA in the automatic mode and the attitude hold mode with the ACA's in detent. When the DEAD BAND switch (panel 3) is set to MIN (narrow deadband), the error signals are first passed through limiters to prevent excessive vehicle rates. The limiters maintain the vehicle rates at a maximum of 10°/sec in pitch and ±5°/sec in roll and yaw during descent or ascent phases. When the DEAD BAND switch is set to MAX (wide deadband), the limiter is eliminated. The error signals are next summed with rate-damping signals from the RGA. In the attitude hold mode, with an ACA out of neutral, proportional attitude rate commands are summed with the RGA rate-damping signals. The gains of the summing amplifiers are changed when the LM is staged, to account for the change in vehicle moment of inertia. The summed a-c signals are changed to dc by keyed demodulators and filters. In the roll and pitch channels, the demodulator output is routed to the DECA to control descent engine trim. The deadband circuitry provides for a wide deadband (-5° to +5°) or a narrow deadband -0.3° to +0.3° roll and pitch; -0.4° to +0.4° yaw). If the ascent or descent engine is turned on, the narrow deadband is selected automatically. When the engines are turned off, the deadband depends on the setting of the DEAD BAND switch.

In the automatic and attitude hold modes, the attitude error signals from the deadband circuits are routed to the summing amplifiers, which drive the proper pulse ratio modulator (PRM) and reaction jet driver. In the pulse mode, d-c voltages from the ACA's are routed directly to the summing amplifiers. Using one summing amplifier to drive one TCA or the other in the eight opposing pairs, depending on the polarity of the ACA output, eliminates the possibility of wasting fuel by simultaneously firing opposing TCA's. Roll, pitch, and X-axis translation are controlled by the vertical TCA's; yaw, Y-axis translation, and Z-axis translation, by the horizontal TCA's. The eight summing amplifiers combine the attitude signals and translation commands from the TTCA and apply the resultant signals to eight PRM's. Logic circuitry determines whether two or four TCA's (jets) fire for X-axis translation, pitch, and roll.

The eight PRM's generate pulses, whose width and frequency vary according to the input voltage, to control the duty cycle of the TCA's. The pulse output of each PRM is fed to a pair of solenoid driver preamplifiers and jet drivers. Each pulse from the PRM fires one of a pair of opposing TCA's, depending on the polarity of the input voltages to the PRM. When the pulse is applied to the jet drivers, it energizes a relay, which then supplies a ground path to the solenoid coil of the TCA. This action completes an electrical path for the solenoid coil, and the TCA fires for the duration of the PRM pulse.

The ATCA consists of an attitude error signal conditioner-limiter, rate signal summation amplifier, demodulator-filter network, deadband circuits, jet select logic, pulse ratio modulators, and solenoid driver preamplifiers and jet solenoid drivers.

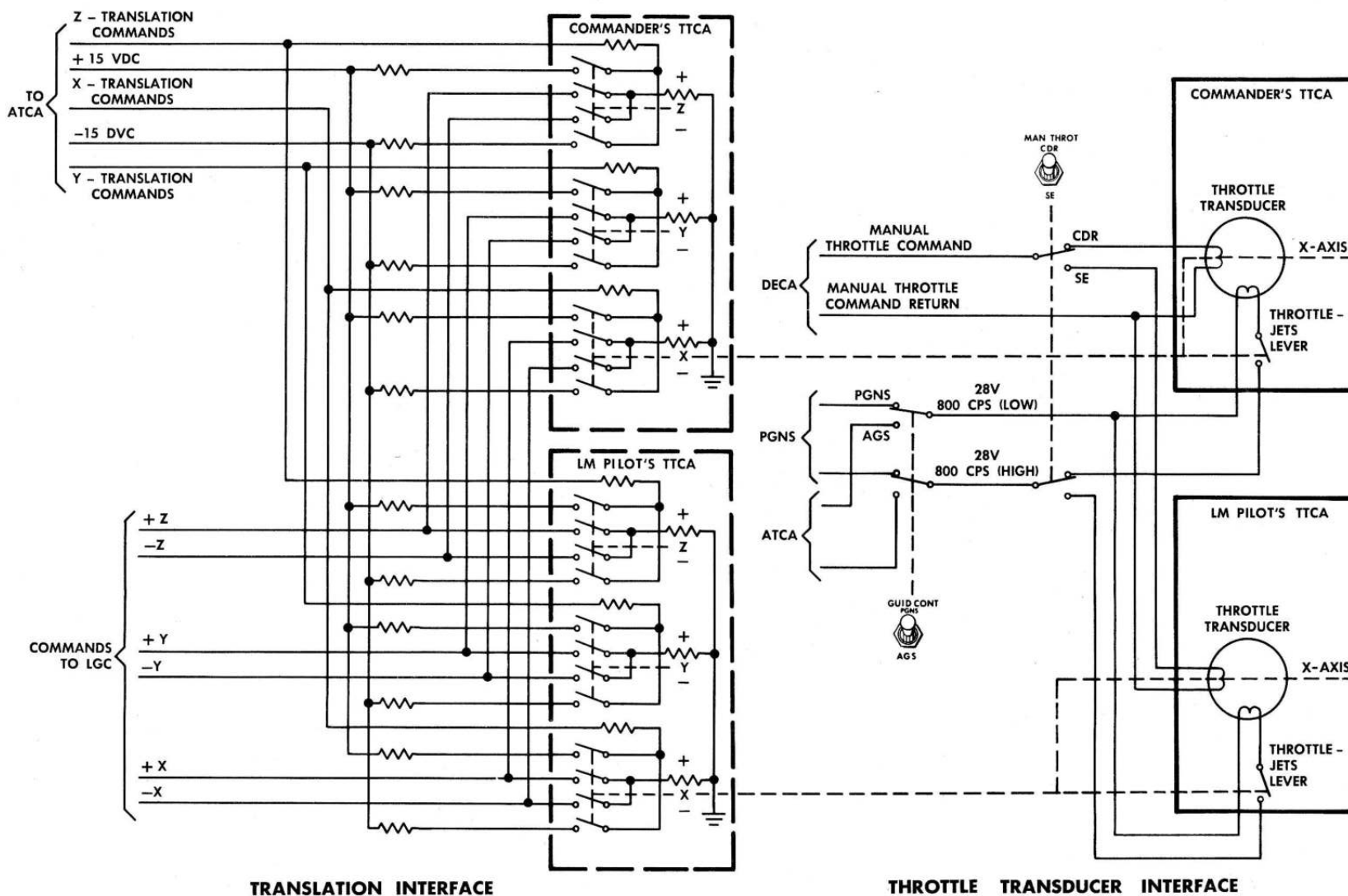


Figure 2-53. Thrust/Translation Controller Assembly Interfaces



1. Only the pitch error channel is shown. The roll and yaw channels are similar to the pitch channel.
2. This telemetry number is for pitch only.
For yaw: GH1455V — Yaw attitude error.
GH1461V — Yaw RGA signal.
For roll: GH1457V — Roll attitude error.
GH1463V — Roll RGA signal.
3. For telemetry numbers of LGC jet commands and jet driver outputs, refer to telemetry measurements GH1418V through GH1433V listed in the telemetry table at the end of the subsystem description.

Figure 2-54. Attitude and Translation Control Assembly - Block Diagram

Attitude Error Signal Conditioner-Limiter. To provide the proper scale factor, impedance match, and limiting, the 800-cps attitude error signal is passed through a signal conditioner-limiter before summation with the rate gyro signal. Limiting the attitude error prevents command of excessive vehicle rates during narrow deadband operation only. The limiting action of the limiter is eliminated during wide deadband operation.

Rate Signal Summation Amplifier. The attitude error, rate, and ACA signals are a-c summed and amplified before demodulation, because they are all synchronized to the 800-cps power source. Amplification and summing at this point helps to minimize error caused by drift.

Demodulator-Filter Network. A keyed demodulator is used to convert summed and amplified error signals to dc. The synchronized 800-cps power source of the ATCA is used for the demodulator reference. An active filter is used to obtain 12-db/octave attenuation for frequencies above 18 cps. The filtered roll and pitch signals are routed to the DECA for descent engine trim.

Deadband Circuits. Either of two deadband circuits can be selected manually with the DEAD BAND switch. The wide deadband (DEAD BAND switch set to MAX) is used for coasting-period limit cycling to conserve fuel. The narrow deadband (DEAD BAND switch set to MIN) is used during periods when the ascent or descent engine is thrusting. In addition to the manual capability, an automatic deadband override is provided for use during ascent or descent engine thrusting.

Jet Select Logic. (See figure 2-55.) For any combination of analog rotation and translation signal inputs to the ATCA, this logic provides signals to the proper TCA. The logic prevents simultaneous ignition of opposing TCA's and ensures maximum moment control for combinational commands when possible. When the ascent or descent engine is thrusting, the ascent engine latching device of an S&C control assembly automatically puts the logic in four TCA roll and pitch operation. In four-TCA operation, the logic corrects roll or pitch errors with four TCA's. This provides additional attitude gain to compensate for possible engine thrust-vector misalignment. The X-TRANSL switch (panel 1) enables the astronauts to command four-TCA X-axis translation to provide additional thrust capability along the vehicle X-axis.

Pulse Ratio Modulators. (See figure 2-54.) The eight PRM's consist of a zero crossover detector, an absolute value circuit, output gating, and the PRM circuit. The PRM's accept d-c analog signals from the jet select logic, detect the polarity, and steer its pulsed output to the proper jet driver. The zero crossover detector detects the polarity of its d-c input, and provides enabling signals to the appropriate gates when the input signals exceed the threshold level (0.5 volt). Because the PRM circuit operates on positive inputs only, the absolute value circuit is required, to invert negative inputs and pass positive inputs to the PRM. The output of the zero crossover detector and the PRM circuit, applied to AND gates, produce a train of pulses at the output of the PRM when the two inputs are coincident.

Solenoid Driver Preamplifiers and Jet Solenoid Drivers. Thirty-two solenoid driver preamplifiers are provided to accept pulsed inputs from the 16 PRM outputs when the AGS is used or from the 16 PGNS outputs when the primary guidance mode is used. When the AGS is used, its 16 preamplifiers are enabled with 28-volt d-c power and the PGNS preamplifiers are disabled, and vice versa. The jet solenoid drivers, driven by either one set of preamplifiers or the other, control the firing of their respective TCA's by providing a ground to the fuel and oxidizer solenoids through output transistors. When the AGS is selected and the main engine (ascent or descent) is firing, X-axis rotation logic inputs cause one or two of the vertical TCA's to fire and oppose the engine thrust. To prevent this from occurring, the BAL CPL switch can be used to disable four of the preamplifiers. Setting the X-TRANSL switch to 4 JETS and the BAL CPL switch to ON provides two-TCA roll and pitch error corrections without opposing the engine thrust.

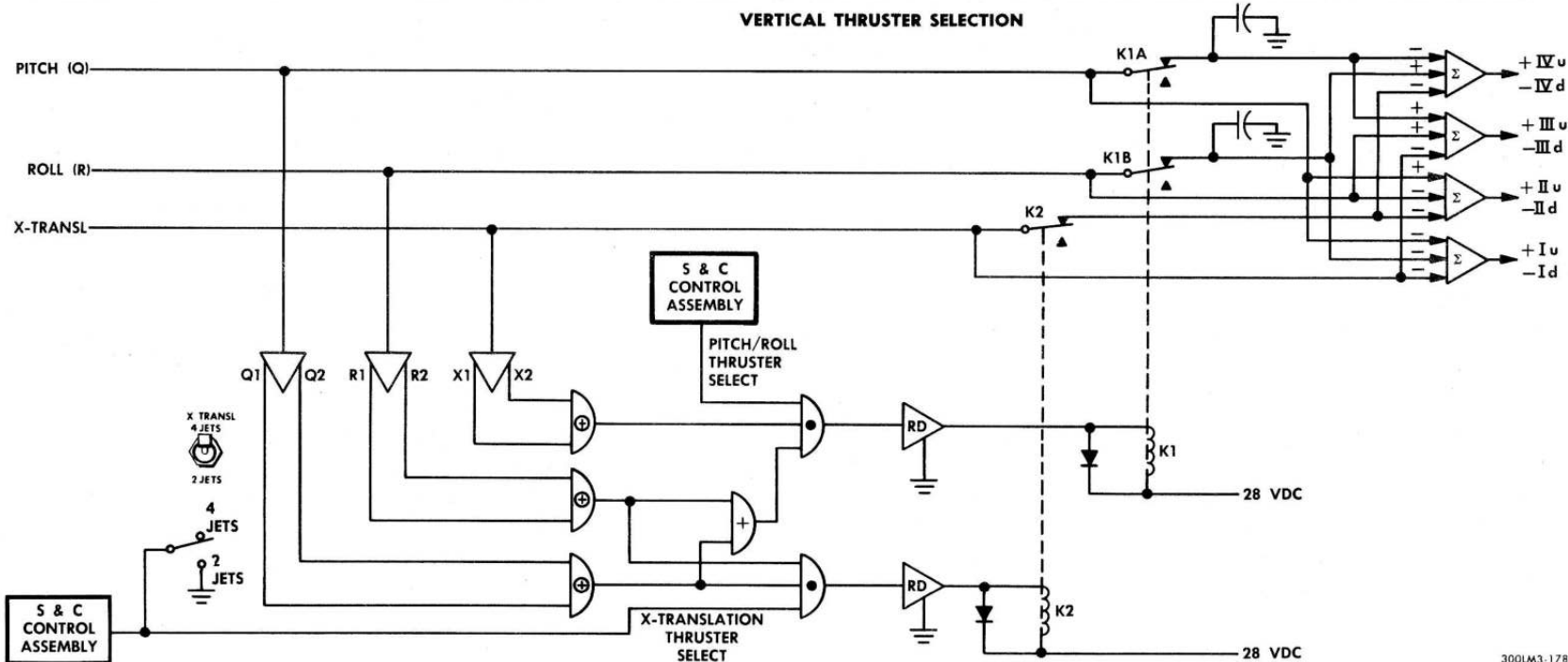
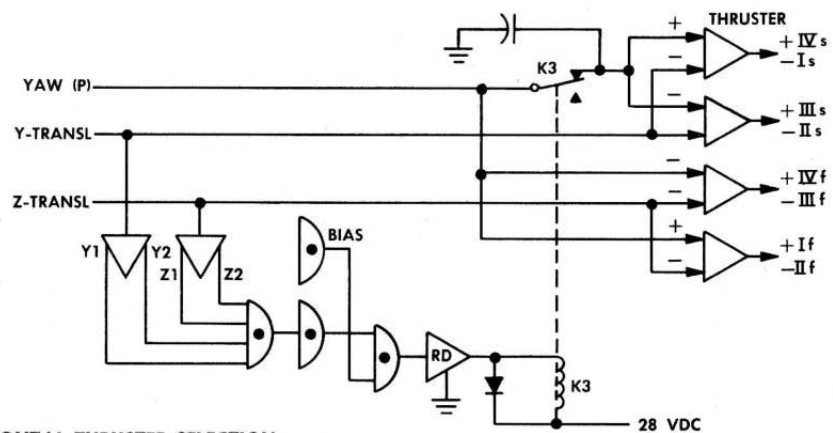
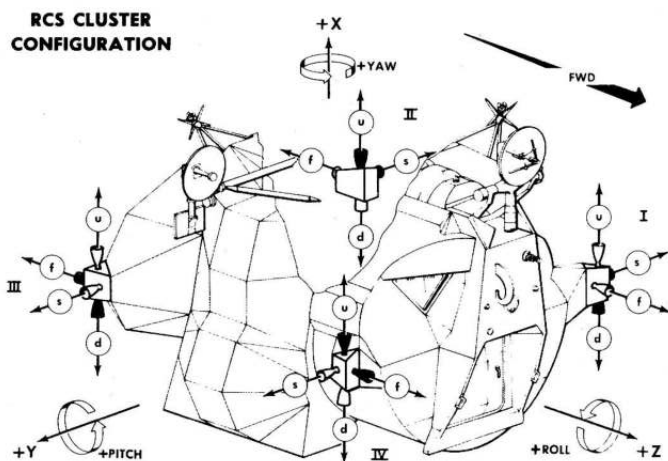


Figure 2-55. Attitude and Translation Control Assembly - Jet Select Logic

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

2.2.3.4.4 Rate Gyro Assembly. (See figure 2-56.)

The RGA consists of three single-degree-of-freedom rate gyros mounted so that they sense vehicle roll, pitch, and yaw rates. Each gyro can measure input rates from -25° to $+25^\circ$ per second; each has self-test features. Each rate gyro senses a rate of turn about its input axis, which is perpendicular to the spin and output axes. This rate of turn is dependent on the gimbal position of the gyro. An electrical analog output (rate of turn) is obtained from the stator-rotor pickoff, which is positioned by the precession of the gimbal. The pickoff voltages (analog outputs) are continuously fed to the FDAI rate indicators. In abort guidance control, the pickoff voltages are routed to the ATCA for rate damping.

Three-phase, 26-volt, 800-cps power generated in the ATCA is applied to the motor of each gyro. Pickoff excitation (28-volt, 800-cps power generated in the ATCA) is applied to the primary coil of a microsyn pickoff. The secondary coil picks off an 800-cps voltage proportional to the precession of the gyro and, hence, proportional to the LM rate about the gyro input axis (0.140 vrms/deg/sec). An in-phase pickoff voltage indicates a positive rate; a 180° phase pickoff voltage, a negative rate.

The self-test capability consists of a spin motor rotation and a self-test torquer (gimbal torquer). The self-test torquer applies torque to the movable gimbal. When 28 volts dc is applied to winding L1 and L2, the secondary of transformer T1 should pick off a voltage equivalent to a 5° /sec rotation. The direction of torquing is reversed by changing the polarity of the d-c voltage.

2.2.3.4.5 Descent Engine Control Assembly. (See figure 2-57.)

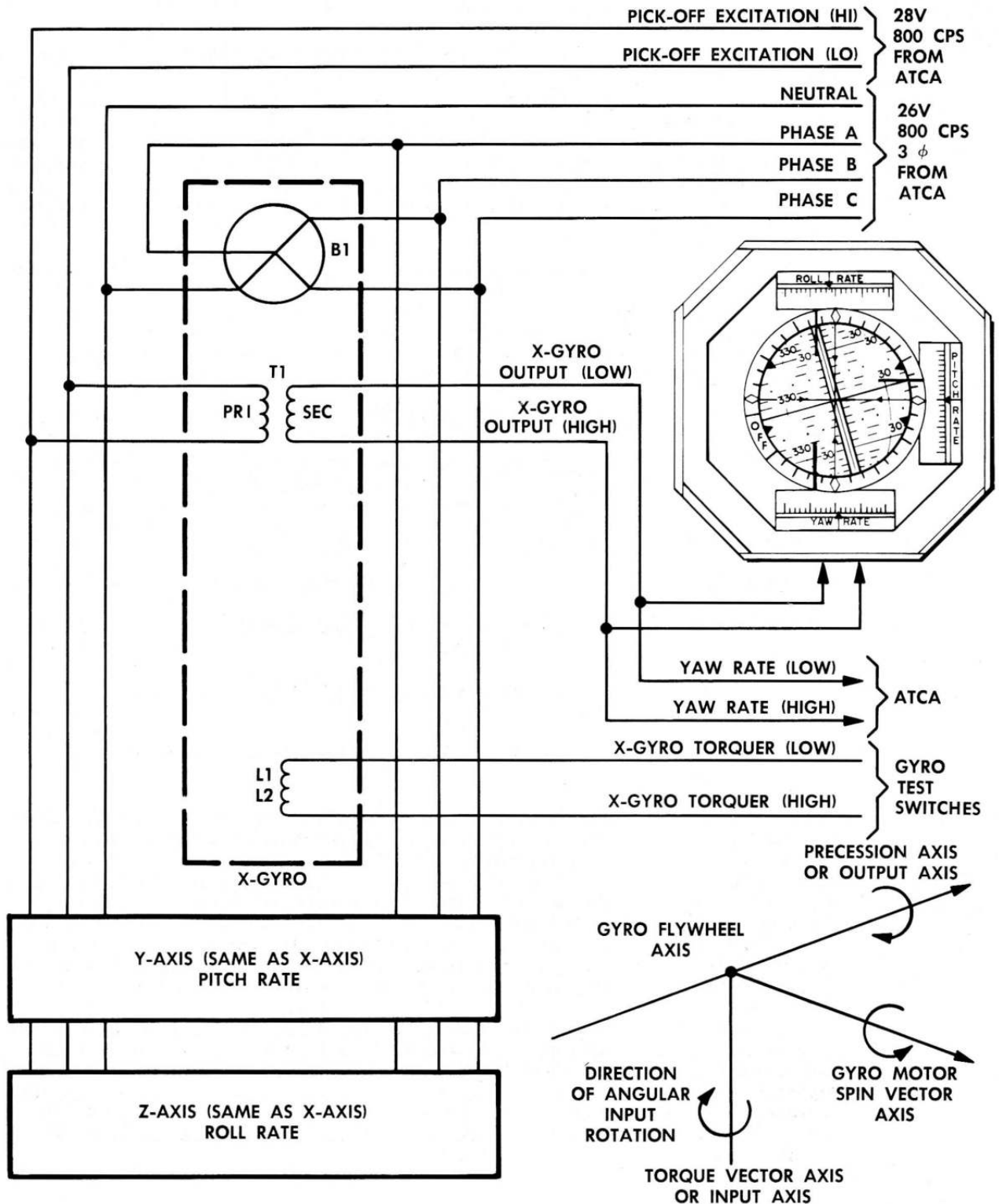
The DECA provides three descent-engine-controlling outputs, as follows:

- Engine-throttling commands from the astronauts (manual) and the PGNS (automatic) (See figure 2-58.)
- PGNS or ATCA signals to position the GDA's to control engine trim (See figure 2-59.)
- On and off commands to control descent engine ignition and shutdown (See figure 2-60.)

To initiate manual throttle commands only, the THR CONT switch (panel 1) must be set to MAN. In manual throttle control, LGC throttle commands are interrupted and only manual commands are displayed on the THRUST indicator. Manual throttle commands consist of a-c voltages, proportional to the active TTCA X-axis displacement, which are applied to the DECA. The active TTCA always provides at least a 10% command. These commands drive a nonlinear circuit that provides the desired thrust level. With nonlinear thrust levels, more resolution is obtained at the lower levels. (See figure 2-61.) Once the nonlinear region of the TTCA is reached, the TTCA should be displaced to its hard stop to prevent erratic operation of descent engine.

To apply automatic throttle commands to the descent engine, the THR CONT switch must be set to AUTO. The automatic commands appear on two separate lines (throttle increase and throttle decrease) as 3,200-cps pulse inputs to an integrating d-c counter (up-down counter). Each pulse corresponds to a 2.7-pound thrust increment. Throttle increases can drive the counter up to 12 volts, which, when combined with the TTCA fixed 10% output in the descent engine throttle servoamplifier, corresponds to 92.5% thrust.

LMA790-3-LM 3
 APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA



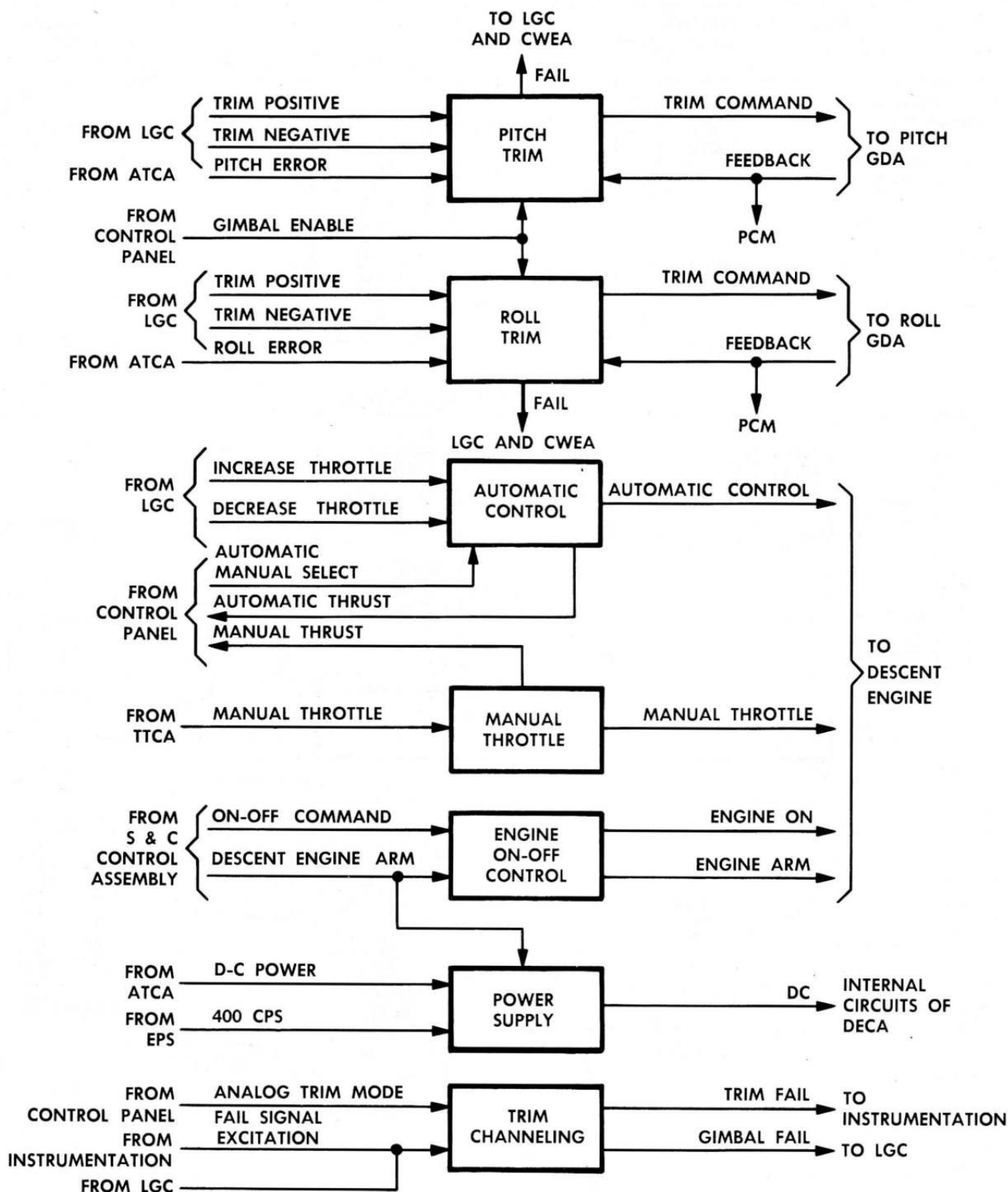
SCHEMATIC DIAGRAM

VECTOR DIAGRAM

300LM3-213

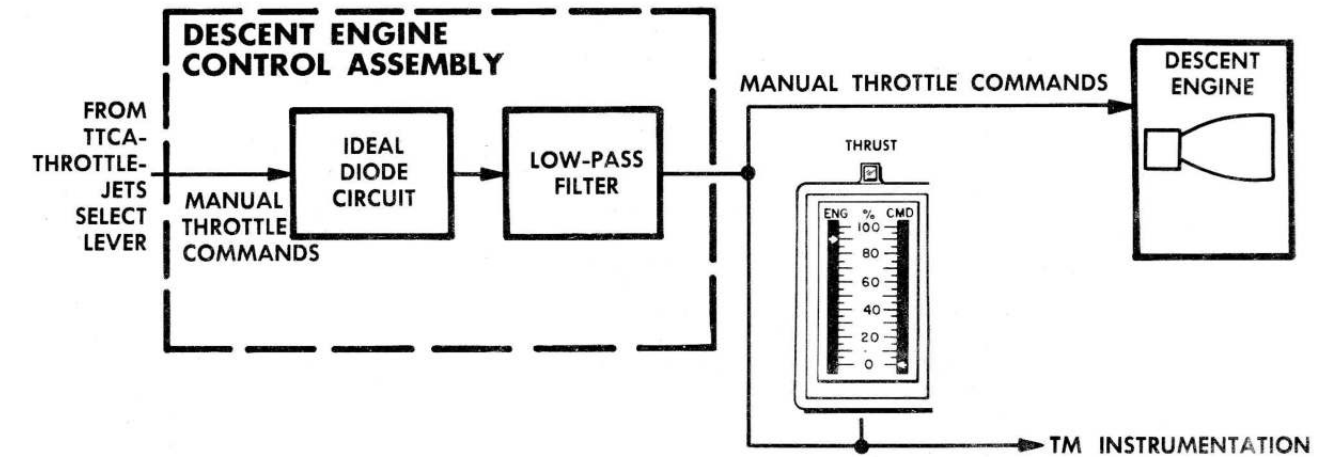
Figure 2-56. Rate Gyro Assembly - Schematic and Vector Diagrams

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

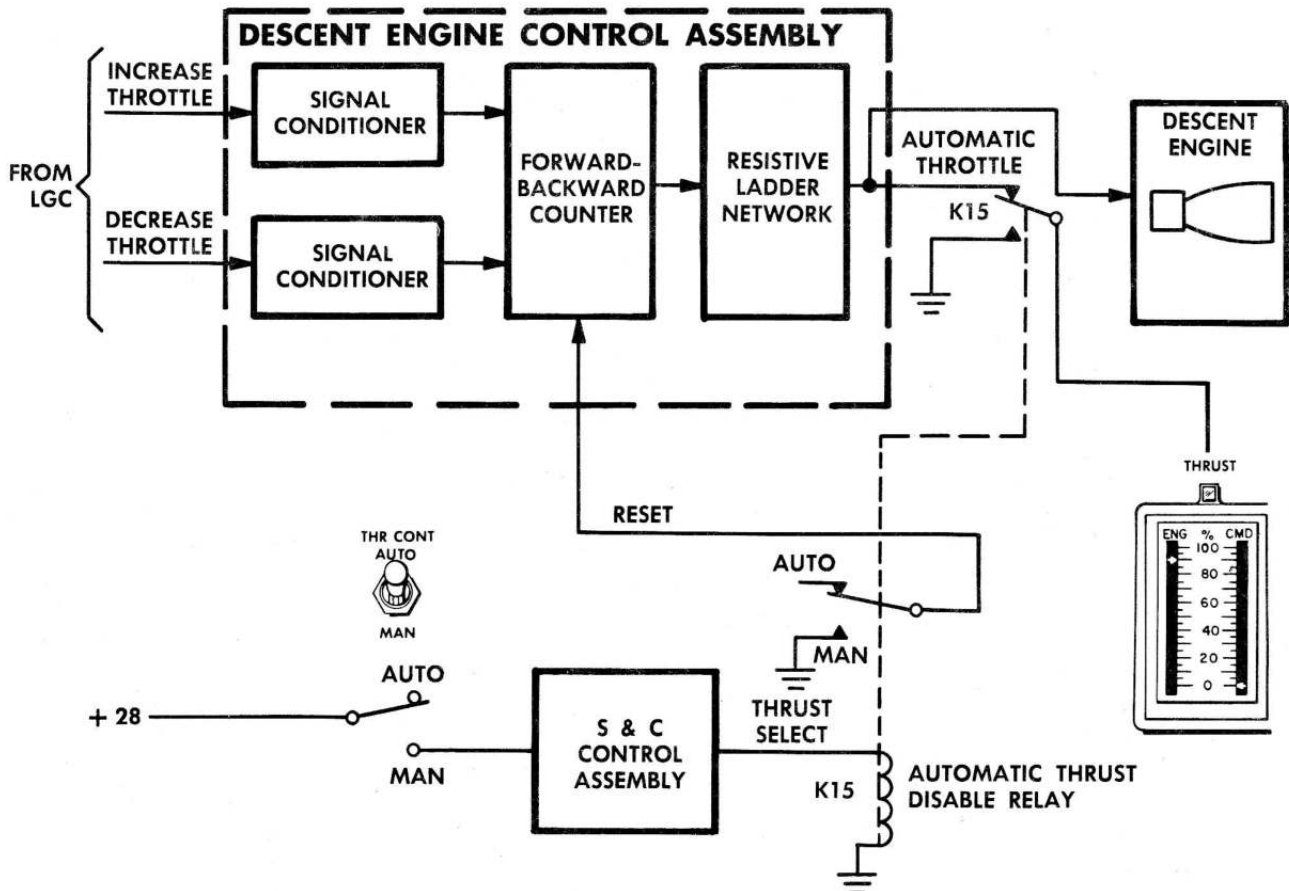


300LM3-256

Figure 2-57. Descent Engine Control Assembly - Block Diagram



MANUAL THROTTLE CONTROL



AUTOMATIC THROTTLE CONTROL

300LM3-257

Figure 2-58. Descent Engine Control Assembly - Throttle Control Diagram

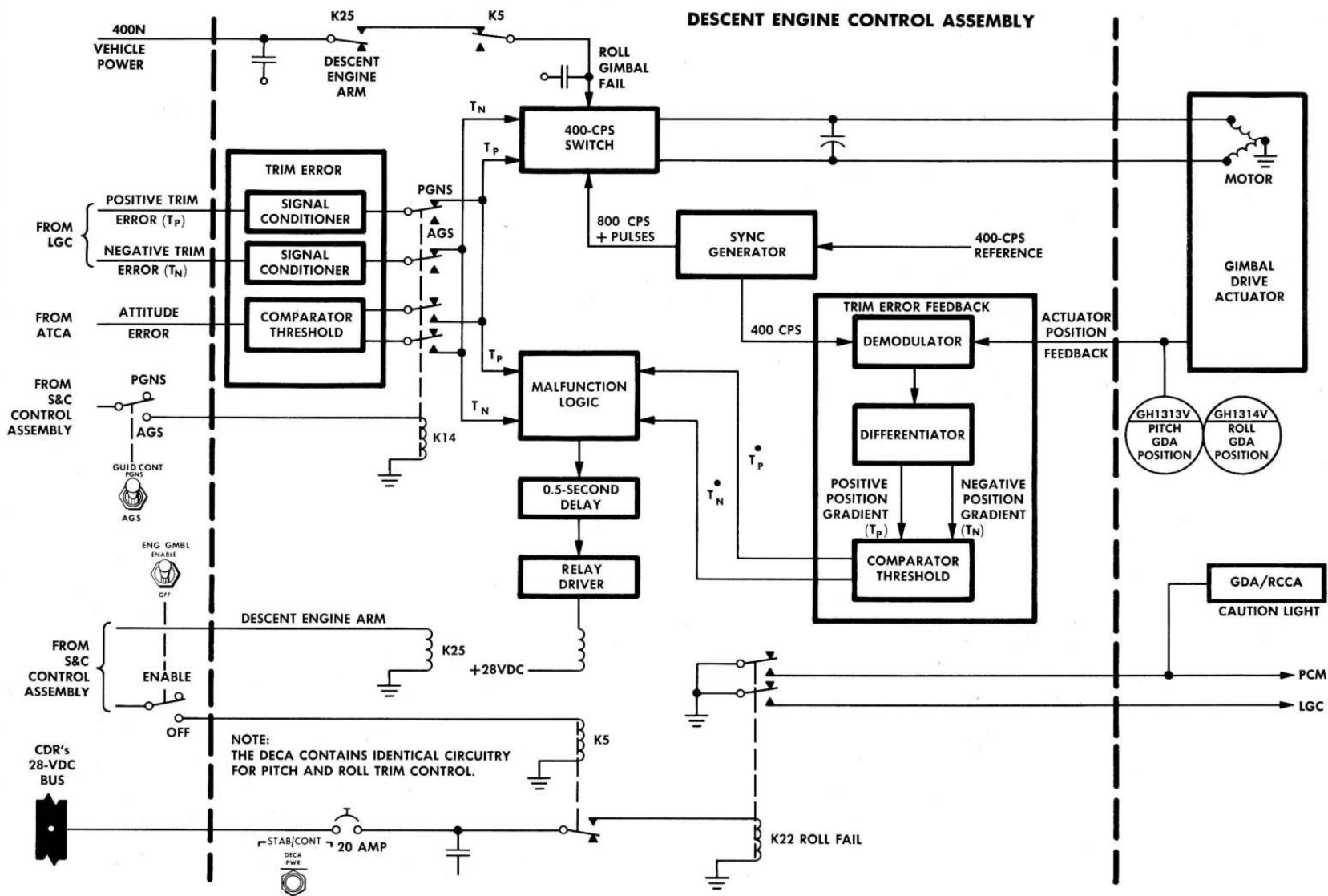
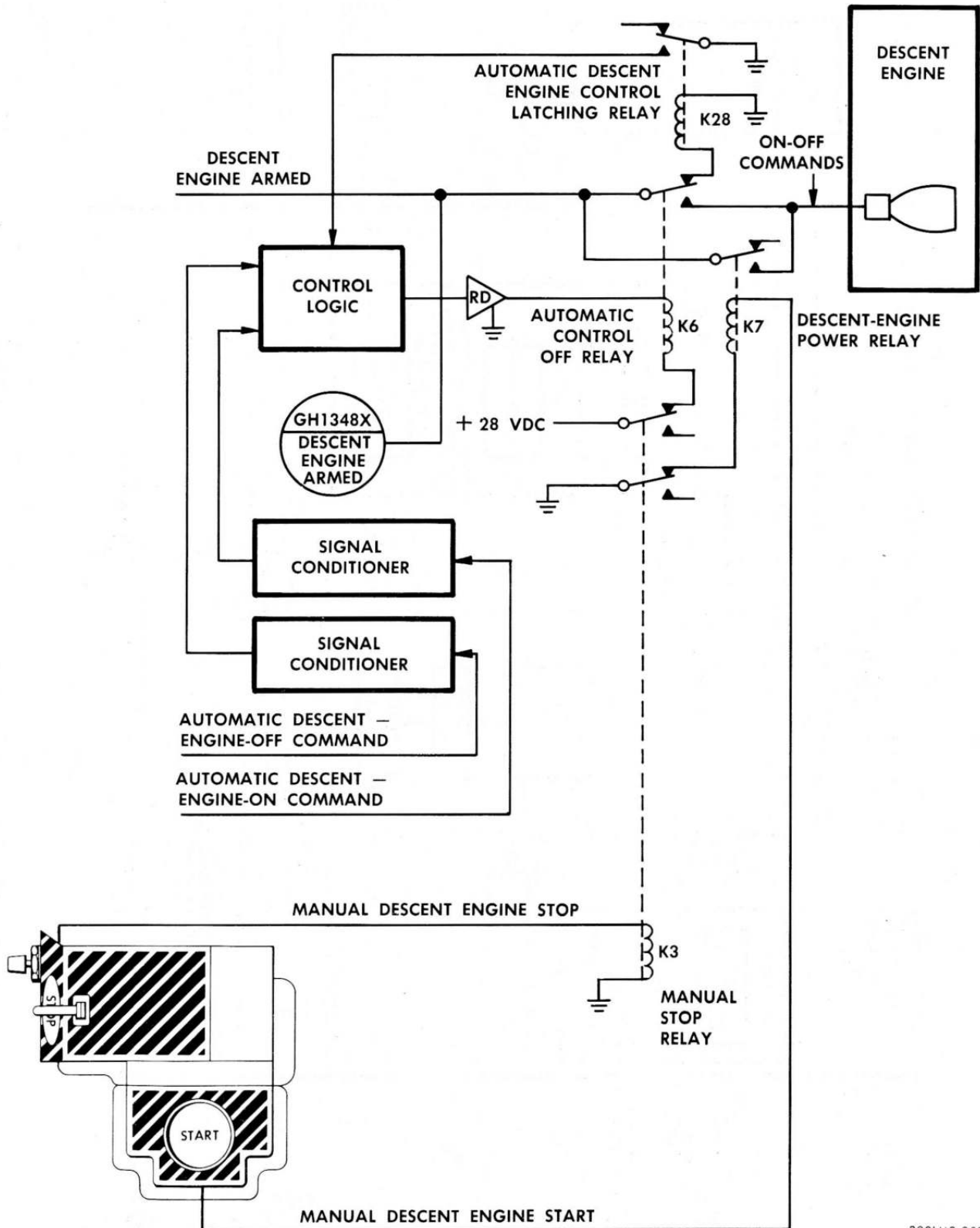


Figure 2-59. Descent Engine Control Assembly - Trim Control Diagram

LMA790-3-LM 3
 APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA



300LM3-250

Figure 2-60. Descent Engine Control Assembly - Engine Control Diagram

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

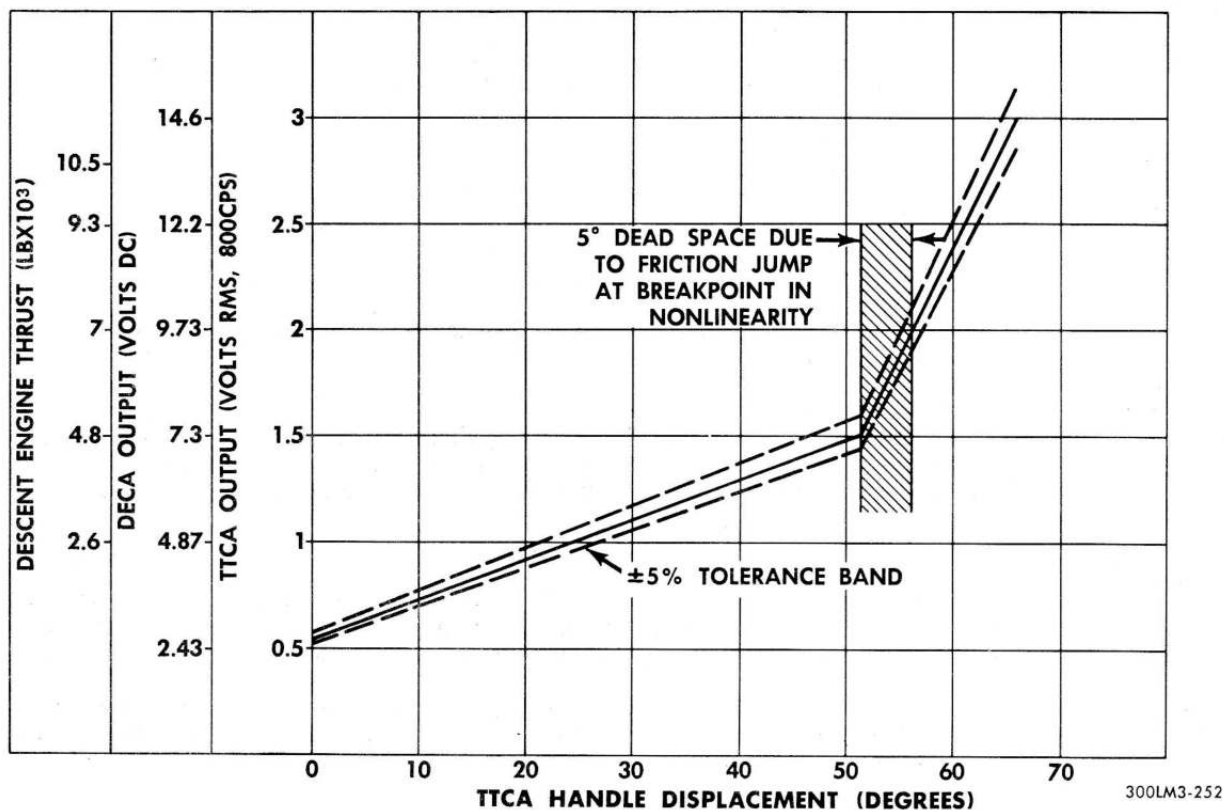


Figure 2-61. Throttle Control vs TTCA Displacement

During automatic throttle operation, the LGC-commanded thrust is summed with the output of the TTCA. When the TTCA is in its minimum position, the LGC-commanded thrust is summed with the fixed 10% output of the TTCA. When an active TTCA is displaced from its minimum position, the amount of manual thrust commanded is summed with the LGC-commanded thrust to produce the desired resultant. In this case, the TTCA overrides LGC control of descent engine thrust. The total thrust commanded (automatic and/or manual) cannot exceed 92.5%. Automatic thrust commands desired by the LGC are always 10% of thrust lower than required to compensate for the fixed output of the TTCA.

In the primary guidance mode, the LGC provides automatic trim control. When the LGC determines the required descent engine trim, it provides a trim command to the DECA, on a positive trim line or a negative trim line for the roll or pitch axis. The trim signal is routed to a malfunction logic circuit and to a power-switching circuit, which applies 115-volt, 400-cps power to the proper GDA. The power-switching circuit is controlled by the malfunction logic. The GDA tilts the descent engine and provides a 400-cps feedback signal (proportional to engine position) to the DECA. The DECA demodulates and differentiates the feedback signal; the resultant signal is fed back to the malfunction logic circuit.

The malfunction logic generates a trim failure signal if any of the following conditions exist:

- The GDA is not moving in the commanded direction
- The malfunction circuitry fails
- The transducer fails
- The 400-cps motor rotates without a command
- The 400-cps motor fails.

The trim failure signal removes the 400-cps power from the power-switching circuit, and is routed to the LGC and the IS.

In the abort guidance mode, roll and pitch trim signals are received from the roll and pitch error channels in the ATCA. A comparator and threshold circuit in the DECA generates negative or positive trim commands and routes them to the malfunction logic, which controls the power-switching circuits as in the primary guidance mode.

2.2.3.4.6 Gimbal Drive Actuators. (See figure 2-62.)

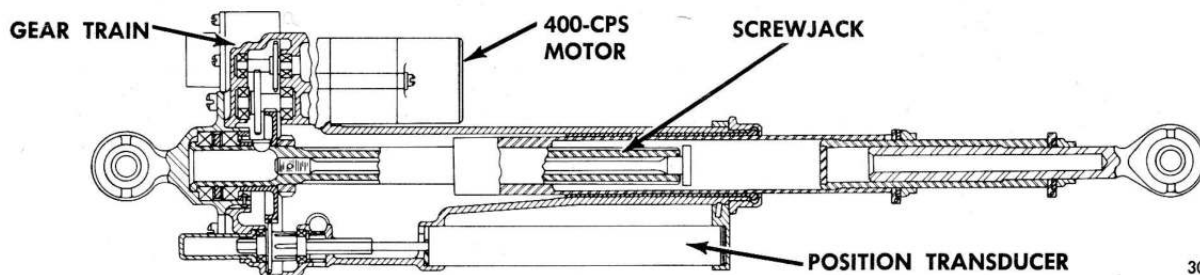
The GDA's, under control of the DECA, tilt the descent engine along the pitch and roll axes so that the thrust vector goes through the LM center of gravity. One GDA controls the pitch gimbal; the other, controls the roll gimbal.

Each GDA consists, primarily, of a single-phase motor, a feedback potentiometer, and associated mechanical devices. Each GDA can extend or retract 2 inches from the midposition to tilt the descent engine a maximum of $+6^\circ$ or -6° along the Y-axis and Z-axis.

On and off signals are supplied to the GDA's from the power gate circuits in the DECA. The DECA provides 115-volt, 400-cps power to the GDA motor, which controls the stroke of the GDA at a rate of 0.0662 inch per second (7.5 volts per inch) $\pm 10\%$, in a positive or negative direction along the Y-axis and Z-axis. Gimbal position signals are supplied by the feedback potentiometer to a failure-detection circuit in the DECA.

2.2.3.4.7 800-cps Synchronization Loop. (See figure 2-63.)

Because the CES uses 800-cps analog signals as a reference, the various assemblies must be synchronized. In the primary guidance mode, the ACA's and TTCA's receive 28-volt, 800-cps signals from the power and servo assembly of the PGNS. The proportional attitude commands to the LGC are either in phase or 180° out of phase with this 800-cps signal. In the abort guidance mode, the ACA's and TTCA's receive 28-volt, 800-cps signals from the ATCA. The proportional attitude commands fed back to



300LM3-255

Figure 2-62. Gimbal Drive Actuator - Pictorial Diagram

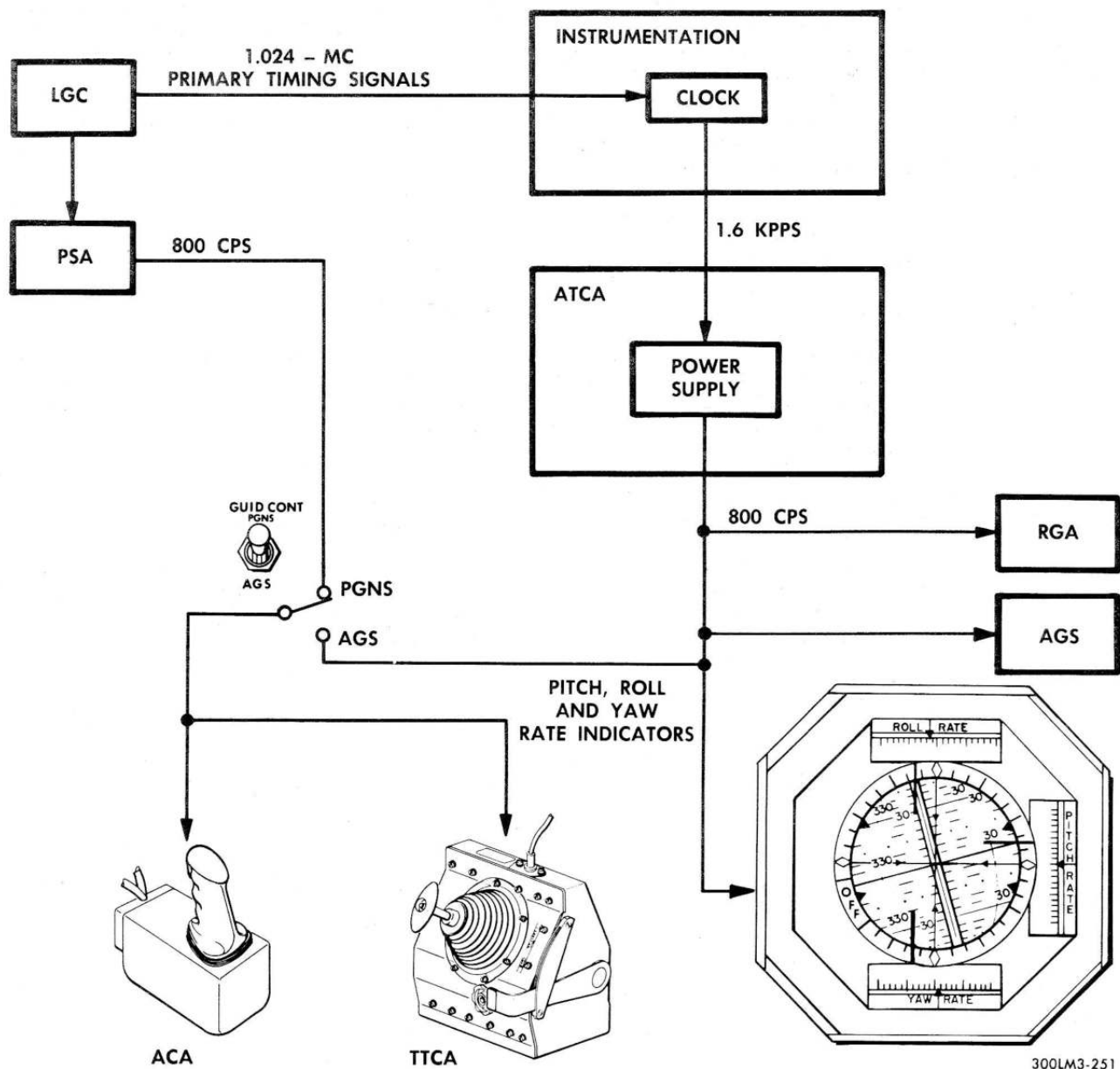


Figure 2-63. Control Electronics Section - 800-cps Synchronization Loop

the ATCA are now synchronized with the ATCA power supply. The AGS and RGA receive 28-volt, 800-cps signals from the ATCA; their outputs returned to the ATCA are synchronized. The FDAI's also receive the 800-cps synchronization voltage to properly display the RGA signals.

2.2.3.4.8 S&C Control Assemblies.

The S&C control assemblies contain three similar assemblies. The S&C control assemblies process, switch, and/or distribute the various signals associated with the GN&CS. One of the assemblies also processes automatic and manual ascent or

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

descent engine on and off commands. The circuits used for the ascent engine commands are called the ascent engine latching device (AELD). The ascent engine commands are processed, and engine ignition and shutdown commands are sent to the ascent engine and staging sequence commands are sent to explosive devices. The first time that the ascent engine is ignited, the engine-on command starts the staging sequence, using the Explosive Devices Subsystem. The S&C control assemblies contain a memory circuit that maintains the ascent engine on if the automatic on signal is lost, until an automatic off signal or a manual stop command is received.

Descent engine commands are processed and sent to the DECA. These commands (descent engine arm, and automatic and manual engine on and engine off) are processed again by the DECA for descent engine ignition and shutdown.

2.2.3.4.9 Gimbal Angle Sequencing Transformation Assembly. (See figure 2-64.)

The GASTA operates in conjunction with the FDAI. The GASTA modifies the analog gimbal angle signals from the IMU before they are applied to the FDAI. Modification conditions the signals to drive the FDAI sphere. The GASTA converts 26-volt, 800-cps signals from the IMU to 15-volt, 800-cps signals. The signals from the IMU must be routed through the GASTA for conditioning; because the AGS has its own GASTA (or conditioning) function, the gimbal angle signals are routed directly to the FDAI.

2.2.3.4.10 Control Electronics Section Modes of Operation. (See figure 2-65.)

The PGNS, in conjunction with the CES, provides automatic control for LM attitude, translation, and descent or ascent propulsion maneuvers. Automatic control can be overridden by the astronauts, with manual inputs. As backup for PGNS control, the AGS, supplemented by manual inputs, can be used if the PGNS malfunctions. Table 2-17 contains a summary of the CES modes of attitude control.

Attitude Control. LM attitude is controlled about the X, Y, and Z axes. There are five modes of attitude control: automatic, attitude hold, pulse, direct, and manual override (hardover). The automatic and attitude hold modes are selected with the MODE CONTROL selector switch; the pulse and direct modes, with the ROLL, PITCH, and YAW switches.

Automatic Mode. The automatic mode provides fully automatic attitude control. In PGNS control, the LGC generates the required TCA commands and routes them to the ATCA. The jet drivers in the ATCA provide TCA on and off commands to selected RCS primary solenoids for attitude changes. In the abort guidance mode, roll, pitch, and yaw attitude error signals are generated in the AGS and sent to the ATCA. These error signals are passed through limiters and then are combined with damping signals from the RGA, demodulated, passed through selectable deadband circuits, jet select logic circuits, PRM's, and jet driver amplifiers, which fire the RCS jets. The jet select logic determines which jets will fire to correct attitude errors. In the abort guidance mode, the astronaut can override attitude control about all three LM axes by initiating hardover commands with the ACA.

Attitude Hold Mode. This is a semiautomatic mode, in which either astronaut commands an angular rate proportional to ACA displacement. LM attitude is held when the ACA is in the neutral position. In the primary guidance mode, rate commands proportional to ACA displacement are sent to the LGC. The LGC operates on these commands and provides signals to the jet drivers in the ATCA to command rotation rates by means of the TCA's. When the ACA is returned to the neutral position, LM rotation stops and the LM is maintained in its new attitude by the LGC. In the abort guidance mode, with the ACA in the neutral position, LM attitude is held by means of AGS error signals. When an ACA is moved out of the detent position, the attitude error signals from the AGS are set to zero. Rate commands from the ACA are processed in the ATCA, and the TCA's are fired until the vehicle rate is proportional to ACA displacement. When the ACA is returned to the neutral position, the vehicle rate is reduced to zero and the AGS holds the LM in the new attitude.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

(To be supplied)

Figure 2-64. Gimbal Angle Sequencing Transformation Assembly - Schematic Diagram

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Pulse Mode. The pulse mode (minimum impulse control) is selected when the PGNS is in control and operating in the attitude hold mode, by a DSKY entry (verb 76). For minimum impulse control, the LGC commands a minimum impulse burn for each movement of the ACA beyond 2.5° of the detent position. The ACA must be returned momentarily to the detent position between each impulse command. The maximum rate at which minimum impulses can be commanded is approximately 5 per second. In this mode, the astronaut performs rate damping and attitude steering. When the AGS is in control, the pulse mode is an open-loop mode. It is selected on an individual-axis (roll, pitch, and yaw) basis by setting the appropriate switch (ROLL, PITCH or YAW) to PULSE. When the pulse mode is selected, the automatic attitude control mode is disabled about the selected axis and a fixed train of pulses is generated when the ACA is displaced. To change attitude in this mode, the ACA must be moved out of detent; this commands acceleration about the selected axis. To terminate LM rotation, an opposite acceleration about the same axis must be commanded.

Direct Mode. The direct mode is also an open-loop acceleration mode. It is selected on an individual-axis basis by setting the appropriate switch (ROLL, PITCH or YAW) to DIR. Automatic AGS attitude control is disabled about the selected axis and direct commands to two TCA's are routed to the RCS secondary solenoids when the ACA is displaced 2.5°. The TCA's fire continuously until the ACA is returned to the neutral position.

Hardover Mode. In an emergency, the ACA can be displaced to the maximum limit (hardover position) to command an immediate attitude change about any axis. This displacement applies signals directly to the RCS secondary solenoids to fire four TCA's. This maneuver can be implemented in any attitude control mode.

Translation Control. Automatic and manual translation control are available in all three axes, using the RCS. Automatic control consists of TCA commands from the LGC to the jet drivers in the ATCA. These commands are used for translations of small velocity increments and for ullage settling before ascent or descent engine ignition after coasting phases. Manual control in the primary guidance mode consists of on and off commands from a TTCA, through the LGC, to the primary preamplifiers. In the abort guidance mode, only manual control is available. Control consists of on and off commands from a TTCA to the jet select logic in the ATCA. The voltage is sufficient to saturate the PRM's and provide control of the TCA's. RCS thrust (+X-axis) is available when the +X TRANSL pushbutton is pressed. The secondary solenoids of the four downward-firing TCA's (B1D, A2D, B3D, A4D) are energized as long as the +X TRANSL pushbutton is pressed.

Descent Engine Control. Descent engine control accomplishes major changes in LM velocity.

Ignition and Shutdown. Descent engine ignition is controlled by the PGNS and the astronaut through the CES. Before ignition, the engine must be armed by setting the ENG ARM switch (panel 1) to DES. This action sends an engine arm discrete to the LGC and to the S&C control assemblies. Engine-on commands from the LGC or AGS are routed to the DECA through the S&C control assemblies. When it receives the engine arm and start discrettes from the S&C control assemblies, the DECA commands the descent engine on. The engine remains on until an engine-off discrete is initiated with either STOP pushbutton (panels 5 and 6). An engine-off discrete is generated when the ΔV reaches a predetermined value. The astronauts can command the engine on or off manually, using the START and STOP pushbuttons.

Throttle Control. The descent engine throttle (thrust) can be controlled by the PGNS and/or the astronauts. Automatic throttle increase/decrease signals from the LGC are sent to the DECA. The analog output of the DECA controls descent engine thrust from 10% to maximum thrust (92.5%). In the automatic mode (THR CONT switch set to AUTO), the astronauts can use the TTCA's to increase descent engine thrust. When the THR CONT switch is set to MAN, the astronaut has complete control over descent engine thrust. If a TTCA is used for throttle control, its manual X-axis translation capability is disabled.

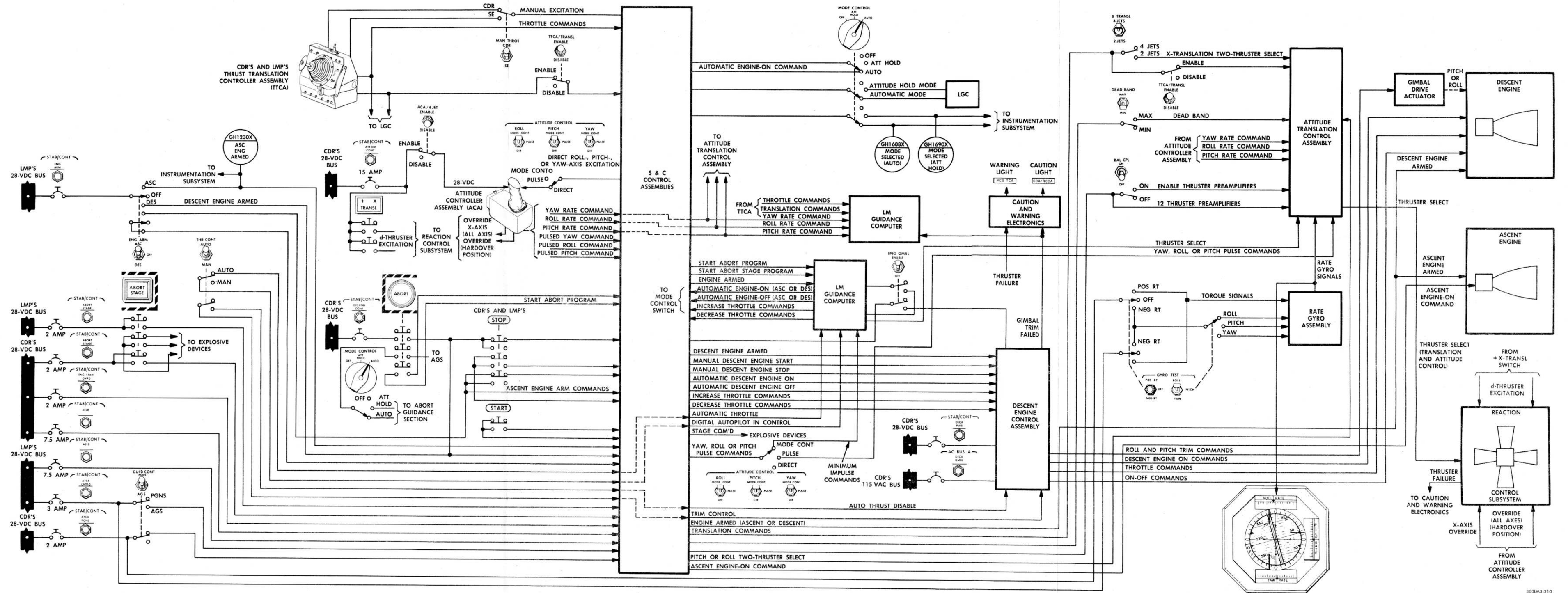


Figure 2-65. Control Electronics Section - Functional Flow Diagram

Table 2-17. Control Electronics Section - Summary of Modes of Attitude Control

Mode	Switches and Positions	Guidance Signals	Manual Attitude Control	Manual Translation Control	Attitude Damping	Engine Gimbal Control	Remarks
Automatic (PGNS control)	MODE CONTROL sel - AUTO GUID CONT sw - PGNS ATTITUDE CONTROL sw - MODE CONT (normally)	Automatic steering and translation are performed by LGC commands to jet drivers.	N/A	Linear translation of LM by on-and-off firing of TCA's when TTCA is move out of detent.	Accomplished in LGC	Pitch and roll gimbal commands from LGC applied to DECA	All TCA commands from LGC go directly to primary preamplifiers. Attitude control function is overridden by operating ACA to hardover position, thereby commanding on-and-off four-jet operation through secondary coils of TCA solenoid valves. +X-axis translation is overridden by commanding four-jet operation direct to RCS secondary coils, by pressing +X TRANSL pushbutton on panel 5.
Attitude hold (PGNS control)	MODE CONTROL sel - ATT HOLD GUID CONT sw - PGNS ATTITUDE CONTROL sw - MODE CONT (normally)	Stabilization is accomplished by LGC commands to jet drivers.	Attitude rate commands are proportional to ACA displacement. LM attitude is held when ACA is in detent.	Linear translation of LM by on-and-off firing of TCA's when TTCA is moved out of detent.	Accomplished in LGC	Pitch and roll gimbal commands from LGC applied to DECA.	Same as for automatic mode (PGNS control). Minimum impulse mode is made available by entering command into DSKY. In this mode, LGC commands one RCS pulse each time the ACA is moved out of detent.
Automatic (AGS control)	MODE CONTROL sel - AUTO GUID CONT sw - AGS ATTITUDE CONTROL sw - MODE CONT	Automatic steering signals from AGS are sent to CES to command changes in LM attitude.	N/A	Linear translation of LM by on-and-off firing of TCA's when TTCA is moved out of detent.	Rate gyro signals summed with steering signals	Pitch and roll gimbal commands derived from ATCA attitude errors	All TCA commands go through ATCA jet select logic and PRM. Attitude control function is overridden by operating ACA to hardover position, thereby commanding on-and-off four-jet operation through secondary coils of TCA solenoid valves and bypassing jet select logic, PRM's, and jet drivers. +X-axis translation is overridden by commanding four-jet operation direct to RCS secondary coils, by pressing +X TRANSL pushbutton.
Attitude hold (AGS control)	MODE CONTROL sel - ATT HOLD GUID CONT sw - AGS ATTITUDE CONTROL sw - MODE CONT	Automatic stabilization signals, which maintain LM attitude	LM attitude rate commands proportional to ACA displacement. LM attitude is held when ACA is in detent.	Translation commands along LM axes by on-and-off firing of TCA's when TTCA is moved out of detent	Rate gyro signals summed with stabilization signals	Pitch and roll gimbal commands derived from ATCA attitude error channels	Same as for automatic mode (AGS control)

Table 2-17. Control Electronics Section - Summary of Modes of Attitude Control (cont)

Mode	Switches and Positions	Guidance Signals	Manual Attitude Control	Manual Translation Control	Attitude Damping	Engine Gimbal Control	Remarks
Pulse	MODE CONTROL sel - AUTO or ATT HOLD GUID CONT sw - AGS ATTITUDE CONTROL sw - PULSE (selected on individual-axis basis)	Abort guidance signals interrupted on individual-axis basis	Astronaut commands angular acceleration through low-frequency pulsing of TCA's (two jets)	Translation commands along LM axes by on-and-off firing of TCA's when TTCA is moved out of detent	No rate damping in axis selected	Pitch and roll gimbal commands derived from ATCA attitude error channels	Same as for automatic mode (AGS control)
Direct	MODE CONTROL sel - AUTO or ATT HOLD GUID CONT sw - AGS ROLL, PITCH, and YAW sw - DIR (selected on individual-axis basis)	Abort guidance signals interrupted on individual-axis basis.	Astronaut commands angular acceleration through on-and-off firing of TCA's (two-jet operation direct to secondary coils).	Translation commands along LM axes by on-and-off firing of TCA's when TTCA is moved out of detent	No rate damping in axis selected	Pitch and roll gimbal commands derived from ATCA attitude error channels	Same as for automatic mode (AGS control), except that attitude commands for selected axis are applied directly to RCS secondary coils

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Trim Control. The descent engine trim is controlled automatically during the primary guidance and abort guidance modes, to compensate for center-of-gravity offsets during descent engine operation. In the primary guidance mode, the LGC routes trim on and off signals in two directions, for each gimbal axis, to the DECA. These signals operate power control circuitry, which drives the GDA's. In the abort guidance mode, Y- and Z-axis error signals that drive the GDA's are routed from the ATCA to the DECA. The GDA's tilt the descent engine along the Y-axis and Z-axis a maximum of $+6^\circ$ or -6° degrees.

Ascent Engine Control. Ascent engine ignition and shutdown can be initiated by the PGNS, AGS, or the astronaut. Automatic and manual commands are routed to the S&C control assemblies. These assemblies provide logically ordered control of LM staging and engine on and off commands. The command to the ascent engine comes from the S&C control assemblies, which provide a positive command for fail-safe purposes if the engine-on command is interrupted. In the event of an abort stage command while the descent engine is firing, the S&C control assemblies provide a time delay before commanding LM staging and ascent engine ignition. The time delay ensures that descent engine thrusting has completely stopped before the LM is staged.

2.2.3.5

LM Mission Programmer. (See figure 2-66.)

An abbreviated version of the mission programmer is used for the LM-3 mission. The LM-3 mission programmer consists of only two assemblies: the digital command assembly (DCA) and the ascent engine arming assembly (AEAA). It provides a means of arming the ascent engine when the LM is unmanned. The ascent engine will be armed via uplink (real-time) commands from MSFN.

The DCA decodes the VHF (450 mc) uplink commands and routes update data and program control commands to the LGC, arming commands to the AEAA, and verification signals to the PCMTEA in the IS. The LGC processes the update data and program control commands to generate the ascent engine-on discrete and routes the command to the ascent engine. A verification signal from the LGC to the PCMTEA is transmitted via the CS to MSFN to indicate that the uplink command or update data have been processed properly by the LGC. The DCA also issues a verification signal to the PCMTEA for transmission to MSFN to indicate that the uplink command or update data are coded properly and have been routed to the proper equipment.

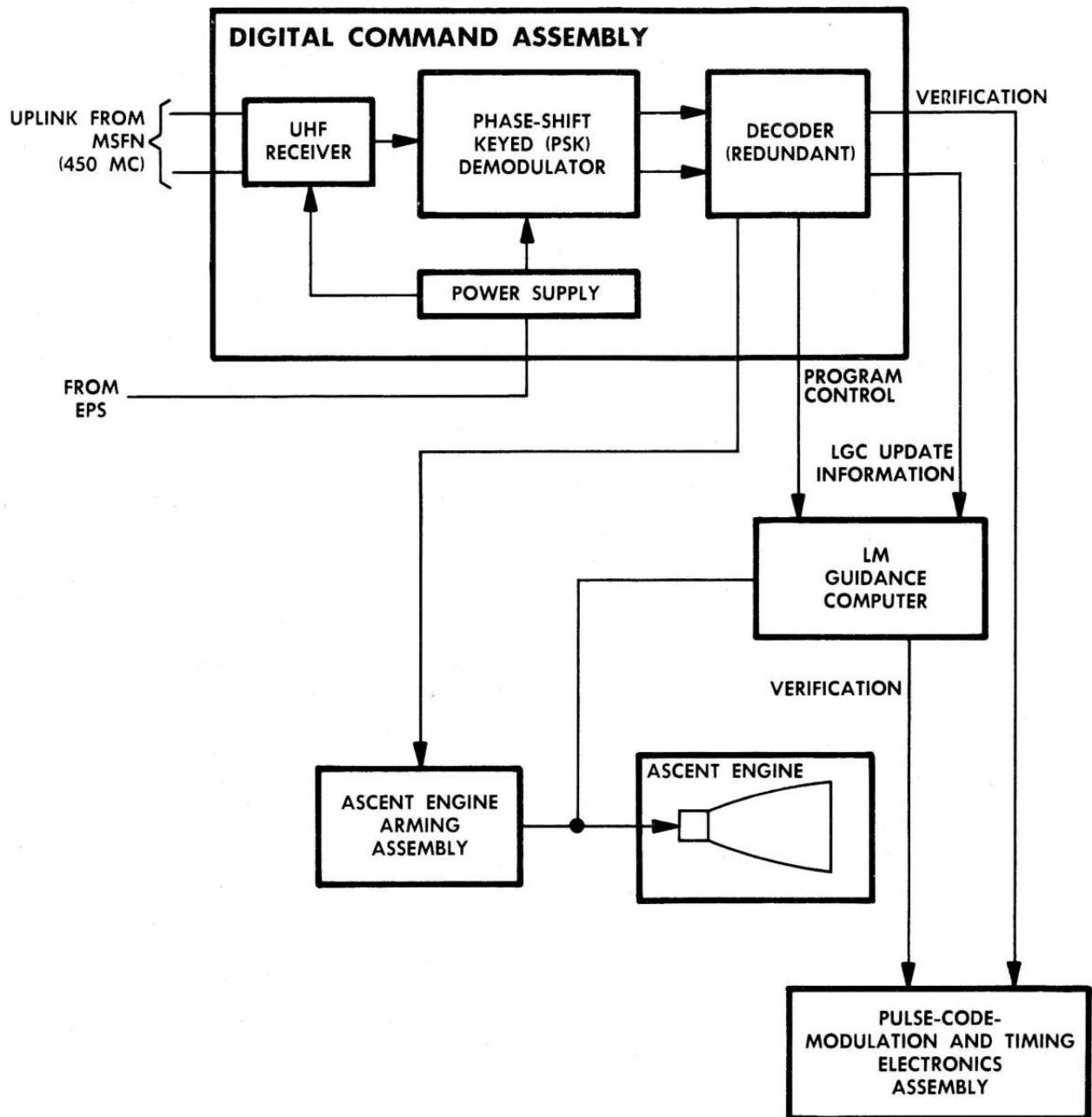
The AEAA arms the ascent engine when the DCA decoder issues the appropriate combination of commands. These commands energize AEAA relays, which perform the function of the ENG ARM switch (panel 1).

2.2.3.5.1

Digital Command Assembly.

The DCA consists of a UHF receiver, demodulator, decoder, and power supply. It receives uplink commands from MSFN at a maximum rate of three 30-bit words per second. The DCA processes these commands, then routes them to the LGC. On receiving an uplink command, the DCA also routes a verification signal to the PCMTEA, for telemetry.

The receiver receives a serially coded digital command modulated on a 450-mc UHF carrier (FM/PSK), from MSFN and routes it to the demodulator. The uplink commands consist of 3 vehicle address bits (always 011), 3 system address bits (message identification), and a maximum of 22 data bits. The UHF receiver output is a two-tone composite modulating signal, consisting of a 2-kc subcarrier and a 1-kc coherent synchronization tone; it frequency-modulates the 450-mc carrier. The 2-kc subcarrier contains the digital uplink commands; it is phase-shift-keyed (PSK) at a binary rate of 1 kc. A subcarrier phase shift of 180° denotes a change in logic level. The synchronization tone is the same frequency as the binary bit command rate; zero crossings are coincident within ± 6 microseconds.



300LM3-133

Figure 2-66. LM Mission Programmer - Block Diagram

The demodulator separates the two-tone composite signal. It detects the phase of the 2-kc subcarrier and provides data pulses, corresponding to received "1" and "0" data bits, to the decoder. The two tones are used to time sequential clock pulses, which are used to strobe information into the decoder.

The decoder processes the uplink data and, at the direction of the uplink data, routes information to the LGC. The decoder generates an 8-bit verification word and routes it

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

to the PCMTEA, for telemetry, when command or data words are processed in the DCA and routed to the LGC. LGC update words consist of 16 bits plus the three-bit vehicle address and the three-bit system address. If the vehicle address is not 011 or the system address is not recognizable, the DCA neither processes the uplink data nor generates the verification word.

The DCA power supply converts the 28 volts from the commander's 28-volt d-c bus from the COMM: UP DATA LINK circuit breaker (panel 11) to the regulated voltages required by the DCA. The power supply contains a dc-to-dc converter with a regulator that provides +4.5 volts dc and a regulator that provides +24 volts dc.

2.2.3.5.2 Ascent Engine Arming Assembly. (See figure 2-67.)

The AEAA performs the same function as the ENG ARM switch, using relay logic. The relay logic consists of a bridging circuit that uses four relays (K1, K2, K3, and K4).

Relays K1 and K2 are prearming relays; K3 and K4, arming relays. Energizing a prearming and arming relay routes 28 volts dc from the ENG ARM circuit breaker to energize the engine arm relay (K14) in the CES. When K14 is energized, the engine arm signal is routed to the LGC. Relay K14 is also energized when the LGC or the AEA issues an engine-on command. This command sets a relay in the differential amplifier. When contacts of the differential-amplifier relay close, a circuit through both STOP pushbuttons and the AEAA is completed, energizing K14. The differential-amplifier relay is deenergized by setting the ENG ARM switch to ASC, or by a reset signal, which can be either an automatic engine off from the LGC or AEA or a pulse from the abort staging circuitry.

Relays K1, K2, K3, and K4 are energized by inputs from the DCA. These inputs (select 1, select 2, set 1, set 2, reset 1, and reset 2) are derived from the UHF uplink commands. A combination of a select input and a set input energizes the coils of a specific relay. The combinations of inputs are listed in the truth table in figure 2-67. The reset inputs are used to deenergize the relays.

2.2.3.6 Orbital Rate Display - Earth and Lunar. (See figure 2-68.)

The ORDEAL is an electromechanical device that contains a pair of resolvers, one for each FDAI. The resolvers are driven by a stepper motor, at the orbital rate selected with the ALT SET control on the ORDEAL panel. They may be switched directly into the pitch total attitude channels of the FDAI's.

The resolvers provide a display of spacecraft attitude with respect to a local horizontal reference frame. They transform the pitch angle in accordance with their shaft position, which is driven by a digital rate servo. The desired shaft rate is obtained by controlling the pulse rate which is applied to the stepper motor. This pulse rate is derived from the LM 400-cps frequency supply, as required by digital logic. Because the transformation is made in the pitch channel only, it is imperative that the inertial reference be aligned with the +Y-axis of the reference along the cross product of the velocity vector (\vec{V}) and the position vector from the center of the earth (\vec{R}).

The ORDEAL is used after obtaining the LM attitude with respect to the local horizontal, from the LGC. The selected FDAI (commander's or LM Pilot's) is slewed to this angle. The ORDEAL then torques its resolvers at the orbital rate, specified by the ALT SET control, of a circular orbit.

2.2.4 FAILURE MODES.

The GN&CS failure modes and the effect on mission capability are given in table 2-18.

300LM3-338

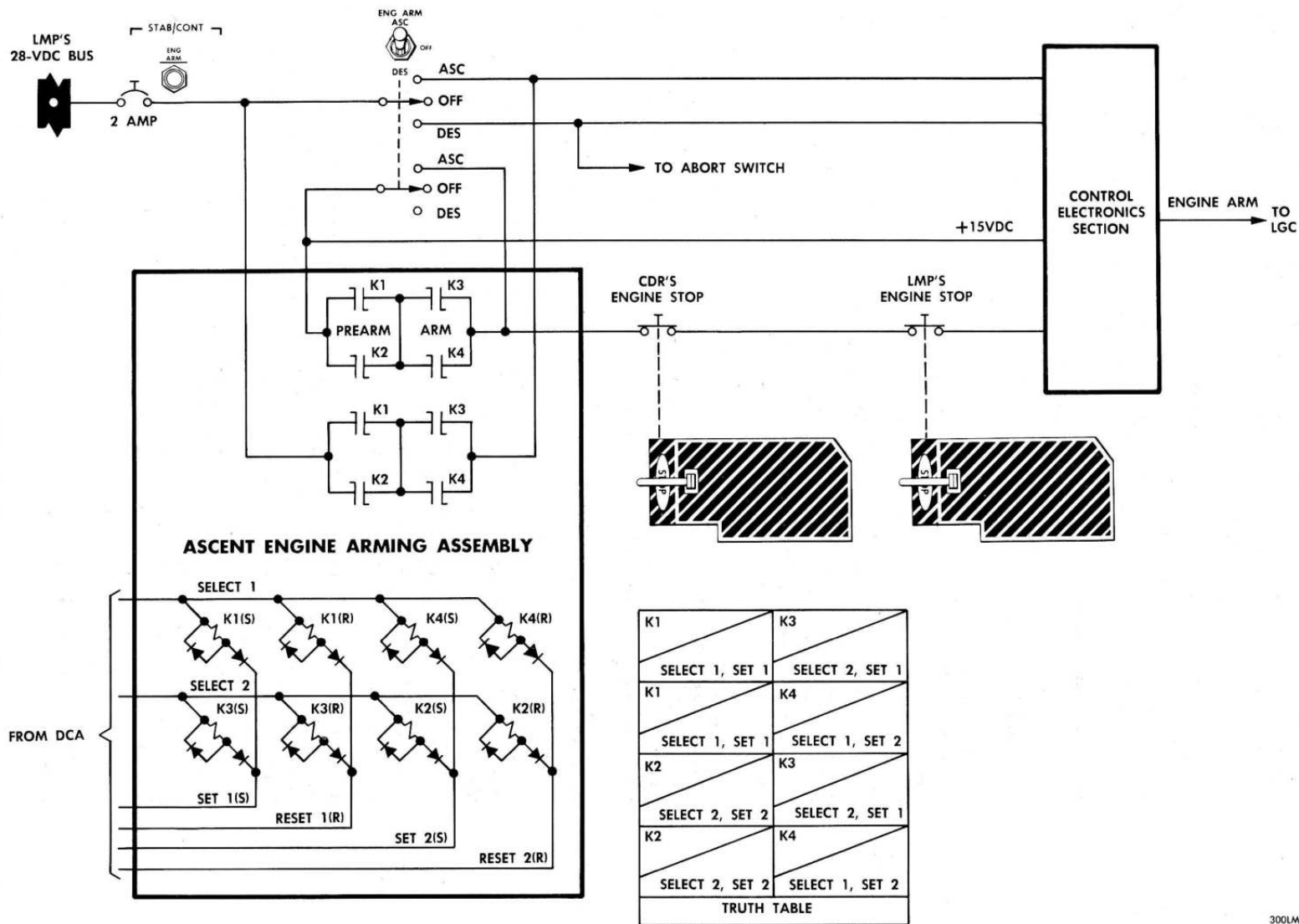


Figure 2-67. Ascent Engine Arming Assembly

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

(To be supplied)

Figure 2-68. Orbital Rate Display - Earth and Lunar - Schematic Diagram

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-18. Guidance, Navigation, and Control Subsystem - Failure Modes

Failure	Indication	Vehicle Capability
PGNS: LGC/DSKY circuit breaker (panel 11) failed open.	LGC cannot be initialized.	Primary mission objectives are lost.
STAB/CONT: ASA circuit breaker (panel 16) failed open.	AGS warning light goes on.	ASA heaters and AGS are lost. PGNS performs all mission objectives.
STAB/CONT: AEA circuit breaker (panel 16) failed open.	AGS warning light goes on.	AEA and AGS are lost. PGNS performs all mission objectives.
PGNS: IMU OPR circuit breaker (panel 11) failed open.	ISS warning light goes on.	PGNS control is lost.
PGNS: IMU STBY circuit breaker (panel 11) failed open.	ISS warning light goes on.	PGNS control is lost.
PGNS: RNDZ RDR circuit breaker (panel 11) failed open.	RNDZ RDR caution light goes on and RR is inoperative.	RR is lost.
GDA's are lost.	GDA/RCCA caution light goes on.	The descent engine cannot be gimbaled. Therefore, DPS burn capability is seriously degraded.
DECA auxiliary 22 vdc power supply		
1. Amplitude is out-of-tolerance.	1. CES DC warning light goes on.	1. DPS manual throttle capability is degraded. It may be impossible to restart descent engine if throttle is set at maximum (92.5%).
2. Signal is lost.	2. CES DC warning light goes on.	2. DPS manual throttle capability is seriously degraded.
ATCA -15-, +15-, and +4.3-vdc supplies failed off at output.	CES DC warning light goes on.	Entire DECA, except descent engine control logic, is disabled. Descent engine can be started with DES ENG CMD OVRD switch (panel 3).
Relay K12 (S&C control assembly No. 2) did not set.	RCS TCA's do not fire correctly	It may be impossible to stabilize vehicle while in PGNS mode and during main propulsion firings. Relay is overridden by using AGS.

GUIDANCE, NAVIGATION, AND CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-18. Guidance, Navigation, and Control Subsystem - Failure Modes (cont)

Failure	Indication	Vehicle Capability
Automatic thrust control logic of DECA failed.	THRUST indicator (panel 1) has erroneous reading.	DPS automatic throttle capability is lost. Full thrust would result in shorter burns for DPS.
ATCA -4-volt d-c supply bias for jet drivers failed.	CES DC warning light goes on.	Attitude control may be degraded because stray signals may fire TCA's inadvertently.
Contacts of relay K20 or K10 in S&C control assembly No. 1 are shorted.	BATTERY caution light goes on.	Switchover from descent to ascent batteries is required due to loss of descent batteries.
DAP in control; status relay K7 of S&C control assembly No. 2 failed in set position.	NO ATT light on DSKY and PGNS caution light (panel 1) go on.	Under PGNS control, attitude control is lost. Attitude control is regained by switching to AGS control.
Relay K13 of S&C control assembly No. 1 failed open or is shorted.	Staging does not take place and ascent engine cannot be fired automatically.	Staging is accomplished manually with STAGE switch (panel 8). Ascent engine must be fired manually with engine START pushbutton (panel 5).
Automatic ascent engine on loop, relay K207, relay K14, logic circuits, and/or driver failed open.	Staging does not take place and ascent engine cannot be fired automatically.	Staging is accomplished manually with STAGE switch. Ascent engine is fired manually with START pushbutton.
Internal ASA heaters and associated circuitry failed.	AGS warning light and HEATER caution light go on.	AGS is seriously degraded or inoperable.
RR power supply voltages failed off.	RR is inoperative and RNDZ RDR caution light goes on.	Primary mission objectives are not affected, but functional check of RR cannot be performed.
RR signal data converter failed or data-good signal from RR to LGC is lost.	RR does not function properly and RNDZ RDR caution light goes on.	Primary mission objectives are not affected, but functional check of RR cannot be performed.
RR frequency synthesizer failed.	RR is inoperative and RNDZ RDR caution light goes on.	Primary mission objectives are not affected, but functional check of RR cannot be performed.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-18. Guidance, Navigation, and Control Subsystem - Failure Modes (cont)

Failure	Indication	Vehicle Capability
LR signal data converter failed or data-good signal from LR to LGC is lost.	LR does not function properly and LDG RDR caution light goes on.	Failure has no effect on LR performance check.
RR heater power supply failed.	RR is inoperative and HEATER and RNDZ RDR caution lights go on.	Primary mission objectives are not affected, but functional check of LR cannot be performed.
LR heater power supply failed.	LR is inoperative and HEATER and LDG RDR caution lights go on.	Primary mission objectives are not affected, but functional check of LR cannot be performed.
ENG ARM switch (panel 1) inadvertently switched to ASC or individual contacts failed.	Descent engine cannot be started. If engine is firing, it will shut down.	DPS burns cannot be performed.
IMU CAGE switch (panel 1) failed on or is shorted.	Stable member gimbals lock up, causing ISS warning light (panel 1) to go on.	During any main propulsion burn, vehicle may not stabilize due to loss of attitude data to LGC.
ABORT STAGE pushbutton (panel 1) has been inadvertently pressed.	Descent engine, if firing, shuts down and staging takes place. There is no indication during ascent engine burn.	Failure precludes DPS testing.
ABORT STAGE switch jammed between open and closed positions.	Ascent engine does not fire and ascent tanks will not become pressurized.	Staging capability exists, using STAGE and ENG ARM switches.
ABORT switch (panel 1) has shorted contact.	Start abort discrete is sent to LGC.	Future DPS burns may be lost (dependent on LGC programming).
BAL CPL switch (panel 1) contacts are shorted to ground.	All TCA's are disabled when operating in AGS mode. RCS TCA caution light goes on.	If PGNS is functioning, DAP must be used to enable TCA's. (GUID CONT switch is set to PGNS.)

GUIDANCE, NAVIGATION, AND CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-18. Guidance, Navigation, and Control Subsystem - Failure Modes (cont)

Failure	Indication	Vehicle Capability
THR CONT switch (panel 1) contacts that route auto disable discrete to DECA shorted when switch was set to AUTO.	Automatic control of descent engine thrust is impossible.	Manual control must be used, to test descent engine (THR CONT set to MAN).
GUID CONT switch (panel 1) failed in PGNS position.	AGS cannot be used as backup.	Failure has no effect on PGNS operation, but AGS cannot be used as backup.
MODE CONTROL selector switch (panel 3) failed in OFF position or between contacts.	Vehicle cannot be stabilized with TCA's.	All mission objectives are lost.
RADAR TEST switch (panel 3) failed in OFF or RNDZ position.	LR self-test cannot be performed.	Radar section cannot be checked.
Engine STOP pushbutton (panels 5 or 6) jammed when pressed.	Engine (ascent or descent), if firing, shuts down. Ascent engine cannot be started if staging has occurred.	Main propulsion burns are lost.
AGS STATUS switch (panel 6) failed in OFF or STANDBY position.	When setting AGS STATUS switch from STANDBY to OPERATE, AGS warning light goes on.	Backup capability of AGS is lost because AEA power supply is inhibited.
STAB/CONT: ABORT STAGE circuit breaker (panel 11 or 16) failed open.	Descent engine does not fire or cannot perform FITH using ABORT STAGE pushbutton.	DES ENG CMD OVRD switch (panel 3) and redundant descent engine shutoff valve feed are lost. Staging is accomplished with STAGE switch.
AC BUS B: AGS circuit breaker (panel 11) failed open.	AGS is lost and AGS warning light goes on.	There is no backup capability if PGNS malfunctions.
STAB/CONT: DES ENG CONT circuit breaker (panel 11) failed open.	Manual DPS burns are lost.	ABORT pushbutton (panel 1) and descent engine are disabled.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-18. Guidance, Navigation, and Control Subsystem - Failure Modes (cont)

Failure	Indication	Vehicle Capability
STAB/CONT: DECA PWR circuit breaker (panel 11) failed open.	CES DC warning light goes on or DPS burn is lost.	DPS burn is available, using DES ENG CMD OVRD switch (panel 3).
STAB/CONT: ATCA PGNS circuit breaker (panel 11) failed open.	PGNS stability control (DAP) is lost.	AGS stability control (AAP) is available with ATCA (AGS) circuit breaker (panel 16).
STAB/CONT: ATCA circuit breaker (panel 16) failed open.	AGS stability control (AAP) is lost.	If DAP is not available, stability control is completely lost; otherwise, DAP must be used to control vehicle.
AC BUS A: DECA GMBL circuit breaker (panel 11) failed open.	Descent engine cannot be gimbaled.	TTCA cannot command descent engine to 92.5% (maximum) thrust, but DPS burn is available.
STAB/CONT: ENG ARM circuit breaker (panel 16) failed open.	Nominal APS or DPS automatic engine arm cannot be performed.	Descent or ascent engine must be fired with engine START pushbutton (panel 5) and MASTER ARM switch (panel 8).
HEATERS: RNDZ RDR OPR circuit breaker (panel 11) failed open.	RNDZ RDR and HEATER caution lights go on.	RR is lost.
HEATERS: LDG RDR circuit breaker (panel 11) failed open.	LDG RDR and HEATER caution lights go on.	LR is lost.
PGNS: LDG RDR circuit breaker (panel 11) failed open.	LDG RDR caution light goes on.	LR test objectives are lost.
AC BUS A and AC BUS B: AOT LAMP circuit breaker (panel 11) failed open.	Reticle cannot be seen through AOT eyepiece.	AOT objective is lost. COAS is used as backup for AOT.

GUIDANCE, NAVIGATION, AND CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

2.2.5 PERFORMANCE AND DESIGN DATA.

The performance and design data for the GN&CS sections are given in tables 2-19 through 2-26.

Table 2-19. Primary Guidance and Navigation Section - Performance and Design Data

Computer type	Automatic, electronic, digital, general-purpose and control
Internal transfer	Parallel (all bits simultaneously)
Memory	Random access
Erasable	Coincident-current core; 2,048-word capacity
Fixed	Core rope; 36,864-word capacity
Word length	Sixteen bits
Number system	Binary ones complement - for manipulation
Circuitry type	Flat pack, NOR micrologic
Machine instructions	56 total
Regular	42 total
Involuntary	9 total - associated with counter interrupts and program interrupts
Peripheral	5 total (for ground testing only)
Program interrupt options	10 total
Counter interrupt options	29 total
Memory cycle time	12 microseconds
Add time	24 microseconds
Telemetry	Synced from PCM
Uplink	Up to 1,000 bits/second
Downlink	Telemetry start and end pulses at 50 or 10 pps
Basic clock oscillator	2.048 mc
LGC power supplies	One +4-volt switching regulator One +14-volt switching regulator
	} Operated from 28-volt d-c input power
Logic	Positive (Positive dc = Binary 1; 0 volts = Binary 0)
Parity	Odd

Table 2-20. Abort Guidance Section - Performance and Design Data

Primary power	28±4 volts dc, 90 watts 115±2.3 volts ac, 400 cps, ±5%, 3.5 watts
---------------	---

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-20. Abort Guidance Section - Performance and Design Data (cont)

ASA clock	128 kpps
DEDA clock	128 kpps
AEA clock	1,024±2 pps
AEA and DEDA logic levels	Zero: 0 to 0.5 volt dc One: +3 to +5 volts dc
AEA memory	4,096 words
Number of bits	18 bits per memory word
Cycle time	5 microseconds
Temperature range	+60° to +80° F

Table 2-21. Rendezvous Radar - Performance and Design Data

Radar radiation frequency	9832.8 mc
Radar received frequency	9792.0 mc + doppler
Radiated power	300 mw (nominal)
Antenna design	Cassegrainian
Angle-tracking method	Amplitude monopulse
Antenna diameter	24 inches
Antenna gain	32 db (nominal), 31.5 db at beam center 28.0 db at 2° off boresight
Antenna beamwidth (3-db points)	4.0°
Antenna sidelobe level	-13 db adjacent to main lobe
Gyroscopes	Four (two redundant)
Modulation	Phase modulation by three tones: 200 cps, 6.4 kc, and 204.8 kc
Receiver channels	Reference, shaft, and trunnion
Receiver noise figure	10 db (maximum)
Receiver intermediate frequencies	40.8, 6.8, and 1.7 mc
Maximum range (unambiguous)	405 nm
Minimum range	80 feet
Range accuracy	Bias: ±800 feet for ranges > 50.8 nm ±80 feet for ranges < 50.8 nm Random (3σ): 1% or 80 feet for ranges between 80 feet and 5 nm; 1/4% or 300 feet for ranges between 5 nm and 400 nm
Range rate	+4,900 to -4,900 fps

GUIDANCE, NAVIGATION, AND CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-21. Rendezvous Radar - Performance and Design Data (cont)

Range data output	15-bit serial format	
Range scale factor		
400 to 50.8 nm	75.04 feet/bit	
50.8 nm to 80 feet	9.38 feet/bit	
Range rate scale factor	19.91 cycles/fps	
Range rate accuracy	±1 fps, 3 σ random ±1 fps, bias	
Acquisition time	4.5 seconds	
Angular accuracy		
Range	<div style="display: flex; justify-content: space-between;"> <div>Maximum error (mr)</div> <div></div> </div> <div style="display: flex; justify-content: space-between;"> <div>Random</div> <div>Bias</div> </div>	
400 nm	4	8
300 nm	3	8
200 nm	2	8
5 nm	2	8
2 nm	5	8
1 nm	10	8
80 feet	10	8
Angle rate accuracy		
Range	Maximum error	
400 nm	0.4 mr/sec	
200 nm to 1,000 feet	0.2 mr/sec	

Table 2-22. Landing Radar - Performance and Design Data

Velocity sensor	Continuous-wave, three-beam
Radar altimeter	FM/CW
Altitude capability	N/A
Velocity capability	N/A
Weight (approx)	39 pounds
Power consumption	125 watts dc (nominal) 147 watts dc (maximum)
Heater power consumption	44 watts dc (maximum)
Altimeter antenna	
Type	Planar array, space-duplexed

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-22. Landing Radar - Performance and Design Data (cont)

Altimeter antenna (cont)	
Gain (two-way)	50.4 db
RF power	100 mw (minimum)
Beamwidth (two-way)	3.9° E-plane 6.5° H-plane
Velocity sensor antenna	
Type	Planar array, spaced-duplexed
Gain (two-way)	49.2 db
RF power	200 mw (minimum)
Beamwidth (two-way)	3.67 E-plane 7.34 H-plane
Doppler input	26 to 64 kc
Transmitter	
Velocity sensor frequency	10.51 gc
Radar altimeter frequency	9.58 gc
Warmup time	1 minute
Operating time	Up to 999.99
FM sweep duration	0.007 second
Transmitter frequency	
Velocity sensor	10.510 kmc ± 5 mc
Altimeter	9.580 kmc ± 5 mc
Acquisition time	
Velocity sensor	12 seconds (maximum)
Altimeter	12 seconds (maximum)
Range input	116 cps to 133 kc
Primary power	25 to 31.5 volts dc (nominal) 3.5 to 6.5 amperes
Temperature range	-20° to +110° F

Table 2-23. Control Electronics Section - Performance and Design Data

Attitude and translation controller assembly	
Input signals	Attitude error, command rate, and rate gyro output
Operating frequency	800 cps

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-23. Control Electronics Section - Performance and Design Data (cont)

Attitude and translation controller
 assembly (cont)

Cooling Conduction through mounting flanges

Temperature range 0° to +160° F

Rate gyro assembly

Input power Single- and three-phase, 800 cps

Starting power 1.8 watts (maximum; three-phase)

Steady-state power 8.5 watts (maximum; three-phase)
 1.5 watts (dc)

Transient power 1.0 watt (single-phase)
 40 watts (dc)

Sensitivity 0.05° per second

Input range -25° to +25° per second

Input rate frequency 20±4 cps

Descent engine control assembly

A-C input power nominal voltage 115 vrms

Steady-state voltage limits +2.5 to -2.5 vrms

Operating temperature range +57° to +97° F

D-C input power nominal voltage +4, +15, +28, and -15 volts dc

A-C power consumption

Transient peak 6 watts (maximum)

Steady-state average 3 watts (maximum)

D-C power consumption

Transient peak 5 watts (maximum)

Steady-stage average 5 watts (maximum)

Total power consumption

Transient 27.6 watts (maximum)

Steady-state 7.9 watts (maximum)

Gimbal drive actuator

A-C power 115±2.5 vrms, single phase, 400 cps

A-C power consumption (steady-
 state average) 35 watts

Stroke +2 to -2 inches ±5%

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-23. Control Electronics Section - Performance and Design Data (cont)

Attitude controller assembly	
Operating power	28 volts, 800 cps
Type of sensor	Proportional transducer
Displacement	0.28 volt/degree
Thrust/translation controller assembly	
Operating power	28 volts, 800 cps
Type of sensor	Proportional transducer

Table 2-24. LM Mission Programmer - Performance and Design Data

Primary power	28 volts dc
Temperature range	0° to +160° F
Digital command assembly	
Steady-state voltage limits	25 to 31.5 volts dc
Input power	1.5 watts
Frequency range	406 to 450 mc

Table 2-25. Orbital Rate Display - Earth and Lunar - Performance and Design Data

Operating power	
AC	115±2.5 vrms, single phase, 400 cps
DC	28±3 volts
Power consumption	
AC	4 watts at 0.9 power factor (minimum)
DC	4 watts
Range of orbital altitude	10 to 310 nm (calibrated in 5-nm steps)
Operating temperature range	0° to +160° F
Weight	5.5 pounds

2.2.6 OPERATIONAL LIMITATIONS AND RESTRICTIONS.

2.2.6.1 General.

The following operational limitations and restrictions pertain to the GN&CS as a whole. Limitations and restrictions that pertain to specific portions of the GN&CS are covered in paragraphs 2.2.6.2 through 2.2.6.6.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

- The IMU, ASA, and LGC must not be placed in their operate modes until after 15 minutes of water sublimator operation. If this requirement is not observed, erroneous and changing IMU, ASA, and LGC outputs occur during temperature cycling.
- Before and during all ΔV maneuvers, narrow deadband operation must be used to achieve proper control of the thrust vector, for trajectory accuracy. Failure to comply with this procedure produces an unacceptable level of uncertainty in the trajectory.
- The AGS must be updated to the PGNS 5 minutes before any burn, to minimize error due to drift. In addition, the time from first star fix to completion of AGS alignment must not exceed 16 minutes for powered descent and ascent. If updating is not performed, erroneous data may be stored in the AEA, resulting in trajectory anomalies if the PGNS fails and the AGS is required for abort.
- Continuous heating must be provided for the ASA, IMU, RR, and LR to maintain minimum survival temperature levels. If survival heating fails, permanent degradation or damage of the assemblies may result.
- The separation distance between the LM and the CSM must not exceed 100 nm. Accurate updating of AGS state vectors, using the RR, is impossible at distance greater than 100 nm.

2.2.6.2

Primary Guidance and Navigation Section.

The operational limitations and restrictions for the PGNS are as follows:

- IMU fine alignment must have been completed before any main engine burn and within 15 minutes before any ΔV maneuver. In addition, the time from first star fix to completion of IMU fine alignment must not exceed 10 minutes. These times are established to compensate for stable member drift, which would result in an unacceptable level of error in thrust vector alignment.
- The IMU requires an operating time of 30 minutes after switching from standby to operate, for temperature stabilization. The first 90 seconds are required by the IMU gyros, to acquire synchronous rotor speed; the remaining time is for temperature stabilization. If the IMU is used during this time, scale factor changes resulting from varying temperature and rotor speed cause degraded attitude data.
- A gimbal lock condition exists if the outer and inner gimbals come within 20° of each other. When these two gimbals become coplanar, attitude data is lost and torquing requirements become infinite.
- To maintain the LGC reference time, the LGC off mode is not used except before, during and following sublimator dryout. If the reference time is lost, it is reestablished by the astronauts with DSKY inputs.
- The LGC must be in the operate mode when the IMU is switched to operate, because IMU moding is performed by LGC commands. If this requirement is not observed, the IMU places itself in the cage mode instead of the operate mode.
- The AOT field of view must cover a suitable starfield, because LGC programming for IMU alignment is based on specific star requirements. IMU alignment will be inadequate if this requirement is not observed.

GUIDANCE, NAVIGATION, AND CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

- The periphery of the AOT field of view must not be within 15° of the sun, because sunlight interferes with the optical assembly.
- The AOT heaters must be on continuously from 30 minutes before first use of the AOT until after last use, to prevent fogging of the lens.
- The AOT must be in the stowed position (azimuth control set to CL) when not in use, to protect the viewing face from RCS plume impingement and space particles. Failure to observe this requirement may result in damage to the lens and will result in inaccurate IMU alignment.
- The RR antenna must be positioned for minimum interference with the AOT when performing IMU alignment; otherwise, the RR occults a large portion of the AOT field of view. The minimum position for the RR antenna is mode No. I (shaft angle of -70°, trunnion angle of 0°).

2.2.6.3

Abort Guidance Section.

The operational limitations and restrictions for the AGS are as follows:

- At least 25 minutes must be allowed for ASA warmup, to stabilize the gyros; otherwise, operation is degraded.
- AEA operation is shut down automatically if its power subassembly d-c input voltage drops below 20 volts dc.
- The ASA gyro rate must not exceed 25°/second; otherwise, output is degraded.

2.2.6.4

Radar Section.

The operational limitations and restrictions for the RR and LR are as follows:

- The RR antenna should be stowed during launch, boost, and docked configuration. If this cannot be done (because the antenna cannot be stowed from inside the LM once the lanyard is pulled), the antenna must be inspected for discoloration and structural damage before use. This inspection should be performed before separating from the CSM after the first rendezvous and docking sequence, with the antenna not stowed.
- The HEATERS: RNDZ RDR - OPR circuit breaker (panel 11) must be closed 1 hour before the RR is used. If the RR temperature is not increased from survival heating level to operating heating level, the RR may be inoperative or its performance may be degraded.
- Trunnion axis coverage (LOS) in mode No. I is +55° to -55° about the Z-axis; in mode No. II, -125° to -235° about the Z-axis.
- Shaft axis coverage (LOS) in mode No. I is -70° to +60° about the X-axis; in mode No. II, +40° to +155° about the X-axis.
- Mechanical movement of the RR shaft cannot exceed +68° to -148° about the X-axis, due to mechanical stops. Trunnion axis movement is restricted from +70° to -235° about the Z-axis.
- When switching the RR antenna from mode No. I to mode No. II, 30 to 40 seconds must be allowed. The time delay is required, because the RR loses lock-on and it must be reestablished.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

- Except for open-loop antenna slewing, manual operation of the RR antenna is only available in mode No. I. If this restriction is not observed, read-out of antenna angles is impossible, because display of RR antenna angles is restricted to mode No. I.
- The RR must be operated within joint specification restrictions on timeline and thermal inputs into the antenna assembly. Components will overheat resulting in degraded operation or possible complete loss of RR.
- Before any maneuver based on RR angular data, 15 minutes of continuous tracking must be completed by the RR. The LGC must compensate for RR-IMU angular misalignment (bias) error. If this requirement is not observed, inaccurate data is fed to the LGC, resulting in excessive fuel consumption.
- During RR-IMU bias determination, the LM-CSM LOS must be within 30° of the LM +Z-axis. If this requirement is not observed, computation of required ΔV corrections is degraded, resulting in excessive use of the RCS.
- The LR must be allowed to warm up for 1.5 minutes for temperature stabilization; otherwise, degraded and changing output will result.
- The antenna tilt angle for position No. 1 is 24°; for position No. 2, zero degrees.
- The LR must be operated within a specific mission timeline; otherwise, the components will overheat and degraded operation or possible loss of LR will result.

2.2.6.5

Control Electronics Section.

The operational limitations and restrictions of the CES are as follows:

- The static operating load limit for the GDA is 2,900 pounds.
- The TTCA provides control over the throttle magnitude, from 10% to 92.5% of maximum thrust.
- When the ascent engine is on, RCS +X TCA's are used only for pitch and roll control (and therefore add to ΔV), except as needed when large commands occur or when moments due to center-of-gravity offset exceed the unbalanced couples control boundary. For AGS operation, manual switching to balanced couples may be required during powered ascent at a predetermined time based on prelaunch center-of-gravity predictions. If -X TCA's are used, excessive fuel consumption results because a portion of the ΔV provided by the ascent engine is cancelled while overcoming the unbalance created by the center-of-gravity offset.

2.2.6.6

LM Mission Programmer.

The operational limitations and restrictions for the LMP are as follows:

- Operation of the LMP is restricted to operation of the ascent engine when the LM is unmanned, because the engine will be operated until propellant depletion. If this restriction is not observed, the LM will have no main propulsion ΔV capability.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

2.2.6.7 Orbital Rate Display - Earth and Lunar.

The operational limitations and restrictions for the ORDEAL are as follows:

- The ORDEAL shall be used only when the LM is in a circular orbit. If this restriction is not observed, FDAI pitch displays are degraded.
- The ORDEAL is limited to altitudes between 10 and 310 nm. If these limits are exceeded, outputs are degraded.

2.2.7 TELEMETRY MEASUREMENTS.

The GN&CS telemetry data are given in table 2-26. "(R)" in the "Telemetry Range" column signifies a real-time telemetry measurement.

Table 2-26. Guidance, Navigation, and Control Subsystem - Telemetry Measurements

Code	Description	Telemetry Range (Nominal)	Display Range	Crew Display
GG0001X	PGNS downlink data (to telemetry)	Digital code (R)		None
GG0117H	Altitude (LGC)	0 to 60.5K feet	0 to 400 nm	ALT indicator
GG0118L	Altitude rate (LGC)	-700 to +700 fps	-700 to +700 fps	ALT RT indicator
GG0119L	Forward velocity (LGC)	-200 to +200 fps	-20 to +20 fps or -200 to +200 fps	X-pointer indicator
GG0120L	Lateral velocity (LGC)	-200 to +200 fps	-20 to +20 fps or -200 to +200 fps	X-pointer indicator
GG1020V	LGC +14-vdc supply	0 to 20 vdc (14 vdc)		None
GG1030V	LGC +4-vdc supply	0 to 5 vdc (4 vdc)		None
GG1040V	120-vdc pulse torque reference	85 to 135 vdc (120 vdc) (R)		None
GG1070V	CDU +4-vdc supply	0 to 5 vdc (4 vdc)		None
GG1100V	-27.5-vdc supply	0 to -35 vdc (-27.5 vdc)		None
GG1110V	PCM 2.5-vdc TM bias	0 to 5 vdc (2.5 vdc) (R)		None
GG1111V	DFI 2.5-vdc TM bias	0 to 5 vdc (2.5 vdc)		None
GG1201V	IMU 28-volt, 800-cps, IP-0D supply	0 to 31.1 vrms (28 vrms) (R)		None
GG1202V	IMU 28-volt, 800-cps, 5P-90D supply	0 to 33.6 vrms (28 vrms)		None
GG1203V	IMU 28-volt, 800-cps, 5P-0D supply	0 to 33.6 vrms (28 vrms)		None
GG1331V	3.2-kc, 28-volt supply	0 to 31.1 vrms (28 vrms) (R)		None

GUIDANCE, NAVIGATION, AND CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-26. Guidance, Navigation, and Control Subsystem - Telemetry Measurements (cont)

Code	Description	Telemetry Range (Nominal)	Display Range	Crew Display
GG1500V	IMU operate +28-vdc level	0 to 35 vdc (28 vdc)		None
GG1510V	IMU standby +28-vdc level	0 to 35 vdc (28 vdc)		None
GG1513X	IMU standby/off	Off or on (R)		None
GG1520V	LGC operate +28-vdc level	0 to 35 vdc (28 vdc)		None
GG1523X	LGC operate	Off or on (R)		None
GG2001V	X PIPA SG output, in-phase	-2.5 to +2.5 vrms (R)		None
GG2011V	X PIPA mode check	(7 volts p-p)		None
GG2021V	Y PIPA SG output, in-phase	-2.5 to +2.5 vrms (R)		None
GG2031V	Y PIPA mode check	(7 volts p-p)		None
GG2041V	Z PIPA SG output, in-phase	-2.5 to +2.5 vrms (R)		None
GG2051V	Z PIPA mode check	(7 volts p-p)		None
GG2106V	IG servo error, total	0 to 3 vrms		None
GG2107V	IG servo error, in-phase	-3 to +3 vrms (zero) (R)		None
GG2110C	IG torque motor input	-0.5 to +0.5 amp (R)		None
GG2112V	IG 1X resolver output, sine	-20.25 to +20.25 vrms (R)		None
GG2113V	IG 1X resolver output, cosine	-20.25 to +20.25 vrms (R)		None
GG2121V	IG 1X resolver (expanded)	-5 to +5 vrms		None
GG2122V	IG 1X resolver output, sine	0 to 28 vrms	0° to 360°	FDAI
GG2123V	IG 1X resolver output, cosine	0 to 28 vrms	0° to 360°	FDAI
GG2136V	MG servo error, total	0 to 3 vrms		None
GG2137V	MG servo error, in-phase	-3 to +3 vrms (zero) (R)		None
GG2140C	MG torque motor input	-0.5 to +0.5 ampere (R)		None

GUIDANCE, NAVIGATION, AND CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-26. Guidance, Navigation, and Control Subsystem - Telemetry Measurements (cont)

Code	Description	Telemetry Range (Nominal)	Display Range	Crew Display
GG2142V	MG 1X resolver output, sine	-20.25 to +20.25 vrms (R)		None
GG2143V	MG 1X resolver output, cosine	-20.25 to +20.25 vrms (R)		None
GG2151V	MG 1X resolver (expanded)	-5 to +5 vrms		None
GG2152V	MG 1X resolver output, sine	0 to 28 vrms	0° to 360°	FDAI
GG2153V	MG 1X resolver output, cosine	0 to 28 vrms	0° to 360°	FDAI
GG2166V	OG servo error, total	0 to 3 vrms		None
GG2167V	OG servo error, in-phase	-3 to +3 vrms (zero) (R)		None
GG2170C	OG torque motor input	-0.9 to +0.9 ampere (R)		None
GG2172V	OG 1X resolver output, sine	-20.25 to +20.25 vrms (R)		None
GG2173V	OG 1X resolver output, cosine	-20.25 to +20.25 vrms (R)		None
GG2181V	OG 1X resolver sine (expanded)	-5 to +5 vrms		None
GG2182V	OG 1X resolver output, sine	0 to 28 vrms	0° to 360°	FDAI
GG2183V	OG 1X resolver output, cosine	0 to 28 vrms	0° to 360°	FDAI
GG2217V	Pitch attitude error (PGNS)	0 to 10 vrms	-30° to +30°	FDAI
GG2219V	Pitch CDU digital- to-analog output	-5 to +5 vrms (zero) (R)		None
GG2220V	IG CDU fine error	0 to 1.5 vrms (zero)		None
GG2221V	IG CDU coarse error	0 to 5 vrms (zero)		None
GG2247V	Roll attitude error (PGNS)	0 to 10 vrms	-30° to +30°	FDAI
GG2249V	Yaw CDU digital- to-analog output	-5 to +5 vrms (zero) (R)		None
GG2250V	MG CDU fine error	0 to 1.5 vrms (zero)		None
GG2251V	MG CDU coarse error	0 to 5 vrms (zero)		None

GUIDANCE, NAVIGATION, AND CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-26. Guidance, Navigation, and Control Subsystem - Telemetry Measurements (cont)

Code	Description	Telemetry Range (Nominal)	Display Range	Crew Display
GG2277V	Yaw attitude error (PGNS)	0 to 10 vrms	-30° to +30°	FDAI
GG2279V	Roll CDU D/A converter output	-5 to +5 vrms (zero) (R)		
GG2280V	OG CDU fine error	0 to 1.5 vrms (zero)		None
GG2281V	OG CDU coarse error	0 to 5 vrms (zero)		None
GG2300T	PIPA temperature	+120° to +140° F (+130° F) (R)		None
GG2301T	IRIG temperature	+123° to +143° F (+133° F) (R)		None
GG2302X	IMU heater off	On or off		None
GG2303X	IMU blower off	On or off		None
GG3304V	RR shaft 1X resolver output, sine	-21.5 to +21.5 vrms (R)		None
GG3305V	RR shaft 1X resolver output, cosine	-21.5 to +21.5 vrms (R)		None
GG3311V	RR shaft CDU fine error	-1.2 to +1.2 vrms (zero)		None
GG3312V	RR shaft CDU coarse error	0 to 5 vrms (zero)		None
GG3321V	RR trunnion CDU fine error	-1.2 to +1.2 vrms (zero)		None
GG3322V	RR trunnion CDU coarse error	0 to 5 vrms (zero)		None
GG3324V	RR trunnion 1X resolver output, sine	-21.5 to +21.5 vrms (R)		None
GG3325V	RR trunnion 1X resolver output, cosine	-21.5 to +21.5 vrms (R)		None
GG4300T	LGC temperature	+47° to +122° F		None
GG6001D	Navigation base (roll)	0g to 2g		None
GG6002D	Navigation base (pitch)	0g to 2g		None
GG6003D	Navigation base (yaw)	0g to 2g		None
GG6020T	PIPA temperature	0° to +150° F (R)		None

GUIDANCE, NAVIGATION, AND CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-26. Guidance, Navigation, and Control Subsystem - Telemetry Measurements (cont)

Code	Description	Telemetry Range (Nominal)	Display Range	Crew Display
GG6021T	PSA temperature	+47° to +122° F		None
GG9001X	LGC (warning)	Contact closure (R)		LGC warning light
GG9002X	ISS (warning)	Contact closure (R)		ISS warning light
GG9003X	PGNS (caution)	Contact closure (R)		PGNS caution light
GG9006V	IMU temperature out of limits			None
GH1204X	ACA out of detent	Contact closure (R)		None
GH1211V	Automatic throttle increase, 3.2 kpps	0 to 2-5 vdc		None
GH1212V	Automatic throttle decrease, 3.2 kpps	0 to 2-5 vdc		None
GH1214X	Automatic engine-on command	Contact closure (R)		None
GH1217X	Automatic engine-off command	Contact closure (R)		None
GH1230X	Ascent engine-arm commanded	0 or 28 vdc (R)		None
GH1240V	X-translation command	-10, 0, or +10 vdc (R)		None
GH1241V	Y-translation command	-10, 0, or +10 vdc (R)		None
GH1242V	Z-translation command	-10, 0, or +10 vdc (R)		None
GH1247V	Yaw logic input error	-13 to +13 vdc (+0.5 vdc) (R)		None
GH1248V	Pitch logic input error	-13 to +13 vdc (+0.5 vdc) (R)		None
GH1249V	Roll logic input error	-13 to +13 vdc (+0.5 vdc) (R)		None
GH1260X	Ascent engine on- off to propulsion	Contact closure (R)		None
GH1283X	Abort stage com- mand	Contact closure (R)		None
GH1286X	Engine fire over- ride	Contact closure (R)		None
GH1301X	Descent engine-on to propulsion	(2.6 to 15 vdc) (R)		None

GUIDANCE, NAVIGATION, AND CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-26. Guidance, Navigation, and Control Subsystem - Telemetry Measurements (cont)

Code	Description	Telemetry Range (Nominal)	Display Range	Crew Display
GH1311V	Manual thrust command	Contact closure (R)	0% to 100%	THRUST indicator
GH1313V	Pitch GDA position (retract/extent)	-15 to +15 vrms (+0.5 vrms) (R)		None
GH1314V	Roll GDA position (extent/retract)	-15 to +15 vrms (+0.5 vrms) (R)		None
GH1318X	Pitch trim extend command from LGC	4 vdc (on) or 28 vdc (off)		None
GH1319X	Pitch trim extend command from LGC	4 vdc (on) or 28 vdc (off)		None
GH1320X	Pitch GDA extend/retract commands	115 vrms (extend) 135 vrms (retract)		None
GH1323X	Pitch trim failure	Contact closure (R)		GDA/RCCA caution light
GH1330X	Roll trim failure	Contact closure (R)		GDA/RCCA caution light
GH1331V	Automatic thrust command	0 to 12 vdc (0.015 vdc) (R)	0% to 100%	THRUST indicator
GH1343X	Roll trim extend from LGC	4 vdc (on) or 28 vdc (off)		None
GH1344X	Roll trim retract from LGC	4 vdc (on) or 28 vdc (off)		None
GH1345X	Roll GDA retract/extend	115 vrms (retract) 135 vrms (extend)		None
GH1348X	Descent engine arm (DECA out)	0 or 28 vdc (R)		None
GH1349V	Descent engine arm (DECA out)	(0 to 15 vdc)		None
GH1397V	Yaw rate gyro null (0 to 8 kc)	30 millivolts		None
GH1398V	Pitch rate gyro null (0.8 kc)	30 millivolts		None
GH1399V	Roll rate gyro null (0.8 kc)	30 millivolts		None
GH1401V	RGA spin motor line A-B (0.8 kc)	23 to 29 vrms (26 vrms)		CES AC warning light
GH1402V	RGA spin motor line B-C (0.8 kc)	23 to 29 vrms (26 vrms)		CES AC warning light
GH1403V	RGA spin motor line C-A (0.8 kc)	23 to 29 vrms (26 vrms)		CES AC warning light
GH1406V	+15-vdc supply	14 to 16 vdc (15 vdc)		CES DC warning light

GUIDANCE, NAVIGATION, AND CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-26. Guidance, Navigation, and Control Subsystem - Telemetry Measurements (cont)

Code	Description	Telemetry Range (Nominal)	Display Range	Crew Display
GH1407V	-15-vdc supply	-16 to -14 vdc (-15 vdc)		CES DC warning light
GH1408V	4.3-vdc supply	3.8 to 4.8 vdc (4.3 vdc)		CES DC warning light
GH1418V	Jet No. B4U driver output	On or off (R)		RCS TCA warning light
GH1419V	Jet No. A4D driver output	On or off (R)		RCS TCA warning light
GH1420V	Jet No. B4F driver output	On or off (R)		RCS TCA warning light
GH1421V	Jet No. A4R driver output	On or off (R)		RCS TCA warning light
GH1422V	Jet No. A3U driver output	On or off (R)		RCS TCA warning light
GH1423V	Jet No. B3D driver output	On or off (R)		RCS TCA warning light
GH1424V	Jet No. B3A driver output	On or off (R)		RCS TCA warning light
GH1425V	Jet No. A3R driver output	On or off (R)		RCS TCA warning light
GH1426V	Jet No. B2U driver output	On or off (R)		RCS TCA warning light
GH1427V	Jet No. A2D driver output	On or off (R)		RCS TCA warning light
GH1428V	Jet No. A2A driver output	On or off (R)		RCS TCA warning light
GH1429V	Jet No. B2L driver output	On or off (R)		RCS TCA warning light
GH1430V	Jet No. A1U driver output	On or off (R)		RCS TCA warning light
GH1431V	Jet No. B1D driver output	On or off (R)		RCS TCA warning light
GH1432V	Jet No. A1F driver output	On or off (R)		RCS TCA warning light
GH1433V	Jet No. B1L driver output	On or off (R)		RCS TCA warning light
GH1434V	Jet No. B4U LGC command	0 or 28 vdc		None
GH1435V	Jet No. A4D LGC command	0 or 28 vdc		None
GH1436V	Jet No. B4F LGC command	0 or 28 vdc		None

GUIDANCE, NAVIGATION, AND CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-26. Guidance, Navigation, and Control Subsystem - Telemetry Measurements (cont)

Code	Description	Telemetry Range (Nominal)	Display Range	Crew Display
GH1437V	Jet No. A4R LGC command	0 or 28 vdc		None
GH1438V	Jet No. A3U LGC command	0 or 28 vdc		None
GH1439V	Jet No. B3D LGC command	0 or 28 vdc		None
GH1440V	Jet No. B3A LGC command	0 or 28 vdc		None
GH1441V	Jet No. A3R LGC command	0 or 28 vdc		None
GH1442V	Jet No. B2L LGC command	0 or 28 vdc		None
GH1443V	Jet No. A2D LGC command	0 or 28 vdc		None
GH1444V	Jet No. A2A LGC command	0 or 28 vdc		None
GH1445V	Jet No. B2L LGC command	0 or 28 vdc		None
GH1446V	Jet No. A1U LGC command	0 or 28 vdc		None
GH1447V	Jet No. B1D LGC command	0 or 28 vdc		None
GH1448V	Jet No. A1F LGC command	0 or 28 vdc		None
GH1449V	Jet No. B1L LGC command	0 or 28 vdc		None
GH1450V	Pitch trim error	-14 to +14 vdc		None
GH1452V	Roll trim error	-14 to +14 vdc		None
GH1453V	Yaw demodulator output	-14 to +14 vdc		None
GH1455V	Yaw attitude error (0.8 kc)	-5 to +5 vrms (R)		None
GH1456V	Pitch attitude error (0.8 kc)	-5 to +5 vrms (R)		None
GH1457V	Roll attitude error (0.8 kc)	-5 to +5 vrms (R)		None
GH1461V	Yaw RGA signal (0.8 kc)	-3.5 to +3.5 vrms (R)		None
GH1462V	Pitch RGA signal (0.8 kc)	-3.5 to +3.5 vrms (R)		None

GUIDANCE, NAVIGATION, AND CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-26. Guidance, Navigation, and Control Subsystem - Telemetry Measurements (cont)

Code	Description	Telemetry Range (Nominal)	Display Range	Crew Display
GH1463V	Roll RGA signal (0.8 kc)	-3.5 to +3.5 vrms (R)		None
GH1488V	Primary -4.7 vdc	-5.2 to -4.2 vdc (-4.7 vdc)		PRE AMPS caution light
GH1489V	Backup -4.7 vdc	-5.2 to -4.2 vdc (-4.7 vdc)		PRE AMPS caution light
GH1493V	+6-vdc supply	5.4 to 6.6 vdc (6 vdc)		CES DC warning light
GH1494V	-6-vdc supply	-6.6 to -5.4 vdc (-6 vdc)		CES DC warning light
GH1497V	Yaw RGA signal (0.8 kc)	-3.5 to +3.5 vrms	-2 to +2°/sec or -20 to +20°/sec	FDAI
GH1498V	Pitch RGA signal (0.8 kc)	-3.5 to +3.5 vrms	-2 to +2°/sec or -20 to +20°/sec	FDAI
GH1499V	Roll RGA signal (0.8 kc)	-3.5 to +3.5 vrms	-2 to +2°/sec or -20 to +20°/sec	FDAI
GH1501X	Roll RGA SMRD on torquer line	0 to 1.6 kpps		None
GH1502X	Pitch RGA SMRD on torquer line	0 to 1.6 kpps		None
GH1503X	Yaw RGA SMRD on torquer line	0 to 1.6 kpps		None
GH1603X	Deadband select (wide)	0 or 28 vdc (R)		None
GH1608X	CES mode select (AUTO)	Contact closure (R)		None
GH1609X	CES mode select (ATT HOLD)	Contact closure (R)		None
GH1621X	Guidance select switch (AGS)	Contact closure (R1)		None
GH1628X	Roll attitude control select (PULSED/ DIRECT)	Contact closure (R)		None
GH1629X	Pitch attitude control select (PULSED/ DIRECT)	Contact closure (R)		None
GH1630X	Yaw attitude control select (PULSED/ DIRECT)	Contact closure (R)		None

GUIDANCE, NAVIGATION, AND CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-26. Guidance, Navigation, and Control Subsystem - Telemetry Measurements (cont)

Code	Description	Telemetry Range (Nominal)	Display Range	Crew Display
GH1852V	Manual throttle command (0.8 kc)	0.54 to 3.0 vrms		None
GH1893X	X-translation override	0 or 28 vdc (R)		None
GH1896X	Unbalanced couples	Contact closure (R)		None
GI0001X	AGS downlink data (to telemetry)	(R)		None
GI3137X	ΔV_y (Y incremental velocity)	0 to 64 kpps		None
GI3138X	ΔV_z (Z incremental velocity)	0 to 64 kpps		None
GI3151V	$\sin \alpha$ (to total attitude display- 0.4 kc)	-15 to +15 vrms	0° to 360°	FDAI
GI3152V	$\cos \alpha$ (to total attitude display- 0.4 kc)	-15 to +15 vrms	0° to 360°	FDAI
GI3153V	$\sin \beta$ (to total attitude display- 0.4 kc)	-15 to +15 vrms	0° to 360°	FDAI
GI3154V	$\cos \beta$ (to total attitude display- 0.4 kc)	-15 to +15 vrms	0° to 360°	FDAI
GI3155V	$\sin \gamma$ (to total attitude display- 0.4 kc)	-15 to +15 vrms	0° to 360°	FDAI
GI3156V	$\cos \gamma$ (to total attitude display- 0.4 kc)	-15 to +15 vrms	0° to 360°	FDAI
GI3166V	E_X (yaw attitude error to display)	-4.5 to +4.5 vrms (zero)	-30° to +30°	FDAI
GI3167V	E_Y (pitch attitude error to display)	-4.5 to +4.5 vrms (zero)	-30° to +30°	FDAI
GI3168V	E_Z (roll attitude error to display)	-4.5 to +4.5 vrms (zero)	-30° to +30°	FDAI
GI3171X	$\Delta \zeta_P$ (yaw increase angle)	0 to 64 kpps		None
GI3172X	$\Delta \zeta_R$ (roll increase angle)	0 to 64 kpps		None
GI3173X	$\Delta \zeta_Q$ (pitch increase angle)	0 to 64 kpps		None
GI3175X	ASA clock	(128 kpps)		None

GUIDANCE, NAVIGATION, AND CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-26. Guidance, Navigation, and Control Subsystem - Telemetry Measurements (cont)

Code	Description	Telemetry Range (Nominal)	Display Range	Crew Display
GI3176T	Block temperature reference	0° to 250° F (120° F)		None
GI3177X	CDU zero	TBD		None
GI3178X	+ Δ AIG (from PGNS)	0 to 6.4 kpps		None
GI3179X	- Δ AIG (from PGNS)	0 to 6.4 kpps		None
GI3180X	+ Δ AMG (from PGNS)	0 to 6.4 kpps		None
GI3181X	- Δ AMG (from PGNS)	0 to 6.4 kpps		None
GI3182X	+ Δ AOG (from PGNS)	0 to 6.4 kpps		None
GI3183X	- Δ AOG (from PGNS)	0 to 6.4 kpps		None
GI3184X	AGS initialization (downlink data)	Digital code		None
GI3185F	1,024-kpps clock	TBD		None
GI3196X	PGNS downlink shift pulses	(51.2 kpps)		None
GI3198X	PGNS downlink stop pulses	(50 kpps)		None
GI3203H	Altitude to display	0 to 70K feet	0 to 400 nm	ALT indicator
GI3204L	Altitude rate to display	-8,200 to +8,200 fps	-700 to +700 fps	ALT RT indicator
GI3205L	V _y (lateral velocity to display)	-200 to +200 fps	-20 to +20 fps or -200 to +200 fps	X-pointer indicator
GI3214V	ASA +28 vdc	25.2 to 30.8 vdc (28 vdc)		AGS warning light
GI3215V	ASA +12 vdc	10.8 to 13.2 vdc (12 vdc)		AGS warning light
GI3232	AEA test mode failure	Off or on		AGS warning light
GI3233F	ASA 28v/400 cps	385 to 415 cps (400 cps)		AGS warning light
GI3301T	ASA temperature	0° to +250° F (+120° F) (R)		None
GI3305X	AGS condition (warmup)	Contact closure (R)		None

GUIDANCE, NAVIGATION, AND CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-26. Guidance, Navigation, and Control Subsystem - Telemetry Measurements (cont)

Code	Description	Telemetry Range (Nominal)	Display Range	Crew Display
GI3306X	AGS condition (standby)	Contact closure (R)		None
GI3311X	V_x (X incre- mental velocity)	0 to 64 kpps		None
GI3340V	E_x (yaw attitude error null)	-4.5 to +4.5 vrms		None
GI3341V	E_y (pitch atti- tude error null)	-4.5 to +4.5 vrms		None
GI3342V	E_z (roll attitude error null)	-4.5 to +4.5 vrms		None
GI3343X	X gyro SMRD	0 to 200 pps		None
GI3344X	Y gyro SMRD	0 to 200 pps		None
GI3345X	Z gyro SMRD	0 to 200 pps		None
GI3351V	-3.0 to -4.5 vdc (to DEDA)	-3.0 to -4.5 vdc (-3.7 vdc)		None
GI3352V	+4 to +5 vdc (to DEDA)	+4.0 to +5.0 vdc (4.5 vdc)		None
GI3353X	DEDA data (to DEDA)	Digital code		None
GI3354X	DEDA address/ data (from DEDA)	Digital code		None
GI3355X	DEDA shift pulses (from DEDA)	(64 kpps)		None
GI3356X	Shift four bits in (to DEDA)	(12.5 kpps)		None
GI3357X	Shift four bits out (to DEDA)	(12.5 kpps)		None
GI3358F	DEDA clock (to DEDA)	(128 kpps)		None
GI3401V	$\sin \alpha$ (to total attitude display)	-15 to +15 vrms		None
GI3402V	$\cos \alpha$ (to total attitude display)	-15 to +15 vrms		None
GI3403V	$\sin \beta$ (to total attitude display)	-15 to +15 vrms		None
GI3404V	$\cos \beta$ (to total attitude display)	-15 to +15 vrms		None
GI3405V	$\sin \gamma$ (to total attitude display)	-15 to +15 vrms		None

GUIDANCE, NAVIGATION, AND CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-26. Guidance, Navigation, and Control Subsystem - Telemetry Measurements (cont)

Code	Description	Telemetry Range (Nominal)	Display Range	Crew Display
GI3406V	Cos γ (to total attitude display)	-15 to +15 vrms		None
GI7031X	GSE (input register unloaded)	Off or on		None
GN7523L	LR (altitude rate) ($K_4 D_4$)	N/A	-700 to +700 fps	ALT RT indicator
GN7524L	LR lateral rate ($K_2 D_2$)	N/A	-20 to +20 fps or -200 to +200 fps	X-Pointer indicator
GN7525L	LR forward rate ($K_1 D_3 + \frac{9}{64} K_1 D_1$)	N/A	-20 to +20 fps or -200 to +200 fps	X-Pointer indicator
GN7527H	LR D_4 data	N/A	0 to 400 nm	ALT/ALT RT indicator
GN7529V	LR range gate strobe	4 to 10 vdc (7 vdc)		None
GN7530V	LR V_{XA} gate strobe	4 to 10 vdc (7 vdc)		None
GN7531V	LR V_{YA} gate strobe	4 to 10 vdc (7 vdc)		None
GN7532V	LR V_{ZA} gate strobe	4 to 10 vdc (7 vdc)		None
GN7533V	LR LGC antenna position command	0 or 28 vdc		None
GN7534V	LR reset strobe	4 to 10 vdc (7 vdc)		None
GN7535V	LR counter read-out command	4 to 10 vdc (7 vdc)		None
GN7536V	LR counter output (0)	4 to 10 vdc (7 vdc)		None
GN7537V	LR counter output (1)	4 to 10 vdc (7 vdc)		None
GN7545E	LR velocity transmitter RF power out	0 to 5 mw	0 to 5 units	SIGNAL STRENGTH indicator (panel 3)
GN7546E	LR altimeter transmitter RF power out	0 to 5 mw	0 to 5 units	SIGNAL STRENGTH indicator (panel 3)
GN7559D	LR antenna	-20 to +20 g/sec		None

GUIDANCE, NAVIGATION, AND CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-26. Guidance, Navigation, and Control Subsystem - Telemetry Measurements (cont)

Code	Description	Telemetry Range (Nominal)	Display Range	Crew Display
GN7560X	LR antenna position No. 1 (descent)	Contact closure		None
GN7561X	LR antenna position No. 2 (hover)	Contact closure		None
GN7563T	LR antenna temperature	-200° to +200° F (R)	-100° to +200° F	TEMP indicator (panel 3) and HEATER caution light
GN7564T	Sensor No. 2, LR antenna tempera- ture	-100° to +500° F		None
GN7565T	Sensor No. 3, LR antenna	-100° to +500° F		None
GN7567V	LR gain state D1	-0.85 to +6.6 vdc		None
GN7568V	LR gain state D2	-0.85 to +6.6 vdc		None
GN7569V	LR gain state D3	-0.85 to +6.6 vdc		None
GN7570V	LR gain state D4	-0.85 to +6.6 vdc		None
GN7571V	LR -25 vdc	-27 to 0 vdc (25 vdc)		None
GN7572V	LR +25 vdc	0 to 27 vdc (25 vdc)		None
GN7573V	LR +25 vdc	0 to 27 vdc (25 vdc)		None
GN7574V	LR +4 vdc	0 to 6 vdc (4 vdc)		None
GN7575V	LR -2 vdc	-4 to 0 vdc (-2 vdc)		None
GN7576V	LR antenna position No. 1 indication	0 or 28 vdc		None
GN7577V	LR antenna position No. 2 indication	0 or 28 vdc		None
GN7582E	LR velocity transmitter RF power output	TBD		None
GN7583E	LR altimeter transmitter RF power output	TBD		None
GN7584V	LR mode control	0 or 25 vdc		None
GN7585F	LR self-test	TBD		None

GUIDANCE, NAVIGATION, AND CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-26. Guidance, Navigation, and Control Subsystem - Telemetry Measurements (cont)

Code	Description	Telemetry Range (Nominal)	Display Range	Crew Display
GN7586F	LR range trans- mitter blanking signal	TBD		None
GN7589V	D1 at angle 0°	0.0025 to 1.26 vdc		None
GN7590V	D2 at angle 0°	0.0025 to 1.26 vdc		None
GN7591V	D3 at angle 0°	0.0025 to 1.26 vdc		None
GN7592V	F _R at angle 0°	0.0025 to 1.26 vdc		None
GN7593V	D1 at angle 90°	0.0025 to 1.26 vdc		None
GN7594V	D2 at angle 90°	0.0025 to 1.26 vdc		None
GN7595V	D3 at angle 90°	0.0025 to 1.26 vdc		None
GN7596V	F _R at angle 90°	0.0025 to 1.26 vdc		None
GN7599F	LR self-test altimeters			None
GN7609H	RR shaft angle (1X)	-70° to +155°	-5° to +5° or -50° to +50°	FDAI
GN7610R	RR shaft angle rate	-10° to +10°/sec	-2 to +2 mrad/ sec or -20 to +20 mrad/sec	X-pointer indicator
GN7611H	RR trunnion angle (1X)	-70° to +70°	-5° to +5° or -50° to +50°	FDAI
GN7612R	RR trunnion angle rate	-10° to -10°/sec	-2 to +2 mrad/ sec or -20 to +20 mrad/sec	X-pointer indicator
GN7613H	RR range (transponder mode)	TBD	0 to 400 nm	ALT/ALT RT indicator
GN7614L	RR range rate (PRF)	-700 to +700 fps	-700 to +700 fps	ALT/ALT RT indicator
GN7615V	RR auto track enable	0 or 4 vdc		None
GN7618V	RR +4-vdc supply	0 to 6 vdc (4 vdc)		None
GN7619V	RR +6-vdc supply	0 to 8 vdc (6 vdc)		None
GN7620V	RR -12-vdc supply	-14 to 0 vdc (-12 vdc)		None
GN7621X	RR no-track indication	Contact closure (R)		NO TRACK light and RNDZ RDR caution light

GUIDANCE, NAVIGATION, AND CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-26. Guidance, Navigation, and Control Subsystem - Telemetry Measurements (cont)

Code	Description	Telemetry Range (Nominal)	Display Range	Crew Display
GN7623V	RR range strobe	4 to 10 vdc (7 vdc)		None
GN7624V	RR range rate strobe	4 to 10 vdc (7 vdc)		None
GN7625V	RR reset strobe	4 to 10 vdc (7 vdc)		None
GN7626X	RR counter readout command	4 to 10 vdc (7 vdc)		None
GN7627V	RR "0" data	4 to 10 vdc (7 vdc)		None
GN7628V	RR "1" data	4 to 10 vdc (7 vdc)		None
GN7629V	RR +12 vdc	0 to 14 vdc (12 vdc)		None
GN7630V	RR +25 vdc	0 to 27 vdc (25 vdc)		None
GN7631V	RR 25 vdc (multiplier chain)	0 to 27 vdc (25 vdc)		None
GN7636V	RR range low scale factor	0 or 28 vdc		None
GN7637V	RR power on and select switch set to LGC	0 or 28 vdc		None
GN7638V	RR trunnion 16X resolver sine	0 to 5 vrms		None
GN7639V	RR shaft 16X resolver sine	0 to 5 vrms		None
GN7642E	RR RF power output	0 to 5 mw	0 to 5 units	SIGNAL STRENGTH indicator (panel 3)
GN7644V	RR ATM output (trunnion)	0 to 5 vdc (2.5 vdc)	0 to 5 units	SIGNAL STRENGTH indicator (panel 3)
GN7645V	RR ATM output (trunnion)	0 to 5 vdc (2.5 vdc)		None
GN7646V	RR ATM output (shaft)	0 to 5 vdc (2.5 vdc)	0 to 5 units	SIGNAL STRENGTH indicator (panel 3)
GN7647V	RR ATM output (shaft)	0 to 5 vdc (2.5 vdc)		None

GUIDANCE, NAVIGATION, AND CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-26. Guidance, Navigation, and Control Subsystem - Telemetry Measurements (cont)

Code	Description	Telemetry Range (Nominal)	Display Range	Crew Display
GN7648V	RR ATM output (AGC)	0 to 5 vdc	0 to 5 units	SIGNAL STRENGTH indicator (panel 3)
GN7649V	RR shaft motor sine	0 to 28 vrms		None
GN7650V	RR trunnion motor sine	0 to 28 vrms		None
GN7652V	RR shaft motor cosine	0 to 28 vrms		None
GN7653V	RR trunnion motor cosine	0 to 28 vrms		None
GN7655V	RR 15-vrms a-c power, single- phase	14 to 16 vrms (15 vrms)		None
GN7656V	RR 15-vrms a-c power, two-phase	15 to 25 vrms (20 vrms)		None
GN7681F	RR tone No. 3	TBD		None
GN7682F	RR tone No. 2	TBD		None
GN7683F	RR tone No. 1	TBD		None
GN7686V	RR 800/400-cps reference	0 to 30 vrms (28 vrms)		None
GN7689V	RR servoampli- fier input (shaft)	-15 to +15 millivolts dc		None
GN7690V	RR servoampli- fier input (trunnion)	-15 to +15 millivolts dc		None
GN7691D	RR antenna dish	-10 to +10 g/sec (zero)		None
GN7696F	RR reference (synthesizer)	TBD		None
GN7698V	RR trunnion 16X resolver cosine	0 to 5 vrms		None
GN7699V	RR shaft 16X resolver cosine	0 to 5 vrms		None
GN7721T	RR antenna sensor No. 1	-100° to +2,000° F		None
GN7722T	RR antenna sensor No. 2	-100° to +2,000° F		None
GN7723T	RR antenna temperature	-200° to +200° F (R)	-100° to +200° F	TEMP indicator (panel 3) and HEATER caution light

GUIDANCE, NAVIGATION, AND CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-26. Guidance, Navigation, and Control Subsystem - Telemetry Measurements (cont)

Code	Description	Telemetry Range (Nominal)	Display Range	Crew Display
GN7724	RR shaft compensated gyro error			None
GN7725	RR trunnion compensated gyro error			None
GN7726	RR shaft manual slew input			None
GN7727	RR trunnion manual slew input			None
GN7728	RR 1.7-mc IF signal (trunnion)			None
GN7729	RR 1.7-mc IF signal (reference)			None
GN7730	RR 1.7-mc IF signal (shaft)			None
GT0441X	DCA uplink verify word	(R)		None
GY0050X	Abort commanded	0 or 28 vdc		None
JG0021X	LGC margin test enable	Contact closure		None
JG0022V	LGC +14-vdc power supply control	-30 to +30 vdc		None
JG0023V	LGC +4-vdc power supply control	-30 to +30 vdc		None
JG2505X	IG servo step input	Contact closure		None
JG2506X	MG servo step input	Contact closure		None
JG2507X	OG servo step input	Contact closure		None
JG9101	ACE uplink			
JH9001	Gimbal trim malfunction reset			None
JH9002	Simulate staging command			None
JH9003	X-translation command to ATCA			None

GUIDANCE, NAVIGATION, AND CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-26. Guidance, Navigation, and Control Subsystem - Telemetry Measurements (cont)

Code	Description	Telemetry Range (Nominal)	Display Range	Crew Display
JH9004	Y-translation command to ATCA			None
JH9005	Z-translation command to ATCA			None
JI7027X	GSE (input reg- ister loaded)	Contact closure		None
JI7028X	GSE (data/ command)	Contact closure		None
JI7033X	GSE data in	Digital code		None
JI7035X	GSE shift pulses	51.2 kpps		None
JI7043X	GSE in use	Contact closure		None
JI7101V	Auxiliary heater power	(28 vdc)		None
JN9001	Gyros No. 1 and 2 activated			None
JN9002	Receiver (shaft error) input signal			None
JN9003	Receiver (sum) input signal			None
JN9004	Receiver (trunnion error) input signal			None
JN9012	LR deviation inhibit			None
JN9013	Gyros No. 3 and 4 activated			None
JW8021	Relay reset K2060R	(28 vdc)		None
JW8033V	Relay reset (PDA) K13	(28 vdc)		None

GUIDANCE, NAVIGATION, AND CONTROL SUBSYSTEM

2.3 MAIN PROPULSION SUBSYSTEM.

2.3.1 INTRODUCTION.

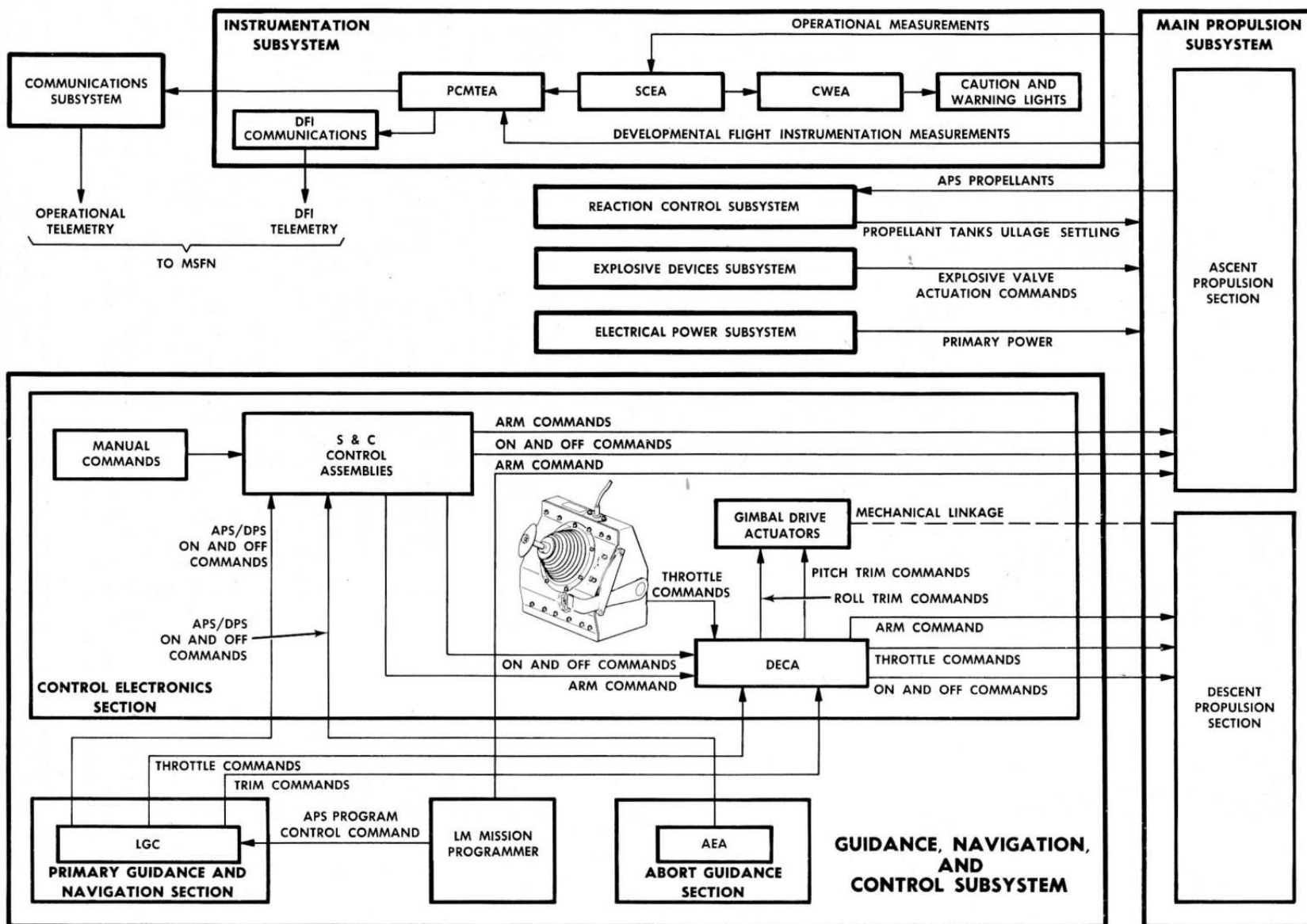
The Main Propulsion Subsystem (MPS) consists of a descent propulsion section and an ascent propulsion section. Each section is complete and independent of the other and consists of a liquid-propellant rocket engine with its own propellant storage, pressurization, and feed components. The descent propulsion section provides the thrust to control descent to the lunar surface. The ascent propulsion section provides the thrust for ascent from the lunar surface. In case of mission abort, the ascent and/or descent propulsion section can place the LM into a rendezvous trajectory with the CSM from any point in the descent trajectory. The choice of engine to be used depends on the cause for abort, on how long the descent engine has been operating, and on the quantity of propellant remaining in the descent stage.

Both propulsion sections use identical hypergolic propellants: a 50-50 mixture, by weight, of hydrazine (N_2H_4) and unsymmetrical dimethylhydrazine (UDMH) as the fuel; nitrogen tetroxide (N_2O_4), as the oxidizer. The injection ratio of oxidizer to fuel is 1.6 to 1, by weight.

Basic operation of the two propulsion sections is similar. In each section, gaseous helium forces the propellants from their tanks, through control valves, to the engine injectors. The descent propulsion section uses supercritical helium for propellant pressurization; the ascent propulsion section uses ambient gaseous helium. The primary reason for using supercritical helium is the weight saving obtained, due to its greater density. Both the descent and ascent engine assemblies consist of a combustion chamber, where the propellants are mixed and burned; an injector that determines the spray pattern of the propellants injected into the combustion chamber, and propellant control valves and orifices that meter and start and stop propellant flow to the engine upon command. The descent engine is larger to produce more thrust, is throttleable for thrust control, and is gimballed for thrust vector control. The ascent engine assembly is non-throttleable and is not gimballed. Redundancy of vital components in both propulsion sections provide for a high reliability factor.

The interface between the MPS and other LM subsystems is shown in figure 2-69. Transducer and valve-position-switch outputs (operational and DFI) that originate in the MPS are processed in the Instrumentation Subsystem (IS). The operational measurements that are monitored throughout the mission (real-time) are transmitted via the Communications Subsystem (CS) to MSFN. Developmental Flight Instrumentation (DFI) data used for postmission evaluation of MPS performance are routed to the communications section of the DFI for transmission to MSFN. The IS also processes MPS caution and warning signals. The switches and circuitry that open the MPS explosive valves to accomplish propellant tank pressurization and DPS venting are provided by the Explosive Devices Subsystem (EDS). Interconnect plumbing between the APS propellant tanks and the RCS thrust chamber assembly feed lines permits the RCS to use APS propellants during certain mission phases, thereby conserving the RCS supply. The electrical components of the MPS are supplied with 28-volt d-c and 115-volt a-c primary power through the Commander's and LM Pilot's buses of the Electrical Power Subsystem (EPS). Before starting the descent or the ascent engine, proper propellant tank ullage, under weightless condition, must be established. This is accomplished by moving the LM in the +X-direction (operating the four downward-firing RCS thrusters) which will cause the propellants to settle at the bottom of the tanks. As the propellants are consumed, tank ullage increases and more propellant settling time is required for each subsequent engine start. The Guidance, Navigation, and Control Subsystem (GN&CS) provides automatic on and off commands for both engines and initiates gimbal-drive-actuator and thrust-level commands for the descent engine. Manual override provisions for certain control functions (on and off, and thrust level commands) are available to the astronauts.

Descent engine arming and ignition are controlled by automatic guidance equipment, or by the astronauts through the stabilization and control (S&C) control assembly and the descent engine control assembly (DECA). A descent engine arm signal is sent to the



300LM3-314

Figure 2-69. Main Propulsion Subsystem - Interface Block Diagram

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

S&C control assembly when the astronauts set the ENG ARM switch (panel 1) to DES. Engine-on signals from the LM guidance computer (LGC) or abort guidance section (AGS) are sent to the DECA through the S&C control assembly. The DECA turns the descent engine on upon receiving the arm and the engine-on signals. The engine remains on until an engine-off command is received from the automatic guidance equipment. The astronauts can also generate engine on and off commands manually; these commands override the automatic commands.

Descent engine throttle control is accomplished by the LGC or the astronauts. The throttling-range limitations are from minimum thrust (approximately 10%) to approximately 60%, and full throttle (approximately 92.5%). The range between 60% and 92.5% is a transient region that cannot be used for extended periods because excessive engine erosion occurs in this zone. Under normal conditions, the engine cannot be operated in the transient region, because automatic or manual throttle commands above 60% automatically produce a full throttle output. Only in case of malfunction can inadvertent throttling occur in the transient region, in which case manual correction must be made. Automatic throttle increase and decrease signals from the LGC are sent to an integrating counter in the DECA. The analog output of the DECA controls descent engine thrust. The thrust/translation control assemblies (TTCA's) can be used by the astronauts to increase descent engine throttle, overriding the automatic throttle mode. In the manual throttle mode, the astronauts have complete control over descent engine thrust.

Descent engine gimbal trim is controlled automatically by the primary guidance and navigation section (PGNS) or the AGS, to compensate for center-of-gravity offsets during descent engine firing. In PGNS operation, the LGC sends trim on and off signals in two directions, for each gimbal axis, to the DECA. These signals operate power control circuitry, which drives the two gimbal drive actuators. In AGS operation, Y- and Z-axis error signals from the attitude and translation control assembly (ATCA) are sent to the DECA to drive the gimbal drive actuators. The gimbal drive actuators tilt the descent engine along the Y-axis and Z-axis a maximum of 6°.

Ascent engine ignition and shutdown can be initiated by the PGNS, the AGS, or the astronauts. Automatic and manual commands are sent to the S&C control assemblies, which provide sequential control of LM staging and engine on and off commands. The command to the ascent engine comes from a latching device, which provides a positive command for fail-safe purposes in the event that the engine-on command is interrupted. In the event of an abort stage command while the descent engine is firing, the S&C control assembly provides a time delay before commanding LM staging and ascent engine firing. The delay ensures that the descent engine has stopped thrusting before LM staging.

A detailed discussion of MPS operation in the various modes is given in subsection 2.2.

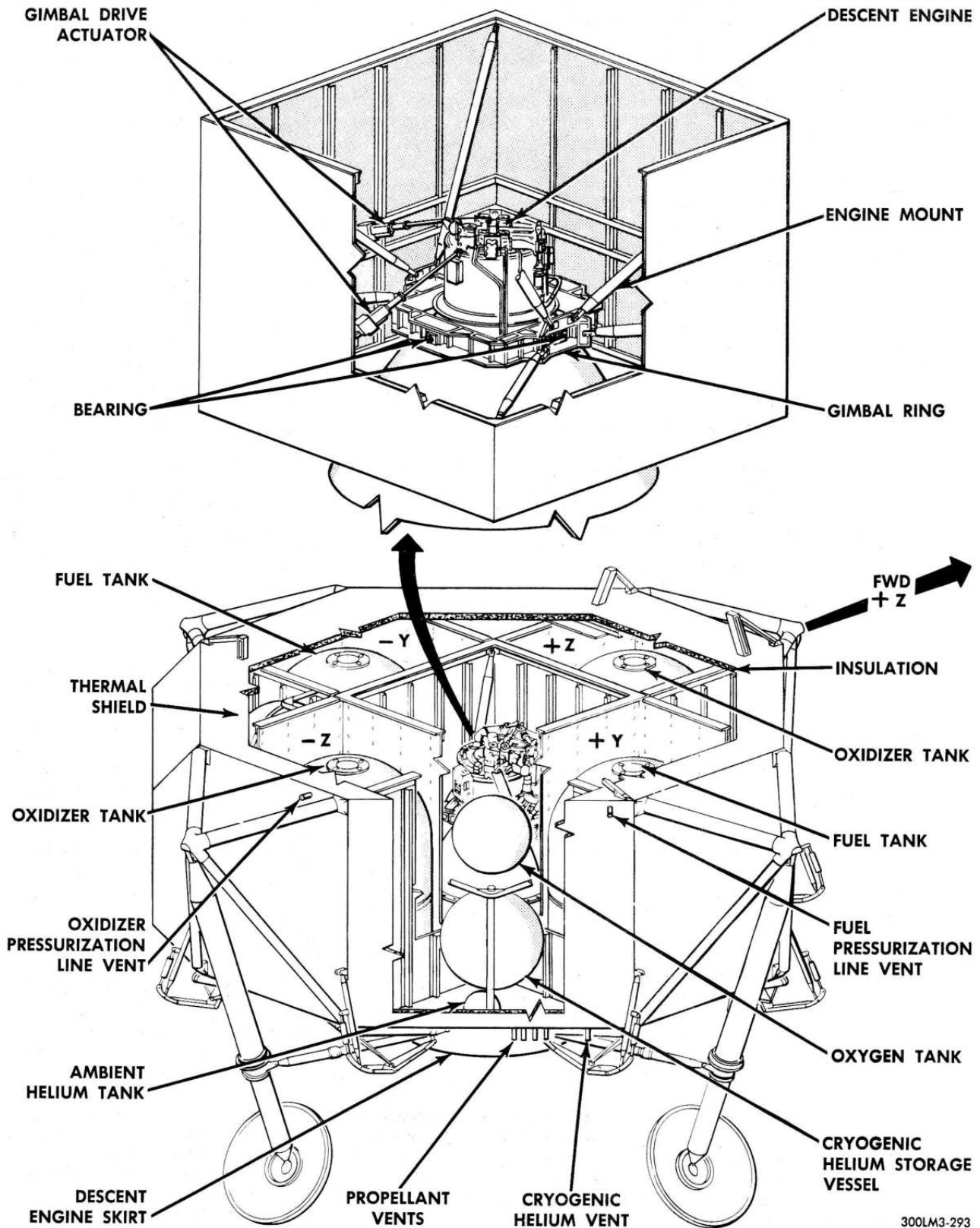
2.3.2

DESCENT PROPULSION SECTION FUNCTIONAL DESCRIPTION.

The descent propulsion section (DPS) consists of an ambient helium bottle and a cryogenic helium storage vessel with associated helium pressurization components; two fuel and two oxidizer tanks with associated feed components; and a pressure-fed, ablative, throttleable rocket engine. The engine can be shut down and restarted, within the operational limitations and restrictions (paragraph 2.3.6), as required by the mission. At the fixed full-throttle position, the engine develops a nominal thrust of 9,870 pounds; it can also be operated within a range of approximately 1,050 to 6,300 pounds of thrust.

The engine is mounted in the center compartment of the descent stage cruciform (figure 2-70); it is suspended at the throat of the combustion chamber on a gimbal ring that is part of the engine assembly. The gimbal ring is pivoted in the descent stage structure, along an axis normal to that of the engine pivots. The engine can be tilted up to +6° or -6°, by means of gimbal drive actuators, to ensure that the thrust vector passes through the center of gravity of the LM.

LMA790-3-LM 3
 APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA



300LM3-293

Figure 2-70. Descent Propulsion Section - Component Location

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Functionally, the DPS can be subdivided into a pressurization section, a propellant feed section, and an engine assembly.

2.3.2.1

Pressurization Section. (See figure 2-71.)

Before earth launch, the propellant tanks are only partly pressurized, so that the tanks will be maintained within a safe pressure level under the temperature changes experienced during launch and earth orbit. Before initial engine start, the ullage space in each propellant tank requires additional pressurization. This initial pressurization (pre-pressurization) is accomplished with ambient helium (supercritical helium cannot be used because the fuel circulating through the fuel/helium heat exchanger may freeze before proper fuel flow is established). A pressure transducer at the outlet port of the ambient helium bottle supplies a signal through the HELIUM MON selector switch (panel 1) (AMB PRESS position) to the HELIUM indicator to enable the astronauts to check the status of the bottle before initial engine start. The propellant tanks are prepressurized by opening explosive valves in the ambient helium line and in the lines leading to the fuel and oxidizer tanks. The valve in the ambient helium line prevents helium flow from the storage bottle before prepressurization. The valves in the lines leading to the fuel and oxidizer tanks prevent propellant vapors from degrading the upstream components due to prolonged exposure before pressurization.

After setting the MASTER ARM switch (panel 8) to ON, the DES START He PRESS switch is set to FIRE, opening the ambient helium isolation explosive valve. Ambient helium flows from the storage bottle through the open explosive valve and through a filter, where debris from the explosive valve is trapped. The ambient helium enters the main pressurization line downstream of the normally closed helium isolation solenoid valve and flows through the secondary pressure regulator, where pressure is reduced to approximately 245 psi. The DES PRPLNT ISOL VLV switch (panel 8) is then set to FIRE to open the fuel and oxidizer compatibility valves. This permits the regulated ambient helium to enter the propellant tanks to provide the normal ullage pressure.

After pressurization with ambient helium, the supercritical helium from the cryogenic helium storage vessel is used. Supercritical helium is stored at a density approximately eight times that of ambient helium. Because heat transfer from the outside to the inside of the cryogenic vessel causes a gradual increase in pressure (approximately 10 psi per hour), the initial pressure within the cryogenic storage vessel is determined by the mission duration. The initial loading pressure and temperature of the supercritical helium is planned so that the supercritical helium will be maintained within a safe pressure/time envelope throughout the mission. Only a component malfunction or significant time slippage can cause the supercritical helium to approach, or exceed, the limits of the pressure/time envelope. An out-of-limit condition may result in rupture of the dual burst disks, terminating descent engine operation.

The cryogenic storage vessel is isolated by an explosive valve, which is fired automatically after an engine-on command has been given. The engine-on command can be given manually by setting the ENG ARM switch (panel 1) to DES and pressing the START pushbutton (panel 5), or it can be given automatically by the LGC or AGS. In either case, a delay circuit causes a 1.3 ± 0.5 -second delay between opening of the propellant shutoff valves and firing of the supercritical helium isolation valve. This time delay prevents the supercritical helium from entering the fuel/helium heat exchanger until proper fuel flow is established and freezing of the fuel in the heat exchanger cannot occur.

The supercritical helium initially passes through the first loop of the two-pass fuel/helium heat exchanger. Here it absorbs heat from the fuel that is routed from the fuel tanks through the heat exchanger, before ultimate delivery to the engine. The helium is warmed to approximately -200°F and routed back through the helium/helium heat exchanger inside the cryogenic helium storage vessel. The -200°F helium transfers heat to the remaining supercritical helium in the vessel, causing an increase in pressure in the vessel that ensures continuous expulsion of helium throughout the entire period of operation. After passing through the helium/helium heat exchanger where it is cooled to

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

approximately -300° F, the helium is routed back through the second loop of the fuel/helium heat exchanger and heated to approximately -35° F before delivery to the pressure regulators.

With the supercritical helium pressurization system operating, the pressure in the cryogenic helium storage vessel stabilizes within 1,200 and 1,600 psia, at approximately -400° F. The pressure is monitored on the HELIUM indicator when the HELIUM MON selector switch is set to SUPCRIT PRESS. The temperature of the supercritical helium during the entire warming process is sensed by transducers at various points throughout the heat exchanger loop and is telemetered to MSFN, where it is recorded for evaluation after completion of the mission. The cryogenic helium storage vessel is protected against overpressurization by a dual burst disk assembly. If an excessive heat transfer across the vessel wall increases the internal pressure above approximately 1,900 psi, the burst disks rupture and the entire helium supply is lost, curtailing operation of the descent engine. A normally open vent relief valve between the two burst disks protects the downstream burst disk in case the upstream burst disk develops a small leak. A thrust neutralizer at the outlet of the downstream burst disk prevents generation of unidirectional thrust if the burst disks rupture.

Downstream of the fuel/helium heat exchanger, the helium flow continues through a filter that traps debris from the explosive valve; then the pressurization line divides into two parallel legs. A normally open, latching solenoid valve and a pressure regulator are in series in the primary leg; a normally closed, latching solenoid valve in series with a pressure regulator are in the secondary leg. The pressure of the helium flowing through the primary leg is reduced by the pressure regulator to the nominal pressure (245 psia) required to pressurize the propellant tanks. If this regulator fails open or closed, pressure at the helium manifold increases or decreases beyond acceptable limits (above 260 psia, below 220 psia) and the DES REG warning light (panel 1) goes on. Under these conditions, the astronauts must close the solenoid valve in the malfunctioning leg and open the solenoid valve in the redundant leg, to restore normal propellant tank pressurization. The normally open (primary) solenoid valve is closed by momentarily setting the DESCENT He REG 1 switch (panel 1) to CLOSE; the DESCENT He REG 1 talkback above the switch then provides a barber-pole display. The normally closed (secondary) solenoid valve is opened by momentarily setting the DESCENT He REG 2 switch to OPEN; the DESCENT He REG 2 talkback above the switch then provides a gray display. Both solenoid valves may be closed during the coast periods of descent, to prevent inadvertent tank overpressurization due to possible helium leakage through the pressure regulators.

The primary and secondary helium flow paths merge downstream of the regulators to form a common helium pressurization manifold. Transducers monitor the manifold pressure; they provide continuous telemetry signals to MSFN, and signals that cause the DES REG warning light to go on when the sensed pressure exceeds 260 psia or drops below 220 psia. The manifold routes the helium into two flow paths: one path leads to the oxidizer tanks; the other, to the fuel tanks. Each path has a quadruple check valve assembly in a series-parallel arrangement. The quadruple check valves isolate the upstream components from the corrosive propellant vapors and prevent hypergolic action, as a result of backflow from the propellant tanks, in the helium pressurization manifold. After passing through the compatibility explosive valves, the helium flows into the top of the fuel and oxidizer tanks. Diffusers at the top of the tanks uniformly distribute the helium throughout the ullage space. Helium crossover lines maintain a balanced ullage pressure in the tanks containing the same propellants.

Immediately upstream and in parallel with the propellant tanks, each helium flow path contains a relief valve assembly to protect the propellant tanks against overpressurization. The assembly (a burst disk in series with a relief valve) vents pressure in excess of approximately 275 psia and reseals the flow path after overpressurization is relieved. A thrust neutralizer eliminates unidirectional thrust generated by the escaping gas. To prevent leakage through a faulty relief valve during normal operation, the burst disk is located upstream of the relief valve. The burst disk ruptures at a pressure slightly above the relief valve setting. The relief valves can pass the entire helium flow from a failed-open regulator without damaging the propellant tanks.

MAIN PROPULSION SUBSYSTEM

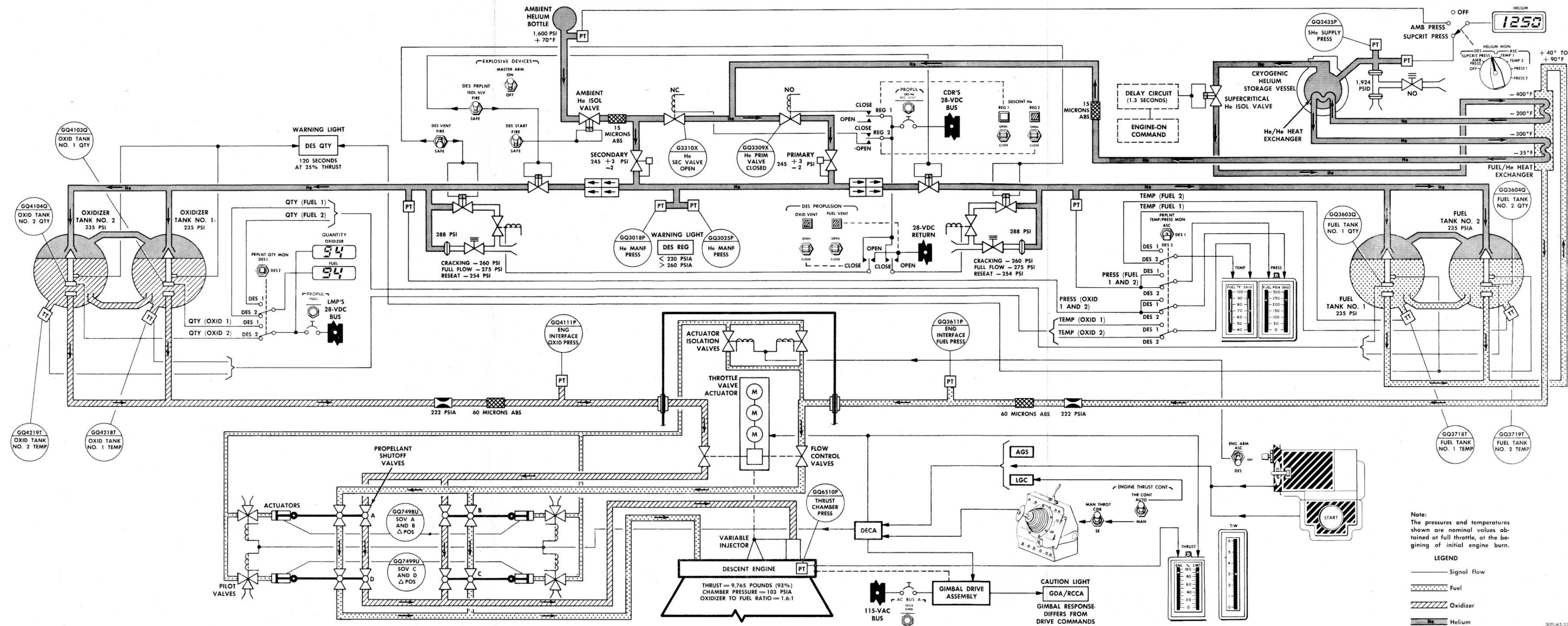


Figure 2-71. Descent Propulsion Section - Simplified Functional Flow Diagram

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Two vent lines, in parallel with the relief valve assemblies, include an explosive valve in series with a normally closed solenoid valve for each propellant tank. The vent lines are intended for planned depressurization of the tanks after lunar landing, when heat soak-back from the engine (after shutoff) causes pressure buildup in the tanks. The planned venting arrangement protects the astronauts against untimely venting of the tanks through the relief valve assemblies. The fumes are vented overboard, one propellant at a time, through the relief valve thrust neutralizers at the fuel and oxidizer pressurization line vents. (See figure 2-70.) To open the vent lines, the MASTER ARM switch is set to ON and the DES VENT switch (panel 8) is set momentarily to FIRE, opening both explosive vent valves simultaneously. The MASTER ARM switch is then set to OFF. The oxidizer tank and pressurization line is vented by setting the OXID VENT switch (panel 8) to OPEN; the OXID VENT talkback will change to gray. Venting of the line is monitored by setting the PRPLNT TEMP/PRESS MON switch (panel 1) to DES 1 and the HELIUM MON selector switch (panel 1) to SUPCRIT PRESS. When the OXID PRESS indicator and the HELIUM indicator indicate less than 20 psia, the HELIUM MON selector switch is set to OFF, the OXID VENT switch is set to CLOSE, and the OXID VENT talkback will change to a barber-pole display. To vent the fuel tank and pressurization line, the FUEL VENT switch is set to OPEN, changing the FUEL VENT talkback to gray. When the FUEL PRESS indicator indicates less than 20 psia, the FUEL VENT switch is set to CLOSE, causing the FUEL VENT talkback to provide a barber-pole display.

2.3.2.2 Propellant Feed Section. (See figure 2-71.)

Each pair of propellant tanks is manifolded into a common delivery line. Each pair is also interconnected by a double crossfeed piping arrangement to maintain a positive pressure balance across the upper (helium) and lower (propellant) portions.

Helium pressure in the propellant tanks is monitored on the PRESS indicator (panel 1), propellant temperature in the tanks is monitored on the TEMP indicator. The PRPLNT TEMP/PRESS MON switch selects the set of fuel and oxidizer tanks (No. 1 or No. 2) for monitoring. Each propellant tank has its own temperature transducer to supply temperature signals to the indicator. One pressure transducer in the fuel pressurization line and one in the oxidizer pressurization line supply pressure signals to the indicator. Therefore, the pressure reading remains constant regardless of whether tanks No. 1 or 2 are monitored. Propellant quantity remaining in the tanks is monitored on the OXIDIZER and FUEL QUANTITY indicators (panel 1). The PRPLNT QTY MON switch selects the set of fuel and oxidizer tanks (No. 1 or No. 2) for monitoring.

Pressurized helium, acting on the surface of the propellant, forces the fuel and oxidizer into the delivery lines through a propellant retention device that maintains the propellant in the delivery lines during negative-g acceleration (up to acceleration in excess of -2g). The oxidizer is piped directly to the engine assembly; the fuel circulates through the fuel/helium heat exchanger before it is routed to the engine assembly. Each delivery line contains a trim orifice and a filter. The trim orifices provide engine interface pressure of approximately 220 psia at full throttle position for proper propellant use. The filters prevent debris, originating at the explosive valves or in the propellant tanks, from contaminating downstream components.

2.3.2.2.1 Propellant Quantity Gaging System. (See figure 2-72.)

The propellant quantity gaging system (PQGS) enables the astronauts to continuously monitor the quantity (from 95% full) of propellants remaining in the four tanks. The capacitance-type PQGS consists of four quantity-sensing probes with low-level sensors, a control unit, two QUANTITY indicators, the PRPLNT QTY MON switch, and the DES QTY warning light. During the lunar-landing mission, the PQGS will operate continuously for 15 minutes; the system will be in operation during the final powered descent phase, from start of the braking maneuver (10 seconds after engine turn-on) until lunar touchdown. The low-level sensors provide a discrete signal to cause the DES QTY warning light to go on when the propellant level in any tank is down to 9.4 inches (equivalent to 5.6% propellant remaining). When the DES QTY warning light goes on, the quantity of propellant remaining is sufficient for only 2 minutes of engine burn at 24% thrust.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

The quantity-sensing probes are double-walled; one probe is installed to run vertically through the center of each propellant tank. Each probe has a 20-volt d-c input. Varying resistance, caused by propellant consumption, causes the output signal to vary from 5 volts dc to zero, in direct proportion to propellant quantity. The output signals, processed through the probe circuitry, are sent directly to the control unit.

The control unit converts the probe output signals to provide the following:

- Indications of the quantity of propellant remaining in the tanks, on the QUANTITY indicators
- Conditioned signals, corresponding to propellant quantities in each of the four tanks, to the telemetry registers
- A warning signal when the propellant in any of the four tanks is depleted to a predetermined level.

The PQGS is accurate within 1% of full tank capacity, except in the range of 8% to 25%, where accuracy is $\pm 0.5\%$. While the engine is shut off, the QUANTITY indicators display the propellant quantity that was in the tanks when the last engine burn was terminated.

2.3.2.3

Engine Assembly. (See figure 2-73.)

Fuel and oxidizer enter the engine assembly through interface flanges on opposite sides of the engine. The fuel line has a tap-off branch (pilot valves actuation line) that leads through two actuator isolation valves (arranged in parallel for redundancy) to the four solenoid-operated pilot valves. The fuel in this line is routed through the pilot valves to the actuators, where it is used as actuation fluid to open the propellant shutoff valves. The main fuel and oxidizer flow is routed through respective flow control valves; then each flow path splits into two parallel paths that route the propellants through the redundant propellant shutoff valves. The propellant shutoff valve assemblies are in a series-parallel arrangement. The series redundancy prevents open failure; the parallel redundancy prevents closed failure. The valves open simultaneously to permit propellant flow to the engine while it is operating; they close simultaneously to terminate propellant flow at engine shutdown. At the fuel shutoff valves, venturis restrict the fuel flow so that the oxidizer reaches the injector between 40 and 50 milliseconds before the fuel. This precludes the possibility of a fuel lead, which would result in rough engine starts. Downstream of the propellant shutoff valves, the parallel paths merge to form one fuel and one oxidizer path. The fuel passes through a final trim orifice and enters the variable-area injector manifold, where a concentric annulus of fuel flow is formed. The oxidizer is routed through the center element of the injector to the combustion chamber, where it mixes with the fuel for combustion.

Before initial engine operation and during engine shutdown, the solenoid-operated actuator isolation valves (pre-valves) are closed to prevent possible fuel loss in the pilot valve actuation line due to leakage at the pilot valves. The actuator isolation valves are opened by setting the ENG ARM switch to DES. This enables the actuation fuel to flow to the pilot valves just before the pilot valves are opened. When the START pushbutton is pressed (or an engine-on command initiated), the four solenoid-operated pilot valves open simultaneously, permitting the actuation fuel to open the propellant shutoff valves, and thus routing fuel and oxidizer to the combustion chamber. During the start, the solenoids in the pilot valves unseat the caged balls from the inlet ports and seat them against the overboard vent ports. Fuel enters the actuator cavities; the actuator pistons are connected to rack-and-pinion linkages that rotate the balls of the shutoff valves 90° to the open position to permit propellant flow to the injector. The series-parallel redundancy in the valve arrangement provides for positive start and shutdown. During shutdown, the solenoids in the pilot valves are deenergized and the vent ports are open. The spring-loaded actuators close the shutoff valves. The residual actuation fuel is vented overboard through four separate lines that lead to vent ports at the bottom of the descent stage. (See figure 2-70.)

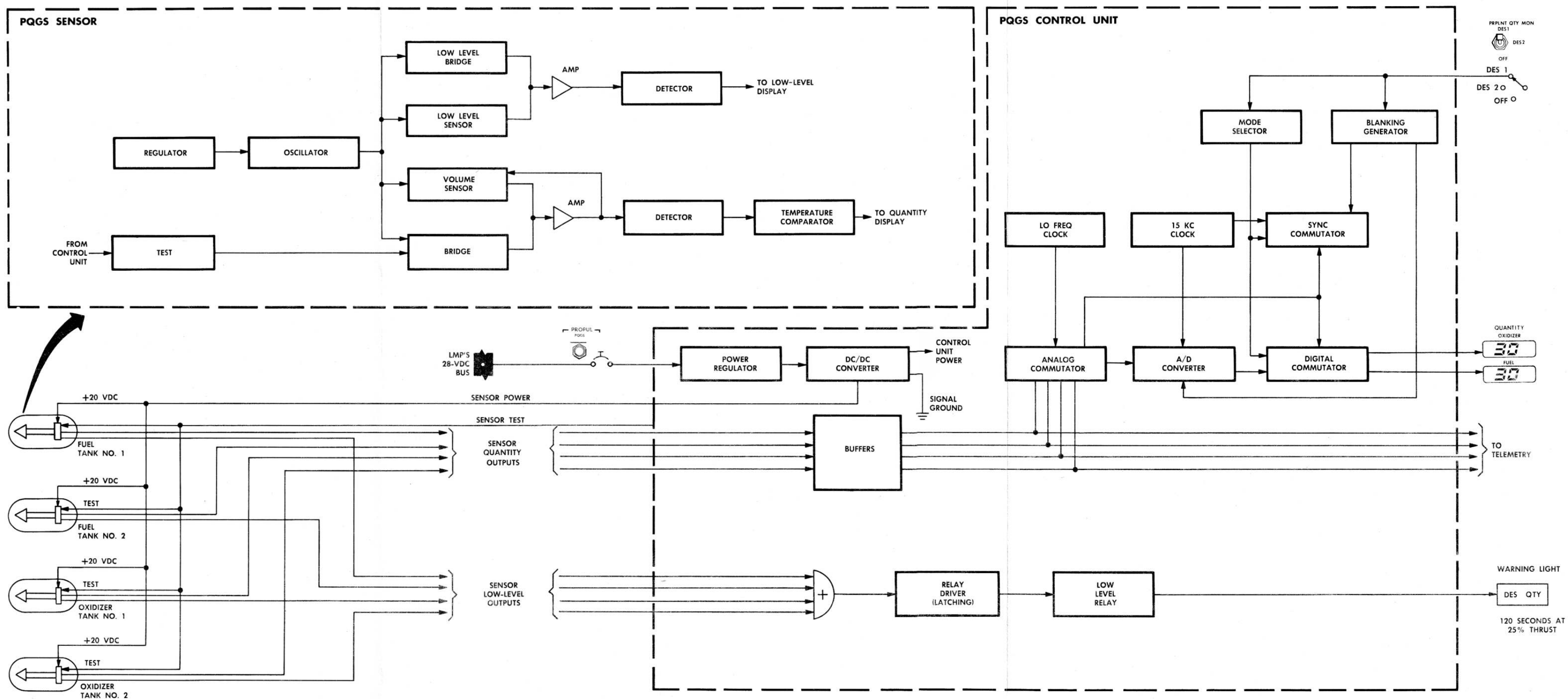


Figure 2-72. Propellant Quantity Gaging System - Simplified Functional Block Diagram

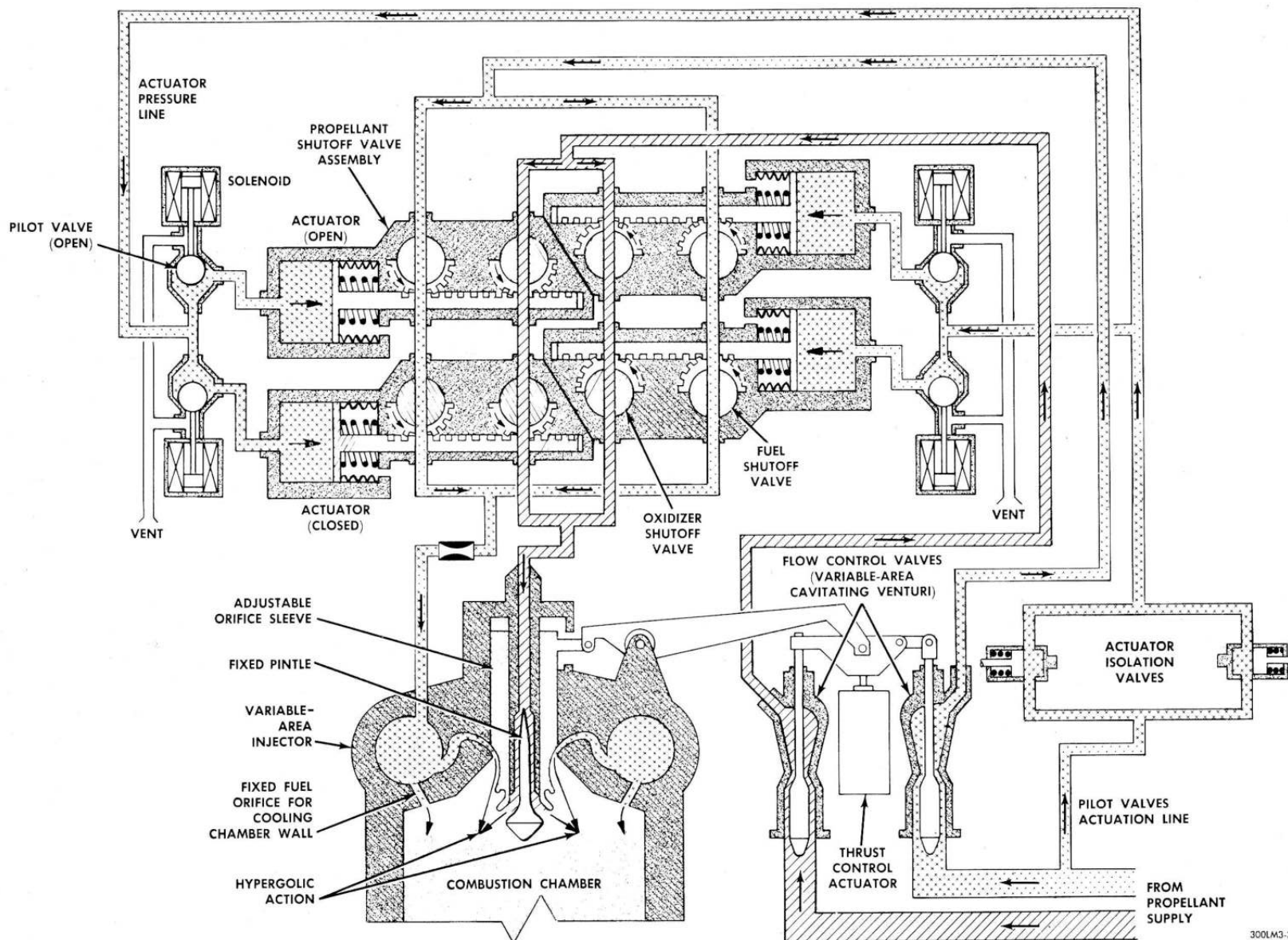


Figure 2-73. Descent Engine Assembly - Flow Diagram

LMA790-3-LM 2
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

The propellants in the main fuel and oxidizer lines flow through cavitating-venturi-type flow control valves that control propellant flow to the engine below the 60% throttle setting. Transition from cavitation to noncavitation occurs between 60% and 70%. At full throttle, and during momentary transition through the full throttle to 60% range, engine throttling takes place primarily in the pintle assembly of the injector and in the flow control valves. At approximately 70% of maximum thrust, cavitation commences in the throats of the flow control valves causing the valves to function as cavitating venturis down to minimum thrust. Once cavitation begins, the propellant metering function is entirely removed from the injector; flow is controlled entirely by the flow control valves.

The throat area of the flow control valves is regulated by a close-tolerance, contoured, metering pintle that is linked directly to the injector sleeve. The linkage is operated by a single actuator so that movement of the actuator simultaneously adjusts the pintles in the flow control valves and the movable sleeve in the injector. The fuel and oxidizer are injected at velocities and angles compatible with variations in weight flow. At full throttle, engine operation is conventional. As the engine is throttled down, the pintles in the flow control valves are moved to decrease the flow control area in the venturis so that the pressure drop across the valves balances out the differential between engine and injector inlet pressures. At the same time, the injector orifice areas are decreased so that the injection velocities and impingement angles of fuel and oxidizer are maintained at near-optimum condition for combustion efficiency.

The injector consists of a faceplate and fuel manifold assembly with a coaxial oxidizer feed tube and an adjustable (metering) orifice sleeve. Oxidizer flows through the center tube and out between a fixed pintle and the bottom of the sleeve; the fuel orifice is an annular opening between the sleeve contour and the injector faceplate. The fuel flows behind the face of the injector to cool the faceplate. Some fuel is tapped off near the chamber wall to be used for barrier cooling of the combustion chamber wall. The fuel is emitted in the form of a thin cylindrical sheet; the oxidizer, in a series of individual sprays. The oxidizer sprays break up the fuel stream and establish the injector pattern at all thrust settings.

The mechanical linkage that connects the pintle of the flow control valves and the injector sleeve is pivoted about a fulcrum attached to the injector body. Throttling is controlled by an electromechanical, linear servoactuator (with three redundant motors) that positions the linkage in response to electrical input signals. At maximum thrust, the actuator positions the linkage to fully open the flow control valves and injector apertures. As commanded thrust is reduced, the actuator reduces the flow at the control valves and moves the injector orifice sleeve to reduce the apertures. As the adjustable orifice sleeve moves upward, the area of the propellant orifices increases.

The engine can be armed and fired automatically or manually. The engine is armed manually by setting the ENG ARM switch to DES. The engine can then be started and stopped by the Commander by pressing the START and STOP pushbuttons on panel 5; it can be stopped by the LM Pilot by pressing the STOP pushbutton on panel 6. The mode of thrust control is determined by the THR CONT switch (panel 1). When this switch is set to AUTO, engine thrust is controlled by the LGC. When the switch is set to MAN, the Commander's or LM Pilot's TTCA (depending on the setting of the MAN THROT switch, panel 1) controls the engine thrust. In the automatic mode, the TTCA is still operational and supplies a 10% thrust command (when set against its low stop) that is summed with the LGC command. The combined signal is then sent to the descent engine. The ENG and CMD THRUST indicators (panel 1) display the percentage of engine thrust and commanded thrust, respectively. The indicator is calibrated such that at full throttle position, the indicator will read 100% instead of 92.5% which is the actual full throttle thrust. Proportional differences between actual and indicated thrust will be obtained in the low-throttle range. The ENG thrust indication is derived from a pressure transducer in the combustion chamber. (Thrust is proportional to chamber pressure.) The CMD thrust indication is the LGC command summed with a 10% bias that represents the 10% TTCA command. The ENG and CMD THRUST indicator readings should be identical. Display of dissimilar readings indicates that the engine is not following the thrust commands or that transfer from automatic to manual throttle control is in process. Smooth transfer is accomplished

MAIN PROPULSION SUBSYSTEM

when the CMD pointer is at 10% thrust, at which time the THR CONT switch is set to MAN and the pointers of the ENG and CMD THRUST indicators again align. Some deviations can be expected due to combustion chamber erosion, which will cause a slight chamber pressure decay with increasing engine operating time.

The T/W (thrust/weight) indicator (panel 1) is used primarily to monitor X-axis acceleration during lunar landing and liftoff. The T/W indicator is a self-contained accelerometer that displays instantaneous X-axis acceleration in lunar-g units (1 lunar g = 5.32 ft/sec²). Inasmuch as a given throttle setting provides a specific acceleration when the vehicle has a given mass, the T/W indicator can be used as backup for the THRUST indicators to monitor engine performance. Information on how the T/W indicator shall be used during an earth-orbital mission and how the percentage of thrust on the ENG THRUST indicator relates to the lunar g's on the T/W indicator at specific time intervals during the mission will be supplied when available.

2.3.3 DESCENT PROPULSION SECTION MAJOR COMPONENT/FUNCTIONAL DESCRIPTION.

2.3.3.1 Explosive Valves.

An ambient helium isolation valve, a supercritical helium isolation valve, a fuel compatibility valve, an oxidizer compatibility valve, a fuel vent valve, and an oxidizer vent valve are the explosive valves used in the DPS. These valves normally are closed; they are controlled by the EDS control and fire circuits and, when fired, fully open and remain open. To prevent valve failure in the closed position, each explosive valve has two cartridges that are fired from redundant systems in the EDS. (See figure 2-74.)

2.3.3.2 Cryogenic Helium Storage Vessel.

The cryogenic helium storage vessel is a double-walled spherical tank that consists of an inner spherical tank and an outer jacket. The void between the tank and the jacket is filled with aluminized mylar insulation and evacuated, minimizing ambient heat transfer into the tank. The vessel has associated fill and vent ports, a pressure-relief device (two burst disks in series), and an internal helium/helium heat exchanger. The vessel is initially vented and loaded with liquid helium; the fill sequence is completed by closing off the vent and introducing a high-pressure head of gaseous helium at a higher temperature than that of the liquid helium. As this occurs, the heat transfer causes the liquid helium to evaporate into a high-density gas.

The burst disk assembly prevents hazardous overpressurization within the vessel. It consists of two burst disks in series, with a normally open, low-pressure vent valve between the disks. The burst disks are identical; they burst at a pressure between 1,881 and 1,967 psid to vent the entire supercritical helium supply overboard. The thrust neutralizer at the outlet of the downstream burst disk diverts the escaping gas into opposite directions to prevent unidirectional thrust generation. The vent valve prevents low-pressure buildup between the burst disks if the upstream burst disk leaks slightly. The valve is open at pressures below 150 psia. It closes when the pressure exceeds 150 psia, so that for faster leaks, the subsequent pressure buildup will eventually rupture the downstream burst disk and all supercritical helium will be vented.

2.3.3.3 Fuel/Helium Heat Exchanger.

Fuel is routed directly from the fuel tanks to the two-pass fuel/helium heat exchanger. The heat exchanger transfers heat from the fuel to the supercritical helium, which is warmed to operating temperature by flowing through the two separate heat exchanger passes. The fuel/helium heat exchanger is of finned tube construction; the first and second helium passes are in parallel crossflow with respect to the fuel. All parts are stainless steel; each fin is lap brazed to an adjacent fin and to the side panels to increase structural rigidity. Helium flows in the tubes and fuel flows in the outer shell across the bundle of staggered, straight tubes.

MAIN PROPULSION SUBSYSTEM

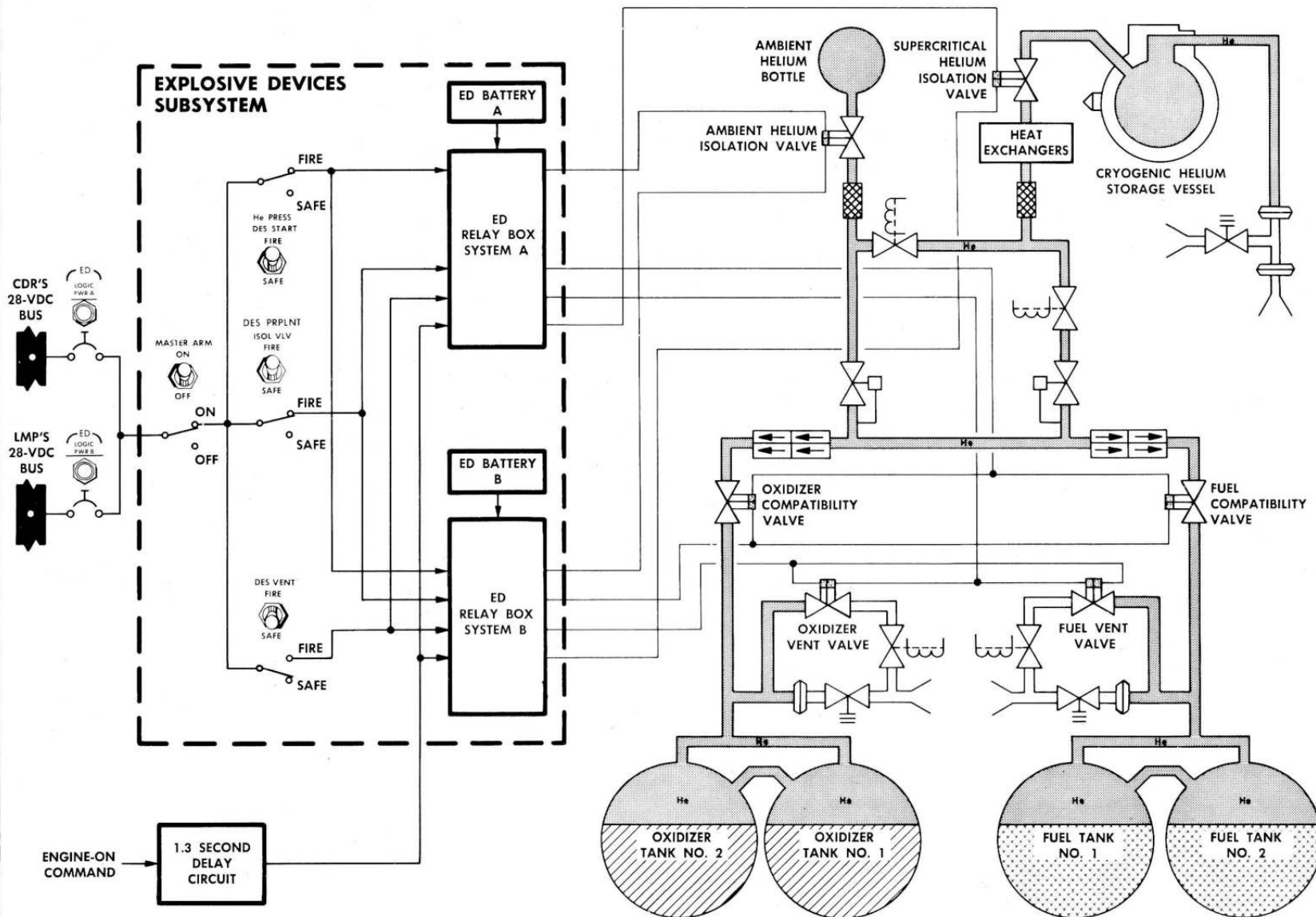


Figure 2-74. Descent Propulsion Section - Explosive Valves, Simplified Functional Diagram

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

2.3.3.4 Helium Isolation Valves. (See figure 2-75.)

The helium isolation valves are latching, solenoid-operated valves that shut off helium flow through one leg of redundant flow lines if the pressure regulator in the leg fails open. The valves are actuated by the DESCENT He REG 1 and REG 2 switches (panel 1), respectively. A position switch in each valve feeds a signal to the DESCENT He REG 1 and REG 2 talkbacks to indicate whether the particular valve is closed (barber-pole display) or open (gray display).

2.3.3.5 Helium Pressure Regulators. (See figure 2-76.)

To be supplied.

2.3.3.6 Relief Valve Assemblies. (See figure 2-77.)

Each helium pressurization line that leads to the propellant tanks has a relief valve assembly that consists of a burst disk in series with relief valve. The burst disk prevents helium loss through the relief valve if it should leak during normal operation. The relief valve prevents helium loss during normal operation once the burst disk is ruptured. Under high pressure, the relief valve opens, dumping helium overboard. A thrust neutralizer provides for omnidirectional thrust generation by the escaping helium. When the pressure drops below the reseal pressure, the relief valve closes to prevent further helium loss. When the relief valve poppet is closed, a low-pressure vent between the burst disk and the relief valve is opened. This prevents pressure buildup against the relief valve in case of a burst-disk leak. Under high pressure (after burst-disk rupture), the vent closes as the relief valve poppet moves off its seat to the open position.

2.3.3.7 Propellant Storage Tanks.

The propellant supply is contained in four cylindrical, spherical-ended titanium tanks of identical size and construction. Two tanks contain fuel; the other two, oxidizer. Each pair of tanks containing like propellants is interconnected at the top and bottom to ensure even distribution of propellant and pressurizing gas. A diffuser at the helium inlet port (top) of each tank distributes the pressurizing helium uniformly into the tank. An antivortex device in the form of a series of vanes, at each tank outlet, prevents the propellant from swirling into the outlet port, thus preventing inadvertent helium ingestion into the engine. Each tank outlet also has a propellant retention device (negative-g can) that permits unrestricted propellant flow from the tank under normal pressurization, but blocks reverse propellant flow (from the outlet line back into the tank) under zero-g or negative-g conditions. This arrangement ensures that helium does not enter the propellant outlet line as a result of a negative-g or zero-g condition or propellant vortexing; it eliminates the possibility of engine malfunction due to helium ingestion.

2.3.3.8 Throttle Valve Actuator. (See figures 2-78 and 2-79.)

The throttle valve actuator is an electromechanical, linear servoactuator, powered by redundant d-c motors. It is between the fuel and oxidizer flow control valves; its base is attached rigidly to the engine head end. The output shaft of the actuator is attached to the throttle linkage. In response to electrical command inputs, it moves the throttle linkage, which positions the flow control valve pintles and the injector sleeve. Changing the position of the flow control valve pintles changes the quantity of fuel and oxidizer metered into the engine and, thus, the magnitude of engine thrust.

Three redundant motors drive the jackscrew. If one motor fails, the actuator can operate at normal speed with two motors. The actuator case is hermetically sealed to prevent cold welding in a vacuum environment. All mechanical elements of the actuator (motors, potentiometers, bearings, jackscrew, etc) are within the hermetically sealed portion of the unit. The amplifiers are mounted in a separate housing, which is mechanically fastened to the main actuator housing. The area that contains the amplifiers is sealed against the ambient environment (not hermetically sealed).

LMA790-3-LM 3
 APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

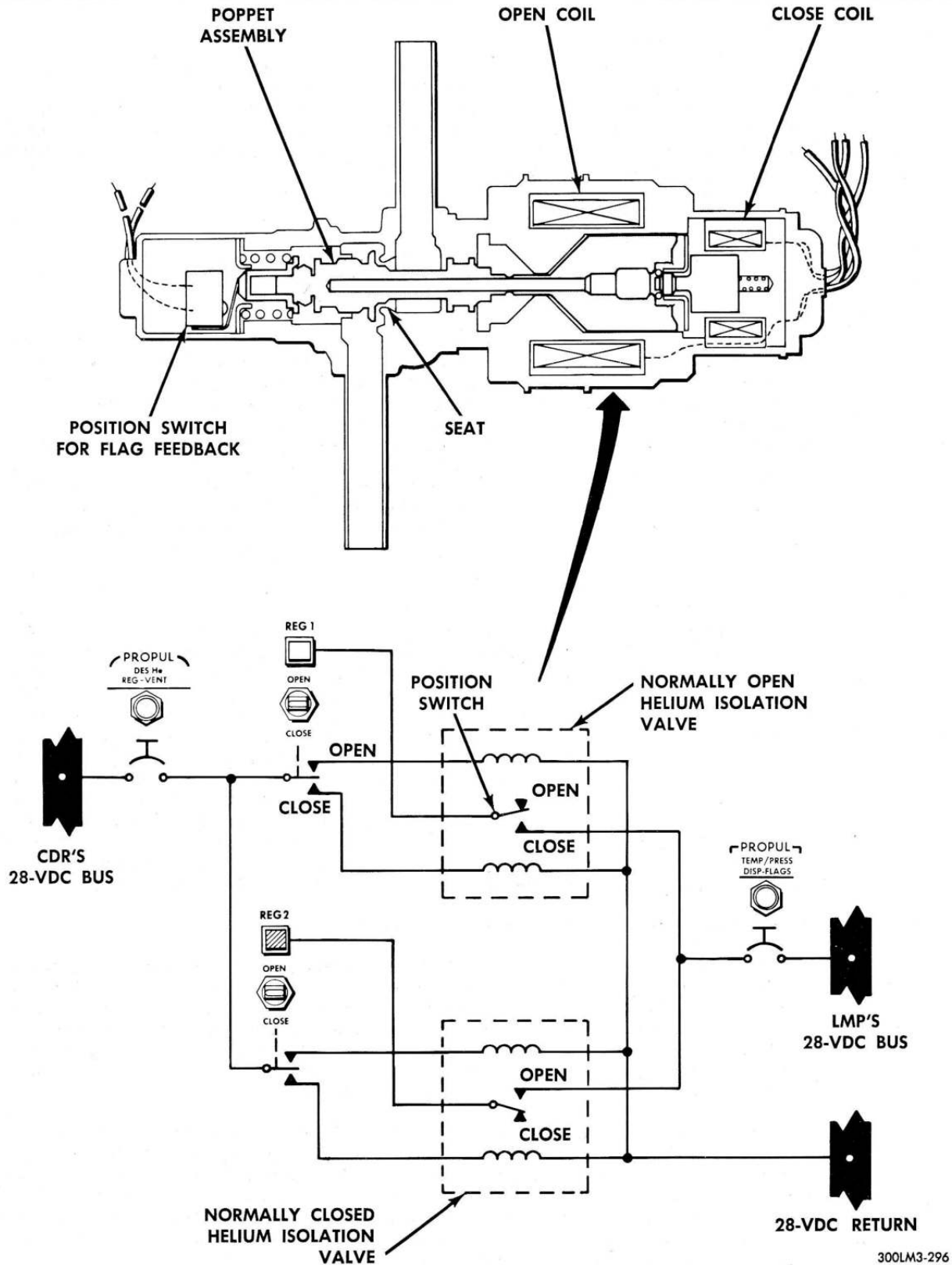
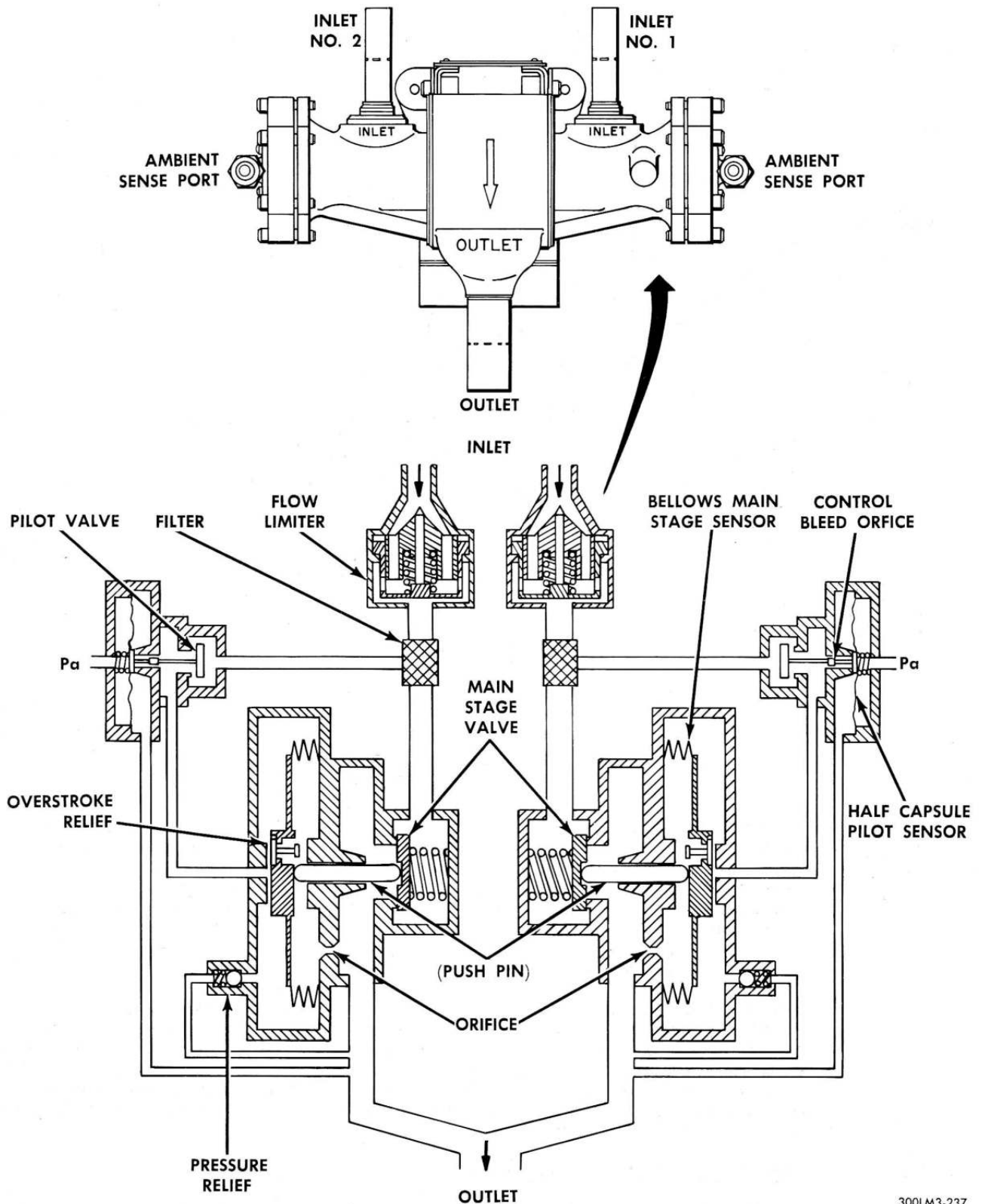


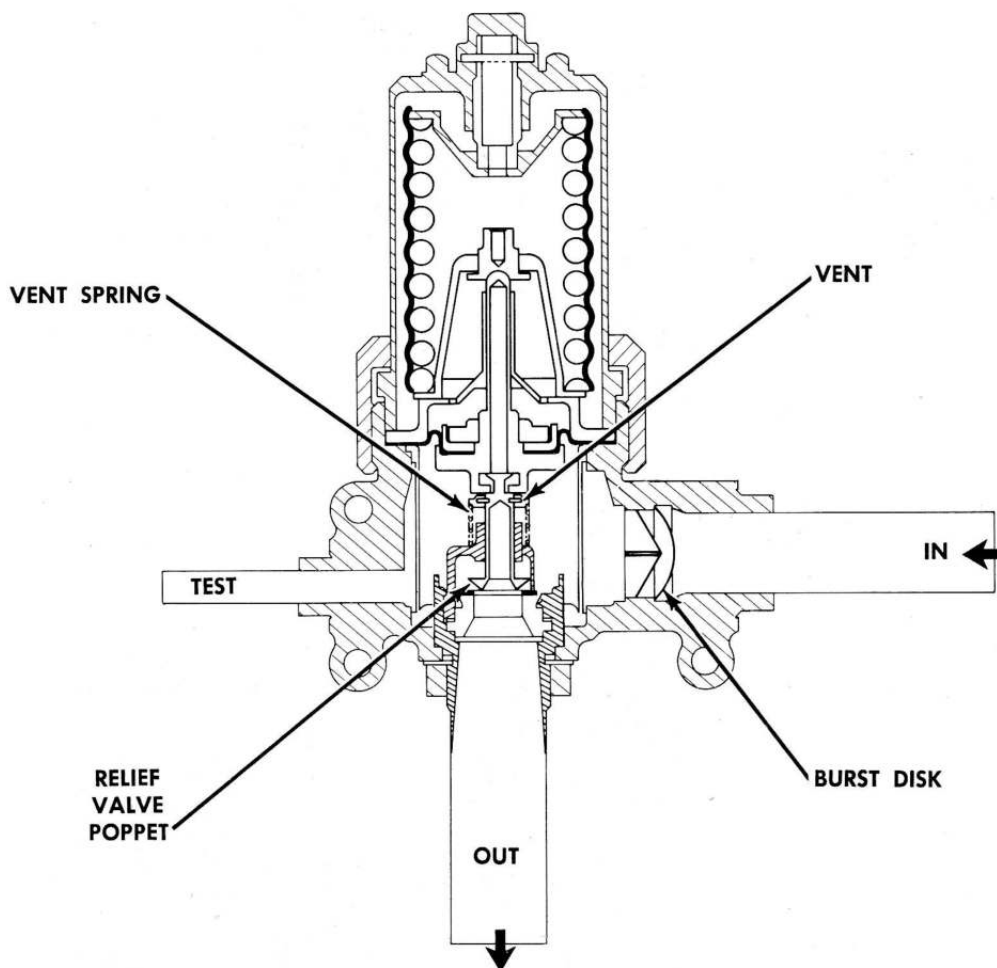
Figure 2-75. Helium Isolation Valves - Cutaway and Circuitry

LMA790-3-LM 3
 APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA



300LM3-237

Figure 2-76. Descent Propulsion Section - Pressure Regulator



300LM3-299

Figure 2-77. Relief Valve Assembly

The actuator uses a five-gang potentiometer, driven by the jackshaft through a single-stage planetary gear reduction. The potentiometer supplies position feedback signals to each of three amplifiers. Redundancy is provided by use of three separate servo channels, which have equal outputs. If one channel fails, the load is effectively increased by the two remaining operating motors, which can override the malfunction (even a hardover in the opposite direction) and provide the required output.

The command-signal voltage and the voltage from the feedback potentiometers are fed to a summing point. If the two voltages are equal, the error-signal voltage is zero. If the command and feedback voltages are not equal, an error voltage results. This error voltage is amplified and applied to the motors, which then rotate clockwise or counter-clockwise, depending on the error signal, to adjust the feedback potentiometers until the error voltage is zero. The 15-volt excitation for the feedback potentiometers is supplied by the EPS; the 5-volt excitation for the position potentiometers, by the electronics package. The position potentiometers supply a telemetry signal (0 to 5 volts dc) that indicates the position of the throttle valve actuator.

2.3.3.9

Flow Control Valves. (See figure 2-80.)

The oxidizer and fuel flow control valves are on the side of the engine, immediately downstream of the propellant inlet lines. They are secured to the throttle valve actuator

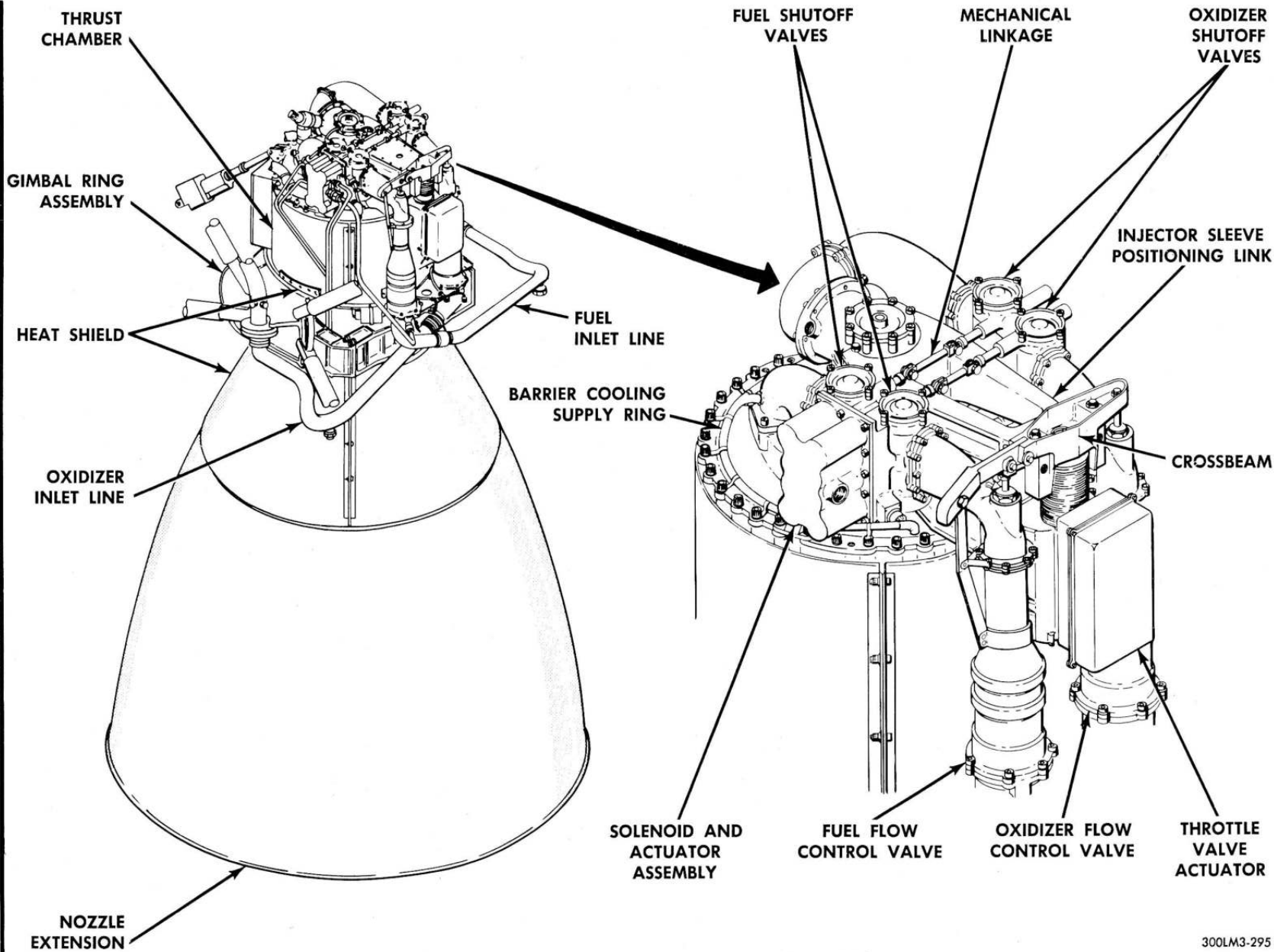
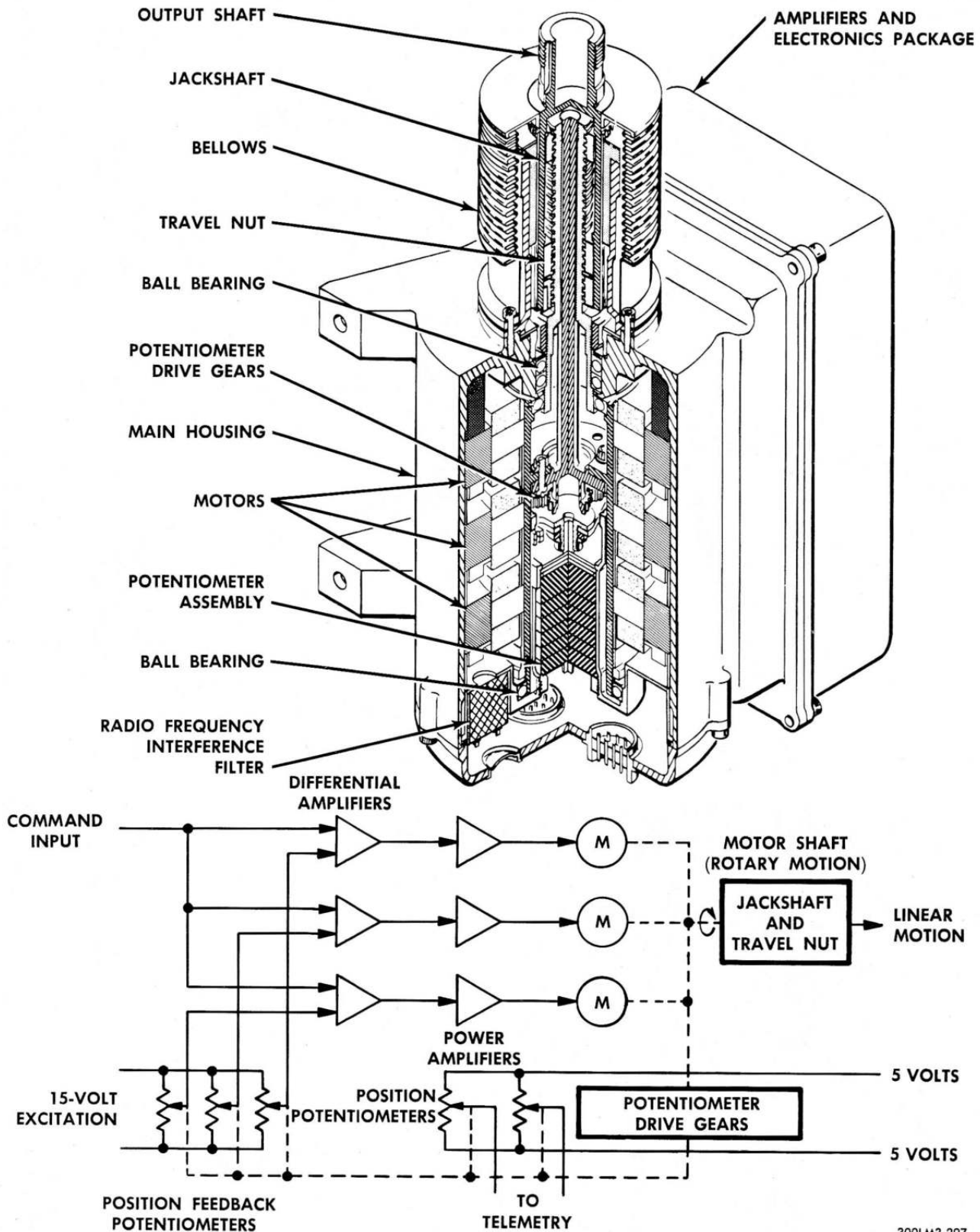


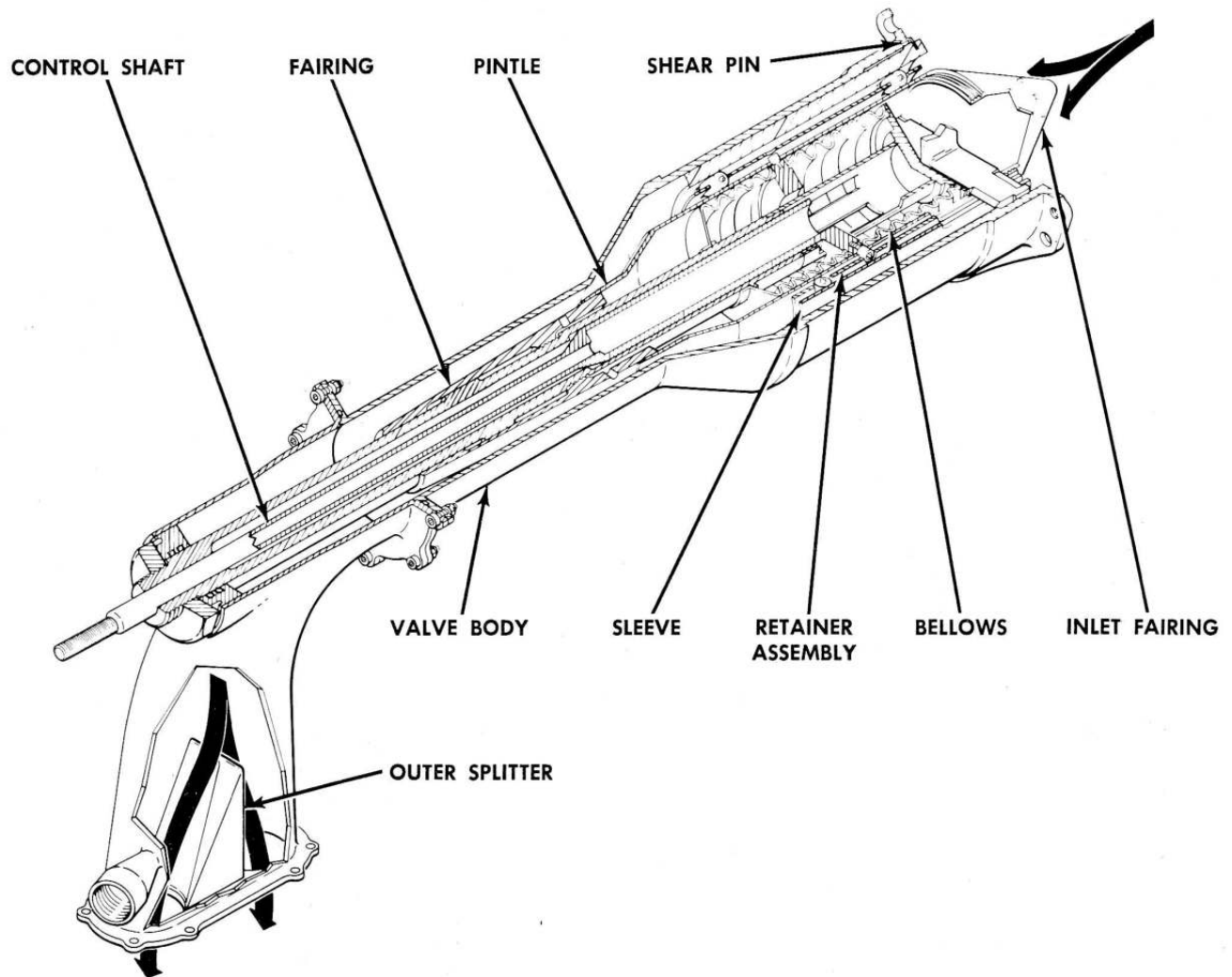
Figure 2-78. Descent Engine and Head End Assembly

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA



300LM3-297

Figure 2-79. Throttle Valve Actuator - Cutaway and Block Diagram



300LM3-298

Figure 2-80. Flow Control Valve

mounting bracket. The flow control valve pintle assemblies are mechanically linked to the throttle valve actuator by a crossbeam.

The flow control valves are nonredundant cavitating venturis with movable pintle sleeves. Engine throttling is initiated by an electrical signal to the throttle valve actuator, commanding an increase or decrease in engine thrust. Operation of the throttle valve actuator drives the crossbeam to a new position, thus repositioning the pintles in the flow control valves. This axial movement of the pintles decreases or increases the pintle flow areas to control propellant flow rate and thrust. Below an approximate 70% thrust setting, flow through the valves cavitates and hydraulically uncouples the propellant transfer system (and thereby, the flow rate) from variations in combustion chamber pressure. The movable pintle sleeve, shaft-driven through the valve case, is sealed by two flexible bellows. Shear pins in the bearing sleeves permit the valve bearings to operate in redundant modes (rolling or sliding) to improve reliability. Normally, the bearings roll; however, under an excessive load, the shear pins give to permit the bearings to slide. Both pintle sleeve shafts are attached to a yoke that is driven by the throttle valve actuator.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

2.3.3.10 Propellant Shutoff Valve Assemblies.

Each of the four propellant shutoff valve assemblies consists of a fuel shutoff valve, an oxidizer shutoff valve, a pilot valve, and a shutoff valve actuator. The shutoff valve actuator and the fuel shutoff valve are in a common housing. The oxidizer shutoff valve is in a separate housing to isolate fuel from oxidizer. It is actuated by a mechanical linkage driven from the fuel shutoff valve. The fuel and oxidizer shutoff valves, downstream of the flow control valves, are exposed to the full propellant pressure before engine firing. Propellant leakage at the valve seats is vented overboard.

2.3.3.10.1 Pilot Valves and Shutoff Valve Actuators.

The four solenoid-operated pilot valves control the actuation fluid (fuel) for the fuel and oxidizer shutoff valves. Normally, the pilot valves are closed, the solenoids are de-energized, and the actuation fluid is shut off by action of the spring-loaded solenoid plungers on the ball poppet seated in the lower pilot valve seats. The back side of the actuator chamber is vented to preclude a fuel buildup, caused by leakage of the pilot valves, and overpressurization, caused by an excessive fuel temperature increase. When the pilot valves are open, all solenoids are energized, and the actuation fluid (at approximately 200 psia) acts against the spring-loaded actuator plunger to open the oxidizer and fuel shutoff valves. At this point, the pilot valve poppets are forced against the upper valve seats, sealing off the vent port. When the electrical signal is removed, the valve poppets return to their lower seat to seal off the actuation fluid. The propellant shutoff valves are closed by the return action of the actuator piston springs, which expels the fuel entrapped in the cylinders and valve passages through the pilot vent port.

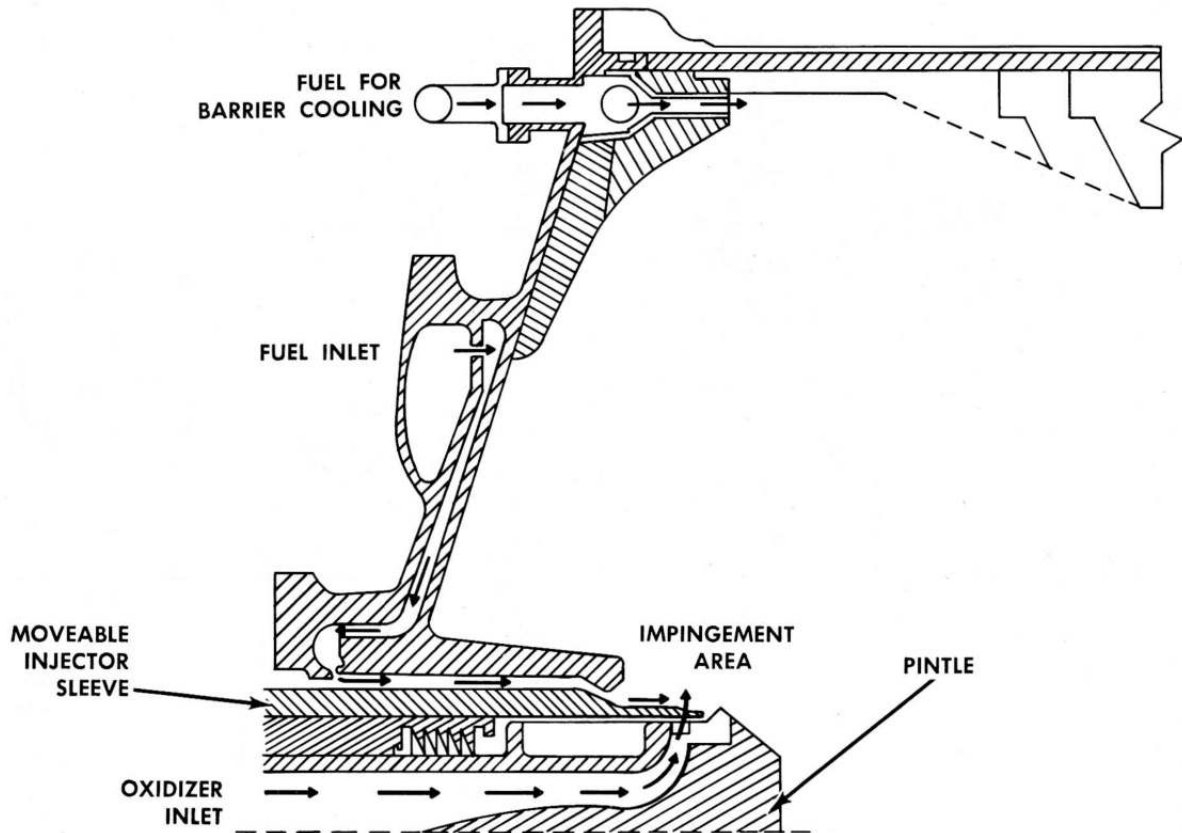
2.3.3.10.2 Fuel and Oxidizer Shutoff Valves.

The fuel and oxidizer shutoff valves are mechanically linked, fuel-actuated ball valves that are arranged in a series-parallel configuration. The valve housings are made of aluminum alloy. The ball element operates against a spring-loaded soft seat to assure positive sealing when the valve is closed. All ball valves are supported by ball bearings. The individual valves are rotated by a rack-and-pinion-gear arrangement, which translates the linear displacement of the pistons in the shutoff valve actuators.

2.3.3.11 Variable-Area Injector. (See figure 2-81.)

The variable-area injector consists of a pintle assembly, drive assembly, and manifold assembly. The pintle assembly introduces the propellant uniformly into the combustion chamber. The drive assembly has a twofold function: first, it serves as a passage for conducting the oxidizer into the pintle assembly; second, it contains the bearing and sealing components that permit accurate positioning of the injector sleeve. The injector sleeve varies the injection area so that near-optimum injector pressure drops and propellant velocities are maintained at each thrust level. The primary function of the manifold assembly is to distribute the fuel uniformly around the outer surface of the sleeve. Fuel enters the manifold assembly at two locations and is passed through a series of distribution plates near the outer diameter of the assembly.

At the center of the manifold, the fuel passes through a series of streamlined hole rings that suppress fuel flow discontinuities. From this point, the fuel is admitted into a narrow passage formed by two parallel conical surfaces (the manifold body and a face-plate). The passage smoothes out remaining gross fuel discontinuities and assists in cooling the injector face. The fuel then passes onto the outer surface of the sleeve, past a fuel-metering lip. The fuel is injected as a hollow cylinder so that it reaches the impingement zone with a uniform circumferential velocity profile and without atomizing, at all flow rates. The oxidizer is injected through a double-slotted sleeve so that it forms a large number of radial filaments. Each filament partially penetrates the fuel cylinder and is enfolded by fuel in such a way that, following fast liquid-phase reactions and gas evolution, little preferential separation of oxidizer and fuel can occur. For given propellant densities, overall mixture ratio, and injector geometry, there is a range of propellant injection velocity ratios that result in maximum mixture ratio uniformity throughout the



300LM3-335

Figure 2-81. Variable-Area Injector - Quarter Section

resultant expanding propellant spray. When they occur, the liquid-phase reactions generate gas and vapor that atomize and distribute the remaining liquid oxidizer and fuel uniformly in all directions, resulting in high combustion efficiency.

2.3.3.12 Combustion Chamber and Nozzle Extension. (See figure 2-82.)

The combustion chamber consists of an ablative-cooled chamber section, nozzle throat, and nozzle divergent section. The ablative sections are enclosed in a continuous titanium shell and jacketed in a thermal blanket composed of stainless-steel foil and glass wool.

The nozzle extension is a radiation-cooled, crushable skirt; it can collapse a distance of 28 inches in lunar impact, to prevent the descent engine from upsetting the vehicle should one leg collapse upon contacting the lunar surface. The nozzle extension is made of columbium coated with aluminide. It is attached to the combustion chamber case at a nozzle area ratio of 16 to 1 and extends to an exit area ratio of 47.4 to 1.

2.3.3.13 Gimbal Ring and Gimbal Drive Actuators.

The gimbal ring is located at the plane of the combustion chamber throat. It consists of a rectangular beam frame and four trunnion subassemblies. The assembly permits up to +6° or -6° roll and pitch trim control of the engine. A description of the two gimbal drive actuators is given in paragraph 2.2.3.4.6.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

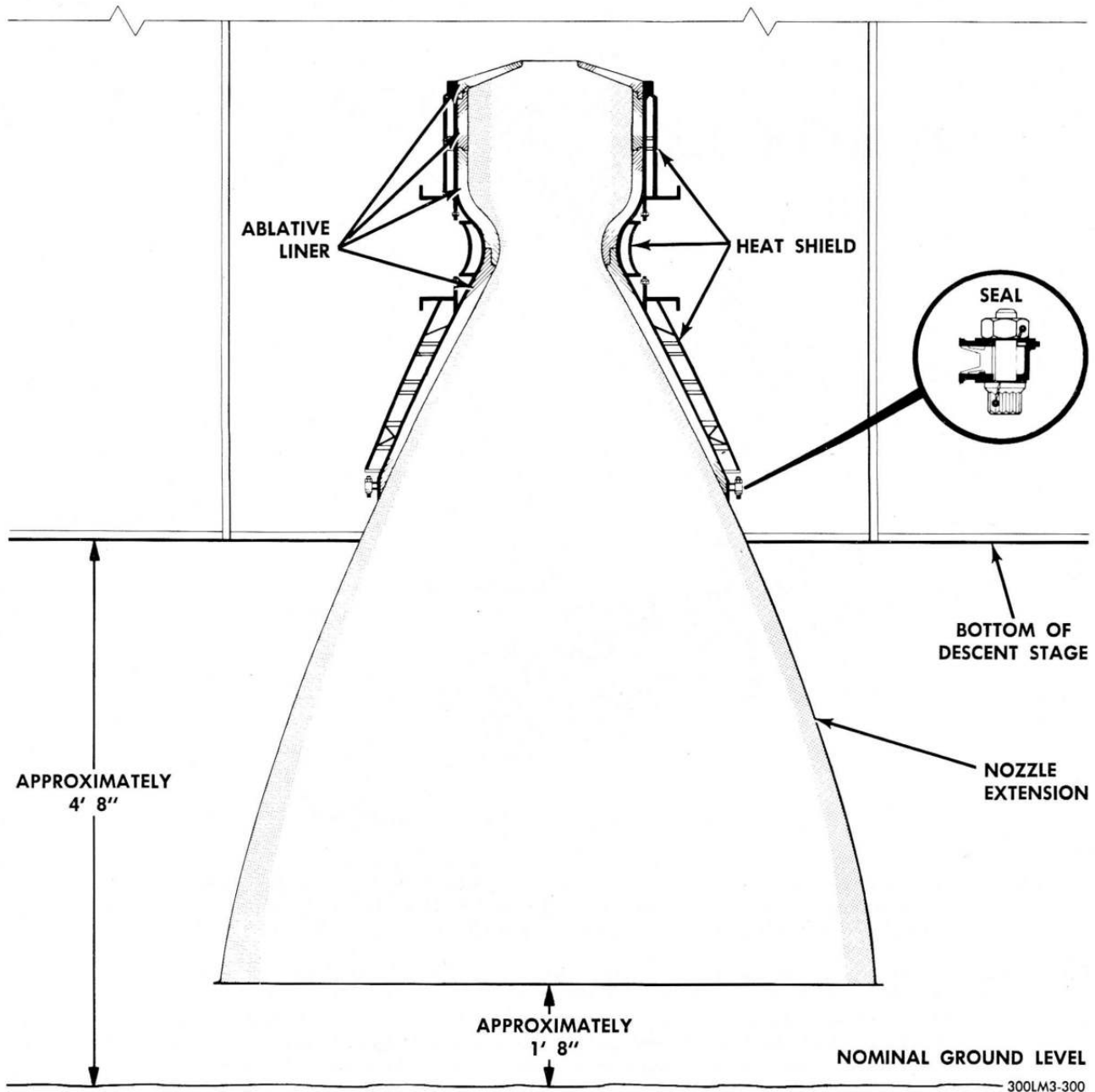


Figure 2-82. Descent Engine Combustion Chamber and Nozzle Extension

2.3.4 DESCENT PROPULSION SECTION FAILURE MODES.

The DPS failure modes and the effect on mission capability are given in table 2-27.

2.3.5 DESCENT PROPULSION SECTION PERFORMANCE AND DESIGN DATA.

The performance and design data for the DPS are given in table 2-28.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

2.3.6

DESCENT PROPULSION SECTION OPERATIONAL LIMITATIONS AND RESTRICTIONS.

The operational limitations and restrictions for the DPS are as follows:

- The landing gear must be deployed before descent engine firing. If not deployed, the landing gear would be in the path of the descent engine plume and would be damaged.
- Before descent engine starts, the RCS +X-axis thrusters must be fired to establish proper propellant tank ullage to settle the propellants under weightless conditions. Unsettled or insufficiently settled propellants will result in rough or erratic starts that could lead to engine failure.
- Normal start profile for all descent engine starts must be at 10 % throttle setting for 26 seconds. Because the thrust vector at engine start may not be directed through the LM center of gravity, a low-thrust start (10 %) will permit corrective gimbaling. If the engine is started at high thrust, RCS propellants must be used to stabilize the vehicle. In the worst case, the momentary unbalance may exceed the RCS compensation capability.
- Propellant bulk temperatures before descent engine start must be between +50° and +90° F. If temperature limits are exceeded, the resultant rough combustion may adversely affect engine-component performance, and ullage pressure limitations may be exceeded.
- Propellant tank pressure during earth launch must be less than 230 psia. If this limit is exceeded, possible structural failure in the propellant tanks will cause loss of the descent engine.
- The first descent engine firing must last at least 30 seconds. This minimum initial operating time is required to ensure full pressurization of the ullage space in the propellant tanks. If this requirement is not met, fuel may freeze in the fuel/helium heat exchanger.
- The descent engine must not be operated in the throttling range of 60 % to 92.5 %. In this range, operation of the cavitating venturis of the flow control valves becomes unpredictable and may cause an improper fuel-oxidizer mixture ratio, which will result in excessive engine erosion and early combustion chamber burn-through.
- The descent engine must be shut down before propellants are depleted to within 10 seconds of burn time remaining, until capability to burn safely to depletion is established. If this requirement is not met, fuel or oxidizer may become depleted, causing possible ingestion of helium into the combustion chamber.
- The PQGS must be used only during the final powered descent phase, with the descent engine firing. It must be turned on approximately 10 seconds before the start of this phase and turned off 10 seconds after engine shut-down. Failure to meet this requirement may lead to loss of the PQGS, due to overheating of the PQGS electronics after 15 minutes of continuous operation.
- The DPS must not remain pressurized longer than 3.5 days before use. If this limit is exceeded, the pressurization section components may fail to operate because of the corrosive nature of the propellants.
- The descent engine combustion chamber must not be subjected to more than 926 seconds of engine operation. Exceeding this limitation will cause the engine to operate with a severely charred combustion chamber possibly resulting in a burn-through.
- The descent engine must not be started more than 20 times.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-27. Descent Propulsion Section - Failure Modes

Failure	Indication	Vehicle Capability
Primary helium isolation solenoid valve failed closed.	DESCENT He REG 1 talkback provides barber-pole display.	Primary pressurization leg is inoperative. Secondary helium isolation solenoid valve must be opened.
Secondary helium isolation solenoid valve failed open.	DESCENT He REG 2 talkback provides gray display.	Failure does not affect vehicle capability.
Primary pressure regulator failed open.	DES REG warning light goes on.	Vehicle capability is not affected, except for loss of pressure regulator redundancy. Primary helium isolation solenoid valve must be closed immediately (to minimize helium loss through relief valve assemblies) and secondary helium isolation valve must be opened.
Secondary pressure regulator failed open.	No indication.	Vehicle capability is not affected, because secondary helium isolation solenoid valve is normally closed.
Secondary pressure regulator failed closed.	Reading on FUEL and OXID PRESS indicators does not increase and reading on HELIUM indicator (HELIUM MON selector switch set to AMB PRESS) does not decrease when DES START He PRESS switch is set to FIRE.	Ambient helium cannot be used for prepressurization. Initial pressure must be relied upon for engine start. Loss of pressure regulator redundancy.
Propellant leak.	OXIDIZER and FUEL QUANTITY indications are not equal.	Could necessitate termination of DPS operation.
Helium leak.	Readings on HELIUM indicator and FUEL and OXID PRESS indicators decrease. DES REG warning light goes on.	Could necessitate termination of DPS operation.
Supercritical helium isolation explosive valve did not open.	Reading on HELIUM indicator (HELIUM MON selector switch set to SUPCRIT PRESS) does not decrease.	DPS operation must be terminated. A short burn (25 to 30 seconds) is possible using the ambient helium bottle.
Supercritical helium isolation explosive valve has internal leak.	Reading on HELIUM indicator (HELIUM MON selector switch set to SUPCRIT PRESS) decreases before supercritical helium isolation explosive valve is fired.	DPS start is curtailed. (Fuel may be frozen in fuel/helium heat exchanger and could possibly result in explosion at descent engine firing.)
Helium filter is clogged.	Decaying ullage pressure is indicated on FUEL and OXID PRESS indicators. DES REG warning light may go on.	Termination of DPS operation could be necessary.
Fuel or oxidizer compatibility explosive valve did not open.	Insufficient pressure is indicated on FUEL or OXID PRESS indicator.	DPS start is curtailed.

MAIN PROPULSION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-27. Descent Propulsion Section - Failure Modes (cont)

Failure	Indication	Vehicle Capability
Fuel or oxidizer filter is clogged.	Readings on CMD and ENG THRUST indicators do not coincide.	DPS operation must be terminated.
Inoperative linkage in flow control valves or mechanical failure of throttle valve actuator.	Readings on CMD and ENG THRUST indicators do not coincide.	DPS operation must be terminated.
Pilot valve vents freeze up.	Engine cannot be shut down.	Loss of subsequent DPS starts.

Table 2-28. Descent Propulsion Section - Performance and Design Data

Pressurization section	
Ambient helium bottle	
Volume	1 cubic foot
Initial filling weight of helium	1 pound
Initial helium pressure and temperature	1,600 psia at +70° F
Proof pressure	2,333 psi
Burst pressure	2,625 psi
Cryogenic helium storage vessel	
Nominal storage pressure and temperature	1,555 psia at -400° F
Maximum storage pressure and temperature	1,710 psia at -320° F
Density	8.2 pounds per cubic foot
Initial filling weight at charge pressure	48.5 pounds
Usable helium	41.9 pounds
Proof pressure	2,274 psi
Burst pressure	3,420 psi
Burst-disk rupture pressure	1,881 to 1,967 psi
Helium filters	
Nominal filtration	5 microns
Absolute filtration	15 microns
Helium pressure regulators	
Outlet pressure	245+3-2 psia
Normal operation flow rate range	0.52 to 5.5 pounds of helium per minute
Inlet pressure range	300 to 1,750 psi
Lockup pressure (maximum)	253 psia
Maximum flow rate	19 pounds of helium per minute
Quadruple check valve assemblies opening pressure	2 to 2.88 psid

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-28. Descent Propulsion Section - Performance and Design Data (cont)

Pressurization section (cont)

Relief valve assembly

Burst-disk rupture pressure	268 to 308 psi
Relief valve cracking pressure	260 psi
Full-flow pressure	275 psi
Reseat pressure (minimum)	254 psi

Propellant feed section

Propellant tanks

Capacity (each tank)	62.8 cubic feet
Total fuel	6,982 pounds
Total oxidizer	11,067 pounds
Ullage volume (minimum)	1,728 cubic inches
Usable fuel	6,759 pounds
Usable oxidizer	10,730 pounds
Unusable fuel	222.8 pounds
Unusable oxidizer	336.4 pounds
Nominal tank ullage pressure (at full throttle position)	235 psia
Proof pressure	360 psia
Burst pressure	405 psia
Nominal propellant temperature	+70° F

Engine interface inlet pressure (trim orifice output at full throttle position)	222±2 psia
---	------------

Propellant filters

Nominal filtration	40 microns
Absolute filtration	60 microns
Fuel filter rated flow	13.3 pounds per second
Fuel filter maximum pressure drop	2 psi
Oxidizer filter rated flow	21.2 pounds per second
Oxidizer filter maximum pressure drop	3 psi

Engine assembly

Nominal engine thrust (full throttle)	9,870 pounds (94%)
Minimum engine thrust	1,050 pounds (10%)
Nominal combustion chamber pressure	103.4 psia
Engine-gimbaling capability	+6° or -6° for trim control along Y-axis and Z-axis
Propellant injection ratio (oxidizer to fuel)	1.6 to 1
Approximate weight	360 pounds
Overall length	85 inches
Nozzle exit diameter	59 inches

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

2.3.7

DESCENT PROPULSION SECTION TELEMETRY MEASUREMENTS.

The DPS telemetry data are given in table 2-29. "(R)" in the "Telemetry Range" column signifies a real-time telemetry measurement. Real-time telemetry points are shown in figure 2-71.

Table 2-29. Descent Propulsion Section - Telemetry Measurements

Code	Description	Telemetry Range (Nominal)	Display Range	Crew Display
GQ3009P	Helium primary upstream regulator inlet pressure	190 to 1,750 psia		DESCENT He REG 1 talkback
GQ3010P	Helium secondary upstream regulator inlet pressure	190 to 1,750 psia		DESCENT He REG 2 talkback
GQ3015P	Ambient helium prepressurization bottle pressure	0 to 1,750 psia	0 to 1,750 psia	HELIUM indicator
GQ3018P	Helium regulator outlet manifold pressure	210 to 270 psia (235 psia) (R)	Less than 220 psia; greater than 260 psia	DES REG warning light
GQ3025P	Helium regulator outlet manifold pressure	210 to 270 psia (235 psia) (R)		None
GQ3309X	Helium primary solenoid valve closed	Contact closure (R)		DESCENT He REG 1 talkback
GQ3310X	Helium secondary solenoid valve open	Contact closure (R)		DESCENT He REG 2 talkback
GQ3435P	Supercritical helium supply tank pressure	0 to 2,000 psia (1,250 psia) (R)		None
GQ3436P	Supercritical helium supply tank pressure	0 to 1,750 psia (1,250 psia)	0 to 1,750 psia	HELIUM indicator
GQ3451T	Supercritical helium supply outlet temperature	-425° to -300° F		None
GQ3455T	Supercritical helium/helium heat exchanger inlet temperature	-210° to +75° F		None
GQ3459T	Supercritical helium/helium heat exchanger outlet temperature	-360° to -50° F		None
GQ3463T	Supercritical fuel/helium heat exchanger outlet temperature	-210° to +75° F		None
GQ3476T	Supercritical helium tank ambient surface No. 1 temperature	+40° to +120° F (+70° F)		None
GQ3501P	Fuel tank No. 1 ullage pressure	None	210 to 270 psia (235 psia)	FUEL PRESS indicator

MAIN PROPULSION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-29. Descent Propulsion Section - Telemetry Measurements (cont)

Code	Description	Telemetry Range (Nominal)	Display Range	Crew Display
GQ3505P	Fuel tank vent relief valve inlet pressure	0 to 300 psia		None
GQ3603Q	Fuel tank No. 1 quantity	0% to 95% (R)		None
GQ3604Q	Fuel tank No. 2 quantity	0% to 95% (R)		None
GQ3605Q	Fuel tank No. 1 or 2 (as selected) quantity	None	0% to 95%	FUEL QUANTITY indicator
GQ3611P	Engine interface fuel pressure	50 to 270 psia (210 psia) (R)		None
GQ3666P	Fuel tank No. 2 bottom - engine interface ΔP	0 to 30 psia		None
GQ3718T	Fuel tank No. 1 fuel bulk temperature	+40° to +100° F (+70° F) (R)	+40° to +100° F	FUEL TEMP indicator
GQ3719T	Fuel tank No. 2 fuel bulk temperature	+40° to +100° F (+70° F) (R)	+40° to +100° F	FUEL TEMP indicator
GQ3811T	Engine interface fuel temperature	+40° to +200° F (+70° F)		None
GQ4001P	Oxidizer tank No. 1 ullage pressure	None	0 to 300 psia (235 psia)	OXID PRESS indicator
GQ4005P	Oxidizer tank vent relief valve inlet pressure	0 to 300 psia (0 psia)		None
GQ4103Q	Oxidizer tank No. 1 quantity	0% to 95% (R)		None
GQ4104Q	Oxidizer tank No. 2 quantity	0% to 95% (R)		None
GQ4105Q	Oxidizer tank No. 1 or 2 (as selected) quantity	None	0% to 95%	OXIDIZER QUANTITY indicator
GQ4111P	Engine interface oxidizer pressure	50 to 270 psia (210 psia) (R)		None
GQ4116P	Oxidizer tank No. 1 bottom - engine interface ΔP	0 to 30 psia		None
GQ4218T	Oxidizer tank No. 1 oxidizer bulk temperature	+40° to +100° F (+70° F) (R)	+40° to +100° F	OXID TEMP indicator
GQ4219T	Oxidizer tank No. 2 oxidizer bulk temperature	+40° to +100° F (+70° F) (R)	+40° to +100° F	OXID TEMP indicator
GQ4311T	Engine interface oxidizer temperature	+40° to +200° F (+70° F)		None
GQ4455X	Propellant tanks liquid level low	Contact closure (R)		DES QTY warning light

MAIN PROPULSION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-29. Descent Propulsion Section - Telemetry Measurements (cont)

Code	Description	Telemetry Range (Nominal)	Display Range	Crew Display
GQ6297V	Actuator isolation valve A current shunt voltage	14 to 21 mv		None
GQ6299V	Actuator isolation valve B current shunt voltage	14 to 21 mv		None
GQ6306X	Shutoff valve A not open	Contact closure		None (See GQ7498U.)
GQ6307X	Shutoff valve A not closed	Contact closure		None (See GQ7498U.)
GQ6308X	Shutoff valve B not open	Contact closure		None (See GQ7498U.)
GQ6309X	Shutoff valve B not closed	Contact closure		None (See GQ7498U.)
GQ6314X	Shutoff valve C not open	Contact closure		None (See GQ7499U.)
GQ6315X	Shutoff valve C not closed	Contact closure		None (See GQ7499U.)
GQ6316X	Shutoff valve D not open	Contact closure		None (See GQ7499U.)
GQ6317X	Shutoff valve D not closed	Contact closure		None (See GQ7499U.)
GQ6331V	Shutoff valve A positive current shunt voltage	8 to 13 mv		None
GQ6332V	Shutoff valve A return current shunt voltage	8 to 13 mv		None
GQ6333V	Shutoff valve B positive current shunt voltage	8 to 13 mv		None
GQ6334V	Shutoff valve B return current shunt voltage	8 to 13 mv		None
GQ6335V	Shutoff valve C positive current shunt voltage	8 to 13 mv		None
GQ6336V	Shutoff valve C return current shunt voltage	8 to 13 mv		None
GQ6337V	Shutoff valve D positive current shunt voltage	8 to 13 mv		None
GQ6338V	Shutoff valve D return current shunt voltage	8 to 13 mv		None
GQ6441V	Channel No. 1 motor positive current shunt voltage	5 to 70 mv		None
GQ6442V	Channel No. 1 motor return current shunt voltage	5 to 70 mv		None
GQ6443V	Channel No. 2 motor positive current shunt voltage	5 to 70 mv		None
GQ6444V	Channel No. 2 motor return current shunt voltage	5 to 70 mv		None

MAIN PROPULSION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-29. Descent Propulsion Section - Telemetry Measurements (cont)

Code	Description	Telemetry Range (Nominal)	Display Range	Crew Display
GQ6445V	Channel No. 3 motor positive current shunt voltage	5 to 70 mv	0% to 100%	None
GQ6446V	Channel No. 3 motor return current shunt voltage	5 to 70 mv		None
GQ6501P	Fuel injector inlet pressure	0 to 250 psia (190 psia)		None
GQ6506P	Oxidizer injector inlet pressure	0 to 250 psia (190 psia)		None
GQ6510P	Thrust chamber pressure	11 to 121 psia (110 psia) (R)		ENG THRUST indicator
GQ6806H	Variable injector actuator position	0% to 100% (R)		None
GQ7206T	Injector surface temperature	0° to +500° F		None
GQ7208T	Engine throat T1 case temperature No. 1	0° to +500° F		None
GQ7209T	Engine throat T1 case temperature No. 2	0° to 500° F		None
GQ7211T	Engine heat shield outer surface temperature No. 1	0° to +500° F		None
GQ7212T	Engine heat shield outer surface temperature No. 2	0° to +500° F		None
GQ7301D	Thrust chamber X-axis vibration	0g to 30g rms		None
GQ7302D	Thrust chamber Y-axis vibration	0g to 30g rms		None
GQ7303D	Thrust chamber Z-axis vibration	0g to 30g rms		None
GQ7498U	Shutoff valves A and B Δ position	Contact closure (R)		None
GQ7499U	Shutoff valves C and D Δ position	Contact closure (R)		None
GQ7501T	Engine throat temperature No. 4	0° to +500° F		None
GQ7502T	Engine throat temperature No. 5	0° to +500° F		None
GQ7503T	Engine throat temperature No. 6	0° to +500° F		None

MAIN PROPULSION SUBSYSTEM

2.3.8

ASCENT PROPULSION SECTION FUNCTIONAL DESCRIPTION.

The ascent propulsion section (APS) consists of a constant-thrust rocket engine that is not gimbale, two propellant tanks, two helium tanks, and associated propellant feed and helium pressurization components. (See figure 2-83.) The engine is installed in the center section of the ascent stage; it is canted so that the center line is tilted 1.5° from the X-axis in the +Z-direction. The engine develops 3,500 pounds of thrust in a vacuum, sufficient to launch the ascent stage from the lunar surface and place it into an 80-nautical-mile lunar orbit. The engine can be shut down and restarted, within the operational limitations and restrictions (paragraph 2.3.12), as required by the mission.

Functionally, the APS can be subdivided into a pressurization section, a propellant feed section, and an engine assembly.

2.3.8.1

Pressurization Section. (See figure 2-84.)

The propellants are pressurized by gaseous helium, supplied from two identical tanks and routed through redundant flow lines into the propellant tanks. The helium is stored at a nominal pressure of 3,050 psia at a nominal temperature of +70° F. A pressure transducer and a temperature transducer at each tank outlet port are connected to the HELIUM indicator via the HELIUM MON selector switch. The HELIUM MON selector switch selects the tank and the temperature or pressure to be displayed.

Before initial ascent engine operation, the helium isolation explosive valves prevent the helium from leaving the tanks. These valves can be opened individually or simultaneously. The propellants are not pressurized until shortly before initial ascent engine start. To accomplish initial pressurization, the helium isolation explosive valves and the fuel and oxidizer compatibility explosive valves (upstream of the propellant tanks) are opened simultaneously. Normally, propellant pressurization is initiated by setting the ASCENT He SEL switch (panel 8) to BOTH. If the HELIUM indicator shows a leak (decaying pressure) in one of the tanks, the ASCENT He SEL switch is set so that only the explosive valve leading from the non-leaking tank opens, thus preventing helium loss through the leaking tank via the helium interconnect line (downstream of the explosive valves). The MASTER ARM switch is then set to ON and the ASCENT He PRESS switch is set to FIRE and released firing all explosive valves in the APS. A filter in each helium flow path traps debris from the explosive valve.

Downstream of the filter, each helium flow path has a normally open latching solenoid valve and two series-connected pressure regulators. The downstream regulator is set to a slightly higher output pressure than the upstream regulator; the regulator pair in the primary flow path produces a slightly higher output than the pair in the secondary (redundant) flow path. This arrangement causes lockup of the regulators in the redundant flow path after the propellant tanks are pressurized, while the upstream regulator in the primary flow path maintains the propellant tanks at their normal pressure of 184 psia. If either regulator in the primary flow path fails closed, the regulators in the redundant flow path sense a demand and open to pressurize the propellant tanks. If an upstream regulator fails open, control is obtained through the downstream regulator in the same flow path. Because the downstream regulator normally does not control the outlet pressure, an open failure of this regulator has no effect. If both regulators in the same flow path fail open, pressure in the helium manifold increases above the acceptable limit of 220 psia, causing the ASC HI REG caution light (panel 2) to go on. This alerts the astronauts that the helium isolation solenoid valve in the malfunctioning flow path must be closed so that normal pressure can be restored. Excessive pressure is vented by the relief valve assemblies in parallel with the propellant tanks. The solenoid valve is closed by setting the ASCENT He REG 1 or REG 2 switch (panel 1) to CLOSE; the talk-back above the switch will change to a barber-pole display.

The primary and secondary helium flow paths merge downstream of the regulators to form a common helium manifold. The manifold routes the helium into two flow paths: one path leads to the oxidizer tank; the other, to the fuel tank. A quadruple check valve assembly, a series-parallel arrangement in each path, isolates the upstream components

MAIN PROPULSION SUBSYSTEM

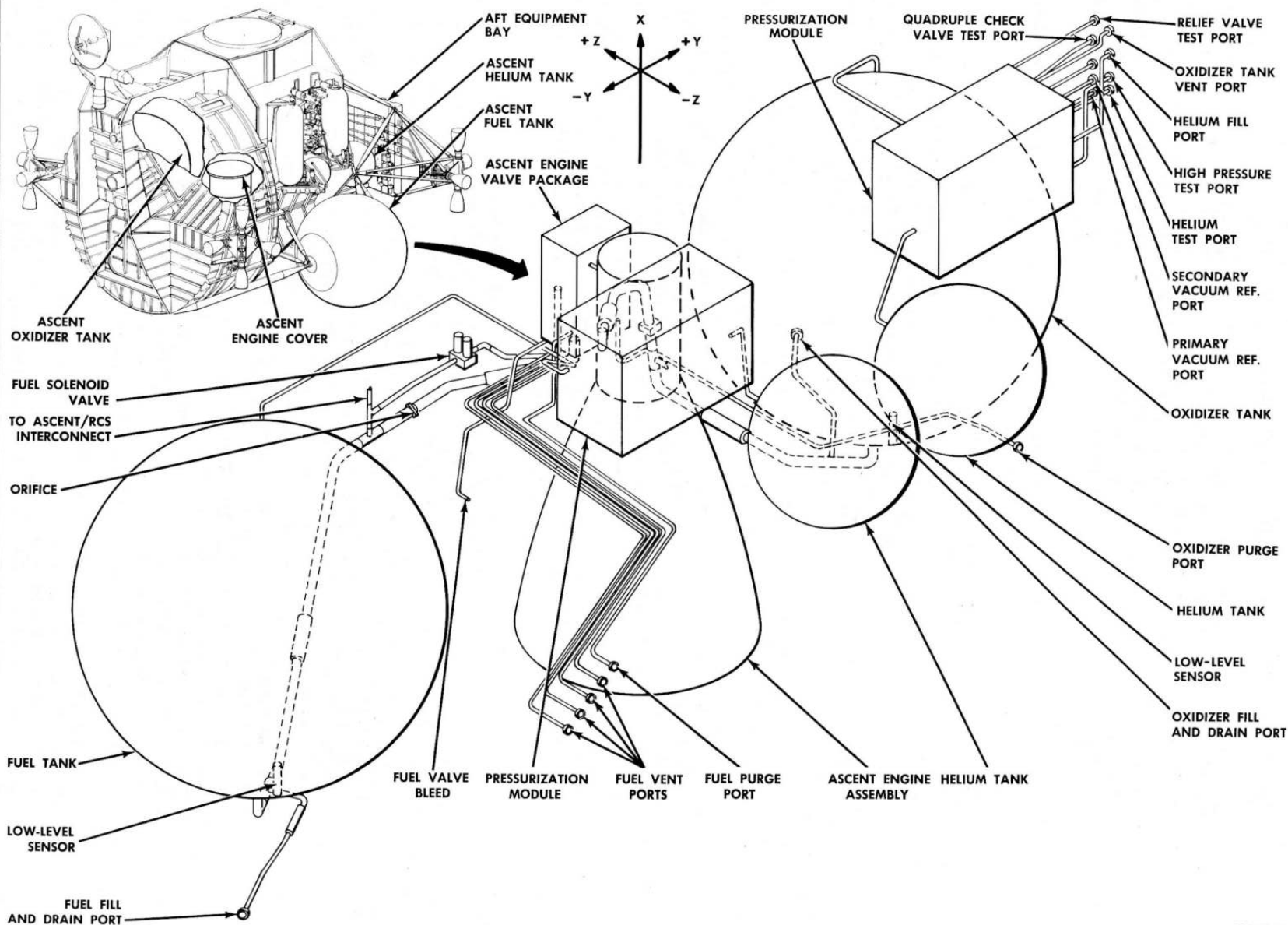


Figure 2-83. Ascent Propulsion Section - Component Location

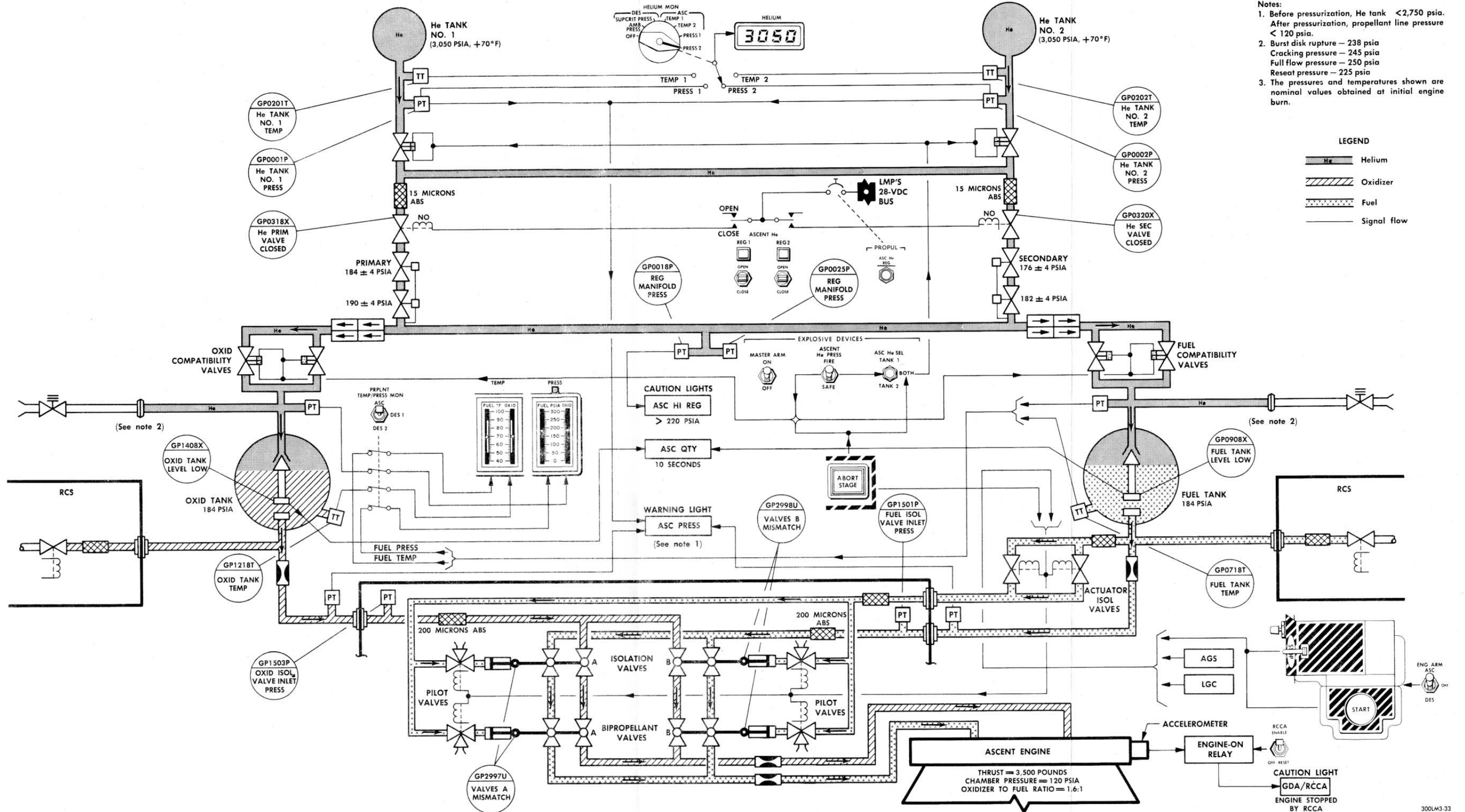


Figure 2-84. Ascent Propulsion Section - Simplified Functional Flow Diagram

from corrosive propellant vapors. The check valves also safeguard against possible hypergolic action in the common manifold resulting from mixing of propellants or fumes flowing back from the propellant tanks. Two parallel compatibility explosive valves, downstream of each quadruple check valve assembly, seal off the propellant tank inlets, isolating the fuel and oxidizer (liquid and vapor) before initial ascent engine start. This reduces contamination problems involving helium components and prolongs the life of the quadruple check valves. The fuel and oxidizer compatibility explosive valves are opened simultaneously with the helium isolation explosive valves before initial engine start. The arrangement of parallel explosive valves in each flow path with dual initiators in one leg provides redundancy. (See figure 2-86.)

Immediately upstream of the fuel and oxidizer tanks, each helium path contains a burst disk and relief valve assembly to protect the propellant tanks against overpressurization. This assembly vents pressure in excess of approximately 238 psia and re-seals the flow path after overpressurization is relieved. A thrust neutralizer eliminates unidirectional thrust generated by the escaping gas. To prevent leakage through a faulty relief valve during normal operation, the burst disk is located upstream of the relief valve. The burst disk ruptures at a pressure slightly below the relief valve setting. The relief valves can pass the entire helium flow from a failed-open pair of regulators without damaging the propellant tanks.

2.3.8.2

Propellant Feed Section. (See figure 2-84.)

The APS has one oxidizer tank and one fuel tank. Each tank has a temperature transducer that supplies propellant temperature signals to the FUEL and OXID TEMP indicators, and a pressure transducer that supplies ullage pressure signals to the FUEL and OXID PRESS indicators. The same TEMP and PRESS indicators are used for the APS and DPS. APS data are displayed when the PRPLNT TEMP/PRESS MON switch is set to ASC. A low-level sensor in each propellant tank causes the ASC QTY caution light (panel 2) to go on when the remaining propellant in either tank is sufficient for only 10 seconds of engine operation. The ASC QTY caution light is inhibited when the ascent engine is not operating.

Helium flows into the top of the fuel and oxidizer tanks. Diffusers at the top of the tanks uniformly distribute the helium throughout the ullage space. The outflow from each propellant tank divides into two paths. In the primary path, each propellant flows through a trim orifice to the propellant filter in the engine assembly, and then to the isolation and bipropellant valve assemblies (propellant shutoff valves). The trim orifice provides an engine interface pressure of 165 psia for proper propellant use. The secondary path connects the ascent propellant supply to the RCS. This interconnection, at the normally closed ascent feed solenoid valves (part of the RCS), permits the RCS to burn ascent propellants providing the APS is pressurized and the ascent or descent engine is operating at the time the RCS thrusters are fired. A line branches off the RCS interconnect fuel flow path and leads to two parallel actuator isolation solenoid valves. From there, this line routes fuel to the engine pilot valves that actuate the propellant shutoff valves in the engine assembly. The normally closed actuator isolation valves prevent possible fuel loss through a leaking pilot valve before initial engine operation or during engine shutdown. The actuator isolation valves, and the propellant shutoff pilot valves in the engine assembly, are opened and closed simultaneously by engine-on and engine-off commands.

2.3.8.3

Engine Assembly. (See figure 2-85.)

The ascent engine is a fixed-injector, restartable, bipropellant rocket engine with an ablative combustion chamber, throat, and nozzle extension. Fuel and oxidizer enter the engine assembly through inlet ports at the interface flanges and are routed through the propellant filters and the propellant shutoff valves to the injector; a separate fuel path (actuator pressure line) leads to the pilot valves, where fuel pressure actuates the propellant shutoff valves.

Propellant flow to the engine combustion chamber is controlled by a valve package assembly, trim orifices, and an injector assembly. The valve package assembly consists

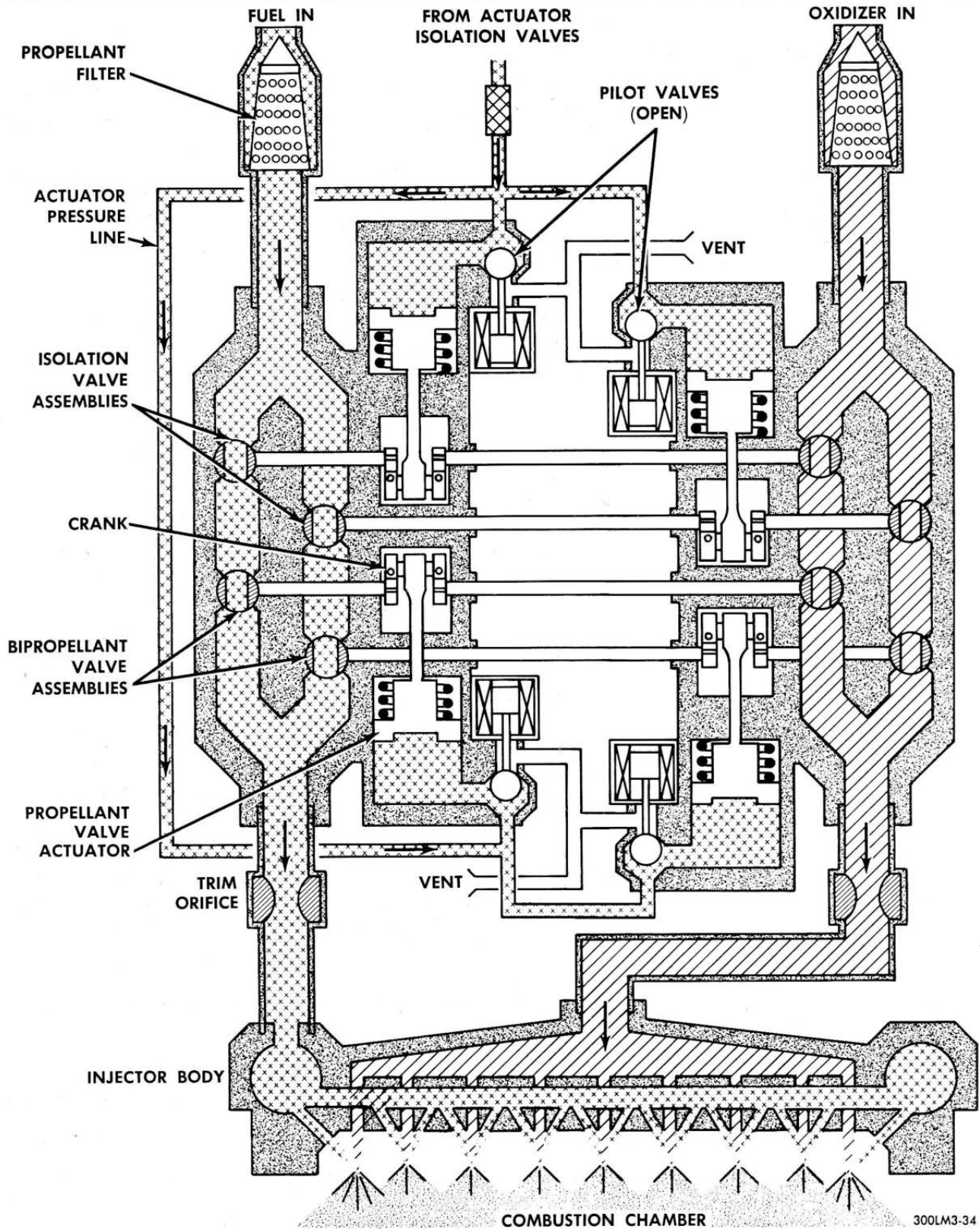


Figure 2-85. Ascent Engine Assembly - Flow Diagram

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

of eight propellant shutoff ball valves that make up the two fuel-and-oxidizer-coupled isolation valve assemblies and the two fuel-and-oxidizer coupled bipropellant valve assemblies, four actuators, and four solenoid-operated pilot valves. Inside the valve package assembly, the fuel and oxidizer passages divide into dual flow paths, with two series ball valves in each flow path. The paths rejoin at the valve package outlet. The propellant shutoff valves are arranged in fuel-oxidizer pairs; each pair is operated on a single crankshaft assembly by an individual fuel-pressure-operated actuator. Shaft seals and vented cavities prevent fuel and oxidizer from coming into contact with each other due to seepage along the shafts.

After the ascent propellants have been pressurized, the ascent engine can be started manually by setting the ENG ARM switch to ASC and by pressing the START pushbutton. (Automatic starts are initiated by LGC or AGS engine-on commands.) At engine start, the two actuator isolation valves in the propellant feed section, and the four pilot valves, are opened simultaneously, routing fuel into the actuator feed line and to the four pilot valves. When the solenoids of the pilot valves are energized, the pilot valve poppets are lifted from the fuel inlet ports and are seated against the overboard vent ports. Fuel enters the actuator chambers and extends the actuator pistons, cranking the propellant shutoff valves 90° to the fully open position. The propellants now pass through the shutoff valves and trim orifices and are piped directly to the injector. The orifices determine the thrust level of the engine and the mixture ratio of the propellants by trimming the pressure differentials of the fuel and oxidizer. The physical characteristics of the injector establish an oxidizer lead of between 40 and 50 milliseconds. This precludes the possibility of fuel lead, which would result in rough engine starts.

At engine cutoff, the pilot valve solenoids are deenergized, opening the actuator ports to the overboard vents so that residual fuel in the actuators is vented into space. (See figure 2-83 for vent locations.) With the actuation fuel pressure removed, the actuator pistons are moved back by spring pressure, causing the propellant shutoff valves to turn 90° to the closed position.

A rough combustion cutoff assembly (RCCA) monitors the vibration level at the ascent engine. It processes the vibration signal to shut down the engine should the vibration level indicate excessively rough combustion. The RCCA has two redundant accelerometers, mounted on the injector assembly, that sense vibration along the X-axis of the ascent engine. The output of each accelerometer is routed to a separate amplifier and trigger network in the RCCA control unit. With the RCCA switch (panel 2) set to ENABLE and either or both STAB/CONT: AELD circuit breakers (panels 11 and 16) open, the RCCA becomes operational. If either of the redundant channels detects rough combustion, the RCCA sends a shutdown signal to the ascent engine control circuitry. The rough combustion characteristic that will shut down the engine is 1,200g (peak to peak), with the significant frequency in the range of 5 to 10 kc. If the engine is shut down by the RCCA, the GDA/RCCA caution light (panel 2) goes on, indicating that the engine has been shut down because of rough combustion. The RCCA remains latched on until the RCCA switch is set to OFF/RESET, thereby interrupting the 28-volt d-c power to the RCCA control unit and removing the shutdown signal. To make the RCCA again operational, the RCCS switch is set to ENABLE before the ascent engine is restarted.

The ascent engine assembly has sensors for measuring fuel and oxidizer inlet pressures, manifold pressures, thrust chamber pressure, vibration, exterior surface temperatures, and propellant shutoff valve positions. The sensor outputs are converted to telemetry data in the IS. These data are transmitted to MSFN, where they are recorded for post-mission evaluation or used to monitor the performance of the ascent engine.

2.3.9 ASCENT PROPULSION SECTION MAJOR COMPONENT/FUNCTIONAL DESCRIPTION.

2.3.9.1 Explosive Valves. (See figure 2-86.)

A high-pressure helium isolation explosive valve at each helium tank outlet, two low-pressure fuel compatibility valves (in parallel), and two low-pressure oxidizer compatibility valves (in parallel), are used in the APS. These valves normally are closed;

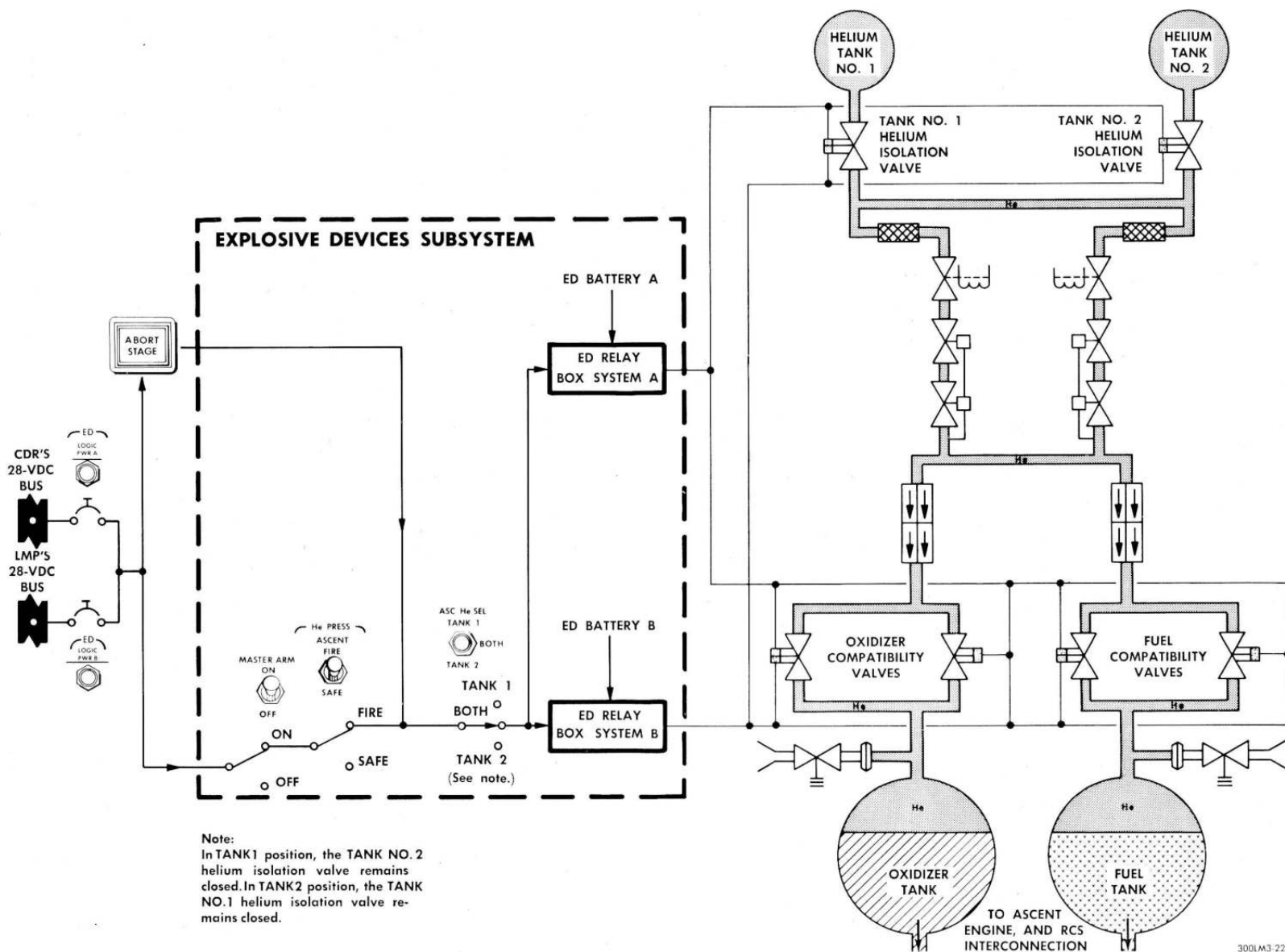


Figure 2-86. Ascent Propulsion Section - Explosive Valves, Simplified Functional Diagram

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

they are opened simultaneously by a command from the EDS control and fire circuits (or from the ABORT STAGE pushbutton on panel 1). When fired, the explosive valves fully open and remain open. The ASC He SEL switch permits isolating a defective helium tank by setting the switch to TANK 1 or TANK 2, thereby firing either valve individually. This applies to manual, automatic and abort stage fire commands. To prevent valve failure in the closed position, the two high-pressure helium isolation valves have dual cartridges that are fired simultaneously by redundant systems in the EDS. The fuel and oxidizer compatibility valves are in redundant parallel flow paths. To ensure propellant tank pressurization, one fuel valve and one oxidizer valve are fired by dual cartridges, the other two compatibility valves are fired by single cartridges.

2.3.9.2 Helium Pressure Regulator Assemblies. (See figure 2-87.)

To be supplied.

2.3.9.3 Relief Valve Assemblies.

Each helium pressurization line that leads to the propellant tanks has a relief valve assembly that consists of a burst disk, a low-pressure vent, and a relief valve. The burst disk prevents helium loss through the relief valve if it should leak during normal engine operation. Once the burst disk is ruptured, the relief valve prevents helium loss during normal engine operation. Under high pressure, the relief valve opens, dumping the helium overboard. A thrust neutralizer provides for omnidirectional thrust generation by the escaping helium. When the pressure drops below the reseal pressure, the relief valve closes to prevent further helium loss. A normally open, low-pressure vent valve, between the burst disk and the relief valve, prevents pressure buildup against the back of the burst disk if the burst disk leaks. If the burst disk ruptures, the vent valve closes under the high pressure and the relief valve opens.

2.3.9.4 Propellant Storage Tanks.

The propellant supply is contained in two spherical titanium tanks. The tanks are of identical size and construction. One tank contains fuel; the other, oxidizer. A helium diffuser at the inlet port of each tank distributes the pressurizing helium uniformly into the tank. An antivortex device (a cruciform at each tank outlet) prevents the propellant from swirling into the outlet port, precluding premature helium ingestion into the engine. Each tank outlet also has a propellant retention device that permits unrestricted propellant flow from the tank under normal pressurization, but blocks reverse propellant flow (from the outlet line back into the tank) under a zero-g or negative-g (more than -2g) condition. This arrangement ensures that helium does not enter the propellant outlet line under any condition; it eliminates the possibility of engine malfunction due to helium ingestion. A low-level sensor in each tank (approximately 4.5 inches above the tank bottom) supplies a discrete signal that causes the ASC QTY caution light to go on when the propellant remaining in either tank is sufficient for approximately 10 seconds of burn time (43 pounds of fuel, 69 pounds of oxidizer).

2.3.9.5 Valve Package Assembly. (See figure 2-88.)

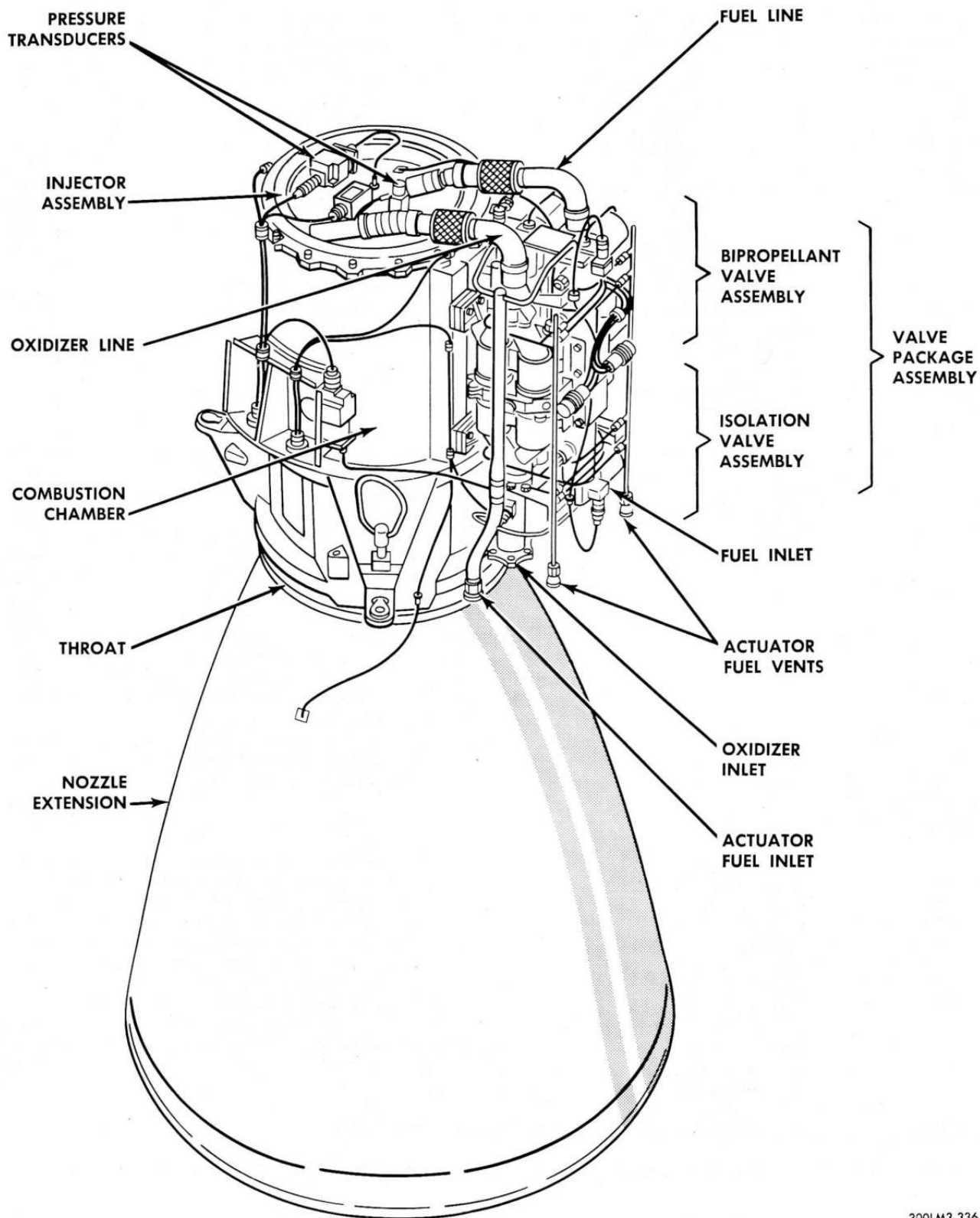
At the propellant feed section/engine assembly interface, the oxidizer and fuel lines lead into the valve package assembly. The individual valves that make up the valve package assembly are in a series-parallel arrangement to provide redundant propellant flow paths and shutoff capability. The valve package assembly consists of two bipropellant valve assemblies, two isolation valve assemblies, and four solenoid pilot valve and actuator assemblies. Each bipropellant valve assembly and each isolation valve assembly consists of one fuel shutoff valve and one oxidizer shutoff valve. These are ball valves that are operated by a common shaft, which is connected to its respective pilot valve and actuator assembly. Shaft seals and vented cavities prevent the propellants from coming into contact with each other. Separate overboard vent manifold assemblies drain the fuel and oxidizer that leaks past the valve seals and the actuation fluid (fuel in the actuators upon pilot valve closing) overboard. (See figure 2-83.) The eight shutoff valves open

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

(To be supplied)

Figure 2-87. Ascent Propulsion Section - Pressure Regulator Assembly

LMA790-3-LM 3
 APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA



300LM3-336

Figure 2-88. Ascent Engine Assembly

simultaneously to permit propellant flow to the engine while it is operating; they close simultaneously to terminate propellant flow at engine shutdown. The two isolation valve assemblies are exposed to the full pressure of the propellant feed system. The four non-latching, solenoid-operated pilot valves control the actuation fluid (fuel) for the isolation and bipropellant valve assemblies. Normally, the solenoids are deenergized, the pilot valves are closed, and the actuation fuel is shut off by action of the spring-loaded solenoid plungers on the ball poppet seated in the lower pilot valve seats. The back sides of the actuator chambers are vented to eliminate a fuel buildup due to leakage of the pilot valves, and to preclude overpressurization of the actuator lines if the fuel temperature increases excessively. When the solenoids are energized, all pilot valves are opened and the actuation fuel acts against the spring-loaded plunger to open the shutoff (ball) valves. At this point, the pilot valve poppets are forced against the upper valve seats, sealing off the vent port. When the electrical signal is removed, the valve poppets return to their lower seat to seal off the actuation fuel. The propellant shutoff valves in the isolation and bipropellant valve assemblies are closed by the return action of the actuator piston springs, and the actuation fuel trapped in the cylinders and valve passages is expelled through the pilot valve vent ports.

2.3.9.6 Injector Assembly.

The injector assembly consists of the propellant inlet lines, a fuel torus manifold, an oxidizer manifold, and an injector orifice plate assembly. Because the fuel torus manifold is larger than the oxidizer manifold, it takes between 40 and 50 milliseconds longer to fill. Consequently, the oxidizer reaches the combustion chamber before the fuel, establishing an oxidizer lead that results in smooth engine starts. The injector assembly is of the fixed-orifice type that uses a baffle for damping induced combustion disturbances. The baffle is cooled by the propellants, which subsequently enter the combustion chamber through orifices on the baffle blade tips. The injector assembly face is divided into three combustion zones: primary, barrier, and baffle. The primary zone uses impinging triplets (two fuel on one oxidizer), which are spaced in concentric radial rings on the injector assembly face. The barrier zone uses fuel-on-oxidizer impinging doublets, which operate at a fuel rich ratio of 1.05 to 1 to provide a barrier of low-temperature gases near the ablative chamber wall. The baffle zone (downstream from the injector face) uses impinging doublets (fuel-on-oxidizer) placed in radial position relative to the injector face. The nominal propellant temperature as propellant enters the injector is +70° F. After approximately 2 seconds of engine operation, the nominal temperature range is +50° to +90° F, with the fuel temperature within 10° F of the oxidizer temperature. (The temperature range at engine start may be +40° F to +120° F.)

2.3.9.7 Combustion Chamber Assembly.

The combustion chamber assembly consists of an engine case and mount assembly and a plastic assembly, which includes the nozzle extension. The engine case and mount assembly is bonded and locked to the plastic assembly to form an integral unit. The plastic assembly provides ablative cooling for the combustion chamber; it consists of the chamber ablative material, the chamber insulator, the nozzle extension ablative material and a structural filament winding. The chamber ablative material extends from the injector to an expansion ratio of 4.6. The chamber insulator, between the ablative material and the case, maintains the chamber skin temperature within the design requirements. The ablative material of the nozzle extension extends from the expansion ratio of 4.6 to 45.6 (exit plane) and provides ablative cooling in this region. The structural filament winding provides the structural support for the plastic assembly and ties the chamber and nozzle extension sections together.

2.3.10 ASCENT PROPULSION SECTION FAILURE MODES.

The APS failure modes and the effect on mission capability are given in table 2-30.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-30. Ascent Propulsion Section - Failure Modes

Failure	Indication	Vehicle Capability
Primary helium isolation solenoid valve failed closed.	ASCENT He REG 1 talkback provides barber-pole display. Ullage pressure indicated on FUEL and OXID PRESS indicator is slightly below nominal value.	Failure does not affect vehicle capability.
Secondary helium isolation solenoid valve failed closed.	ASCENT He REG 2 talkback provides barber-pole display.	Failure does not affect vehicle capability.
Primary upstream pressure regulator failed open.	No indication.	Failure does not affect vehicle capability.
Primary downstream pressure regulator failed open.	Ullage pressure indicated on FUEL and OXID PRESS indicator is slightly above nominal value.	Failure does not affect vehicle capability.
Secondary upstream or downstream pressure regulator failed open.	No indication.	Failure does not affect vehicle capability.
Primary or secondary pair of pressure regulators failed open.	ASC HI REG caution light goes on. FUEL and OXID PRESS indicators indicate approximately 250 psia. HELIUM indicator indicates rapidly decaying pressure.	Vehicle capability is not affected, except for loss of some helium and pressure regulator redundancy. Helium isolation solenoid valve in affected leg must be closed immediately to minimize helium loss through relief valve assemblies.
Propellant tank leak.	FUEL or OXID PRESS indicator indicates decaying pressure. ASC PRESS warning light may go on. ASC QTY caution light may go on.	Depending on amount of leakage, APS operation is shortened, subsequent APS operation is lost, or APS operation is immediately curtailed.
Helium tank No. 1 or 2 leaks.	ASC PRESS warning light goes on. HELIUM indicator indicates decaying pressure.	Depending on amount of leakage, APS operation is shortened, subsequent APS operation is lost, or APS operation is immediately curtailed.
Fuel or oxidizer filter is partially clogged.	Combustion is unstable due to improper fuel-oxidizer ratio. In worst case, ascent engine stops and GDA/RCCA caution light goes on.	RCCA can be reset, but subsequent APS operation may be lost.

2.3.11 ASCENT PROPULSION SECTION PERFORMANCE AND DESIGN DATA

The performance and design data for the APS are given in table 2-31.

Table 2-31. Ascent Propulsion Section - Performance and Design Data

Pressurization section	
Helium tank initial filling weight	6.5 pounds per tank
Helium tank initial pressure and temperature	3,050 psia at +70° F
Helium tank volume	5,800 cubic inches

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-31. Ascent Propulsion Section - Performance and Design Data (cont)

Pressurization section (cont)

Helium tank maximum operating pressure and temperature	3,500 psia at +160° F
Helium tank burst pressure	5,250 psia
Helium filters	
Absolute filtration	15 microns
Nominal filtration	5 microns
Filter element burst pressure	4,000 psi
Helium isolation explosive valves	
Operating pressure range	425 to 4,000 psia
Maximum design pressure	5,320 psia
Helium isolation solenoid valves	
Operating pressure range	400 to 3,500 psia
Maximum design pressure	4,660 psia
Helium pressure regulator assemblies	
Primary path outlet pressure	
Upstream regulator	184±4 psia
Downstream regulator	190±4 psia
Secondary path outlet pressure	
Upstream regulator	176±4 psia
Downstream regulator	182±4 psia
Maximum lockup pressure	203 psia
Maximum outlet flow rate	4.5 pounds of helium per minute
Inlet pressure range	400 to 3,500 psia
Nominal helium flow rate	1.45 pounds per minute
Maximum design pressure	
Inlet	5,320 psia
Outlet	325 psia
Quadruple check valve assemblies	
Maximum operating inlet pressure	270 psia
Maximum pressure drop	5 psi
Maximum design pressure	540 psia
Compatibility explosive valves operating pressure range	100 to 270 psia
Relief valve assembly	
Burst-disk rupture pressure	226 to 250 psia
Relief valve cracking pressure	245 psia
Full-flow pressure	250 psia

MAIN PROPULSION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-31. Ascent Propulsion Section - Performance and Design Data (cont)

Pressurization section (cont)	
Relief valve assembly (cont)	
Reseat pressure	225 psia
Fully open flow rate	4 pounds of helium per minute
Propellant feed section	
Propellant tanks	
Capacity (each tank)	36 cubic feet
Total fuel	2,008 pounds
Total oxidizer	3,179 pounds
Ullage	0.5 cubic foot per tank at +90° F
Usable fuel	1,937 pounds
Usable oxidizer	3,087 pounds
Propellant temperature range	+50° to +90° F
Nominal propellant temperature	+70° F
Nominal ullage pressure	184 psia
Proof pressure	333 psia
Burst pressure	375 psia
Trim-orifice outlet pressure	165±4 psia
Engine assembly	
Propellant filters	
Nominal filtration	175 microns
Absolute filtration	200 microns
Fuel flow rate	4.3 pounds per second
Oxidizer flow rate	7.0 pounds per second
Propellant injection ratio (oxidizer to fuel)	1.6:1
Engine thrust	3,500 pounds
Injector inlet pressure	
Steady-state operation	145 psia
Engine start	185 to 203 psia
Engine start to 90% of rated thrust	0.310 second
Engine shutdown to 10% of rated thrust	0.200 second
Combustion chamber pressure	120 psia
Nominal propellant temperature at injector inlet	+70° F
Approximate weight	214 pounds
Overall length	47 inches
Nozzle exit diameter	31 inches

MAIN PROPULSION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

2.3.12

ASCENT PROPULSION SECTION OPERATIONAL LIMITATIONS AND RESTRICTIONS.

The operational limitations and restrictions for the APS are as follows:

- Propellant tank pressure before pressurization must be between 100 and 205 psia. If these limits are exceeded during dynamic loading, structural failure may result in the propellant tanks, causing loss of the ascent engine.
- Propellant bulk temperature before ascent engine start must be between +50° and +90° F. If the temperature limits are exceeded, the resultant rough combustion may adversely affect engine-component performance.
- Before ascent engine starts (except FITH with DPS burn), the RCS +X-axis thrusters must be fired to establish proper propellant tank ullage, to settle the propellants under weightless conditions, and to prevent helium from entering the RCS interconnect lines. Unsettled or insufficiently settled propellants may result in rough or erratic starts that could lead to engine failure.
- The ascent engine must be shut down before the propellants are depleted to within 10 seconds of burn time remaining, until capability to burn safely to depletion is established. If this requirement is not met, fuel or oxidizer may become depleted, causing possible ingestion of helium into the combustion chamber.
- The APS must not remain pressurized longer than 24 hours before use. If this limit is exceeded, the pressure regulator assemblies may not operate.
- The ascent engine combustion chamber must not be subjected to more than 460 seconds of engine operation. Exceeding this limitation will cause the engine to operate with a severely charred combustion chamber, resulting in burn-through.
- The ascent engine must not be started more than 35 times.
- In the blow-down mode, the ascent engine must not be operated when chamber pressure has decayed to less than 100 psia. At a pressure of less than 100 psia, engine operation may be unstable.

2.3.13

ASCENT PROPULSION SECTION TELEMETRY MEASUREMENTS.

The APS telemetry data are given in table 2-32. "(R)" in the "Telemetry Range" column signifies a real-time telemetry measurement. Real-time telemetry points are shown in figure 2-84.

Table 2-32. Ascent Propulsion Section - Telemetry Measurements

Code	Description	Telemetry Range (Nominal)	Display Range	Crew Display
GP0001P	Helium tank No. 1 pressure	190 to 3,500 psia (3,250 psia) (R)	1. 190 to 3,500 psia 2. Less than 3,000 psia before ascent pressuriza- tion	1. HELIUM indicator 2. ASC PRESS warning light

MAIN PROPULSION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-32. Ascent Propulsion Section - Telemetry Measurements (cont)

Code	Description	Telemetry Range (Nominal)	Display Range	Crew Display
GP0002P	Helium tank No. 2 pressure	190 to 3,500 psia (3,250 psia) (R)	1. 190 to 3,500 psia 2. Less than 3,000 psia before ascent pressuriza- tion	1. HELIUM indicator 2. ASC PRESS warning light
GP0018P	Regulator outlet manifold pressure	100 to 250 psia (195 psia) (R)		None
GP0019P	Helium primary upstream regulator inlet pressure	190 to 3,500 psia (3,250 psia)		None
GP0020P	Helium secondary upstream regulator inlet pressure	190 to 3,500 psia (3,250 psia)		None
GP0025P	Regulator outlet manifold pressure	100 to 250 psia (195 psia) (R)	More than 220 psia	ASC HI REG caution light
GP0201T	Helium tank No. 1 tem- perature	+40° to +100° F (+70° F) (R)	+40° to +100° F	HELIUM indicator
GP0202T	Helium tank No. 2 tem- perature	+40° to +100° F (+70° F) (R)	+40° to +100° F	HELIUM indicator
GP0318X	Helium primary line solenoid valve closed	Contact closure (R)		ASCENT He REG 1 talkback
GP0320X	Helium secondary line solenoid valve closed	Contact closure (R)		ASCENT He REG 2 talkback
GP0501P	Fuel tank ullage pressure	None	100 to 250 psia (195 psia)	FUEL PRESS indicator
GP0504P	Fuel tank vent relief valve inlet pressure	0 to 300 psia (0 psia)		None
GP0616P	Fuel tank bottom - engine interface ΔP	0 to 300 psia (30 psia)		None
GP0718T	Fuel tank fuel bulk tem- perature	+40° to +100° F (+70° F) (R)	+40° to +100° F	FUEL TEMP indi- cator
GP0908X	Fuel tank fuel level low	Contact closure (R)	10 seconds burn time	ASC QTY caution light
GP1001P	Oxidizer tank ullage pressure	None	100 to 250 psia (195 psia)	OXID PRESS indicator
GP1004P	Oxidizer tank vent relief valve inlet pressure	0 to 300 psia (0 psia)		None
GP1116P	Oxidizer tank bottom - engine interface ΔP	0 to 30 psid		None
GP1218T	Oxidizer tank oxidizer bulk temperature	+40° to +100° F (+70° F) (R)	+40° to +100° F	OXID TEMP indi- cator
GP1408X	Oxidizer tank oxidizer level low	Contact closure (R)	10 seconds burn time	ASC QTY caution light

MAIN PROPULSION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-32. Ascent Propulsion Section - Telemetry Measurements (cont)

Code	Description	Telemetry Range (Nominal)	Display Range	Crew Display
GP1501P	Fuel isolation valve inlet pressure	50 to 250 psia (165 psia) (R)	Less than 120 psia	ASC PRESS warning light
GP1503P	Oxidizer isolation valve inlet pressure	50 to 250 psia (165 psia) (R)	Less than 120 psia	ASC PRESS warning light
GP1801X	Isolation valve A not open	Contact closure		None (See GP2997U.)
GP1802X	Isolation valve B not open	Contact closure		None (See GP2998U.)
GP1805X	Bipropellant valve A not open	Contact closure		None (See GP2997U.)
GP1806X	Bipropellant valve B not open	Contact closure		None (See GP2998U.)
GP1811X	Isolation valve A not closed	Contact closure		None (See GP2997U.)
GP1812X	Isolation valve B not closed	Contact closure		None (See GP2998U.)
GP1813X	Bipropellant valve A not closed	Contact closure		None (See GP2997U.)
GP1814X	Bipropellant valve B not closed	Contact closure		None (See GP2998U.)
GP2001P	Fuel injector inlet pressure	0 to 250 psia (165 psia)		None
GP2006P	Oxidizer injector inlet pressure	0 to 250 psia (165 psia)		None
GP2010P	Thrust chamber pressure	90 to 121 psia (110 psia) (R)		None
GP2701T	Thrust chamber external wall temperature No. 1	0° to +500° F		None
GP2702T	Thrust chamber external wall temperature No. 2	0° to +500° F		None
GP2703T	Thrust chamber external wall temperature No. 3	0° to +500° F		None
GP2704T	Thrust chamber external wall temperature No. 4	0° to +500° F		None
GP2706T	Injector surface temperature	0° to +500° F		None
GP2801D	Thrust chamber X-axis vibration	-1,000g to +1,000g		None
GP2802D	Thrust chamber Y-axis vibration	0g to 25g rms		None
GP2803D	Thrust chamber Z-axis vibration	0g to 25g rms		None

MAIN PROPULSION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-32. Ascent Propulsion Section - Telemetry Measurements (cont)

Code	Description	Telemetry Range (Nominal)	Display Range	Crew Display
GP2997U	Isolation and bipropellant valves A mismatch	Contact closure (R)		None
GP2998U	Isolation and bipropellant valves B mismatch	Contact closure (R)		None
GP7551X	Actuator isolation valve A open	Contact closure		None
GP7552X	Actuator isolation valve B open	Contact closure		None
GP7615T	Fuel tank outlet temperature	+40° to +200° F (+70° F)		None
GP7625T	Oxidizer tank outlet temperature	+40° to +200° F (+70° F)		None

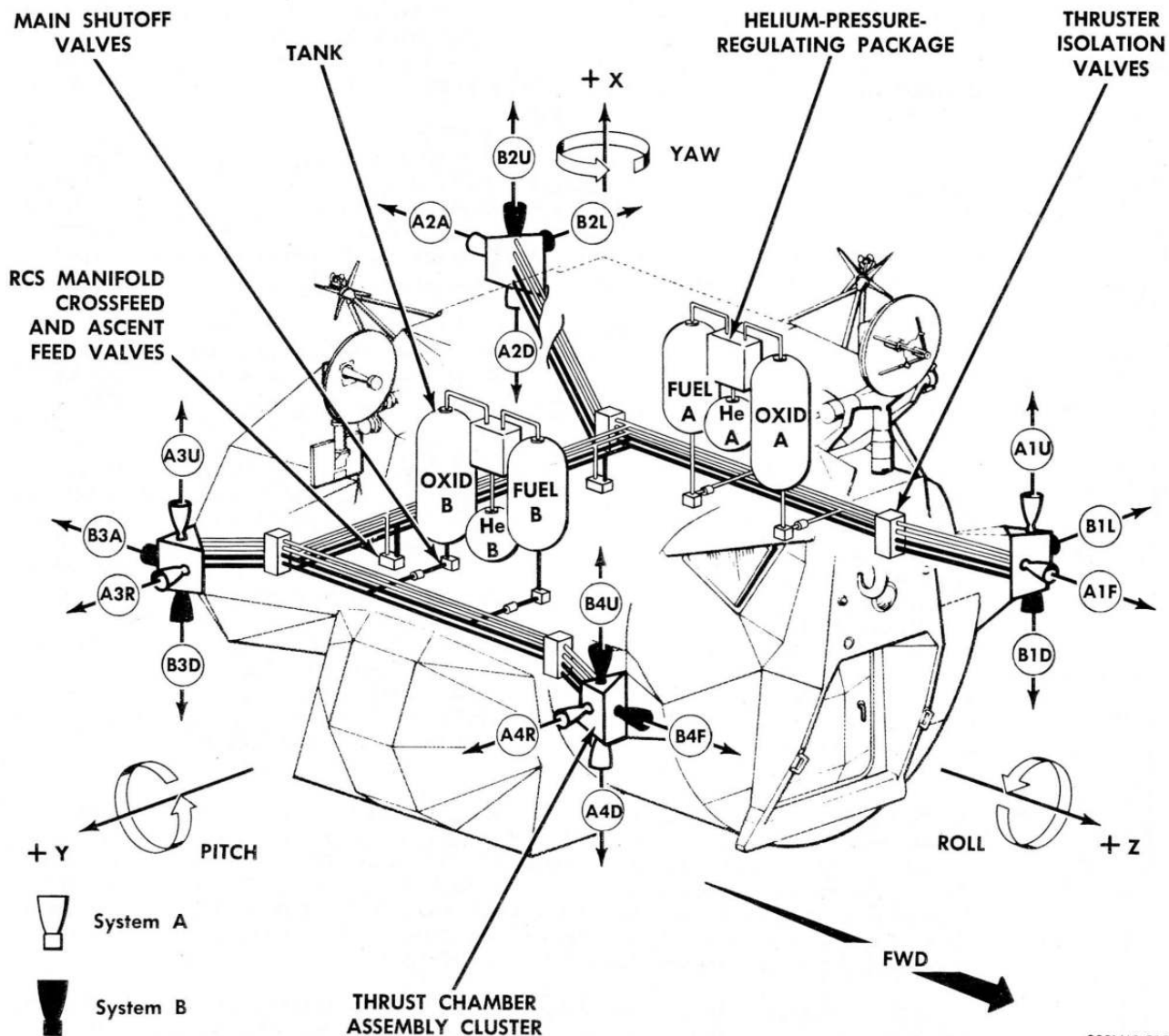
MAIN PROPULSION SUBSYSTEM

2.4 REACTION CONTROL SUBSYSTEM.

2.4.1 INTRODUCTION.

The Reaction Control Subsystem (RCS) stabilizes the LM during descent and ascent, and controls LM attitude and translation about, or along, all axes during hover, rendezvous, and docking maneuvers. It also provides acceleration for ullage settling for the descent and ascent propellant tanks. Attitude and translation are controlled with 16 RCS thrust chamber assemblies (TCA's), which are fed by the RCS propellant supplies or by propellants obtained from the ascent propulsion section (APS). The 16 TCA's are arranged in clusters of four, mounted on four outriggers that are equally spaced around the LM ascent stage. In each cluster, two TCA's are mounted parallel to the LM X-axis, facing in opposite directions; the other two are spaced 90° apart, in a plane normal to the X-axis. (See figure 2-89.)

RCS



300LM3-212

Figure 2-89. Reaction Control Subsystem - Component Location

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

The RCS consists of two parallel, independent systems (A and B), which, under normal conditions, function simultaneously. Each system has its own pressurized propellant supply that feeds eight TCA's (two in each cluster). The arrangement of the TCA's is such that either system, functioning alone, can provide complete control in all axes. Moreover, if the propellant supply of one system is depleted or fails, a crossfeed capability permits routing propellants from the operative system to all 16 TCA's.

Interface between the RCS and other LM subsystems is shown in figure 2-90. Transducer and valve-position-switch outputs (operational and DFI) that originate in the RCS are processed in the Instrumentation Subsystem (IS). The operational measurements (real-time) that are monitored throughout the mission are transmitted via the Communications Subsystem (CS) to MSFN. Developmental Flight Instrumentation (DFI) data used for postmission evaluation of RCS performance are routed through the IS to the communications section of the DFI for transmission to MSFN. The IS also processes RCS caution and warning signals. The RCS propellant tanks are pressurized immediately before separation of the LM from the CSM, by firing of explosive valves by the Explosive Devices Subsystem (EDS). Interconnect plumbing between the TCA feed lines and the APS propellant tanks permits the RCS to use APS propellants during certain phases of the mission, thereby conserving the RCS supply. The electrical components of the RCS are supplied with 28-volt d-c primary power through the Commander's and LM Pilot's buses of the Electrical Power Subsystem (EPS).

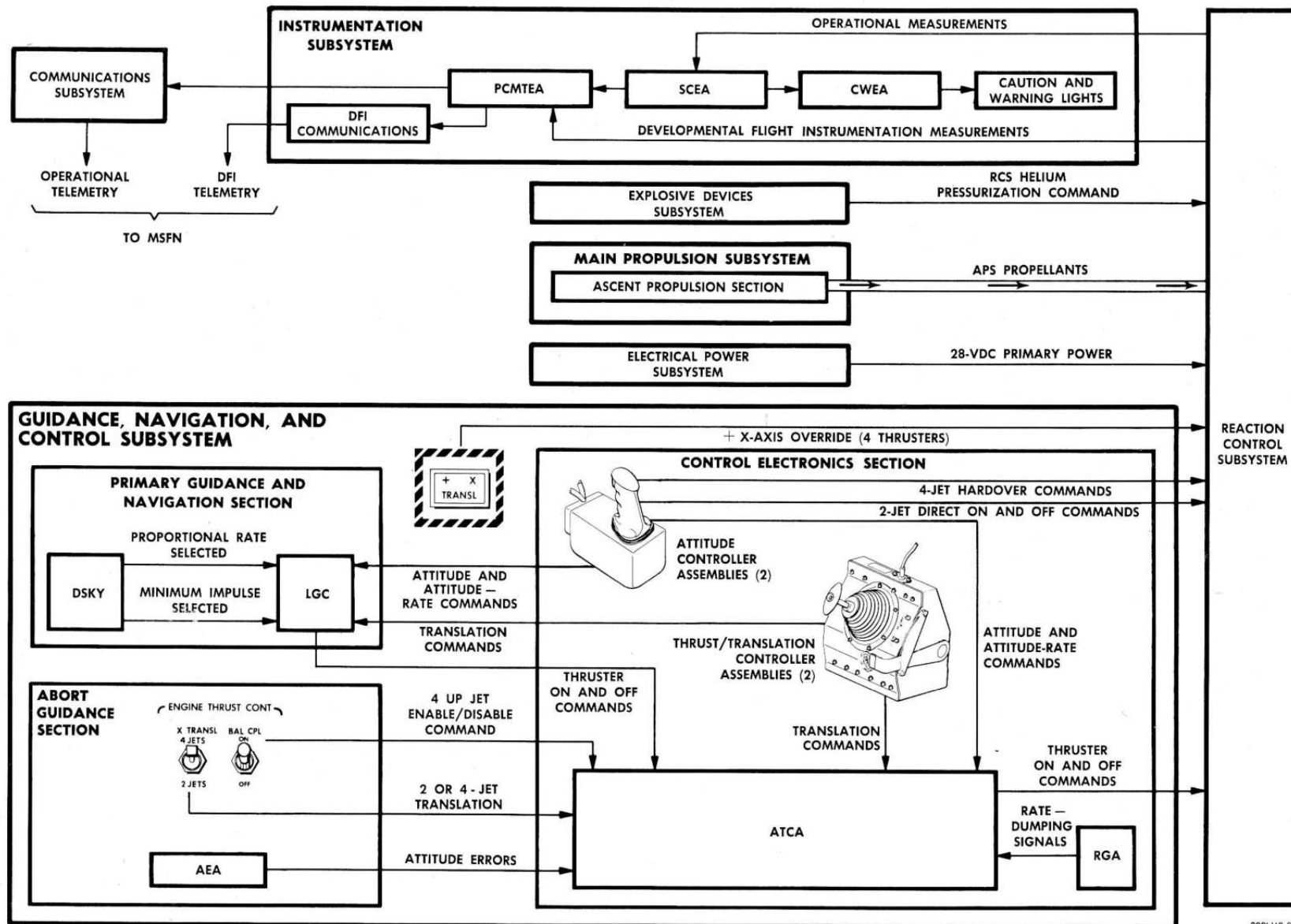
The Guidance, Navigation, and Control Subsystem (GN&CS) provides commands that select and fire TCA's for durations ranging from a pulse of less than 1 second to steady-state operation. The TCA's can be operated in an automatic mode, an attitude hold mode, or a manual override mode. RCS operation can be controlled by the primary guidance and navigation section (PGNS) or by the abort guidance section (AGS). A detailed description of RCS operation by the GN&CS is given in subsection 2.2.

Normally, translation and attitude are controlled by the PGNS in the automatic mode, in which all navigation, guidance, stabilization, and steering functions are controlled by the LM guidance computer (LGC). Under AGS control, the abort electronics assembly (AEA) and the attitude and translation control assembly (ATCA) take the place of the LGC.

The attitude hold mode provides semiautomatic operation. In this mode, either astronaut can manually determine attitude changes by displacing his attitude controller assembly (ACA), and three-axis translation changes by displacing his thrust/translation controller assembly (TTCA). The amount of ACA displacement causes a proportional impulse to be routed to the LGC. The LGC uses this impulse to perform steering calculations and to generate a thruster-on command. The thruster-on command is routed to appropriate jet drivers in the ATCA, firing selected TCA's. A DSKY input to the LGC determines whether the LGC commands an angular rate change proportional to ACA displacement, or a minimum impulse for each ACA displacement. When the ACA is returned to the detent position, the LGC sends a command to hold the attitude. For translation, displacement of the TTCA sends a discrete to the LGC, which sends a thruster-on command to selected TCA's. When the TTCA is returned to neutral, the TCA's are turned off.

In the attitude hold mode, under AGS control, the AEA generates attitude errors that are summed, in the ATCA, with proportional rate commands from the ACA and a rate-damping signal from the rate gyro assembly (RGA). The ATCA then performs the steering calculations and generates the thruster on and off commands. Two or four X-axis TCA's for translation maneuvers and a manual override for attitude control in each axis (2-jet direct) can be selected. The four upward-firing TCA's can be inhibited to conserve RCS propellants during the ascent engine thrust phase.

The manual override mode, under PGNS or AGS control, overrides the automatic mode. The four-jet hardover command from the ACA is a manual override command, which is applied directly to the TCA's. The hardover output fires four TCA's simultaneously.



300LM3-210

Figure 2-90. Reaction Control Subsystem - Interface Block Diagram

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

The +X TRANSL pushbutton provides a command to operate the four downward-firing TCA's, which continue firing until the pushbutton is released.

Fuel and oxidizer are loaded into bladders within the propellant tanks and into the manifold plumbing that extends from the tanks to the isolation valves leading to the thruster pairs. Gaseous helium, reduced to a working pressure, enters the propellant tanks, forcing the fuel and oxidizer through the normally open main shutoff valves and isolation valves (opened before separation of the LM from the CSM) to the TCA's. Here, the propellants are blocked by normally closed fuel and oxidizer valve assemblies until a thruster-on command is issued. As the selected TCA receives a thruster-on command, its fuel and oxidizer valve assemblies open, routing the propellants through the TCA injector into the combustion chamber, where they impinge and ignite. Malfunctioning pairs of TCA's or a malfunctioning system can be isolated and made inoperative by manually closing switches on the REACTION CONTROL panel (panel 2). Each switch is connected to two valves so that the fuel and oxidizer supply is shut off simultaneously. Talkbacks on panel 2 indicate the status of the RCS valves.

2.4.2 FUNCTIONAL DESCRIPTION. (See figure 2-91.)

Functionally, each RCS system (A or B) can be subdivided into a helium pressurization section, a propellant section, a propellant quantity measuring device, and eight TCA's. All RCS components are located in the ascent stage. Because RCS systems A and B are identical, only one system is described.

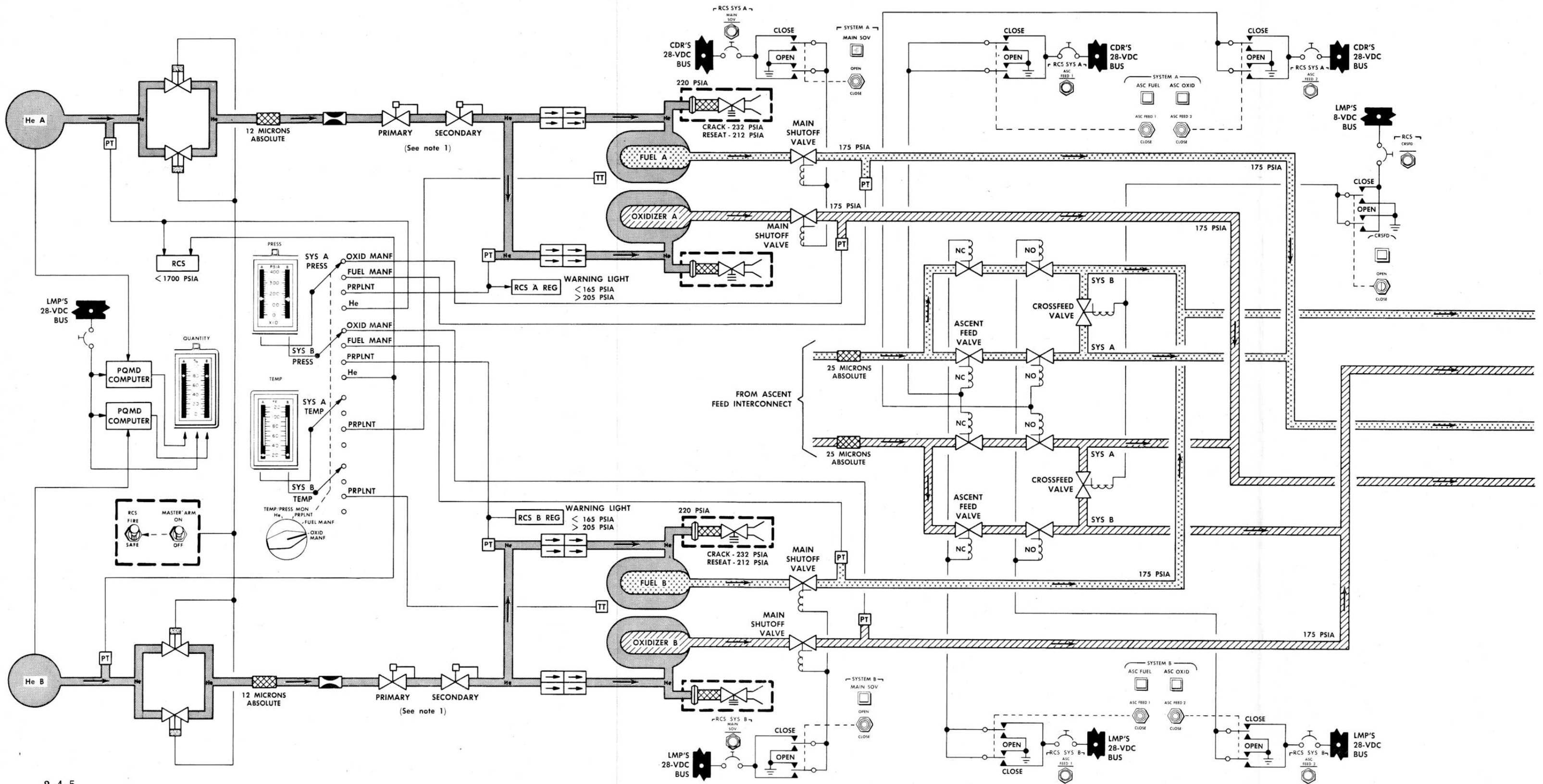
2.4.2.1 Helium Pressurization Section.

Approximately 1 pound of gaseous helium, at a nominal pressure of 3,050 psia at +70° F, is stored in the helium tank. Flow from the tank separates into two parallel paths. Each flow path contains a normally closed explosive valve that isolates the helium tank from the downstream components before RCS pressurization. A sensor (part of the propellant quantity measuring device) in the helium tank senses the pressure-temperature ratio of the helium. The sensor output is conditioned and routed to the A or B QUANTITY indicator (panel 2), which indicates the combined (fuel and oxidizer) percentage of propellants remaining. A pressure transducer at the outlet port of the helium tank monitors the helium pressure. It supplies a signal to the PRESS indicator (panel 2) when the TEMP/PRESS MON selector switch (panel 2) is set to He. (When the switch is set to He, the X10 light of the PRESS indicator goes on to indicate that the values displayed must be multiplied by 10.) The pressure transducer also supplies a signal that causes the RCS caution light (panel 2) to go on, when helium pressure at the tank outlet port drops below 1,700 psia.

When the MASTER ARM switch (panel 8) is set to ON and the RCS He PRESS switch is set to FIRE, the explosive valves open simultaneously to pressurize the RCS. Because of the redundant paths, failure of one explosive valve does not affect pressurization of the propellant tanks. Downstream of the explosive valves, the two flow paths merge and the helium flows through a filter that prevents contamination of downstream components by trapping debris generated by firing the cartridges in the explosive valves. A restrictor orifice, downstream of the filter, dampens the initial helium surge, thereby minimizing the possibility of rupturing the burst disk in the downstream pressure relief valve assemblies.

Downstream of the restrictor, the flow path contains two series-connected pressure regulators. The primary (upstream) regulator is set to reduce pressure to approximately 181 psia. The secondary (downstream) regulator is set for a slightly higher output (approximately 185 psia). In normal operation, the primary regulator provides proper propellant tank pressurization. A pressure transducer senses the pressure at the output of the regulators and provides an input to the PRESS indicator via the TEMP/PRESS MON selector switch (PRPLNT position). If one regulator fails closed, or if both regulators fail open, the downstream pressure decreases or increases beyond acceptable limits (minimum pressure of 175 psia; maximum pressure of 195 psia) and the RCS A REG or RCS B REG warning light (panel 1) goes on. (If the main propellant shutoff

REACTION CONTROL SUBSYSTEM



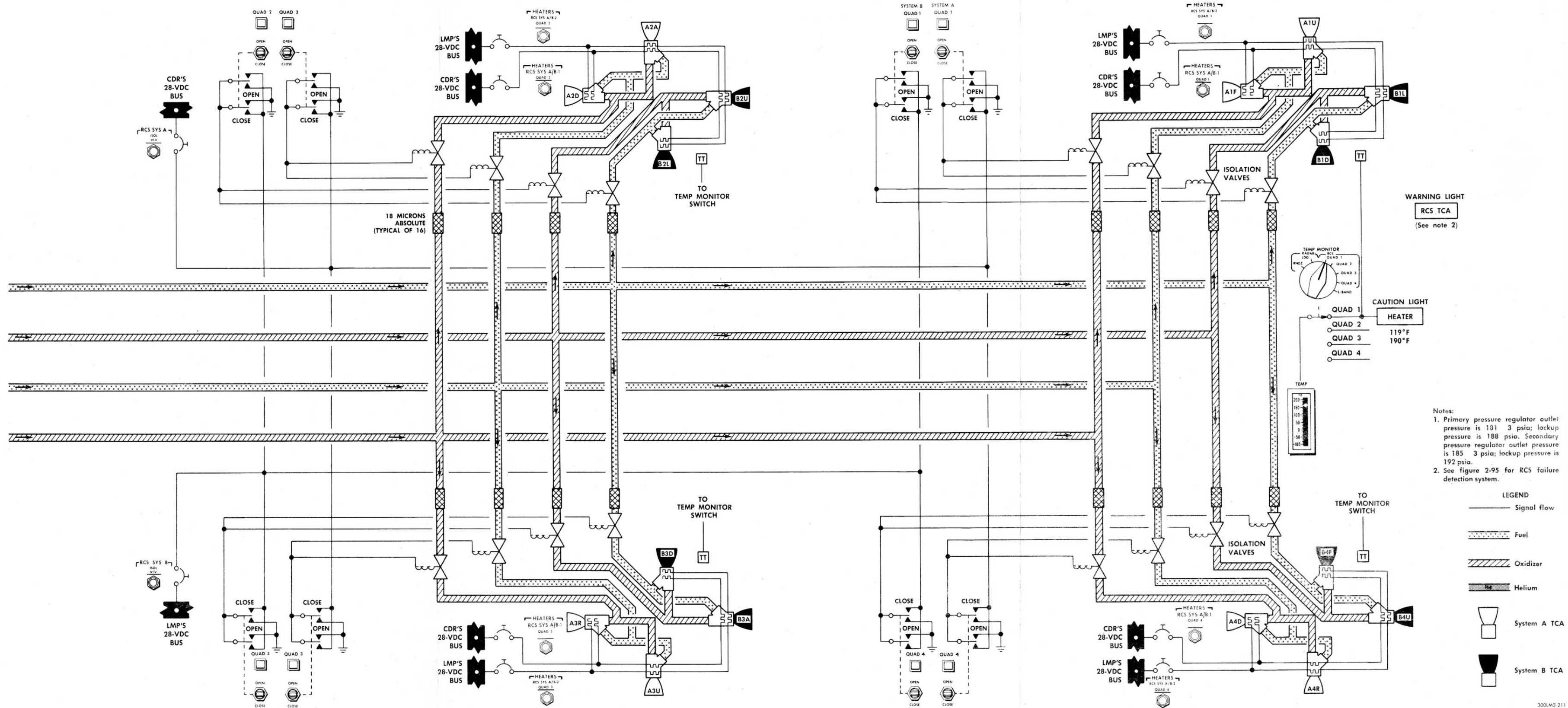


Figure 2-91. Reaction Control Subsystem - Simplified Functional Flow Diagram

valves are closed, this warning light is inhibited and does not go on, regardless of the pressure at the helium regulator manifold.) Downstream of the pressure regulators, a helium manifold divides the flow into two paths: one leads to the oxidizer tank; the other, to the fuel tank. Each flow path has quadruple check valves in a series-parallel arrangement to prevent back-flow of propellant vapors into the helium manifold if seepage occurs in the propellant tank bladders. The helium flows through the check valves into the propellant tanks. A relief valve assembly at the inlet port of each propellant tank protects the propellant tank against overpressurization. If pressure in the helium lines exceeds 220 psia, a burst disk in the relief valve assembly ruptures. When the pressure reaches 232 psia, helium is vented overboard through the relief valve vent port. When the pressure drops below 232 psia, the relief valve closes, permitting normal system operation.

2.4.2.2

Propellant Section.

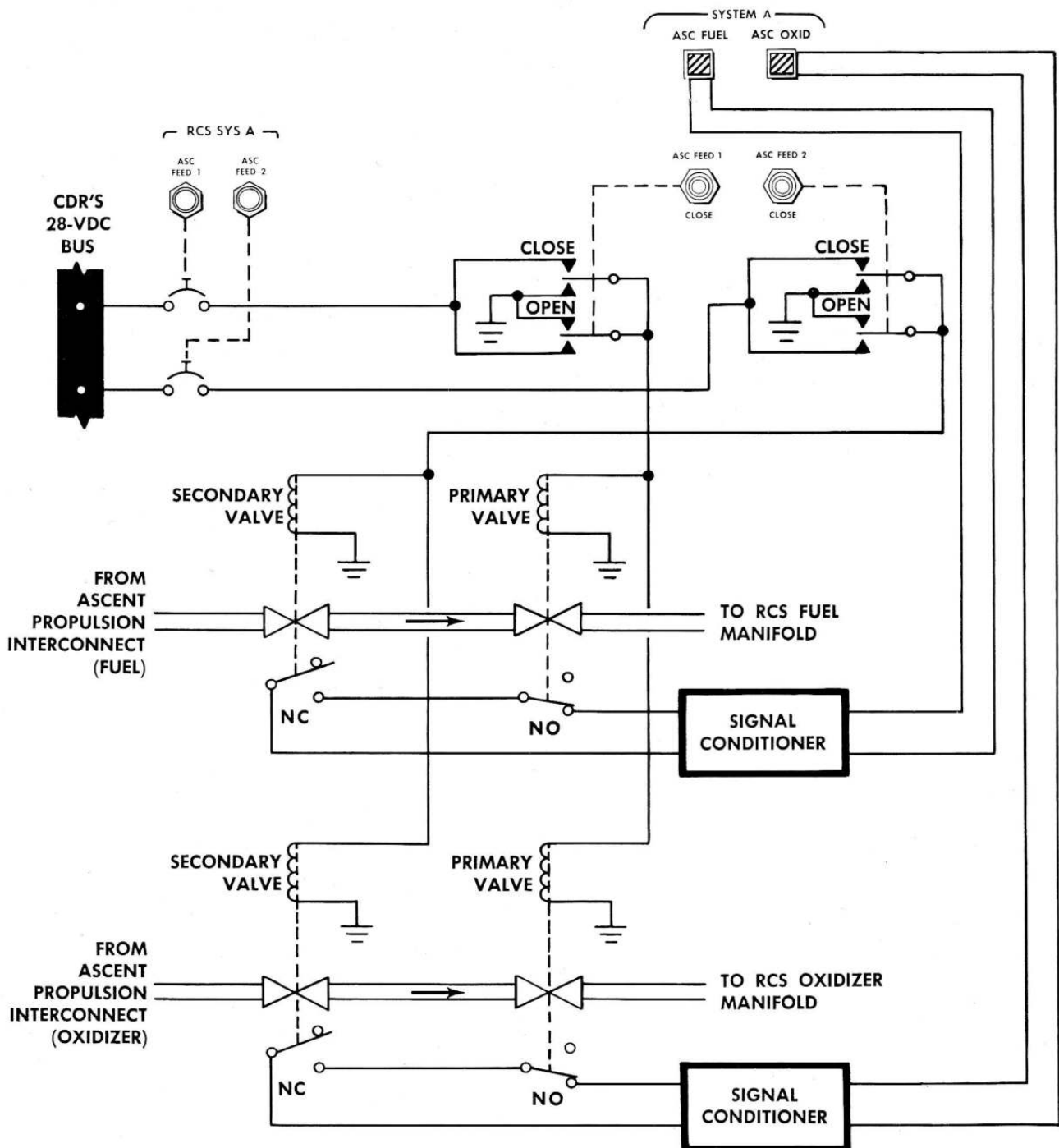
Each RCS system has an oxidizer tank and a fuel tank. The propellant is in a bladder inside the tank. Helium enters the void between the bladder and the tank wall and acts upon the bladder to provide positive propellant expulsion at all times. A temperature transducer at the fuel tank senses fuel temperature, and supplies a signal to the TEMP indicator when the TEMP/PRESS MON selector switch is set to PRPLNT. Because fuel and oxidizer temperatures are identical under normal conditions, the TEMP indicator displays fuel temperature as propellant temperature.

From the tank bladder, the propellants flow through the normally open main shutoff valves into separate manifolds that lead to the TCA's. If a malfunction occurs upstream of the main shutoff valves or if propellants of one system are depleted, setting the MAIN SOV switch to CLOSE closes both main shutoff valves in the system simultaneously and isolates the system's propellant tanks from its TCA's. The MAIN SOV talkback provides a gray display when either or both valves are open, a barber-pole display when both valves are closed. After the propellant supply of a system is shut off, the crossfeed valves between the system A and B manifolds can be opened to enable operation of all TCA's, but using propellants from only one system. This is accomplished by setting the CRSFD switch to OPEN. When both crossfeed valves (fuel and oxidizer) are closed, the CRSFD talkback provides a barber-pole display. When the valves are open, the talkback is gray.

During ascent engine thrusting, APS propellants may be used by the RCS (within the operational limitations and restrictions listed in paragraph 2.4.6). Fuel and oxidizer from the APS enter the RCS at the interconnect ports and flow through a filter that prevents contamination of the RCS components. Downstream of the filters, the propellant lines divide so that a separate fuel and oxidizer line interconnects with the RCS system A and system B propellant lines. Normally, the interconnect lines are blocked by the ascent feed interconnect valves, which prevent APS propellants from entering the RCS. The valves can be opened in fuel-oxidizer pairs to interconnect the APS with RCS system A or B, or systems A and B simultaneously. The redundant arrangement of these valves (figure 2-92) prevents APS fuel or oxidizer from inadvertently entering the RCS. Normally, the secondary (upstream) valve in each ascent interconnect line is closed and the primary (downstream) valve is open. The ASC FUEL and ASC OXID talkbacks provide a barber-pole display when either or both valves are closed. When both valves in the line are open (by use of ASC FEED 1 and ASC FEED 2 switches), the talkbacks provide a gray display.

Each system manifold feeds propellants to eight TCA's, two in each cluster. The thruster pair isolation valves normally remain open during RCS operation. They can be closed to isolate malfunctioning or damaged TCA's. The valves are controlled in pairs (fuel and oxidizer) by the QUAD switches. Each QUAD switch provides or terminates fuel and oxidizer flow to a pair of like system TCA's in one cluster. When both isolation valves (fuel and oxidizer) are closed, the QUAD talkback for the specific thruster pair provides a barber-pole display. When either or both valves of a pair are open, the talkback is gray. A filter upstream of each isolation valve prevents contaminants from entering the TCA's.

LMA790-3-LM 3
 APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA



300LM3-337

Figure 2-92. RCS System A - Ascent Feed Interconnect Valve Arrangement

2.4.2.3 Propellant Quantity Measuring Device. (See figure 2-93.)

The propellant quantity measuring device (PQMD) measures the total quantity of propellants (sum of fuel and oxidizer) in the fuel and oxidizer tanks. The analog voltage output of the PQMD is fed to the QUANTITY indicator and is displayed on the A and B scales (one for each RCS system) as percentage of propellant remaining in the tanks.

The PQMD measures the quantity of propellant by first sensing the pressure/temperature ratio of the gas in the helium tank. This ratio is directly proportional to the mass of the gas. The analog computer then subtracts this mass from the total helium mass in the system, to obtain the helium mass in the propellant tanks. This value is used to compute the volume of gas in the ullage of the propellant tanks. Finally, the volume of the gas in the propellant tanks is subtracted from the total tank volume to obtain the total quantity of propellant remaining in the tanks. The QUANTITY indicator reading before firing the explosive helium isolation valve exceeds 100%, so that after the valve is fired (when the helium becomes less dense in the helium tank) the indicated quantity is 100%.

The input device of the PQMD is a Wheatstone bridge that senses pressure/temperature (P/T) ratio. The bridge is energized by a bridge amplifier in an analog computer. The analog computer contains a power supply, three amplifiers, and three internal system-calibrating adjustments. The output voltage of the P/T sensor is applied to the pre-amplifier. The amplified signal is fed to the output amplifier, which sums this signal with the input reference voltage and provides an analog output (0 to 5 volts) to the QUANTITY indicator. The power supply receives an input voltage from the RCS SYS B: PQGS DISP circuit breaker.

2.4.2.4 Thrust Chamber Assemblies.

The TCA clusters (figure 2-94) are enclosed in thermal shields so that only the nozzles protrude. The thermal shields aid in maintaining a temperature-controlled environment for the propellant lines from the ascent stage to the TCA's.

Each TCA contains an oxidizer solenoid valve and a fuel solenoid valve, which, when open, pass propellant through an injector into the combustion chamber, where ignition occurs. Each solenoid valve contains a primary (automatic) coil and a secondary (direct) coil, either of which, when energized, opens the valve. Primary power (28 volts) is applied to the TCA primary coils via the RCS SYS A and RCS SYS B: QUAD TCA circuit breakers (panels 11 and 16, respectively). (See figure 2-95.) Each circuit breaker controls power to the primary coils of two TCA's in each quad. In the automatic mode, the on and off commands are applied to the primary coils of the TCA's. When a manual override command (such as attitude hardover or +X translation) is issued, the command is applied directly to the secondary coils of the TCA's.

For attitude control, the duration of TCA firing ranges from a pulse to steady-state operation. The pulse mode is used for small attitude changes in the selected axis. In this mode, TCA operation lasts for less than 1 second; the minimum pulse for TCA firing is 13 milliseconds. In the steady-state mode, operation lasts for 1 second or longer. For a short-duration pulse (figure 2-96), engine thrust is just beginning to rise when the shutdown command is given, and only a very small amount of propellant is injected into the combustion chamber. Under these conditions of minimum impulse, the full 100 pounds of thrust cannot be achieved and TCA operation is comparatively inefficient.

If a pressure regulator in the helium pressurization section fails closed, TCA operation continues briefly until helium pressure drops below the acceptable limit and propellants are no longer injected into the TCA combustion chamber. If both pressure regulators fail open, the relief valves in the pressurization section will vent the helium overboard; however, TCA operation continues until near-depletion of the helium. In either type of pressurization failure, use of the eight TCA's of the affected system is lost until the main shutoff valves are closed and the crossfeed valves are opened to allow the operative system to supply propellants to the TCA's of the malfunctioning system.

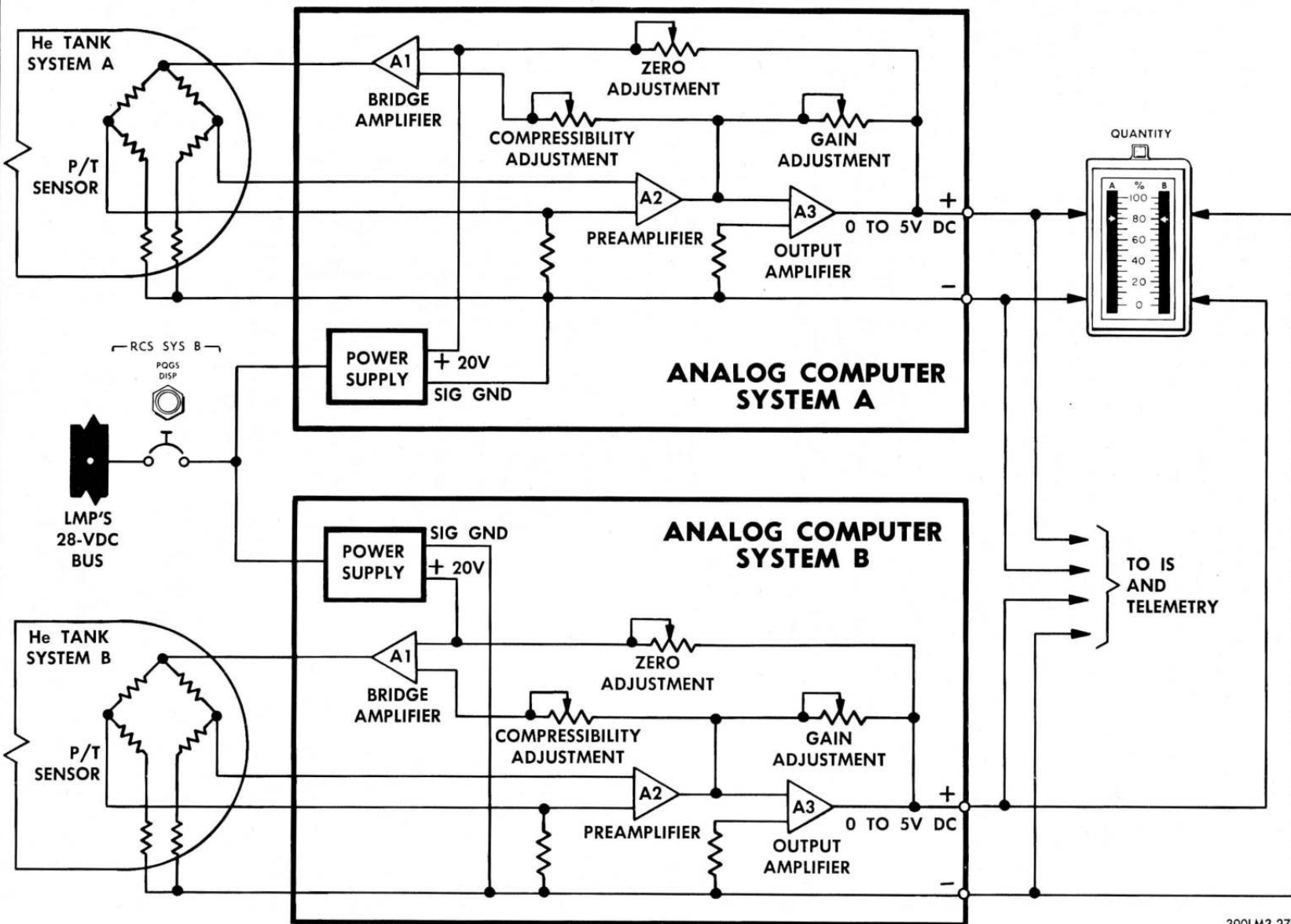
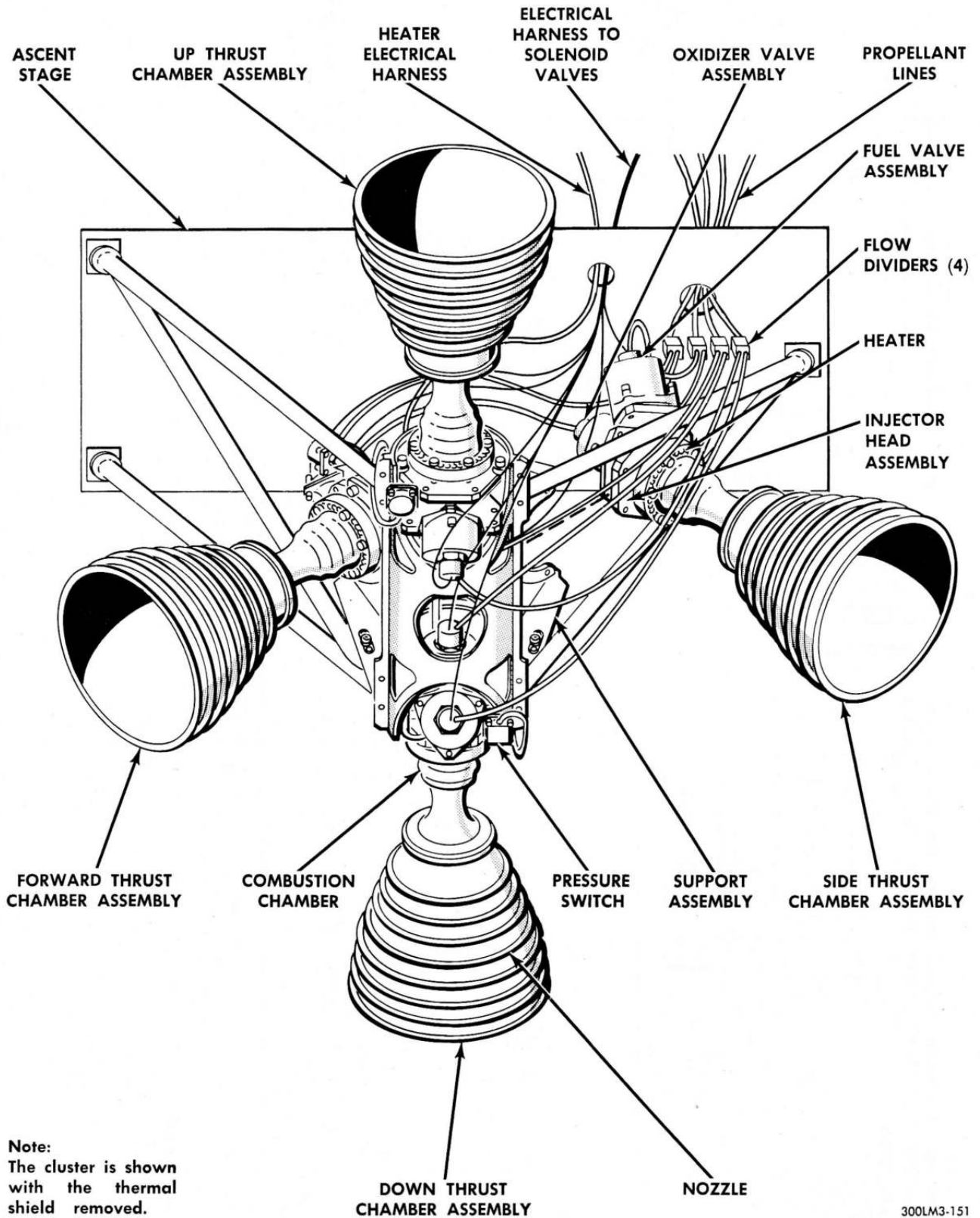


Figure 2-93. Propellant Quantity Measuring Device

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA



300LM3-151

Figure 2-94. Thrust Chamber Assembly Cluster

REACTION CONTROL SUBSYSTEM

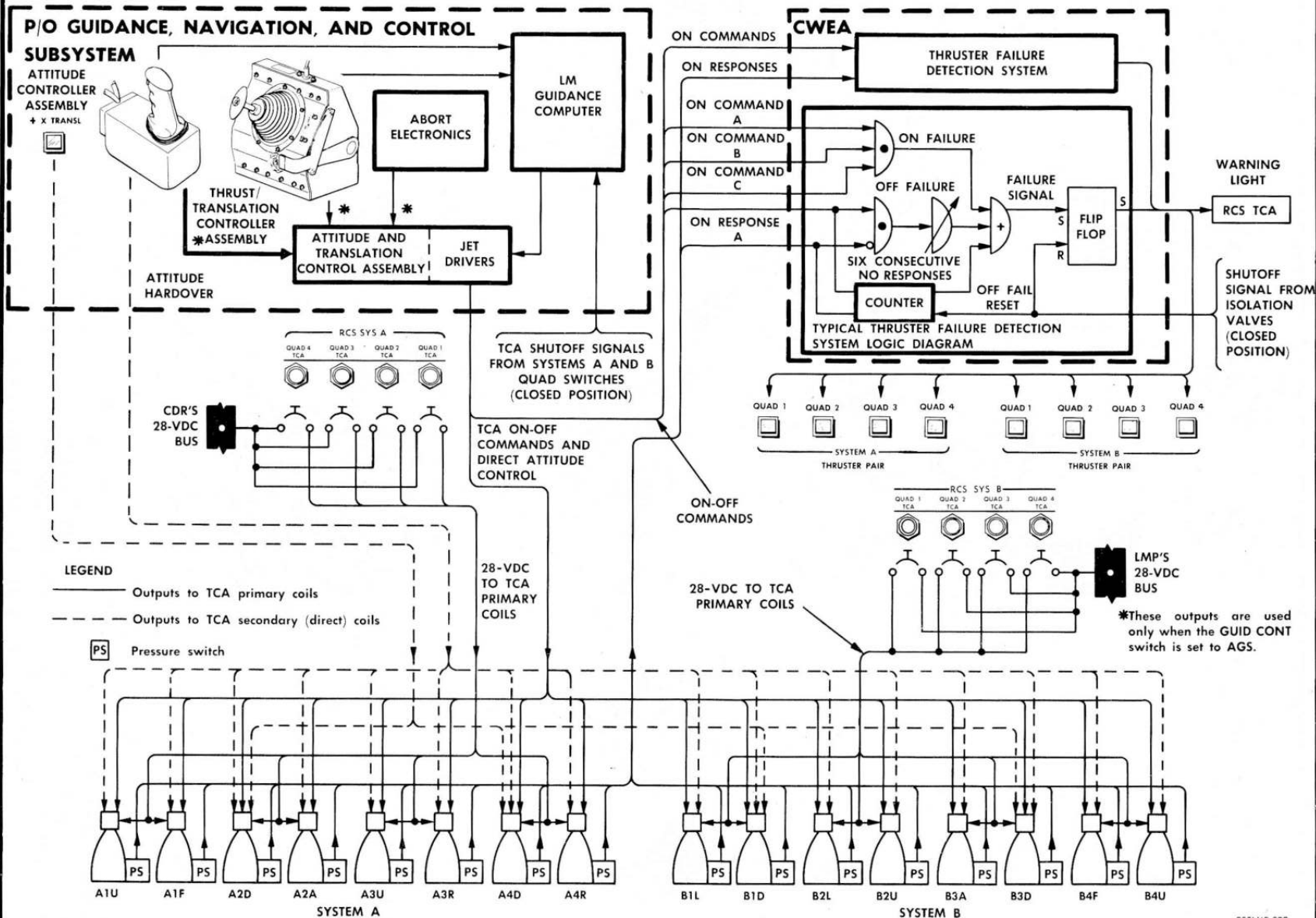


Figure 2-95. Thrust Chamber Assembly - Operation and Failure Detection System

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

(To be supplied)

Figure 2-96. Thrust Chamber Assembly - Thrust Versus Time

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Initial combustion occurs in a preigniter cup that prevents ignition delay, which could cause destruction of a TCA. (See figure 2-97.) Fuel and oxidizer pass through preigniter tubes to their respective preigniter injection orifices. The fuel is sprayed into the preigniter cup; the oxidizer is ejected and impinges with the fuel, causing spontaneous ignition and establishing combustion in the preigniter cup. The main fuel flow is routed through four equally spaced holes in the side of the preigniter tube, to a chamber that channels the fuel to an annulus. The annulus routes fuel into 24 passages that lead to three concentric fuel rings. Fuel is sprayed from eight orifices in the outermost ring onto the combustion chamber wall, where it forms a boundary layer for cooling. The intermediate middle ring has eight orifices that spray fuel onto the outer wall of the preigniter cup. This fuel cools the preigniter cup before it vaporizes. Eight primary fuel orifices of the middle ring eject fuel to mix with the oxidizer. The main oxidizer flow is routed through four equally spaced holes in the side of the oxidizer preigniter tube, to a chamber that supplies the eight primary oxidizer orifices of the innermost ring. The eight primary oxidizer orifices and eight primary fuel orifices are arranged in doublets, at angles to each other, so that the emerging propellant streams impinge. Due to the hydraulic delay built into the injector, ignition at these eight doublets occurs 4 milliseconds later than ignition inside the preigniter cup.

When the thruster-off command is given, the primary or secondary coils become de-energized, releasing the armature poppets. Spring and propellant pressure return the armature poppet of each valve to its seat, shutting off propellant flow into the injector. Propellant trapped in the injector is ejected and burned for a short time, while thrust decays to zero pounds.

2.4.2.4.1

Thrust Chamber Assembly Failure Detection System. (See figure 2-95.)

The failure detection system can detect thruster-on or thruster-off failures when the RCS is under PGNS or AGS control.

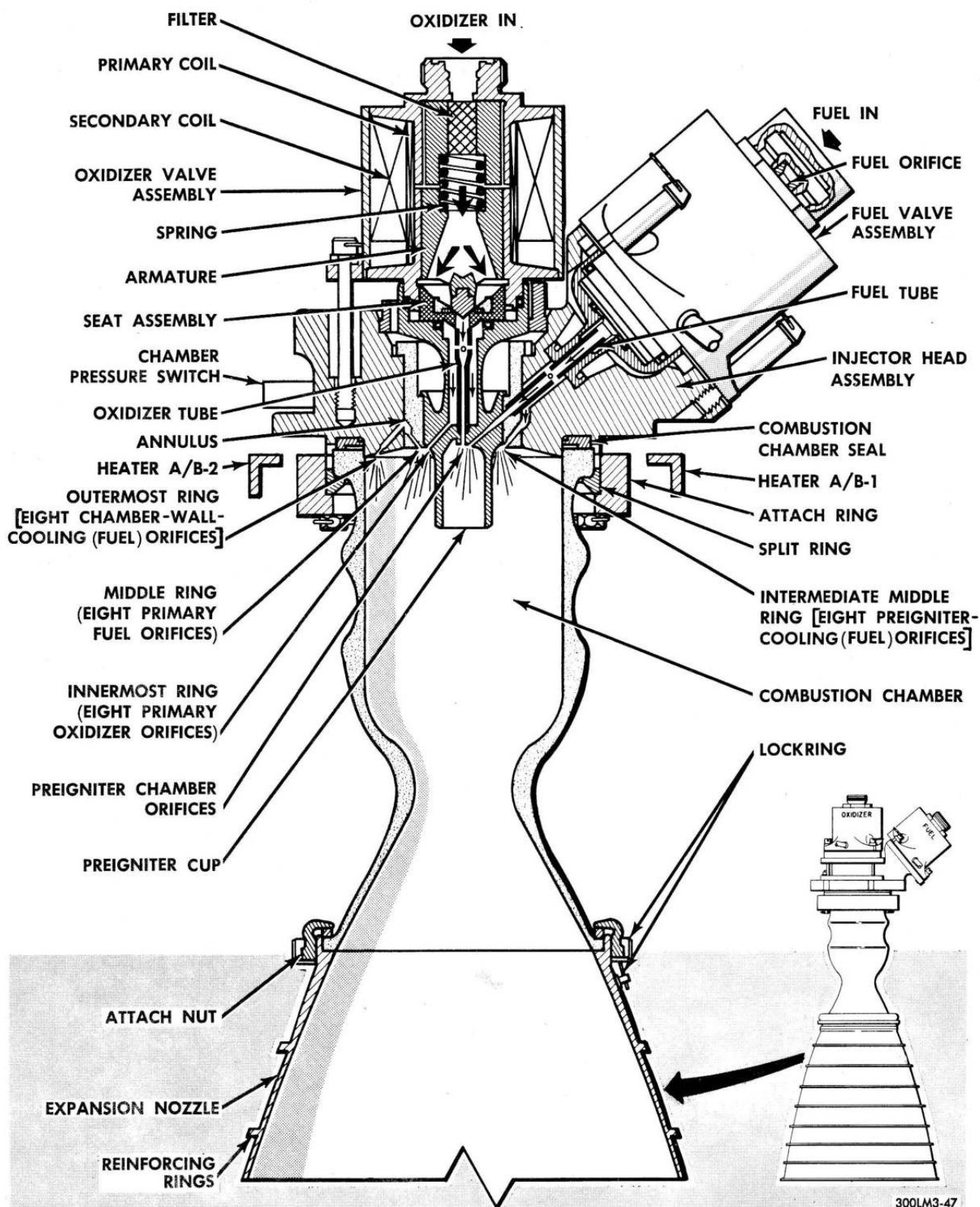
Thruster-On Failures. A thruster-on failure, defined as a TCA thrusting condition without an on command from its jet driver, is indicated by the RCS TCA warning light (panel 1). All engine commands are routed through the caution and warning electronics assembly (CWEA) of the IS, which detects the presence of opposing command signals. Opposing collinear TCA's are fired simultaneously only to compensate for the effect of a failed-on thruster. The command, from the jet drivers, to turn on a particular TCA is routed to the thruster failure detection system, where it is applied simultaneously to two AND gates in each failure detection circuit.

When a thruster turn-on command (command A, figure 2-95) and the opposing thruster-on commands (commands B and C) are applied simultaneously to the AND gate, the output (an on-failure signal) is applied to the flip-flop via the OR gate. Setting the flip-flop causes the RCS TCA warning light to go on, and the respective QUAD talkback provides a red (TCA failure) display. To isolate the failed TCA, the related QUAD switch is set to CLOSE. The CLOSE position applies a reset signal to the flip-flop and counter, turning off the RCS TCA warning light and changing the respective QUAD talkback to a barber-pole display. In addition, a TCA shutoff signal (from the QUAD switch) is applied to the LGC to prevent the TCA valves from being cycled. If a thruster-on failure occurs, opposing TCA's fire to nullify the effect of TCA firing due to the failure. (See figure 2-98.) As an example, if TCA B4U fails on, TCA's A4D and B2U receive on commands.

Thruster-Off Failures. A thruster-off failure is defined as a nonthrusting condition with an on command (command A) from the jet drivers. With command A (figure 2-95), and the absence of a response from the pressure switch in the TCA, an off-failure signal is initiated at the AND gate. The TCA pressure switch closes by the time a maximum pressure of 10.5 psia is sensed in the combustion chamber; it opens by the time pressure has decayed to minimum of 3 psia. Under normal operating conditions, the TCA's may not respond to all individual on commands, if these commands (pulses) are of short duration (less than 80 milliseconds). If the output (off-failure signal) of the AND gate lasts longer than 80 milliseconds, it is inverted and applied to the set side of the flip-flop via the OR gate.

REACTION CONTROL SUBSYSTEM

LMA790-3-LM 3
 APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA



300LM3-47

Figure 2-97. Thrust Chamber Assembly

REACTION CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEM DATA

THRUSTER FAILED ON	ON COMMAND SIGNALS															
	A1U	B1D	A1F	B1L	B2U	A2D	A2A	B2L	A3U	B3D	B3A	A3R	B4U	A4D	B4F	A4R
A1U	●	●							●							
B1D	●	●								●						
A1F			●				●								●	
B1L				●				●								●
B2U					●	●							●			
A2D					●	●								●		
A2A			●				●				●					
B2L				●				●				●				
A3U	●								●	●						
B3D		●							●	●						
B3A							●				●				●	
A3R								●				●				●
B4U					●								●	●		
A4D						●							●	●		
B4F			●								●				●	
A4R				●								●				●

LEGEND



System A



System B

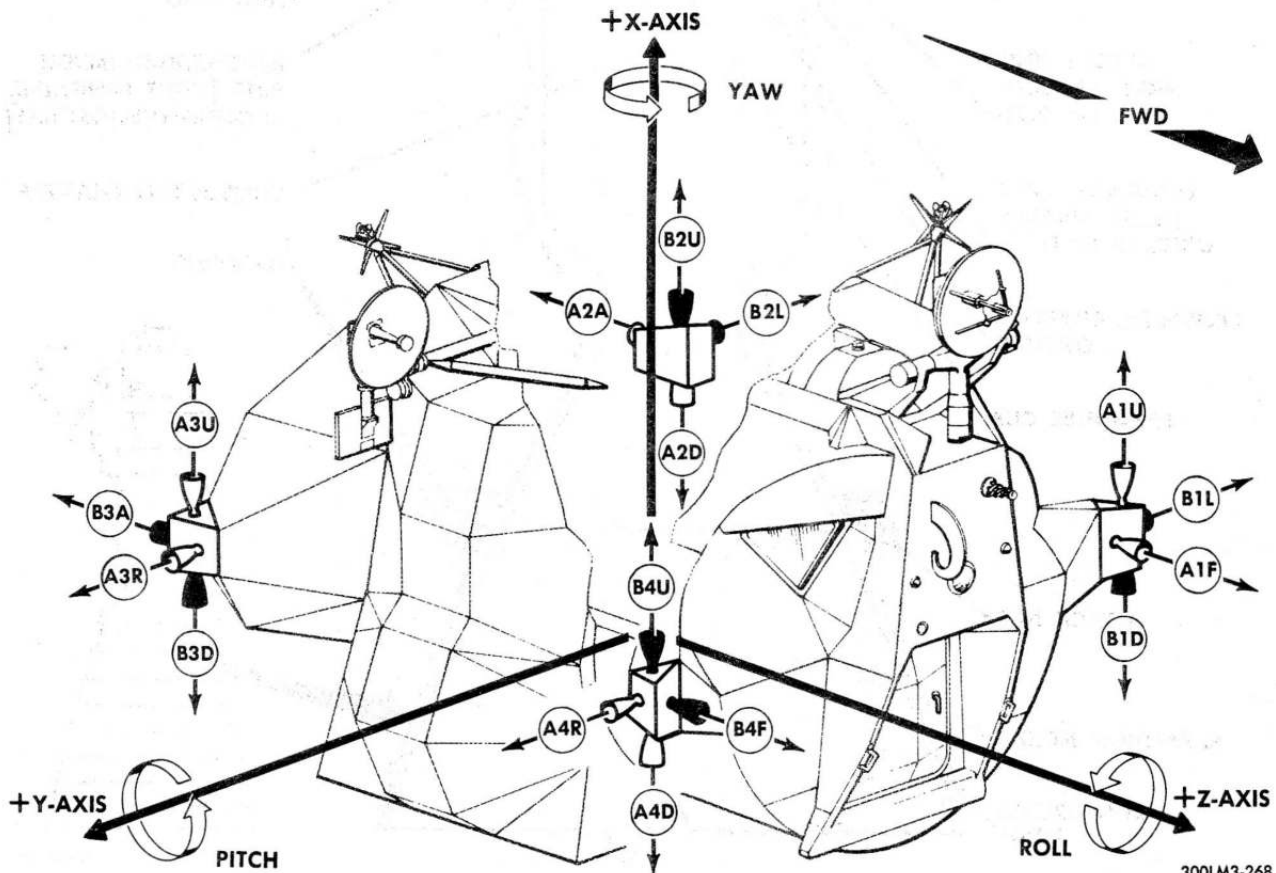


Figure 2-98. Reaction Control Subsystem - Thruster-On Failure Correction

Pulse skipping is not critical until a number of consecutive short pulses are skipped. When six short pulses do not produce an on response, an output is generated by the counter. The output of the counter sets the flip-flop via the OR gate and lights the RCS TCA warning light. A thruster-on or thruster-off failure signal produces the same failure indications and requires the same thruster turnoff procedure.

2.4.2.4.2

Heaters.

Each TCA cluster contains eight heating elements and associated sensors. Two heaters, attached to each TCA flange, maintain the engine injector head at its red-line temperature (+120° F). The heaters require a 28-volt d-c input; they can operate in an intermittent heating cycle or continuously. All heaters operate in an automatic mode, in which the thermal sensor in the heater continuously sends temperature signals to a controller that turns the heaters on and off, as required, to maintain the proper temperature.

The heaters of system A/B-1 are connected directly to their circuit breakers and will cycle on and off, as required, unless the appropriate circuit breaker (HEATERS RCS SYS A/B-1: QUAD circuit breakers on panel 11) is opened. The heaters of system A/B-2 are connected to their circuit breakers (HEATERS: RCS SYS A/B-2 QUAD circuit breakers on panel 16) through four three-position switches (one for each cluster). Normally, these switches (RCS SYS A/B-2 QUAD 1 through QUAD 4 on panel 3) are set to AUTO to cycle the heaters on and off to maintain the desired temperature. With the switch set to OFF, the circuit is interrupted and the heaters in the particular cluster are off. With the switch set to MAN, the controller is bypassed and the heaters remain on regardless of the temperature.

If an out-of-limit temperature (less than +120° F or more than +190° F) occurs, the HEATER caution light (panel 2) goes on and the astronaut can determine the off-temperature cluster by using the TEMP MONITOR selector switch and TEMP indicator (panel 3). The inputs to the TEMP indicator originate at four temperature transducers, one for each quad. The heaters of the off-temperature cluster can be disconnected from the electrical power supply by opening the appropriate heater QUAD circuit breaker.

2.4.3

MAJOR COMPONENT/FUNCTIONAL DESCRIPTION.

2.4.3.1

Explosive Valves.

The explosive valves are single-cartridge-actuated, normally closed valves. Setting the MASTER ARM switch (panel 8) to ON and momentarily holding the RCS He PRESS switch to FIRE completes the circuit between the explosive-valve cartridge and the EDS buses. Firing the cartridge causes gases to drive a piston, forcing the valve to open. Once opened, the valves remain open; they cannot be closed.

2.4.3.2

Pressure Regulator Assembly.

(To be supplied.)

2.4.3.3

Pressure Relief Valve Assemblies.

The pressure relief valve assemblies consist of a burst disk, low-pressure vent valve, filter, and relief valve. The burst disk ensures a sealed helium section during normal operation. The normally open low-pressure vent valve, between the burst disk and the relief valve, prevents pressure buildup if the burst disk leaks. The vent valve closes under high pressure, when the relief valve opens. The filter traps debris from the burst disk to prevent particles from getting lodged in the relief valve seat. This ensures positive closure of the relief valve after the excessive pressure has been vented.

2.4.3.4 Fuel and Oxidizer Tanks. (See figure 2-99.)

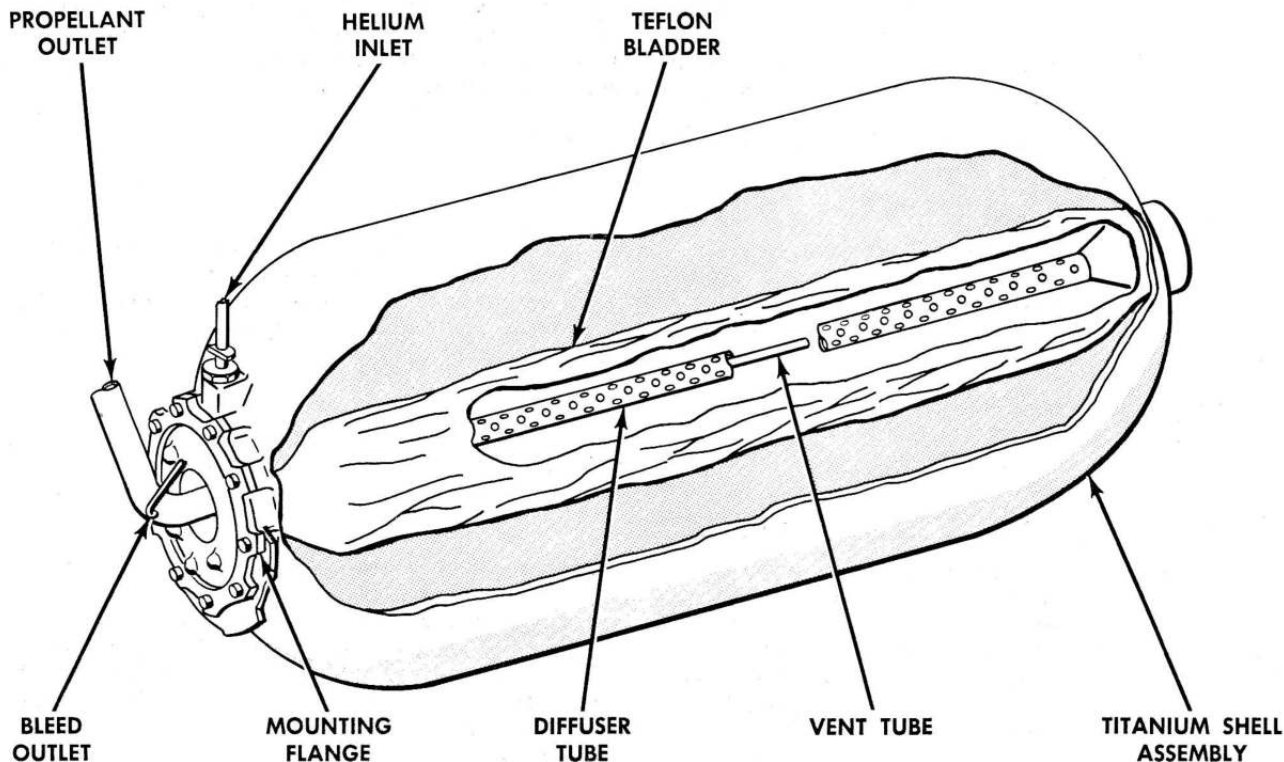
The propellants are stored in cylindrical titanium-alloy tanks with hemispherical ends. The propellant is in a Teflon bladder, which is chemically inert and resistant to the corrosive action of the propellants. The bladder is supported by a standpipe running lengthwise in the tank. The propellant is fed into the tank from a fill point accessible from the exterior of the LM. A bleed line that extends up through the standpipe draws off gases trapped in the bladder. The helium side of the bladder is vented to atmosphere. Helium flows between the bladder and the tank wall and acts upon the bladder to provide positive propellant expulsion.

2.4.3.5 Thrust Chamber Assembly. (See figure 2-97.)

2.4.3.5.1 Fuel and Oxidizer Valve Assemblies.

The fuel valve assembly and oxidizer valve assembly are normally closed, two-coil, solenoid valves. Each valve consists of a spool assembly, spring, armature, and seat assembly. A filter at the inlet of each valve provides final filtration of the propellants before they reach the injector. The fuel and oxidizer valve assemblies are identical, except for the seat assemblies and spool assemblies. The exit diameter of the metal seat of the oxidizer valve assembly is larger than that of the fuel valve seat. The fuel valve spool assembly gives a faster armature response than the oxidizer valve spool assembly, resulting in a nominal electrical fuel lead of 2 milliseconds.

The seat assembly retains the spring and armature in the cavity of the spool assembly. The spring load maintains constant pressure on the armature, forcing the armature's poppet-type head into the angled seat to form an integral seal. A passage in the



3000LM3-269

Figure 2-99. Propellant Tank Assembly

REACTION CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

armature permits propellant to enter the seat-area cavity. The spool assembly consists of a concentric metal body with a three-hole mounting flange; it contains two independent coils (primary and secondary) wound on a magnetic core.

2.4.3.5.2 Injector Head Assembly.

The injector head assembly provides support for the fuel and oxidizer valve assemblies, the mounting flange for the combustion chamber seal and combustion chamber, the fuel passages to the fuel annulus, the pressure pickup tap for measuring combustion chamber pressure, and a propellant impingement arrangement (eight-on-eight doublets with unlike impingement) for mixing propellants. The injector head assembly consists of an injector head housing, injector insulator, injector insert, and preigniter inserts (fuel and oxidizer). The injector insulator provides thermal insulation between the fuel and oxidizer valves and the injector head housing. The injector head assembly has four concentric rings of equally spaced holes on its face, and a preigniter cup.

2.4.3.5.3 Combustion Chamber and Nozzle.

The combustion chamber consists of a coated molybdenum combustor. The expansion nozzle is fabricated of stainless steel; eight stiffening rings are machined around its outer surface. The combustion chamber and expansion nozzle are joined together by a large coupling nut and lockring. The combustion chamber is mounted on the injector head assembly, with an attach ring assembly and bolts.

2.4.4 FAILURE MODES.

The RCS failure modes and the effect on mission capability are given in table 2-33. Regulator design is such that if failure occurs, the regulators fail open. The propellant latching solenoid valves can fail in the open or closed position; they are more likely to fail in their normal operating position. When a TCA pair cannot be fired because of a failure, a subsequent selective TCA failure could result in inability to stabilize the vehicle.

Table 2-33. Reaction Control Subsystem - Failure Modes

Failure	Indication	Vehicle Capability
Explosive valve(s) failed closed.	If one valve fails in system, there is no indication. If both valves fail, PRESS indicator does not show increase in pressure over previous indication, with TEMP/PRESS MON selector switch set to PRPLNT.	Failure of one valve in system A or B does not affect vehicle capability. System A or B cannot be pressurized. However, functioning system can supply propellants to inoperative system if crossfeed valves are opened. Vehicle capability is affected due to reduced propellant supply.
Regulator(s) failed open.	If one regulator in system fails, PRESS indicator might indicate slight increase in pressure, with TEMP/PRESS MON switch set to PRPLNT. If both regulators of system fail open, RCS A REG (or RCS B REG) warning light goes on. PRESS indicator indicates pressure above 195 psia, with TEMP/PRESS MON selector switch set to PRPLNT.	Failure of one regulator in system A or B does not affect vehicle capability. System A or B is inoperative. However, functioning system can supply propellants to inoperative system if crossfeed valves are opened. Vehicle capability is affected due to reduced propellant supply.

REACTION CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-33. Reaction Control Subsystem - Failure Modes (cont)

Failure	Indication	Vehicle Capability
Quadruple check valve(s) failed open.	If one check valve fails, there is no indication. If all check valves (two in series on fuel side and two in series on oxidizer side) fail in system, hypergolic action could take place in the helium manifold. It is improbable that this would happen.	Failure of one check valve in system A or B does not affect vehicle capability.
Relief valve burst disk is blown and relief valve failed open.	PRESS indicator indicates rapid decrease in pressure, with TEMP/PRESS MON selector switch set to He.	System A or B is inoperative. However, functioning system can supply propellants to inoperative system if crossfeed valves are opened. Vehicle capability is affected due to reduced propellant supply.
Main shutoff valve failed open.	MAIN SOV talkback does not provide barber-pole display when MAIN SOV switch is set to CLOSE.	Fuel or oxidizer cannot be isolated from TCA in system that has failed valve. Vehicle capability is not affected if there is no requirement to isolate propellants from manifold. If such requirement exists due to failure, vehicle capability is affected to extent of loss of one RCS system (eight TCA's).
Main shutoff valve failed closed.	If one main shutoff valve fails closed, MAIN SOV talkback does not indicate this condition. PRESS indicator indicates lower pressure at failed valve, with TEMP/PRESS MON selector switch set to OXID MANF or FUEL MANF.	System A or B is inoperative. However, functioning system can supply propellants to inoperative system if crossfeed valves are opened. Vehicle capability is affected due to reduced propellant supply.
Main shutoff valve leaks.	Leak may not be detected.	Vehicle capability may be reduced slightly.
Isolation valve failed open.	QUAD talkback does not provide barber-pole display when QUAD switch is set to CLOSE.	Fuel or oxidizer cannot be isolated from associated TCA pair. Associated RCS SYS A (or SYS B): QUAD TCA circuit breaker is normally opened to prevent primary TCA solenoid coil from being energized.
Isolation valve failed closed.	If one isolation valve fails closed, QUAD talkback does not indicate this condition. Associated TCA pair cannot be fired.	Efficiency of vehicle is reduced slightly due to loss of two TCA's.
Isolation valve leaks.	Leak may not be detected.	Fuel or oxidizer cannot be isolated from associated TCA pair. However, associated RCS SYS A (or SYS B): QUAD TCA circuit breaker can be opened to prevent primary TCA solenoid coil from being energized.
Thruster fuel and oxidizer valves failed open or closed.	QUAD talkback provides red display.	Malfunctioning TCA pair is removed from system operation by setting SYSTEM A (or SYSTEM B) QUAD switch to CLOSE. Efficiency of vehicle is reduced slightly.
Thruster fuel or oxidizer valve leaks.	If one valve leaks, puddling can result, causing rough or sporadic TCA operation, possibly resulting in TCA failure.	Malfunctioning TCA pair is removed from system operation by setting SYSTEM A (or SYSTEM B) QUAD switch to CLOSE. Efficiency of vehicle is reduced slightly.
Heaters	HEATER caution light goes on. Propellant leaking into TCA chamber can result in puddles, causing possible explosion upon TCA activation.	Malfunctioning TCA pair is removed from system operation by setting SYSTEM A (or SYSTEM B) QUAD switch to CLOSE. Efficiency of vehicle is reduced slightly.

REACTION CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-33. Reaction Control Subsystem - Failure Modes (cont)

Failure	Indication	Vehicle Capability
Helium tank leaks.	PRESS indicator indicates decaying pressure when TEMP/PRESS MON selector switch is set to He. RCS caution light goes on at 1,700 psia.	Leaking system may be used to depletion. After helium is depleted, other system can supply propellants via crossfeed valves. Vehicle capability is affected due to reduced propellant supply.
Helium filter is clogged.	RCS A REG or RCS B REG warning light may go on.	System with clogged filter is inoperative. Other system can supply propellants via crossfeed valves. Vehicle capability is affected due to reduced propellant supply.
One of eight individual QUAD circuit breakers failed open.	TCA's related to failed circuit breaker do not fire.	Efficiency of vehicle is reduced slightly due to loss of two TCA's.

2.4.5 **PERFORMANCE AND DESIGN DATA.**

The performance and design data for the RCS are given in table 2-34.

Table 2-34. Reaction Control Subsystem - Performance and Design Data

Helium pressurization section	
Helium tank volume	910 cubic inches
Helium tank initial fill pressure and temperature	3,050±50 psia at +70° F
Helium weight (initial fill conditions)	1.03 pounds
Helium tank maximum working pressure	3,500 psia
Helium operating temperature range	+40° to +100° F
Helium tank proof pressure	4,650 psia
Helium tank burst pressure	5,250 psia
Helium filter efficiency	5 microns nominal 12 microns absolute
Primary regulator pressure output	181±3 psia
Primary regulator lockup pressure	188 psia
Secondary regulator pressure output	185±3 psia
Secondary regulator lockup pressure	192 psia
Flow rate through pressure regulator assembly (single TCA operation)	0.036 pound per minute nominal
Quadruple check valve assembly cracking pressure	3 psig
Quadruple check valve assembly reverse leakage rate	5×10^{-5} scc/sec
Relief valve burst-disk rupture pressure	220 psia

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-34. Reaction Control Subsystem - Performance and Design Data (cont)

Helium pressurization section (cont)

Relief valve venting pressure 232 psia

Relief valve reseal pressure 212 psia

Propellant section

Oxidizer Nitrogen tetroxide (N_2O_4)

Oxidizer tank volume (including ullage) 2.38 cubic feet

Oxidizer tank ullage volume 210 cubic inches

Oxidizer flow rate to each TCA 0.240 lb/sec nominal

Usable oxidizer in each system 194.9 pounds

Oxidizer loaded in each system (tank and manifold) 207.5 pounds

Fuel 50-50 mixture of hydrazine (N_2H_4) and unsymmetrical dimethylhydrazine (UDMH)

Fuel tank volume (including ullage) 1.91 cubic feet

Fuel tank ullage volume 115 cubic inches

Fuel flow rate to each TCA 0.117 lb/sec nominal

Usable fuel in each system 99.1 pounds

Fuel loaded in each system (tank and manifold) 106.5 pounds

Propellant tank working pressure 176 psia nominal

Propellant tank proof pressure 331 psia

Propellant tank burst pressure 372 psia

Propellant storage temperature range $+40^\circ$ to $+100^\circ$ F

Propellant pad pressure 50 psia nominal

Propellant temperature $+70^\circ$ F nominal

Propellant filter efficiency
 5 microns nominal
 18 microns absolute

Ascent feed filter efficiency
 15 microns nominal
 25 microns absolute

Main shutoff valves, thruster pair isolation valves, ascent feed interconnect valves, cross-feed valves:

ΔP oxidizer flow	2 psi at 0.88 pound per second
ΔP fuel flow	2.5 psi at 0.88 pound per second
Response time	0.25 second at 250-psi inlet pressure

Thrust chamber assembly

Engine thrust 100 pounds

Nozzle expansion ratio 40 to 1

REACTION CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-34. Reaction Control Subsystem - Performance and Design Data (cont)

Thrust chamber assembly (cont)	
Chamber-cooling method	Fuel-film cooling and radiation
Combustion chamber pressure	96 psia
Propellant injection ratio (oxidizer to fuel)	2.05 to 1 nominal
Oxidizer inlet pressure (steady state)	170±10 psia
Fuel inlet pressure (steady state)	170±10 psia
Approximate weight	5.25 pounds
Overall length	13.5 inches
Nozzle exit diameter	5.75 inches

2.4.6

OPERATIONAL LIMITATIONS AND RESTRICTIONS.

The operational limitations and restrictions for the RCS are as follows:

- The total firing time for a TCA must not exceed 1,000 seconds. The maximum firing time under steady-state condition (firing periods of 1 second or longer) must not exceed 500 seconds. The performance of a TCA is uncertain if these limits are exceeded.
- The RCS/APS interconnect must not be opened until the ascent engine is firing and the LM is moving in the +X-direction (positive X-axis acceleration). The interconnect valves must be closed 10 seconds before ascent engine shutdown (except when the +X-axis TCA's are to be fired beyond APS shutdown, in which case the interconnect valves must be closed 10 seconds before +X-axis TCA's shutdown). This ensures that minimum helium enters the RCS, because maximum entrapment of helium in the ascent propellant tanks exceeds the limit for RCS operation. Failure to meet this requirement may result in erratic thrusting and possible TCA failure.
- The TCA's must not be operated when the propellant tank temperature is less than +40° F or more than +100° F. TCA performance outside the propellant temperature limits has not been determined.
- If the RCS heaters have been turned off after the TCA's have been fired, the TCA's must be warmed before subsequent firing. A cold TCA cannot be fired safely, and TCA failure may occur if this requirement is not observed.
- Maximum allowable continuous firing time for the +X-axis TCA's (unstaged) is 15 seconds. If this firing time limit is exceeded, damage to the descent stage thermal insulation may result.
- Maximum allowable continuous firing time for the -X-axis TCA's in clusters 1, 3, and 4 is 30 seconds. If this firing time limit is exceeded, damage to the S-band steerable antenna, the VHF antenna, and the RR antenna may result due to overheating.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

- The TCA's must not be fired if the cluster temperature is less than +120° F. If some heaters fail, a TCA may be as cool as +85° F while the TEMP indicator (panel 3) indicates +120° F for the cluster with the failed heaters. Firing a TCA whose temperature is less than +85° F may result in an explosion.
- The RCS must not be pressurized until the TEMP indicator (panel 3) indicates that the cluster temperature is more than +60° F. Because the TCA isolation valves thermally lag the indicated cluster temperature, failure to observe this limitation may result in the propellants contacting components that are below the critical temperature limit.

2.4.7

TELEMETRY MEASUREMENTS.

The RCS telemetry data are given in table 2-35. "(R)" following an entry in the "Telemetry Range" column signifies a real-time telemetry measurement. Real-time telemetry points are shown in figure 2-100.

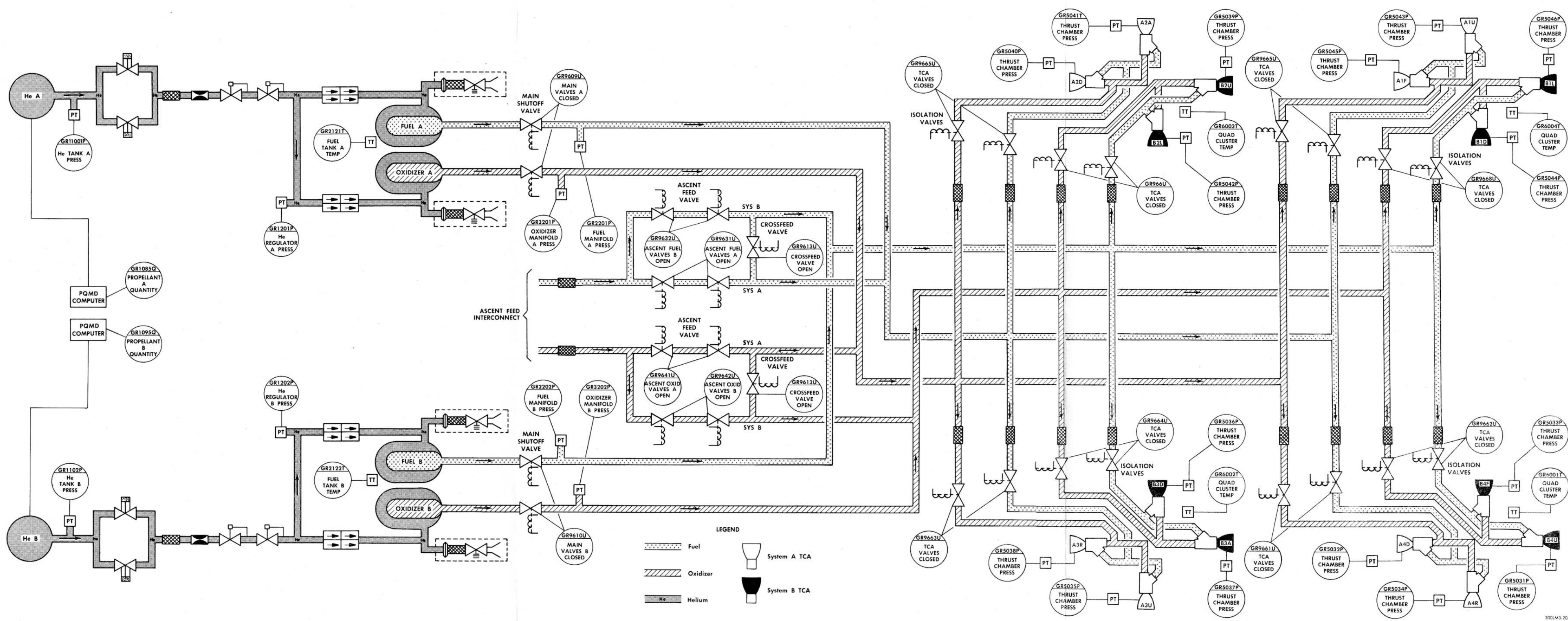


Figure 2-100. Reaction Control Subsystem - Telemetry Points

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-35. Reaction Control Subsystem - Telemetry Measurements

Code	Description	Telemetry Range (Nominal)	Display Range	Crew Display
GR1085Q	System A propellant quantity (PQMD)	0% to 100% (R)	0% to 100%	QUANTITY indicator
GR1095Q	System B propellant quantity (PQMD)	0% to 100% (R)	0% to 100%	QUANTITY indicator
GR1101P	Helium tank A pressure	0 to 3,500 psia (R)	0 to 4,000 psia	PRESS indicator
GR1102P	Helium tank B pressure	0 to 3,500 psia (R)	0 to 4,000 psia	PRESS indicator
GR1201P	Helium regulator A output pressure	0 to 350 psia (181 psia) (R)	0 to 400 psia	PRESS indicator
GR1202P	Helium regulator B output pressure	0 to 350 psia (181 psia) (R)	0 to 400 psia	PRESS indicator
GR2121T	Fuel tank A temperature	+20° to +120° F (+70° F) (R)	+20° to +120° F	TEMP indicator
GR2122T	Fuel tank B temperature	+20° to +120° F (+70° F) (R)	+20° to +120° F	TEMP indicator
GR2201P	Fuel manifold A pressure	0 to 350 psia (175 psia) (R)	0 to 400 psia	PRESS indicator
GR2202P	Fuel manifold B pressure	0 to 350 psia (175 psia) (R)	0 to 400 psia	PRESS indicator
GR2361X	Fuel manifold crossfeed valve is not closed.	Contact closure		None (See GR9613U.)
GR2362X	Oxidizer manifold crossfeed valve is not closed.	Contact closure		None (See GR9613U.)
GR2461X	Fuel main feed shutoff valve A closed.	Contact closure		None (See GR9609U.)
GR2462X	Fuel main feed shutoff valve B closed.	Contact closure		None (See GR9610U.)
GR3201P	Oxidizer manifold A pressure	0 to 350 psia (175 psia) (R)	0 to 400 psia	PRESS indicator
GR3202P	Oxidizer manifold B pressure	0 to 350 psia (175 psia) (R)	0 to 400 psia	PRESS indicator
GR3461X	Oxidizer main feed shutoff valve A closed.	Contact closure		None (See GR9609U.)
GR3462X	Oxidizer main feed shutoff valve B closed.	Contact closure		None (See GR9610U.)
GR4261X	TCA isolation fuel valve cluster 4 system A closed.	Contact closure		None (See GR9661U.)
GR4262X	TCA isolation fuel valve cluster 4 system B closed.	Contact closure		None (See GR9662U.)
GR4263X	TCA isolation fuel valve cluster 3 system A closed.	Contact closure		None (See GR9663U.)
GR4264X	TCA isolation fuel valve cluster 3 system B closed.	Contact closure		None (See GR9664U.)

REACTION CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-35. Reaction Control Subsystem - Telemetry Measurements (cont)

Code	Description	Telemetry Range (Nominal)	Display Range	Crew Display
GR4265X	TCA isolation fuel valve cluster 2 system A closed.	Contact closure		None (See GR9665U.)
GR4266X	TCA isolation fuel valve cluster 2 system B closed.	Contact closure		None (See GR9666U.)
GR4267X	TCA isolation fuel valve cluster 1 system A closed.	Contact closure		None (See GR9667U.)
GR4268X	TCA isolation fuel valve cluster 1 system B closed.	Contact closure		None (See GR9668U.)
GR4269X	TCA isolation oxidizer valve cluster 4 system A closed.	Contact closure		None (See GR9661U.)
GR4270X	TCA isolation oxidizer valve cluster 4 system B closed.	Contact closure		None (See GR9662U.)
GR4271X	TCA isolation oxidizer valve cluster 3 system A closed.	Contact closure		None (See GR9663U.)
GR4272X	TCA isolation oxidizer valve cluster 3 system B closed.	Contact closure		None (See GR9664U.)
GR4273X	TCA isolation oxidizer valve cluster 2 system A closed.	Contact closure		None (See GR9665U.)
GR4274X	TCA isolation oxidizer valve cluster 2 system B closed.	Contact closure		None (See GR9666U.)
GR4275X	TCA isolation oxidizer valve cluster 1 system A closed.	Contact closure		None (See GR9667U.)
GR4276X	TCA isolation oxidizer valve cluster 1 system B closed.	Contact closure		None (See GR9668U.)
GR4322T	TCA fuel inlet, pair B4 surface temperature	+20° to +120° F (+70° F)		None
GR4323T	TCA fuel inlet, pair A3 surface temperature	+20° to +120° F (+70° F)		None
GR4326T	TCA fuel inlet, pair B2 surface temperature	+20° to +120° F (+70° F)		None
GR4327T	TCA fuel inlet, pair A1 surface temperature	+20° to +120° F (+70° F)		None
GR4424T	TCA oxidizer inlet, pair A3 surface face temperature	+20° to +120° F (+70° F)		None
GR4435T	TCA oxidizer valve A3R surface temperature	0° to +200° F		None
GR4441T	TCA fuel valve A4D surface temperature	0° to +200° F		None
GR4448T	TCA fuel valve B1D surface temperature	0° to +200° F		None
GR4570T	TCA injector head A4D temperature	0° to +500° F		None

REACTION CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-35. Reaction Control Subsystem - Telemetry Measurements (cont)

Code	Description	Telemetry Range (Nominal)	Display Range	Crew Display
GR4571T	TCA injector head B4F temperature	0° to +500° F		None
GR4573T	TCA injector head A3U temperature	0° to +500° F		None
GR4574T	TCA injector head B3D temperature	0° to +500° F		None
GR4577T	TCA injector head B2U temperature	0° to +500° F		None
GR4578T	TCA injector head A2D temperature	0° to +500° F		None
GR4582T	TCA injector head B1D temperature	0° to +500° F		None
GR4583T	TCA injector head A1F temperature	0° to +500° F		None
GR5031X	Thrust chamber B4U pressure	Contact closure (R)		RCS TCA warning light
GR5032X	Thrust chamber A4D pressure	Contact closure (R)		RCS TCA warning light
GR5033X	Thrust chamber B4F pressure	Contact closure (R)		RCS TCA warning light
GR5034X	Thrust chamber A4R pressure	Contact closure (R)		RCS TCA warning light
GR5035X	Thrust chamber A3U pressure	Contact closure (R)		RCS TCA warning light
GR5036X	Thrust chamber B3D pressure	Contact closure (R)		RCS TCA warning light
GR5037X	Thrust chamber B3A pressure	Contact closure (R)		RCS TCA warning light
GR5038X	Thrust chamber A3R pressure	Contact closure (R)		RCS TCA warning light
GR5039X	Thrust chamber B2U pressure	Contact closure (R)		RCS TCA warning light
GR5040X	Thrust chamber A2D pressure	Contact closure (R)		RCS TCA warning light
GR5041X	Thrust chamber A2A pressure	Contact closure (R)		RCS TCA warning light
GR5042X	Thrust chamber B2L pressure	Contact closure (R)		RCS TCA warning light
GR5043X	Thrust chamber A1U pressure	Contact closure (R)		RCS TCA warning light
GR5044X	Thrust chamber B1D pressure	Contact closure (R)		RCS TCA warning light

REACTION CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-35. Reaction Control Subsystem - Telemetry Measurements (cont)

Code	Description	Telemetry Range (Nominal)	Display Range	Crew Display
GR5045X	Thrust chamber A1F pressure	Contact closure (R)		RCS TCA warning light
GR5046X	Thrust chamber B1L pressure	Contact closure (R)		RCS TCA warning light
GR6001T	Quad cluster No. 4 temperature	+20° to +200° F (R)	1. -100° to +200° F 2. Less than +119° F, more than +190° F	1. TEMP indicator (panel 3) 2. HEATER caution light
GR6002T	Quad cluster No. 3 temperature	+20° to +200° F (R)	1. -100° to +200° F 2. Less than +119° F, more than +190° F	1. TEMP indicator (panel 3) 2. HEATER caution light
GR6003T	Quad cluster No. 2 temperature	+20° to +200° F (R)	1. -100° to +200° F 2. Less than +119° F, more than +190° F	1. TEMP indicator (panel 3) 2. HEATER caution light
GR6004T	Quad cluster No. 1 temperature	+20° to +200° F (R)	1. -100° to +200° F 2. Less than +119° F, more than +190° F	1. TEMP indicator (panel 3) 2. HEATER caution light
GR7001X	Ascent interconnect fuel valve A is not closed.	Contact closure		None (See GR9611U.)
GR7002X	Ascent interconnect fuel valve B is not closed.	Contact closure		None (See GR9612U.)
GR7003X	Ascent interconnect oxidizer valve A is not closed.	Contact closure		None (See GR9611U.)
GR7004X	Ascent interconnect oxidizer valve B is not closed.	Contact closure		None (See GR9612U.)
GR9609U	Main propulsion valves A closed.	Contact closure (R)		SYS A MAIN SOV talkback
GR9610U	Main propulsion valves B closed.	Contact closure (R)		SYS B MAIN SOV talkback
GR9613U	Manifold crossfeed valves are not closed.	Contact closure (R)		CRSFD talkback
GR9631U	Ascent fuel interconnect valves A open.	Contact closure (R)		SYSTEM A ASC FUEL talkback
GR9632U	Ascent fuel interconnect valves B open.	Contact closure (R)		SYSTEM B ASC FUEL talkback
GR9641U	Ascent oxidizer interconnect valves A open.	Contact closure (R)		SYSTEM B ASC FUEL talkback
GR9642U	Ascent oxidizer interconnect valves B open.	Contact closure (R)		SYSTEM B ASC OXID talkback
GR9661U	TCA isolation valves A4 closed.	Contact closure (R)		SYSTEM A QUAD 4 talkback

REACTION CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-35. Reaction Control Subsystem - Telemetry Measurements (cont)

Code	Description	Telemetry Range (Nominal)	Display Range	Crew Display
GR9662U	TCA isolation valves B4 closed.	Contact closure (R)		SYSTEM B QUAD 4 talkback
GR9663U	TCA isolation valves A3 closed.	Contact closure (R)		SYSTEM A QUAD 3 talkback
GR9664U	TCA isolation valves B3 closed.	Contact closure (R)		SYSTEM B QUAD 3 talkback
GR9665U	TCA isolation valves A2 closed.	Contact closure (R)		SYSTEM A QUAD 2 talkback
GR9666U	TCA isolation valves B2 closed.	Contact closure (R)		SYSTEM B QUAD 2 talkback
GR9667U	TCA isolation valves A1 closed.	Contact closure (R)		SYSTEM A QUAD 1 talkback
GR9668U	TCA isolation valves B1 closed.	Contact closure (R)		SYSTEM B QUAD 1 talkback

REACTION CONTROL SUBSYSTEM

2.5 ELECTRICAL POWER SUBSYSTEM.

2.5.1 INTRODUCTION. (See figure 2-101.)

The Electrical Power Subsystem (EPS), the principal source of electrical power for the LM mission, has a d-c section and an a-c section. Both sections supply operating power to respective electrical buses, which supply all LM subsystems via appropriately rated circuit breakers. Ground facility power is supplied to the LM from T-7 hours until T-30 minutes, through the launch umbilical tower (LUT). At T-30 minutes, the LM descent stage batteries (No. 1 through 4) are turned on and ground facility power is turned off via switching commands from the LUT. The descent stage batteries provide power to the LM until the docked phases of the mission, at which time the batteries are disconnected and the LM receives electrical power from the CSM. The CSM electrical power is disconnected and descent stage battery power is restored during the LM-CSM separation phase. During descent propulsion section (DPS) engine burns, the ascent stage batteries (No. 5 and 6) are paralleled with the descent stage batteries to ensure at least the minimum voltage output (26.5 volts dc) at the subsystem's buses in the event of a descent battery failure. Ascent stage battery power is introduced before staging, at which time the descent battery power is terminated and descent feeder lines are severed. Ascent stage battery power is then used until final docking and astronaut transfer to the CSM are completed.

EPS

The EPS batteries are controlled and protected by respective electrical control assemblies, a relay junction box, and a deadface relay box, in conjunction with the control and display panel. Primary a-c power is provided by two inverters, which supply 117 volt $\pm 1\%$, 400 ± 2 -cps (sync'd condition), a-c power to LM subsystems. The operating frequency of the inverters is 400 ± 10 cps, in the nonsync'd, free-running condition.

Batteries in the Explosive Devices Subsystem (EDS) provide primary power to trigger LM explosive devices. (Refer to subsection 2.8.)

2.5.2 FUNCTIONAL DESCRIPTION.

2.5.2.1 General. (See figures 2-101 through 2-103.)

Four descent stage batteries and two ascent stage batteries make up the EPS d-c section power source. The output of each battery is applied to an electrical control assembly (ECA). The descent stage ECA's provide an independent control circuit for each descent battery. The ascent stage ECA's provide four independent battery control circuits, two control circuits for each ascent battery. Over-temperature, reverse-current, and overcurrent conditions are monitored by the ECA's. Each ECA battery control circuit can detect a battery or feeder malfunction and operate a main feeder contactor (MFC) associated with the malfunctioning battery to remove the battery from the EPS distribution system (overcurrent only).

Descent stage battery power (figure 2-102), controlled and monitored by the descent ECA's, is switched and applied to the relay junction box (RJB) and the deadface relay box (DRB). The power feeders of descent batteries No. 1 and 2 are routed through the RJB deadface relays to the LM Pilot's circuit breaker panel (16). The power feeders of batteries No. 3 and 4 are routed through the DRB deadface relays to the Commander's circuit breaker panel (11). This circuit arrangement provides for deadfacing all descent battery power in the event of normal staging or abort stage situations. Ascent stage battery power (figure 2-103), controlled and monitored by the ascent ECA's, is switched and applied, through power feeders, to terminal junction points at the RJB and DRB.

Ascent and descent battery main power feeders are routed through circuit breakers to the d-c buses. The circuit breakers protect against bus short circuits. From the d-c buses, d-c power is distributed through circuit breakers to all LM systems.

Two inverters, which make up the EPS a-c section power source, supply all a-c power requirements of the LM. The INVERTER switch (panel 14) connects either

inverter to the circuit breakers that supply the a-c buses. The selection of inverter output to specific a-c bus is determined by the position of the AC BUS circuit breakers on panel 11. Either inverter can adequately supply the LM a-c load requirements.

2.5.2.2

D-C Section.

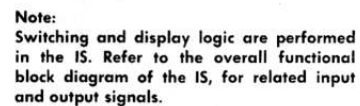
The EPS d-c section consists of the four descent stage batteries, two descent stage ECA's, two relay switching boxes, two ascent stage batteries, two ascent stage ECA's, a control panel, two circuit breaker panels, and two sensor power fuse assemblies.

The basic EPS power distribution is shown in figure 2-101. From T-7 hours until T-30 minutes, ground facility power (10-ampere capability) is supplied to the LM from the LUT through the LUT deadface relay (LDR) in the RJB. At T-30 minutes, the four descent stage batteries are connected to the main power feeders and the LDR is opened on command from the ground, via the LUT. The descent stage batteries are connected at their low-voltage (LV) taps. These batteries are under light load (less than 200 watts) at this time; therefore, the LV taps (at the 17th cell of these 20-cell batteries) are used to facilitate discharge of the inherent initial high voltage of the battery. The descent stage batteries supply d-c power to the LM until the transposition and docking phase of the mission, after which the CSM supplies the LM with electrical power. (The CSM can supply a maximum of 180 watts.) Descent battery power is reconnected to the power distribution system after astronaut transfer to the LM, before LM-CSM separation.

During normal EPS operation, beginning with subsystem activation, the descent battery high-voltage taps are selected with the HI VOLTAGE switches (panel 14). Power is then fed from the descent stage batteries, through their associated ECA's (batteries No. 1 and 2, and No. 3 and 4, through ECA No. 1 and 2, respectively), to the ascent stage via the RJB and DRB, terminating at the LM Pilot's and Commander's d-c buses. The battery feeders are connected to the d-c buses through the 100-ampere EPS: BAT FEED TIE circuit breakers (panels 11 and 16).

D-C power is then distributed to the LM subsystems and to the EPS inverters through circuit breakers on panels 16 and 11. During non critical phases of normal operation, the 30-ampere EPS: CROSS TIE BAL LOADS circuit breakers (panels 11 and 16) are closed to distribute unbalanced current requirements between buses so that the batteries discharge evenly. The ascent stage batteries supply d-c power to the LM Pilot's and Commander's buses in essentially the same manner as the descent stage batteries. The batteries are selected with the ASCENT POWER switches (panel 14). The corresponding descent and ascent stage batteries (by respective bus) are paralleled during DPS engine burns, and the EPS: CROSS TIE circuit breakers (panels 11 and 16) are opened, thereby isolating the Commander's and LM Pilot's d-c buses.

Each descent battery is connected to a separate power feeder (jumped to one other battery power feeder at the output of the ECA's and at the 100-ampere EPS: BAT FEED TIE circuit breakers). Failure of one descent battery therefore permits its associated descent battery to supply both power feeders. A power feeder short while operating on descent battery power is detected by overcurrent-sensing circuits in the respective ECA, which disconnects the two descent batteries associated with the shorted power feeder. The d-c buses are isolated from the shorted feeder by opening the respective EPS: BAT FEED TIE circuit breakers. During an emergency, either operating d-c bus can supply power to the other (inoperative) isolated bus if the EPS: CROSS TIE BUS circuit breakers (panels 11 and 16) are closed. A similar condition, whereby a shorted feeder is automatically isolated, exists when operating on both ascent batteries. However, the battery associated with the shorted feeder can be connected manually to the power feeder of the other ascent battery, using the BACK UP FEED switches (panel 14), thereby permitting continued use of the battery.



300LM3-202

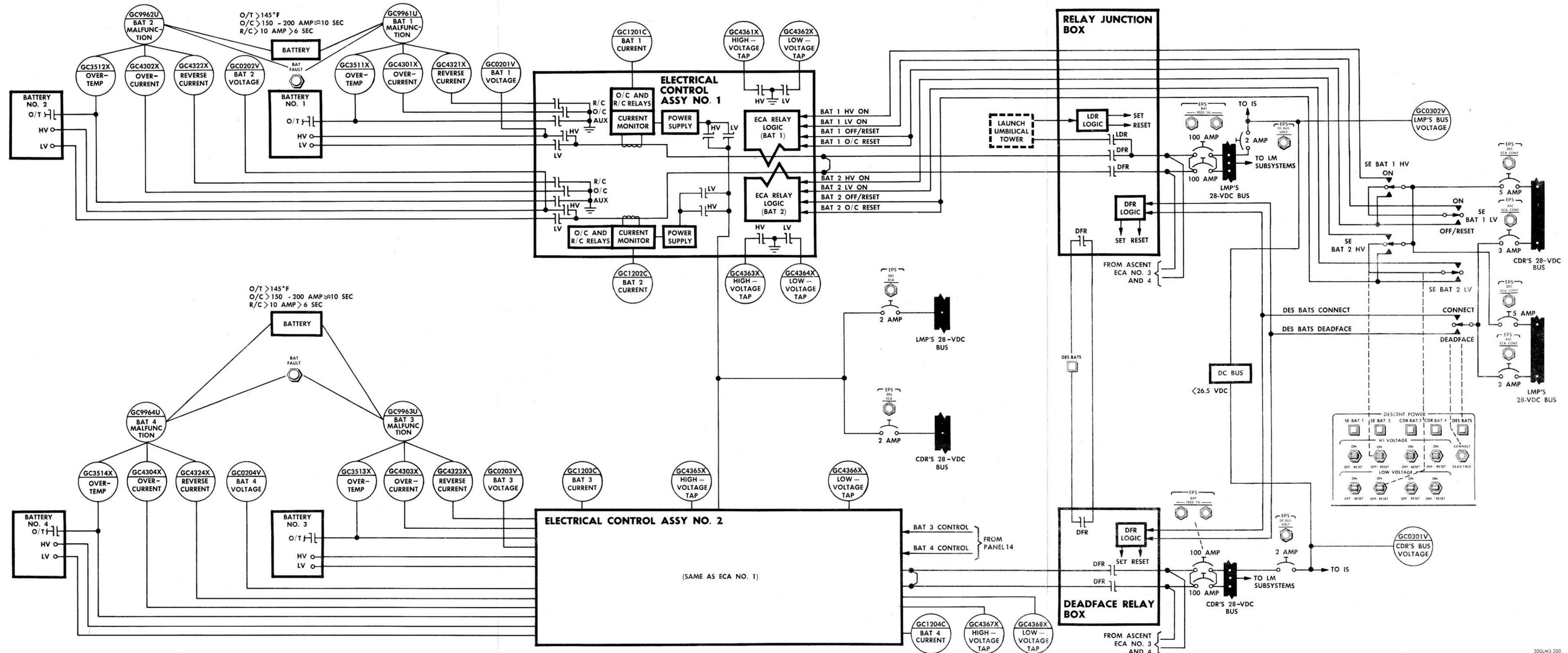


Figure 2-102. Descent Power Distribution - Functional Block Diagram

1
2
3
4
5



Figure 2-103. Ascent Power Distribution - Functional Block Diagram

2.5.2.3 A-C Section. (See figure 2-101.)

A-C power is provided to LM subsystems by either of two identical, redundant inverters; it is controlled by the EPS: INV 1 and INV 2 circuit breakers (panel 11 and 16, respectively), the INVERTER switch, and the AC BUS: BUS TIE circuit breakers on panel 11. The EPS: INV 1 or INV 2 circuit breaker supplies 28 volts dc from the LM Pilot's or Commander's 28-volt d-c bus to the chosen normally synched inverter, where the d-c is changed to 117-volt, 400-cps, a-c power (350 volt-amperes maximum). The INVERTER switch selects and routes the output of either inverter to the a-c buses via the respective AC BUS A: BUS TIE or AC BUS B: BUS TIE circuit breakers. Normally, inverter No. 2 is energized when the LM subsystems are first activated and connected to the a-c buses. Inverter No. 1 functions as backup during the mission, except that it is the operating inverter during DPS engine burns. An a-c bus voltage and frequency read-out signal is supplied from a-c bus A via the AC BUS A: AC BUS VOLT circuit breaker (panel 11) to the Instrumentation Subsystem (IS) for telemetry and caution light display. An out-of-tolerance frequency (less than 398 cps or more than 402 cps) or low-voltage condition (below 112 volts ac) causes the INVERTER caution light (panel 2) and MASTER ALARM pushbutton/lights (panels 1 and 2) to go on, and a tone to be generated. The astronaut makes a determination of the indication and performs corrective action. The INVERTER caution light goes out when the malfunctioning condition is remedied; the MASTER ALARM light goes out and the audio tone is discontinued when the MASTER ALARM pushbutton/light is pressed. When positioned to AC BUS, the POWER/TEMP MON selector switch (panel 14) selects a-c bus A for voltage display on the VOLTS indicator (panel 14).

2.5.2.4 Power Distribution.

Electrical power is distributed to LM subsystems via the LM Pilot's d-c bus, the Commander's d-c bus, and a-c buses A and B. A complete description of the d-c and a-c circuit breakers is in section 3. Secondary d-c power distribution is provided by the two sensor power fuse assemblies, which supply d-c power to sensors of the Environmental Control Subsystem (ECS), Reaction Control Subsystem (RCS), and Main Propulsion Subsystem (MPS).

2.5.2.5 Power Monitoring.

The primary a-c and d-c voltage levels, d-c current consumption, and the status of all main power feeders must be monitored periodically to ensure availability of proper power for all LM subsystems throughout the mission. This monitoring is normally the responsibility of the LM Pilot, who controls the ELECTRICAL POWER panel (14). This panel has talkbacks that indicate main power feeder status, indicators that display battery and bus voltages and battery current, and component caution lights that are used for monitoring shorted buses or main power feeder lines and for isolating a malfunctioning battery. Availability of redundant a-c and d-c power permits the astronaut to disconnect, substitute, or reconnect batteries, feeder lines, buses, or inverters to assure a continuous electrical supply, thereby averting an emergency condition.

2.5.2.5.1 Battery Status-Monitoring Circuits. (See figure 2-104.)

Talkbacks on panel 14 indicate the status of the descent and ascent batteries (on or off the line). A DESCENT POWER talkback barber-pole display signifies that the related battery is disconnected from its main power feeder; a white (LO) display, that the battery low-voltage tap is connected to the power distribution system via the main power feeder; a gray display, that the high-voltage tap is connected to the power distribution system. A DES BATS talkback gray display signifies that the descent battery outputs are connected to the ascent stage; a barberpole display, that these power lines are disconnected and the ascent stage is isolated electrically from the descent stage. The ASCENT POWER talkbacks indicate that their related ascent battery is connected (gray) or disconnected (barber pole) from the respective normal feed or backup feed main power feeder lines.

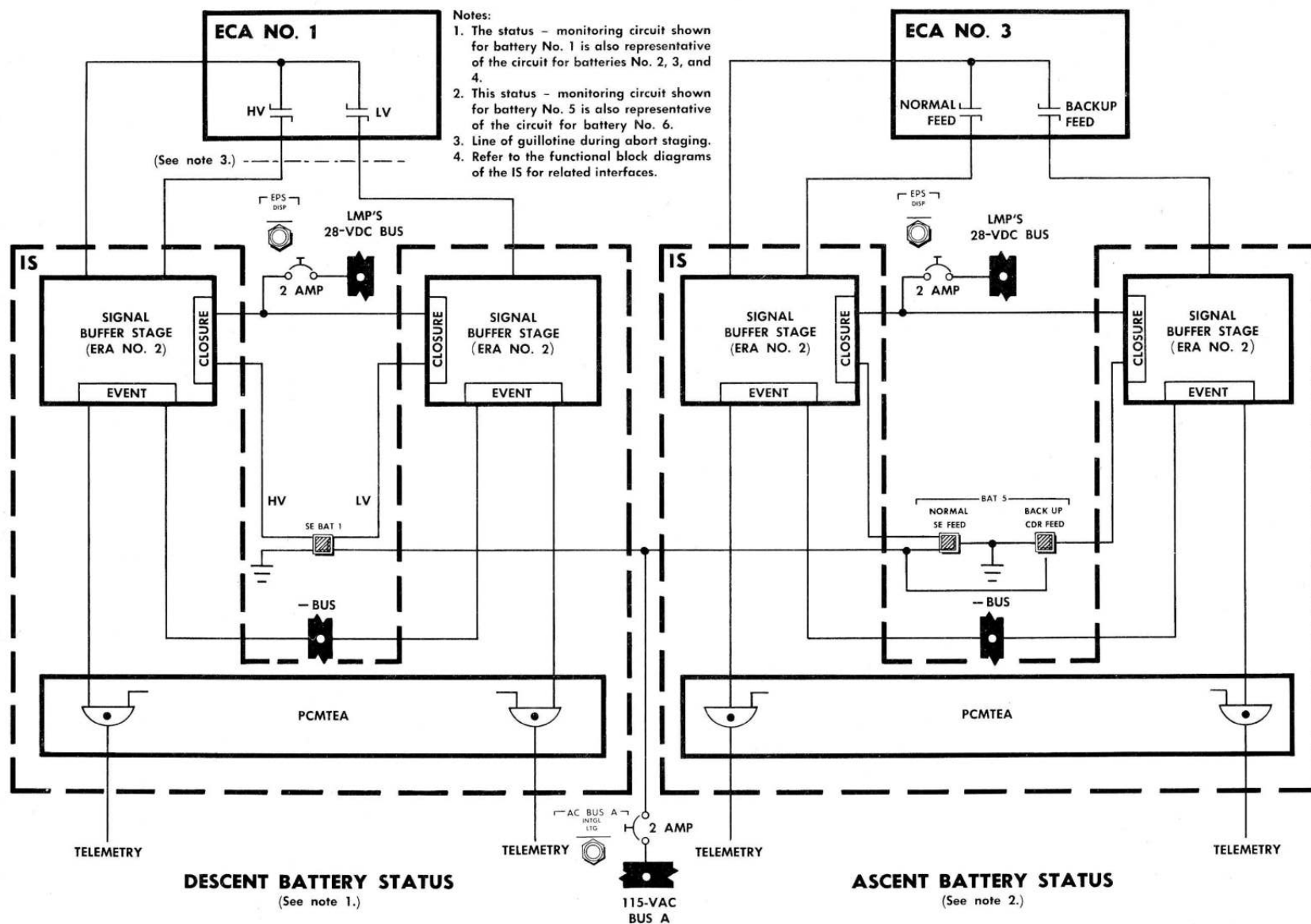


Figure 2-104. Battery Status-Monitoring Circuits - Simplified Schematic Diagram

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

When a descent battery is disconnected from its main feeder line, its related talkback provides a barber-pole display. Setting a HI VOLTAGE (or LOW VOLTAGE) switch (panel 14) to ON energizes the related high-voltage (or low-voltage) MFC relay in the respective ECA. The relay contacts close, permitting a signal to pass to a buffer signal stage in Electronic Replaceable Assembly (ERA) No. 2 of the IS. D-C power, supplied to the buffer stage from the LM Pilot's d-c bus, passes to the talkback, upon arrival of the ECA output signal. Output closure signals of the high-voltage (or low-voltage) signal buffer stages are connected to individual coils (in the talkback assembly) which, when energized, activate flags to display the existing status of the batteries. In addition, receipt of an ECA output signal at the signal buffer stages causes an event signal to be routed to the pulse-code-modulation and timing electronics assembly (PCMTEA) of the IS, for telemetry. Three conditions are associated with each descent battery: high-voltage tap on the power feeder line, low-voltage tap on the power feeder line, and battery completely off the power feeder line.

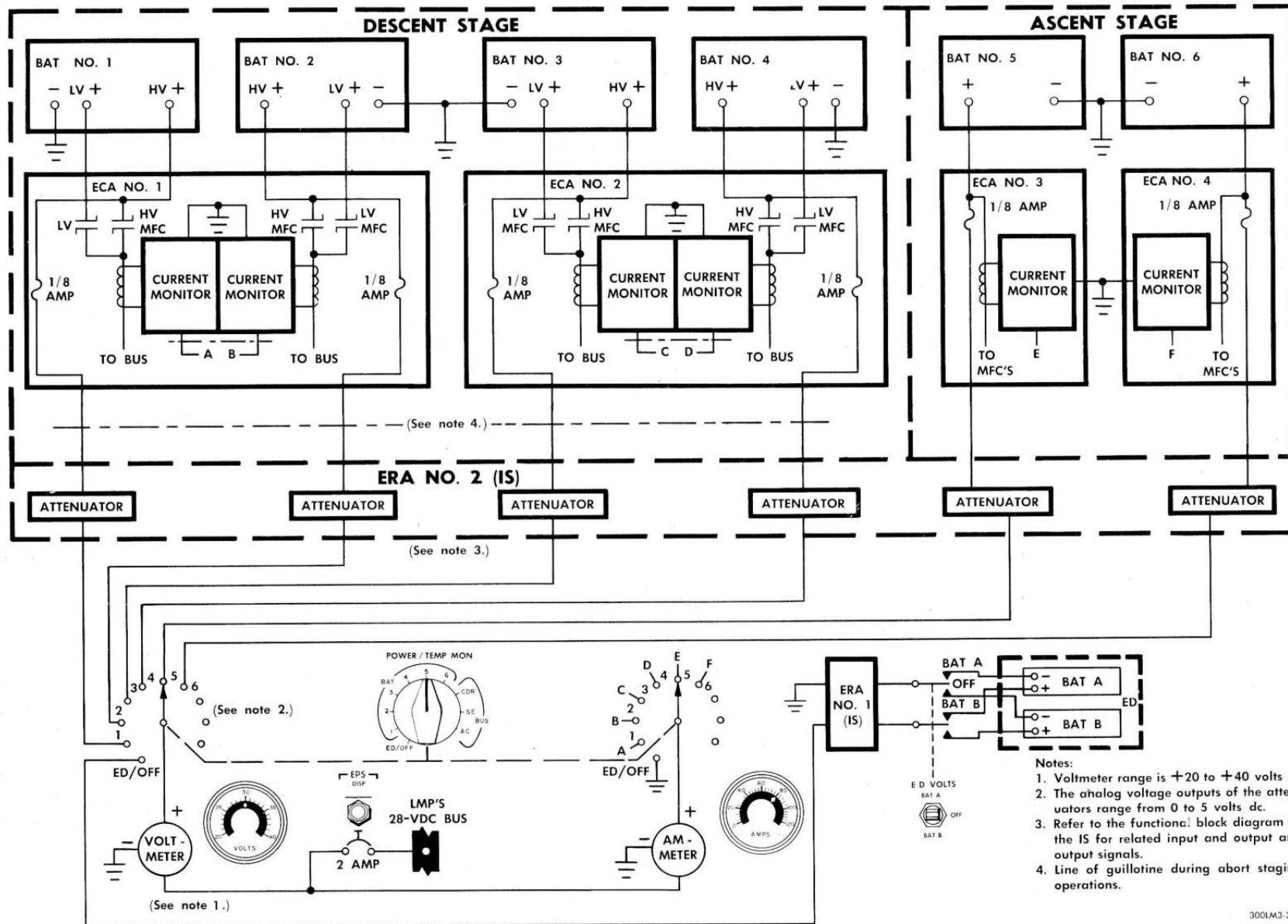
Four conditions are associated with each ascent battery: battery on or off the normal power feeder line (for that particular battery) and battery on or off the backup power feeder line. These conditions are determined by the setting of the NORMAL FEED and BACK UP FEED switches (panel 14). Operation of the ASCENT POWER talkbacks and generation of the activating signals are similar to that of the DESCENT POWER talkbacks, except that each signal buffer stage output closure signal is routed to an individual talkback, and each talkback provides only two displays (gray or barber pole). Telemetry signals are also generated within the PCMTEA for ascent battery monitoring.

2.5.2.5.2 Battery Voltage- and Current-Monitoring Circuits. (See figure 2-105.)

The VOLTS and AMPS indicators (panel 14) enable monitoring the terminal voltage and current draw of each descent battery (high-voltage tap for voltage only) and ascent battery. In addition, the VOLTS indicator, when used in conjunction with the POWER/TEMP MON selector switch and ED VOLTS switch (panel 14), monitors the terminal voltage of ED batteries A and B of the EDS. Except that a descent ECA controls two batteries and an ascent ECA controls one battery, the voltage- and current-monitoring circuits of each EPS battery are essentially the same. Therefore, the voltage- and current-monitoring circuits of only one EPS battery are described.

The positive terminal of the EPS battery is connected through a 1/8-ampere fuse (in the respective ECA) to an attenuator in ERA No. 2 of the IS. The attenuator input signal is in the range of 28 to 37 volts dc. The resultant attenuator output (0 to 5 volts dc) is an analog of the input signal. This output is routed directly to its assigned terminal of the POWER/TEMP MON selector switch. When the switch is set to the battery position (BAT 1 through BAT 6), the analog is routed to the positive terminal of the VOLTS indicator and displayed. (The indicator scale is graduated from 20 to 40 volts dc, although the input signal is of considerably smaller magnitude.) Only the high-voltage positive tap of each descent battery is monitored in this manner. Each ascent battery has only one positive terminal.

Battery current flowing through the main feeder line (normal or backup feeder for ascent batteries; high- or low-voltage feeder for descent batteries) is sensed by the related current monitor coil in its respective ECA. Each battery has an individual current monitor. The monitor senses the magnitude of current flow through the associated main feeder line and provides a representative analog output. This analog is routed to a specific terminal (assigned by battery number) on a deck of the POWER/TEMP MON selector switch, as are the current analogs of all other ascent and descent batteries. When the switch is set to the battery position (BAT 1 through BAT 6), the analog is routed to the positive terminal of the AMPS indicator and displayed. (The indicator scale is graduated from 0 to 120 amperes, although its input signal is of considerably smaller magnitude.) Ascent battery current is read directly from the indicator; for descent battery current, the indicator reading must be halved.



- Notes:
1. Voltmeter range is +20 to +40 volts dc.
 2. The analog voltage outputs of the attenuators range from 0 to 5 volts dc.
 3. Refer to the functional block diagram of the IS for related input and output and output signals.
 4. Line of guillotine during abort staging operations.

300LM3-233

Figure 2-105. Battery Voltage- and Current-Monitoring Circuits - Simplified Schematic Diagram

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

The positive and negative terminals of the two ED batteries are connected to respective contacts of the ED VOLTS switch. When the switch is set momentarily to BAT A or BAT B, that particular battery is connected to signal conditioner (SC) No. 1 in the IS. The SC output is a conditioned analog (0 to +5 volts dc) that represents the actual ED battery terminal voltage (+20 to +40 volts dc), which is routed to the ED/OFF terminal of the POWER/TEMP MON selector switch, for voltage monitoring.

2.5.2.5.3 Primary Bus Voltage-Monitoring Circuits. (See figure 2-106.)

The Commander's d-c bus, the LM Pilot's d-c bus, and a-c bus A are monitored periodically for the proper voltage level, to ensure application of adequate power to all LM subsystems. Monitoring is accomplished by selecting the bus, with the POWER/TEMP MON selector switch, and reading the associated voltage on the VOLTS indicator. D-C bus voltages are read directly from the indicator scale, which is graduated from 20 to 40 volts dc; for a-c readings, conversion is required. The d-c scale is equivalent to a range of 62.5 to 125 volts ac, when monitoring the a-c bus. The indicator green band is equivalent to the nominal a-c range of 112 to 118 volts.

The Commander's d-c bus is connected via the EPS: DC BUS VOLT circuit breaker (panel 11) to an attenuator in ERA No. 1 of the IS. The attenuated signal is routed to the caution and warning electronics assembly (CWEA) and through an isolation amplifier. The 0- to 5-volt attenuated d-c signal is an analog, which is fed to the PCMTEA for telemetry and to the CDR terminal of the POWER/TEMP MON selector switch. Except that it is processed through ERA No. 2, the LM Pilot's d-c bus analog is connected to the SE terminal of the switch in like manner. The attenuated analogs of the Commander's and LM Pilot's d-c bus voltages are fed through buffer amplifiers and an OR gate. If the d-c voltage on either bus drops below 26.5 volts, a CWEA relay is energized; its contacts close to provide a ground return to the DC BUS warning light (panel 1), causing it to go on. In addition, the master alarm circuit is completed; the MASTER ALARM pushbutton/lights go on and a tone is generated. The astronauts, thereby alerted visually and aurally to the emergency condition, must correct the condition immediately. The warning light goes off when the bus voltage is again within limits. The master alarm tone is turned off and the MASTER ALARM pushbutton/light goes out when the MASTER ALARM pushbutton/light is pressed.

A-C bus A (115 volts) is connected via the AC BUS A: AC BUS VOLT circuit breaker (panel 11) to a frequency-to-dc stage and an ac-to-dc stage in ERA No. 1. The d-c output signals are fed to the CWEA and to isolation amplifiers. The amplifier outputs are fed to the PCMTEA for telemetry. A 0- to 5-volt d-c analog signal from the ac-to-dc stage isolation amplifier is sent to the AC terminal of the POWER/TEMP MON selector switch. Selecting this switch position routes the analog signal to the positive terminal of the VOLTS indicator. The output signals of the frequency-to-dc and ac-to-dc converters are also fed through buffer amplifiers and an OR gate to an AND gate in the CWEA. An inhibit signal is routed to this AND gate when the INVERTER switch is set to OFF, thereby inhibiting signal passage. Setting the switch to 1 or 2 removes the inhibit signal and enables the gate. If the a-c bus A voltage is less than 112 volts, or if the a-c bus frequency is less than 398 cps or more than 402 cps, a CWEA relay is energized; its contacts close to provide a ground return to the INVERTER caution light (panel 2), causing it to go on. In addition, the master alarm circuit is completed; the MASTER ALARM lights go on and a tone is generated. The master alarm tone and light are discontinued when the MASTER ALARM pushbutton/light is pressed. The INVERTER light goes off when the a-c bus voltage and frequency are again within limits.

2.5.2.5.4 Malfunctioning-Battery Isolation Circuitry. (See figure 2-107.)

The BATTERY caution light (panel 2) goes on when there is an overtemperature, overcurrent, or reverse-current condition in any EPS battery. The malfunction isolation circuitry associated with each battery, within its respective ECA, is essentially the same. Only the battery No. 1 isolation circuitry in ECA No. 1 is discussed.

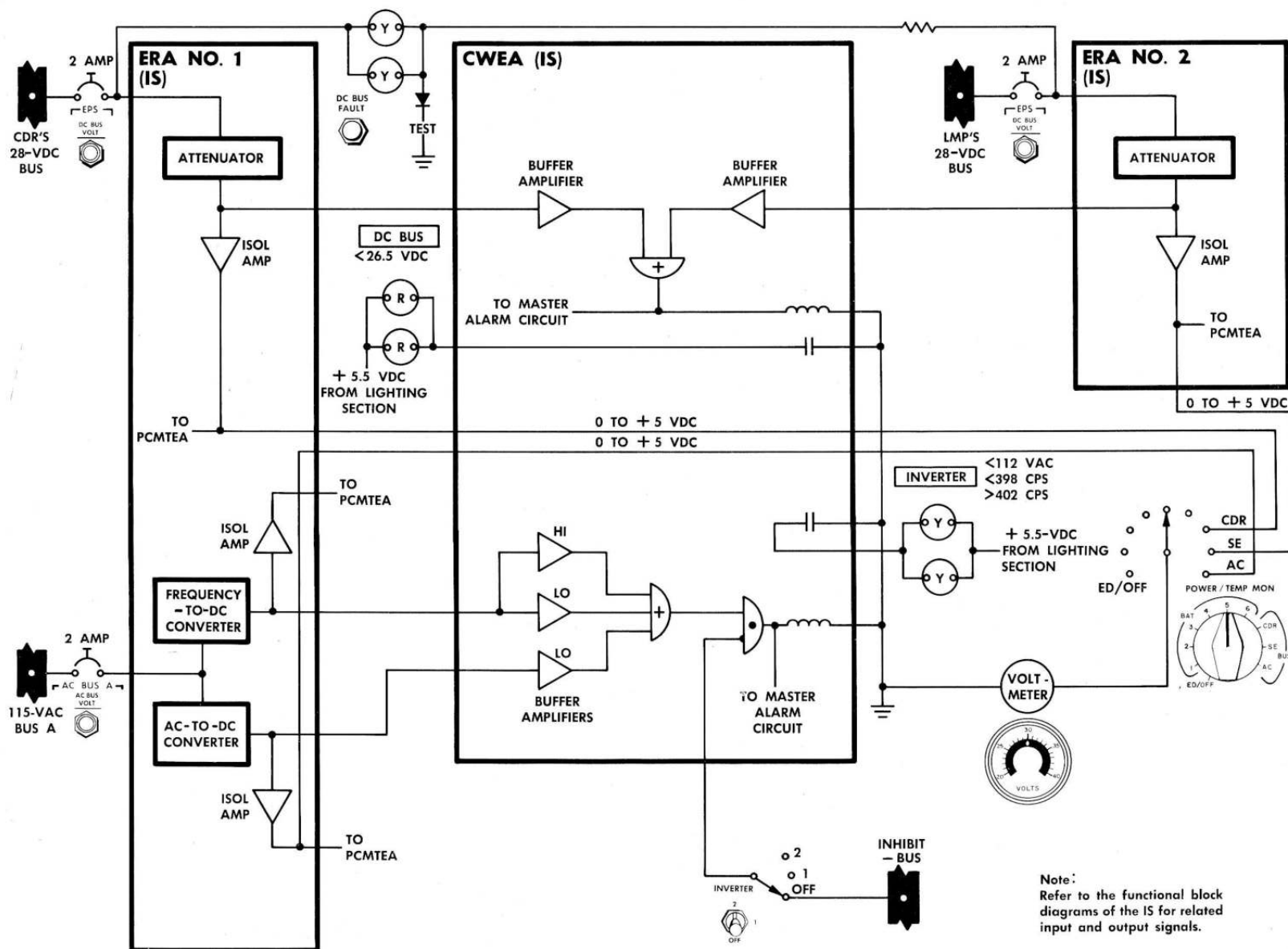


Figure 2-106. Primary Bus Voltage-Monitoring Circuits - Simplified Schematic Diagram

ELECTRICAL POWER SUBSYSTEM

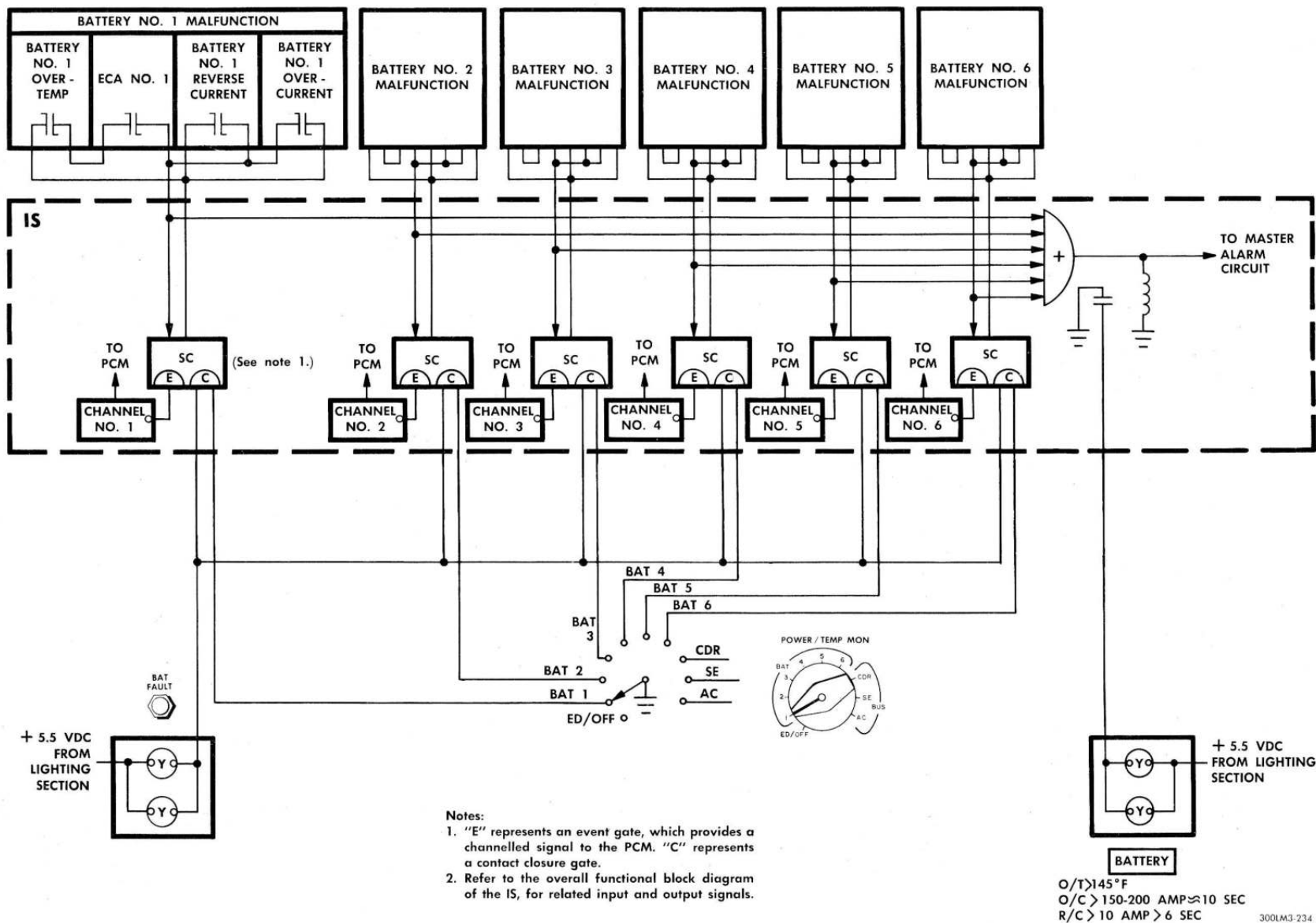


Figure 2-107. Malfunctioning-Battery Isolation Circuitry - Simplified Schematic Diagram

D-C power from the related signal conditioner (SC) in the IS is supplied to the paralleled array of malfunction relay contacts within ECA No. 1. Thermal sensors in parallel within the battery close if any cells overheat; a reverse-current or overcurrent condition causes the respective relays in the ECA to become energized and related relay contacts close. If either of these conditions exist, the d-c power from the SC flows through the respective set of contacts back to the SC and to a CWEA OR gate.

The OR-gate output energizes a CWEA relay that provides a ground return to the BATTERY caution light, causing it to go on. In addition, the master alarm circuit is completed; the MASTER ALARM lights go on and a tone is generated. The BATTERY light goes off when the malfunction that caused it to go on is eliminated. The master alarm tone and light are discontinued when the MASTER ALARM pushbutton/light is pressed.

The d-c signal fed back to the SC from the ECA activates an event gate, which provides a channeled signal to the pulse code modulator of the IS, for telemetry. This same d-c signal also activates a contact closure gate, completing a circuit from the BAT FAULT component caution light (panel 14) to the respective battery terminal of the POWER/TEMP MON selector switch. Setting the switch to this battery position applies a ground return to the light, causing it to go on. The malfunctioning battery is identified by the placarded switch position. The light goes off when the malfunction is corrected, or the battery is removed from its main power feeder line, by momentarily setting the respective switch (panel 14) to OFF/RESET.

2.5.2.6

EPS Stages of Operation.

The EPS operates in seven basic stages, as follows:

- GSE-vehicle ground power supply (VGPS) to LM until T-7 hours (ac and dc)
- GSE-launch umbilical tower (LUT) power to LM from T-7 hours until T-30 minutes (dc only)
- Descent stage power from T-30 minutes through CSM transposition and docking (descent batteries on low-voltage taps)
- Earth orbit - CSM/LM power
- Descent stage power (descent batteries manually switched to high-voltage taps)
- Ascent stage power (on normal main feeders)
- Staging (normal or abort).

2.5.2.6.1

GSE-Supplied Prelaunch Power. (See figure 2-108.)

Before earth launch, a-c and d-c power are supplied to the LM by the VGPS. An umbilical cable or a portable power supply is carried on board the LM and connected to two GSE connectors: one located under the lower circuit breaker tier (panel 11), the other under the lower circuit breaker tier (panel 16). At approximately T-7 hours, the VGPS power is replaced by LUT power. The SLA/LM assembly is now connected to the LUT by umbilical cable. LUT power is supplied to the LM Pilot's bus through the RJB. LUT remote control includes LUT deadface relay (LDR) set and reset commands, and LM high-voltage and low-voltage off and low-voltage on signals. The LDR supplies power through the LM Pilot's main power feeders to the LM Pilot's d-c bus. D-C power is supplied to the Commander's bus through the EPS: CROSS TIE circuit breakers.

ELECTRICAL POWER SUBSYSTEM

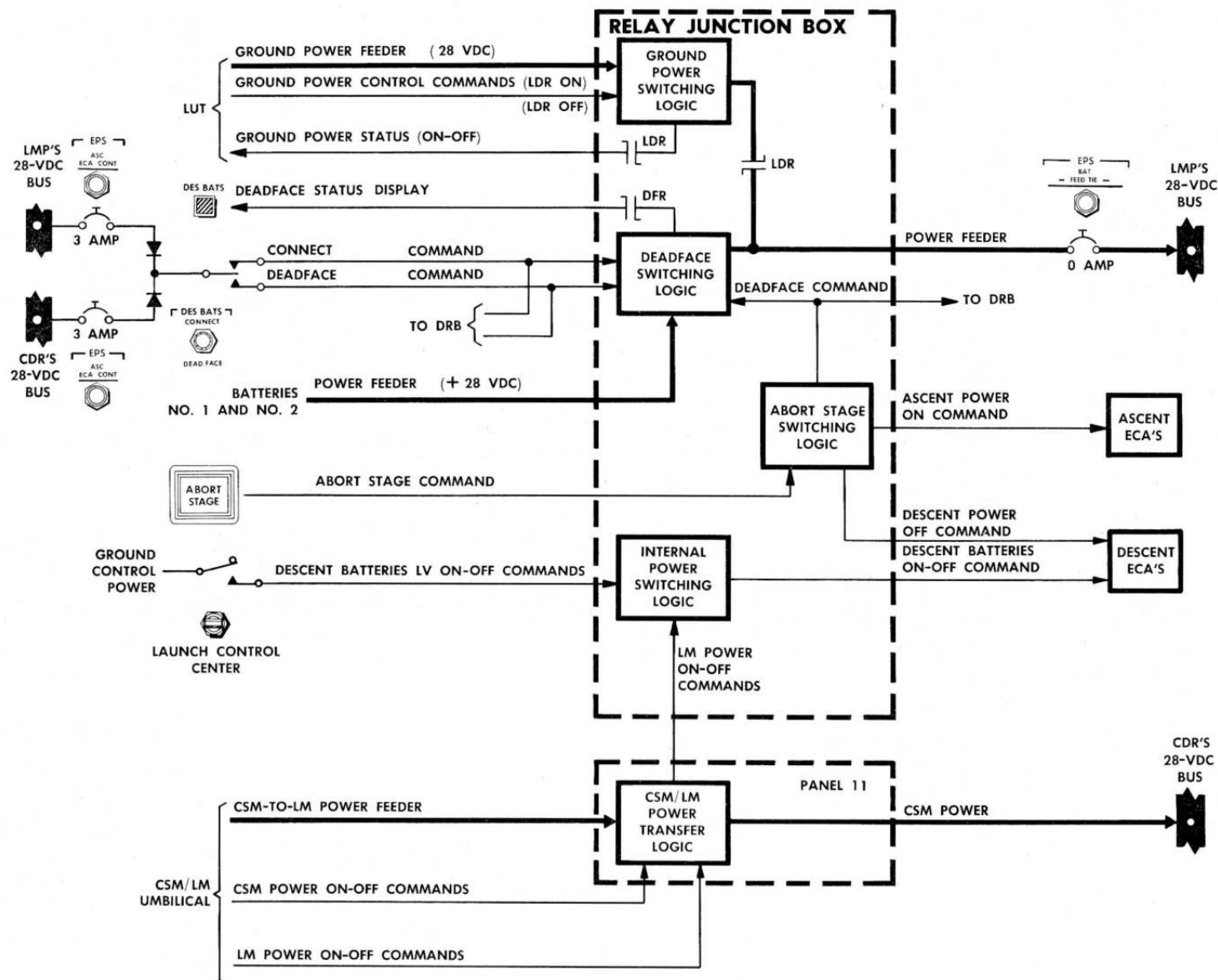


Figure 2-108. Relay Junction Box - Functional Block Diagram

300LM3-229

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

2.5.2.6.2 Descent Stage Power (Low-Voltage Taps).

At T-30 minutes, the LUT resets the LDR and connects the EPS descent battery low-voltage taps to the respective feeder lines. The descent batteries supply limited power to certain critical equipments from T-30 minutes until completion of CSM transposition and docking.

2.5.2.6.3 Earth Orbit - CSM/LM Power. (See figure 2-109.)

On completion of CSM transposition and docking, an astronaut connects power and control umbilical cables to the LM. The CSM deactivates LM power and then supplies power to the LM critical equipment, using the LM translunar negative bus. CSM/LM control logic prohibits CSM power to the LM power distribution system while the LM descent stage batteries are on the main power feeder lines. CSM/LM control logic is as follows:

- CSM deactivates LM power (high voltage and low voltage off)
- CSM initiates CSM power to LM
- CSM deactivates CSM power to LM
- CSM initiates LM power on (low voltage on).

2.5.2.6.4 Descent Stage Power (High-Voltage Taps).

Each of the four descent batteries has a HI VOLTAGE and LOW VOLTAGE switch and a talkback on panel 14. Descent stage battery low-voltage and off/reset control lines are routed through the RJB to the appropriate ECA; high-voltage control lines are routed directly to the respective ECA. Additional low-voltage and off/reset control is effected within the RJB through internal logic control signals. Descent batteries No. 1 and 2 supply electrical power to the LM Pilot's d-c bus via ECA No. 1 and the RJB. Descent batteries No. 3 and 4 supply the Commander's d-c bus via ECA No. 2 and the DRB.

2.5.2.6.5 Ascent Stage Power.

Each of the two ascent batteries has a NORMAL and BACK UP feeder switch and related talkbacks on panel 14. Battery No. 5 normally supplies power to the LM Pilot's d-c bus via ECA No. 3. Battery No. 6 normally supplies power to the Commander's d-c bus via ECA No. 4.

2.5.2.6.6 Staging-Normal or Abort (See figure 2-110.)

The EPS staging operation consists of transferring the LM d-c bus loads from the descent stage batteries to the ascent stage batteries prior to LM stage separation, while maintaining uninterrupted d-c power to the bus power distribution system. Automatic transfer is initiated by pressing the ABORT STAGE pushbutton (panel 1); this applies 28 volts dc to the EPS abort stage relays in the RJB. These relays close the normal main feed contactors (MFC's) of each ascent ECA (if the ECA's have not been selected previously in the backup feed mode). After the ascent stage battery MFC's have placed the ascent stage batteries on the line, additional abort stage relay contacts supply an off/reset signal, through the RJB, to each descent stage battery and to the deadface relays (DFR's). Transfer from descent stage battery power to ascent stage battery power can also be initiated manually by setting the DES BATS switch (panel 14) to DEADFACE. Auxiliary DFR contacts in the RJB and DRB provide direct control to the DES BATS talkback for monitoring the deadface operation.

ELECTRICAL POWER SUBSYSTEM

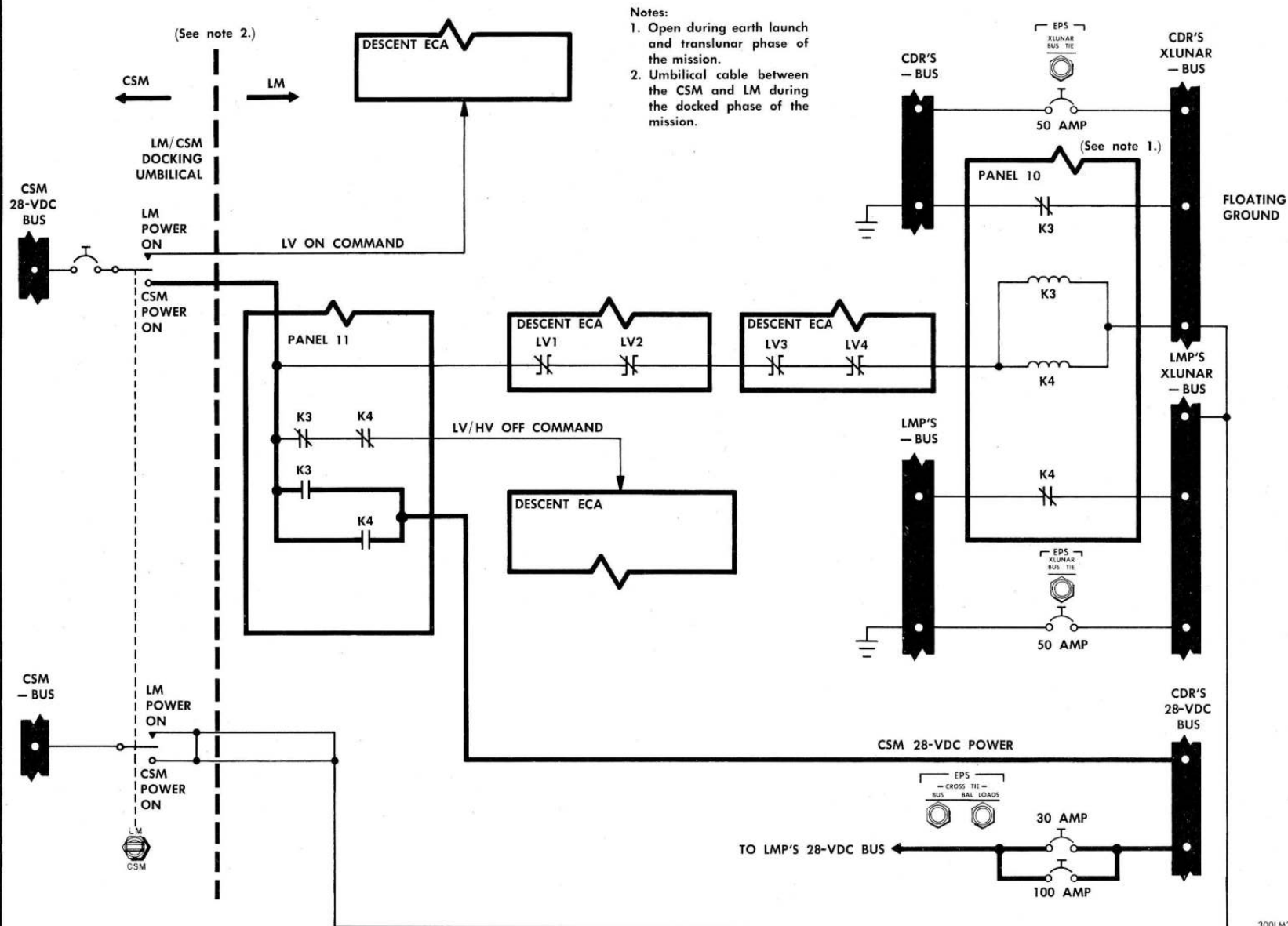
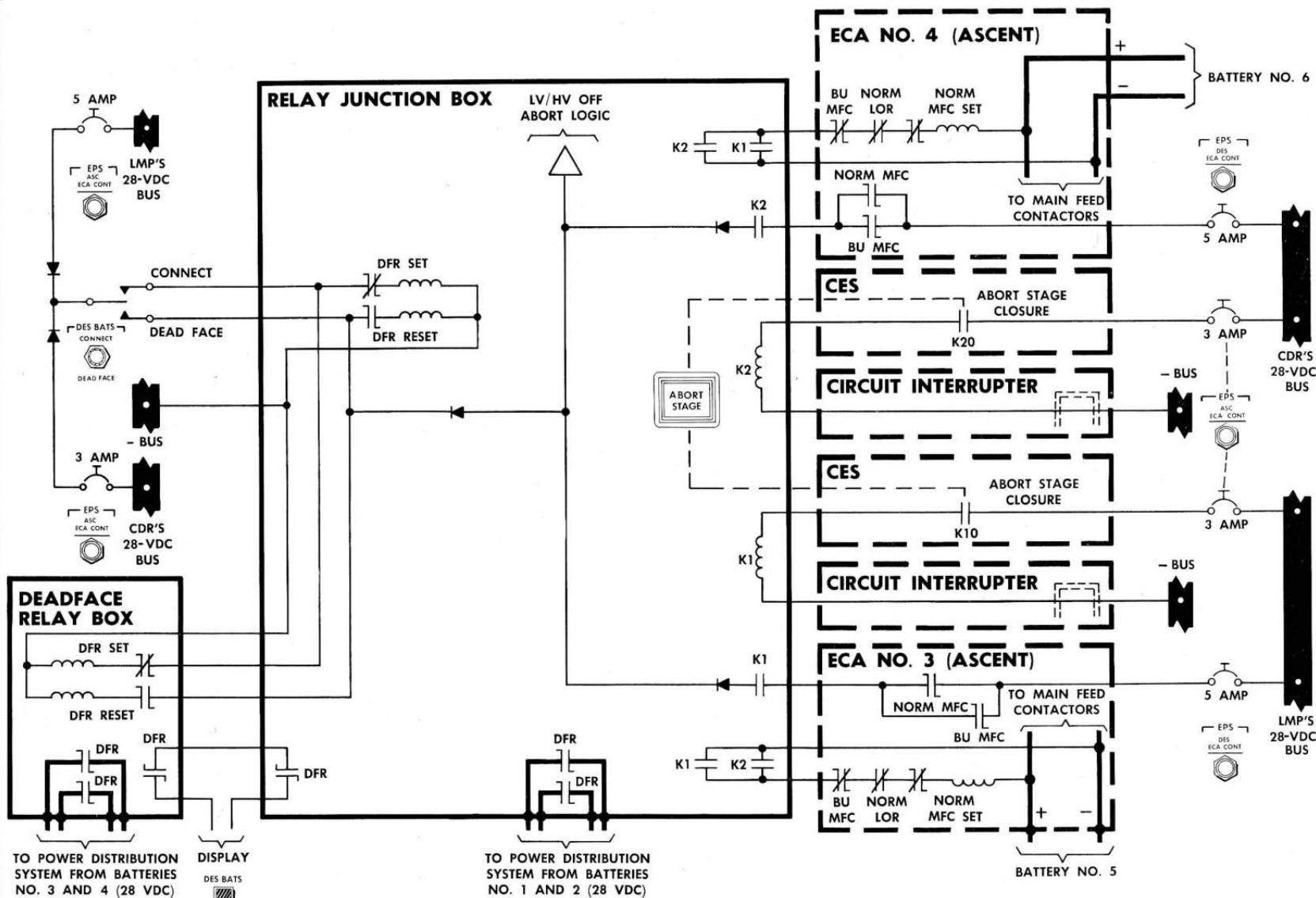


Figure 2-109. CSM/LM Primary Power Transfer Logic - Simplified Schematic Diagram



300LM3-235

Figure 2-110. Deadface Relay and Staging Logic - Simplified Schematic Diagram

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

2.5.3 MAJOR COMPONENT/FUNCTIONAL DESCRIPTION.

2.5.3.1 Descent Stage Batteries.

Each descent stage battery (No. 1 through 4) is composed of silver-zinc plates, with a potassium hydroxide electrolyte. Each battery has 20 cells, weighs 139.6 pounds, and has a 400-ampere-hour capacity (25 amperes at 28 volts dc for 16 hours, at +80°F) when discharged in accordance with the nominal power profile of the mission. The batteries can operate in a vacuum while cooled by an Environmental Control Subsystem (ECS) cold rail assembly to which the battery heat sink surface is mounted. If one descent stage battery fails, the remaining descent stage batteries can provide sufficient power for a curtailed mission. Five thermal sensors monitor cell temperature limits (+145° ±5°F) within each battery; they cause the BATTERY caution light and MASTER ALARM lights to go on to alert the astronaut to a battery overtemperature malfunction. These batteries initially have high-voltage characteristics; a low-voltage tap is provided (at the 17th cell) for use from T-30 minutes through transposition and docking. The high-voltage tap is used for all other normal LM operations. (Manual switchover from low to high voltage usually occurs when the battery has discharged to approximately 80% of capacity.) Normally, the battery high- or low-voltage outputs are connected to the main feeder lines, using the DESCENT POWER switches, but electrical contactor switching is ultimately performed in the battery's respective ECA. Normally, the descent stage batteries are paralleled so that all batteries discharge evenly. See figure 2-102 for a functional block diagram of descent stage battery power distribution. The terminal voltages of a descent battery are as follows:

Nominal Voltage - 30.0 volts dc

Minimum voltage during 40-ampere discharge -28.0 volts dc

Maximum voltage during 5-ampere discharge - 32.5 volts dc.

2.5.3.2 Ascent Stage Batteries.

Each ascent stage battery (No. 5 and 6) is composed of silver-zinc plates, with a potassium hydroxide electrolyte. Each battery weighs 131.7 pounds and has a 296-ampere-hour capacity (50 amperes at 28 volts dc for 5.92 hours, at +80°F) when discharged in accordance with the nominal power profile of the mission. The batteries can operate in a vacuum while cooled by ECS cold rails to which the battery heat sink surface is mounted. The nominal operating temperature of the ascent stage batteries is approximately +100°F. Battery temperature in excess of +145° ±5°F closes a thermal sensor, causing the BATTERY caution light and MASTER ALARM pushbutton/lights to go on. (The lights do not go on if the ascent battery normal main feed contactor is open.) The astronaut then takes corrective action to eliminate the faulty battery. Two ascent stage batteries ordinarily supply the d-c power requirements, from normal staging to final docking of the ascent stage with the orbiting CSM or during any malfunction that requires separation of the ascent and descent stages. However, if one ascent stage battery fails, the remaining battery provides sufficient power to accomplish safe rendezvous and docking with the CSM during any part of the mission.

The ascent batteries do not have low-voltage taps; inherent high-voltage characteristics are eliminated quickly during high-powered descent engine burns, at which time the ascent stage batteries are paralleled with the descent stage batteries. Normally, the ascent stage batteries are paralleled to ensure that both batteries discharge evenly. See figure 2-103 for a functional block diagram of ascent stage battery power distribution. The terminal voltages of an ascent stage battery are as follows:

Nominal voltage - 30.0 volts dc

Minimum voltage - 28.0 volts dc

Maximum voltage - 32.5 volts dc.
(under load)

ELECTRICAL POWER SUBSYSTEM

2.5.3.3

Descent Stage Electrical Control Assemblies. (See figure 2-111.)

The two descent stage ECA's protect and control the four descent stage batteries. Each ECA has a set of control circuits for each battery accommodated. A failure in one set of battery control circuits does not effect the other set. The primary function of the ECA is to connect the two related batteries (normal) or one battery (contingency) to the associated main feeder line through the low-voltage (LV) or high-voltage (HV) MFC's. The protective circuits of the ECA automatically disconnect a descent stage battery if an overcurrent condition is detected, and cause the BATTERY caution light and MASTER ALARM pushbutton/lights to go on if a battery overcurrent, reverse-current, or over-temperature condition is detected.

Analogous of battery voltage and current (monitored constantly in the ECA) are routed to the IS to provide indications on the VOLTS and AMPS indicators (panel 14). Battery talkbacks (low voltage, high voltage, and off) receive drive signals derived from ECA-supplied discrete levels processed through the IS. The major elements in the descent stage ECA's are low- and high-voltage MFC's, current monitors, overcurrent relays, reverse-current relays, and power supplies. An auxiliary relay supplies system logic contact closures to other control assemblies in the LM power distribution system.

The MFC's are electrically interlocked to prevent closing a HV contactor when a LV contactor is already closed, and vice versa. This prevents short-circuiting the tapped sections of the respective descent stage battery. The MFC's are operated with the DESCENT POWER HI VOLTAGE and LOW VOLTAGE switches.

The ECA current monitor produces isolated outputs for the IS, overcurrent relay, and reverse-current relay from the battery current that flows through the HV or LV main feeder contactors. The current monitor supplies a d-c level (proportional to battery current) to the overcurrent relay. Voltage in the relay circuit builds up until the close coil of the overcurrent relay is energized (reflecting 150 to 200 amperes for approximately 10 seconds), at which time the HV or LV contactor opens to disconnect the battery from its power feeder. The magnitude of battery current is inversely proportional to the time it takes for the close coil of the relay to be energized; the greater the initial overcurrent, the less time required for tripping. The overcurrent relay is not sensitive to the direction of current flow, only to its magnitude. The relay must be reset manually (OFF/RESET position of the DESCENT POWER HI VOLTAGE and LOW VOLTAGE switches) once it is tripped. For each overcurrent circuit, the ECA provides an alarm signal to the caution and warning circuits in the IS, causing the BATTERY caution light and MASTER ALARM pushbutton/lights (panels 1 and 2) to go on, and a tone to be generated.

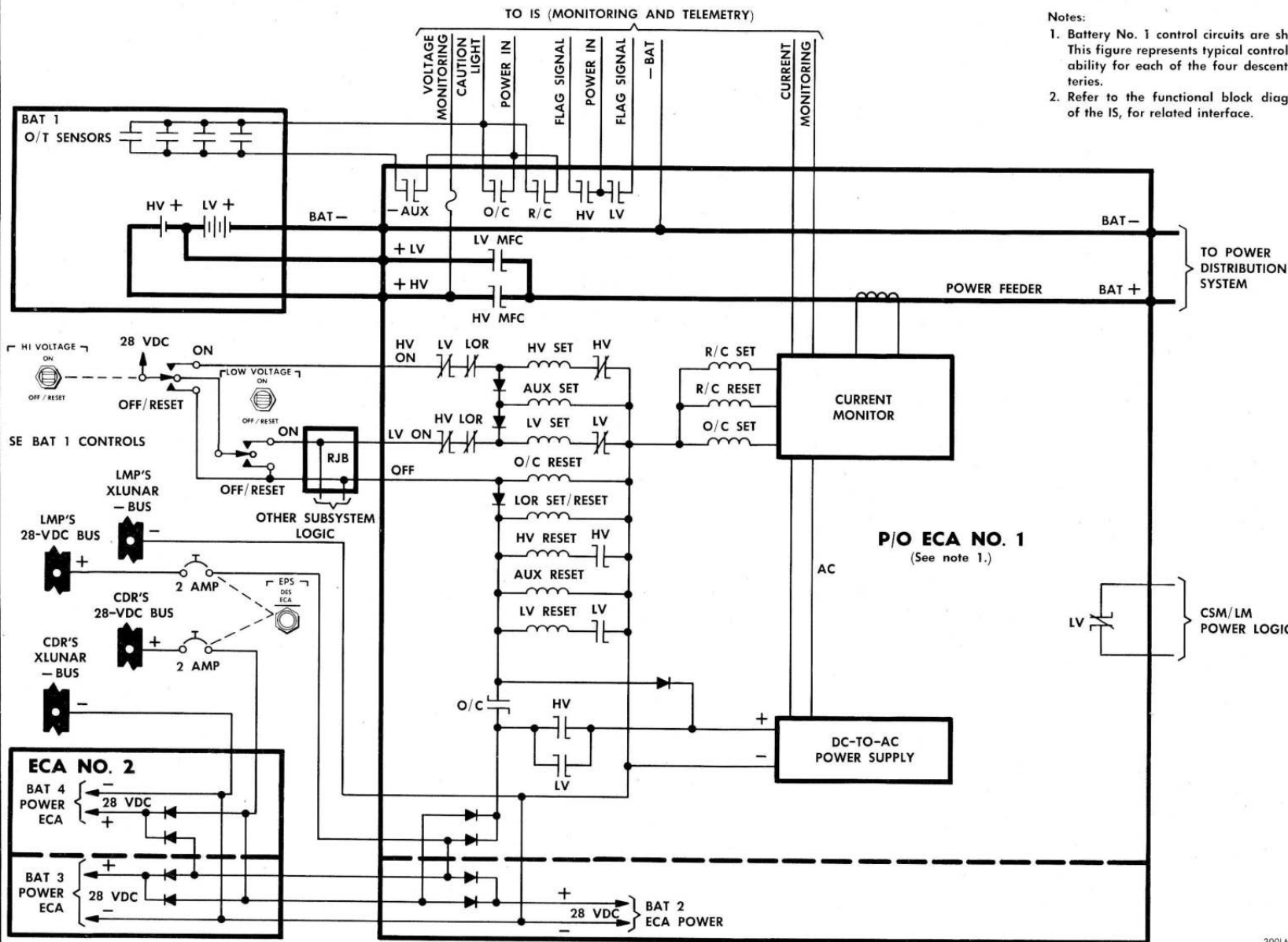
The reverse-current relay causes the BATTERY caution light to go on when current flow in the direction opposite to normal current flow exceeds 10 amperes for at least 6 seconds. Unlike the overcurrent relay, the reverse-current relay does not open the related MFC's and is self-resetting when the current monitor ceases to detect a reverse-current condition. During reverse-current conditions, the related MFC must be switched open manually by setting the DESCENT POWER switches to OFF/RESET. The descent stage ECA power supplies provide ac for current-monitor excitation, and regulated dc for the other ECA circuits.

2.5.3.4

Ascent Stage Electrical Control Assemblies. (See figure 2-112.)

The two ascent stage ECA's individually control and protect the two ascent stage batteries (No. 5 and 6) in nearly the same manner as the descent stage ECA's control and protect the descent stage batteries. Each ascent stage ECA contains electrical power feeder contactors, an overcurrent relay, a reverse-current relay, and a current monitor. Each ascent stage battery can be connected to its normal or back up main feeder line via the normal MFC or the backup main feed contactor (BU MFC) in its respective ECA. Both batteries are thereby connected to the primary d-c power buses.

ELECTRICAL POWER SUBSYSTEM



- Notes:
1. Battery No. 1 control circuits are shown. This figure represents typical control capability for each of the four descent batteries.
 2. Refer to the functional block diagram of the IS, for related interface.

Figure 2-111. Descent Stage Electrical Control Assembly - Simplified Schematic Diagram

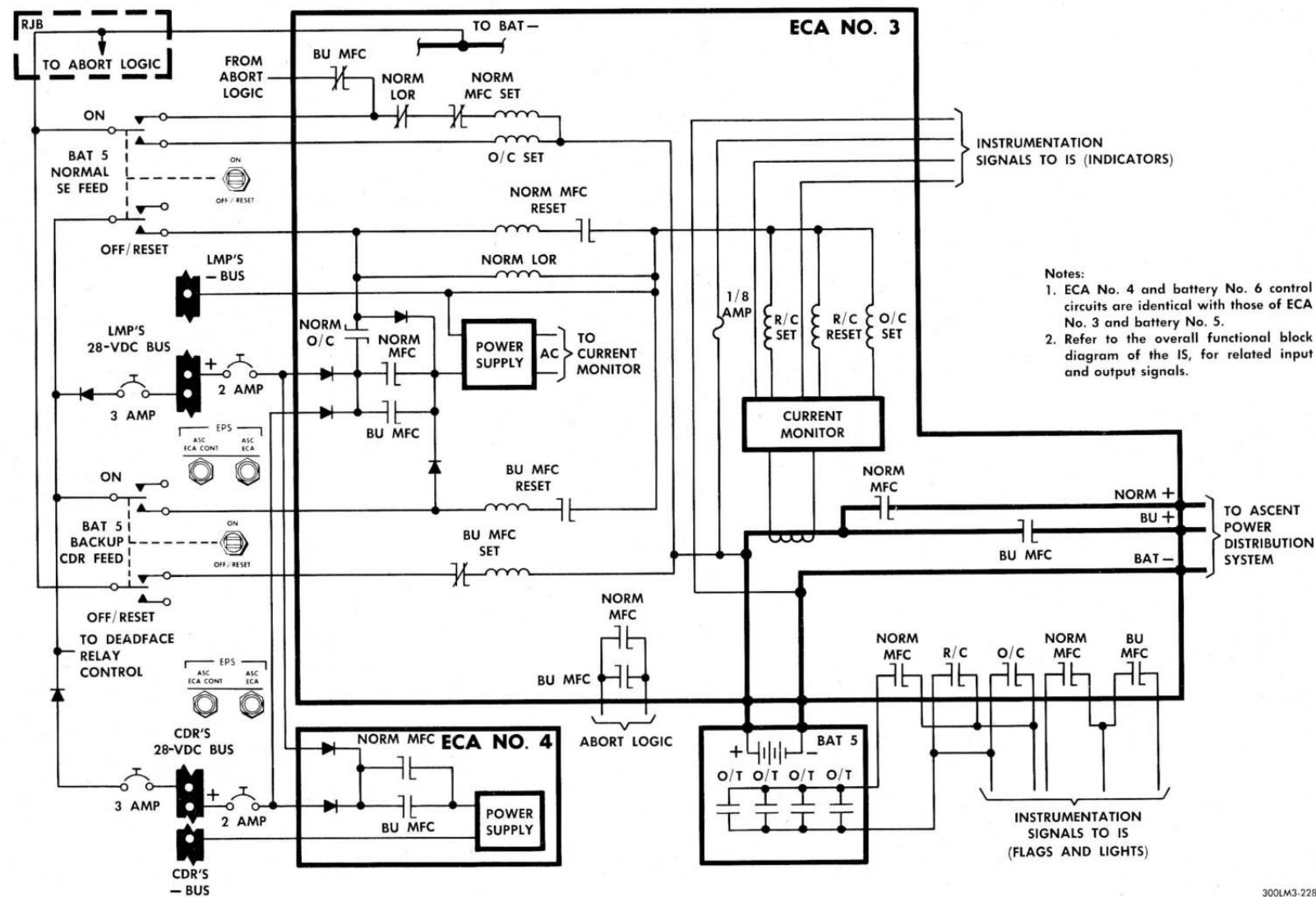


Figure 2-112. Ascent Stage Electrical Control Assembly - Simplified Schematic Diagram

The normal feeder line has overcurrent protection; the backup feeder line does not. Otherwise, the ascent stage ECA's function the same as the descent stage ECA's. The ascent stage ECA's provide reverse-current monitoring, overcurrent protection, and contact closures for indicators. Auxiliary relays supply system logic contact closures to other assemblies in the LM power distribution system. The MFC's and BU MFC's in the ascent stage ECA's are manually operated with the respective ASCENT POWER switches.

2.5.3.5 Relay Junction Box. (See figure 2-108.)

The RJB provides the following:

- Control logic and junction points for connecting external prelaunch power (via the LUT) to the LM Pilot's d-c bus
- Control and power junction points for connecting descent stage and ascent stage ECA's to the LM Pilot's bus
- Deadfacing of half the power feeders between the descent and ascent stages.

The RJB provides control of all LV contactors (on and off) from the LUT and CSM, and control of all low- and high-voltage descent power contactors (off) on receipt of an abort stage command. On and off control of ground facility power through the LUT is provided by the LDR. The RJB includes abort logic relays, which, when energized by an abort stage command, close the ascent stage battery MFC's and open the deadface relays. The RJB deadface relays provides on and off control of the main power feeders of descent batteries No. 1 and 2. These relays are opened and closed with the DES BATS switch, or are opened automatically when the abort logic relays close. The deadface relays in the relay junction box deadface half of the main power feeders between the descent and ascent stages; the other half of the power feeders is deadfaced by the deadface relays in the DRB. The ascent stage then provides primary d-c power to the LM.

2.5.3.6 Deadface Relay Box. (See figure 2-110.)

The DRB contains deadface relays, which control the output of descent stage batteries No. 3 and 4 in the same manner as the RJB deadface relays control descent stage batteries No. 1 and 2. Because the Commander's and LM Pilot's circuit breaker panels are located on opposite sides of the LM cabin, two individual deadfacing facilities (one for each circuit breaker panel) provide a physically expedient deadfacing process.

2.5.3.7 Inverters. (See figure 2-113.)

Two redundant 400-cps inverters individually supply the primary a-c power required in the LM. Inverter output is controlled by application of 28 volts dc from the Commander's or LM Pilot's 28-volt d-c bus through the EPS: INV 1 and INV 2 circuit breakers, the INVERTER switch, and the AC BUS A and AC BUS B: BUS TIE circuit breakers. The inverters are identical; therefore, only the inverter No. 1 circuitry is discussed. The 28 volts dc is applied through an electromagnetic interference (EMI) filter and an input filter to a dc-to-dc converter. The regulated output of the converter is changed to a 400-cps square wave in the inverter stage. The output of the inverter stage is controlled by 400-cps pulse drives developed from a 6.4-kilopulse-per-second (kpps) oscillator, which is, in turn, synchronized by timing pulses from the IS. The output of the inverter stage is 400 ± 2 cps, synchronized; 400 ± 10 cps, with a free-running oscillator. The 6.4-kpps oscillator output is divided precisely by 16 in the divider logic circuit and routed to the inverter stage, the electronic tap changer, and short-circuit protection circuits. The electronic tap changer sequentially selects the output of the tapped transformer in the inverter stage, converting the 400-cps square wave to an approximate sine wave of the same frequency. The output filter minimizes harmonic distortion. The voltage regulator maintains the inverter output at 117 volts ac $\pm 1\%$ during normal load conditions by controlling the amplitude of the dc-to-dc converter output. The voltage regulator also compensates for variations in the d-c input and a-c output load.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Setting the INVERTER switch to 1 routes the inverter No. 1 output to the AC BUS A: BUS TIE INV 1 circuit breaker for a-c bus A application and to the AC BUS B: BUS TIE INV 1 circuit breaker for a-c bus B application. A-C power at bus A is monitored for proper voltage amplitude and frequency by the IS via the AC BUS A: AC BUS VOLT circuit breaker (panel 11). When the voltage at bus A is less than 112 volts ac, or the frequency is less than 398 cps or more than 402 cps, the INVERTER caution light and MASTER ALARM pushbutton/light go on. The INVERTER caution light goes off when the malfunctioning condition is rectified. The MASTER ALARM display and audio tone are discontinued when the MASTER ALARM pushbutton/light is pressed.

2.5.3.8 Circuit Breaker and EPS Control Panels.

All primary a-c and d-c power feed circuits are protected by appropriately rated circuit breakers on the Commander's and LM Pilot's buses. The two d-c buses are electrically connected by the main power feeder network. Functionally redundant LM equipment is placed on both d-c buses (one on each bus), so that each bus can individually perform an abbreviated abort mission during emergencies. EPS circuit controls and monitoring displays are on panel 14. Section 3 contains a description of all EPS controls, displays, and circuit breakers. Circuit breaker characteristics are given in table 2-36.

2.5.3.9 Sensor Power Fuse Assemblies. (See figure 2-114.)

Two sensor power fuse assemblies in the aft equipment bay, provide a secondary d-c bus system that supplies excitation to ECS, RCS, and MPS transducers that develop display and telemetry data. During prelaunch procedures, the INST: SIG SENSOR circuit breaker (panel 16) is open, and primary power is supplied to the assemblies from the Commander's 28-volt d-c bus, via the EPS: DC BUS VOLT circuit breaker (panel 11) and the closed contacts of relay K6 in panel 11. The coil of K6 is energized by the ground-supplied GSE umbilical cable. Before launch, the GSE umbilical is disconnected and K6 is deenergized. Power is then supplied directly to the sensor power fuse assemblies from the LM Pilot's 28-volt d-c bus by closing the INST: SIG SENSOR circuit breaker. Each assembly comprises a positive d-c bus, negative return bus, and 40 fuses. Refer to table 2-37 for sensor power fuse characteristics.

Table 2-36. Circuit Breaker Characteristics

D-C Circuit breaker	
Operating voltage	28 volts
Operating voltage limit	32.5 volts
Transient voltage limits	50 volts above, 100 volts below operating voltage
Ripple voltage	Less than 1.5 volts, peak
A-C circuit breaker	
Steady-state operating voltage	115±2.5 volts rms
Transient voltage limits	144 to 225 volts, peak
Transient voltage recovery time	50 milliseconds

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

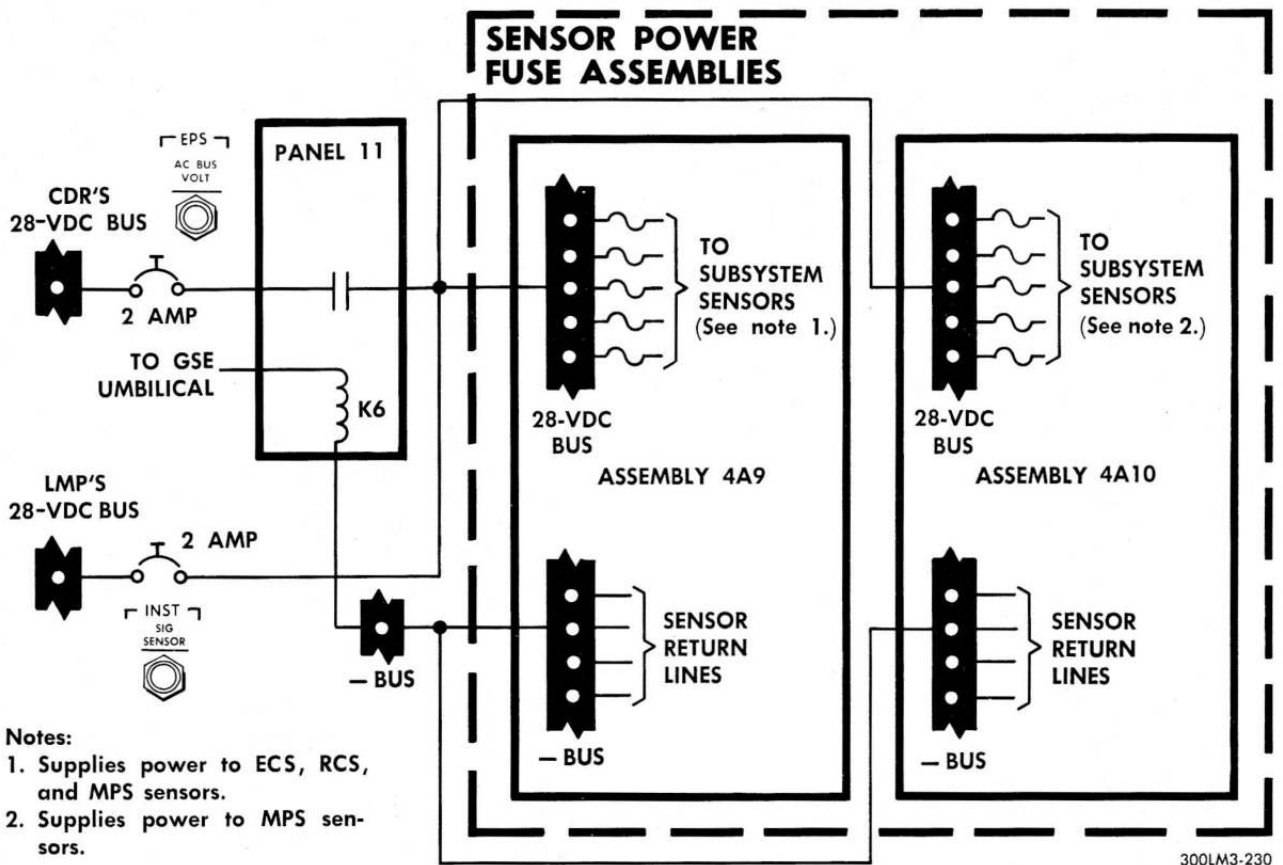


Figure 2-114. Sensor Power Fuse Assemblies - Simplified Power Distribution Diagram

Table 2-37. Sensor Power Fuses - Characteristics

Reference Designation	Ampere Rating	IS Sensor Powered	Related Subsystem
NOTE			
D-C power to all sensor power fuses is derived from the 28-volt d-c buses. All sensor return lines are routed to a common (N2) ground bus.			
Assembly 4A9			
F1	0.25	Ascent oxygen pressure - tank No. 1	ECS
F2	0.25	Ascent oxygen pressure - tank No. 2	
F3	0.25	Descent oxygen pressure - tank	
F4	0.25	Coolant discharge pressure - primary loop	
F5	0.25	Coolant discharge pressure - redundant loop	

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-37. Sensor Power Fuses - Characteristics (cont)

Reference Designation	Ampere Rating	IS Sensor Powered	Related Subsystem
Assembly 4A9 (cont)			
F6	0.25	Quantity - descent water tank	ECS
F7	0.25	Quantity - ascent water tank No. 1	
F8	0.25	Quantity - ascent water tank No. 2	
F9	0.25	Spare	
F10	0.25	Helium pressure - tank A	RCS
F11	0.25	Helium pressure - tank B	
F12	0.25	Helium pressure regulator A output pressure	
F13	0.25	Helium pressure regulator B output pressure	
F14	0.25	Capped	
F15	0.25	Capped	
F16	0.25	Fuel manifold A pressure	
F17	0.25	Fuel manifold B pressure	
F18	0.25	Capped	
F19	0.25	Capped	
F20	0.25	Oxidizer manifold A pressure	MPS
F21	0.25	Oxidizer manifold B pressure	
F22	0.5	Spare	
F23	0.25	Helium pressure - supply tank No. 1	
F24	0.25	Helium pressure - supply tank No. 2	
F25	0.25	Pressure regulator output manifold	
F26	0.25	Fuel tank - low level	
F27	0.25	Oxidizer tank - low level	
F28	0.25	Pressure - fuel isolation valve inlet	
F29	0.25	Pressure - oxidizer isolation valve inlet	
F30	0.25	Pressure - thrust chamber	
F31	0.25	Pressure regulator output manifold (redundant)	
F32	0.25	Pressure - helium regulator output manifold	
F33	0.25	Fuel pressure - engine interface	
F34	0.25	Pressure - supercritical helium supply tank	
F35	0.25	Pressure - thrust chamber	

ELECTRICAL POWER SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-37. Sensor Power Fuses - Characteristics (cont)

Reference Designation	Ampere Rating	IS Sensor Powered	Related Subsystem
Assembly 4A9 (cont)			
F36	0.25	Oxidizer pressure - engine interface	MPS
F37	0.25	Pressure - helium regulator output manifold (redundant)	
F38	0.25	Pressure - supercritical helium supply tank (redundant)	
F39	0.5	Spare	
F40	0.5	Throttle - instrumentation reference power supply	
Assembly 4A10			
F1	0.25	Pressure - fuel tank ullage	MPS
F2	0.25	Pressure - oxidizer tank ullage	
F3	0.25	Pressure - fuel tank No. 1 ullage	
F4	0.25	Pressure - oxidizer tank No. 1 ullage	
F5	0.25	Ambient pressure - helium prepressure bottle	
F6	0.25	Spare	
F7	0.25	Spare	
F8	0.25	Spare	
F9	0.25	Spare	
F10	0.25	Capped	
F11	0.25	Capped	
F12	0.25	Capped	
F13	0.25	Capped	
F14	0.25	Capped	
F15	0.25	Capped	
F16	0.25	Capped	
F17	0.25	Capped	
F18	0.25	Capped	
F19	0.25	Capped	
F20	0.25	Capped	
F21	0.25	Capped	
F22	0.5	Capped	
F23	0.25	Spare	
F24	0.25	Spare	

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-37. Sensor Power Fuses - Characteristics (cont)

Reference Designation	Ampere Rating	IS Sensor Powered	Related Subsystem
Assembly 4A10 (cont)			
F25	0.25	Spare	
F26	0.25	Spare	
F27	0.25	Spare	
F28	0.25	Spare	
F29	0.25	Spare	
F30	0.25	Spare	
F31	0.25	Spare	
F32	0.25	Spare	
F33	0.25	Spare	
F34	0.25	Spare	
F35	0.25	Spare	
F36	0.25	Spare	
F37	0.25	Spare	
F38	0.25	Spare	
F39	0.5	Spare	
F40	0.5	Spare	

2.5.4

FAILURE MODES.

The EPS failure modes and the effect on mission capability are given in table 2-38.

Table 2-38. Electrical Power Subsystem - Failure Modes

Failure	Indication	Vehicle Capability	
		Before Staging	After Staging
Descent Stage Power			
One descent battery failed.	BATTERY caution light and BAT FAULT component caution light go on. (See notes 1 and 2.)	Abbreviated mission may still be effected, using remaining descent batteries.	N/A

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-38. Electrical Power Subsystem - Failure Modes (cont)

Failure	Indication	Vehicle Capability	
		Before Staging	After Staging
Descent Stage Power (cont)			
Two or more descent batteries failed.	BATTERY caution light and BAT FAULT component caution light go on. (See notes 1 and 2.)	Mission must be severely curtailed. Mission may be aborted, with unstaged vehicle rendezvousing with CSM (using ascent power and remaining descent power); vehicle may be staged, followed by normal resumption of ascent stage mission procedures (using ascent power) and rendezvous and docking with the CSM.	N/A
One bus or main feeder line failed (CDR's side -EPS: CROSS TIE circuit breakers open). (See note 3.)	DC BUS warning light and DC BUS FAULT component caution light go on, and associated DESCENT STAGE talkbacks provide barber-pole display. (See note 1.)	Mission must be aborted after faulty bus or main feeder line is isolated from power distribution network and ascent power is supplied to operational feeder.	See ascent stage power section of table.
One bus or main feeder line failed (LMP's side -EPS: CROSS FEED circuit breakers open). (See note 3.)	DC BUS warning light, C/W PWR caution light, and DC BUS FAULT component caution light go on, and all related DESCENT POWER talkbacks provide barber-pole display. (See note 1.)	Mission must be aborted, after faulty bus or main feeder line is isolated from power distribution network and ascent power is supplied to operational feeder.	See ascent stage power section of table.
Ascent Stage Power			
One ascent battery failed.	BATTERY caution light and BAT FAULT component caution light go on. (See notes 1 and 2.)	Mission must be aborted. Rendezvous and docking by unstaged vehicle may be achieved, using one ascent battery and remaining descent power.	Mission must be aborted. Remaining ascent battery is sufficient to ensure safe rendezvous and docking of LM ascent stage and CSM.
One bus or main feeder line failed (CDR's or LMP's side - EPS: CROSS TIE circuit breakers open). (See note 3.)	DC BUS warning light and DC BUS FAULT component caution light go on and associated ASCENT POWER talkbacks provide barber-pole display. (See note 1.)	N/A	Mission must be aborted. Faulty bus or main feeder line must be isolated from power distribution network, and associated battery must be removed from faulty feeder line (and respective bus) and connected to remaining bus.
Inverter No. 1 failed.	INVERTER caution light goes on with INVERTER switch set to 1. (See note 1.)	Mission must be aborted after inverter No. 2 is selected to replace inverter No. 1.	Same as effect before staging.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-38. Electrical Power Subsystem - Failure Modes (cont)

Failure	Indication	Vehicle Capability	
		Before Staging	After Staging
Ascent Stage Power (cont)			
Inverter No. 2 failed.	INVERTER caution light goes on with INVERTER switch set to 2. (See note 1.)	Redundant inverter No. 1 output is sufficient to continue nominal mission.	Same as effect before staging.
A-C bus failed.	INVERTER caution light goes on with INVERTER switch set to 1 or 2. (See note 1.)	Mission must be aborted. Faulty bus must be isolated from a-c power distribution network, with remaining a-c bus continuing to operate normally.	Same as mission effect before staging.
D-C Electrical Power - General			
Control of any ascent battery or any two descent batteries is lost.	Talkbacks (panel 14) do not display proper command feedback.	Mission must be aborted, using remaining available power.	Same as mission effect before staging.
NOTES			
1. When any caution or warning light goes on, the MASTER ALARM pushbutton/lights also go on and a tone is generated.			
2. The BAT FAULT component caution light is used in conjunction with the POWER/TEMP MON selector switch to identify malfunctioning batteries.			
3. A d-c bus or main feeder line short with the EPS: CROSS TIE circuit breakers closed results in automatic opening of these circuit breakers. The effect of the short on vehicle capability is then as stated.			

2.5.5 PERFORMANCE AND DESIGN DATA.

The performance and design data for the EPS are given in table 2-39.

Table 2-39. Electrical Power Subsystem - Performance and Design Data

AC	
Inverter input voltage	24 to 32 volts dc
Inverter output (with PCMTEA sync)	117 \pm 1.2 volts rms, 400 \pm 0.4 cps, single phase
Inverter output (with internal sync)	117 \pm 1.2 volts rms, 400 \pm 10 cps, single phase
Normal load range	0 to 350 volt-amperes (at power factors 0.65 lagging to 0.80 leading)
Maximum overload at constant voltage output	525 volt-amperes for 10 minutes

ELECTRICAL POWER SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-39. Electrical Power Subsystem - Performance and Design Data (cont)

DC	
Steady-state bus voltage limits	26.5 to 32.5 volts dc
Nominal supply bus voltage	28 volts dc
Transient voltages	50 volts above, 100 volts below, nominal supply voltage
Power requirements	
Ascent ECA's	84 watts, momentarily during battery switching; 10 watts, steady state
Descent ECA's	84 watts, momentarily during battery switching; 20 watts, steady state
EPS displays	2 watts

2.5.6

OPERATIONAL LIMITATIONS AND RESTRICTIONS.

The operational limitations and restrictions for the EPS are as follows:

- When EPS batteries are in use, the primary glycol cooling loop (ECS) must be operating. If this restriction is not observed, EPS components will be damaged. The only deviation to this is at low power levels (200 watts or less); then batteries can operate for 8 hours without cooling.
- When supplying power, temperature must be maintained between +29° and +100° F. If this restriction is exceeded, battery could be damaged or voltage output could go out of specification (less than 26.5 volts dc).
- Maximum continuous inverter power output must not exceed 350 volt-amperes. Demand can go to 525 volt-amperes for up to 10 minutes. If this limitation is exceeded, inverter components could be damaged.
- Maximum CSM power to LM during docked coast phases is 180 watts. If this restriction is exceeded, the current rating of the wire is exceeded.
- Available ascent electrical energy is 17.8 kilowatt-hours at maximum steady-state current drain of 50 amperes per battery, at 28 volts dc. Available descent electrical energy is 46.9 kilowatt-hours maximum at steady-state current drain of 25 amperes per battery, at 28 volts dc.
- During descent engine burns, the corresponding descent and ascent stage batteries (by supplied bus) must be paralleled. If abort stage contingency is required during these high-power phases, and batteries are not paralleled, low-voltage transients may appear on buses and degrade equipment operation (LM guidance computer, etc). Paralleling also precludes a low bus voltage due to descent battery failure.
- All EPS: CROSS TIE circuit breakers must be opened during main engine burns, thereby isolating the Commander's bus from the LM Pilot's bus. (Effects split d-c bus configuration.) If this restriction is not observed, a short on one bus will affect the other bus.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

2.5.7

TELEMETRY MEASUREMENTS.

The EPS telemetry data are given in table 2-40. "(R)" in the "Telemetry Range" column signifies a real-time telemetry measurement. Real-time telemetry points are shown in figures 2-102 and 2-103 (d-c circuits) and 2-113 (a-c circuits).

Table 2-40. Electrical Power Subsystem - Telemetry Measurements

Code	Description	Telemetry Range (Nominal)	Display Range	Crew Display
GC0071V	A-C bus voltage	0 to 125 vac (115 vac) (R)	62.5 to 125 vac (20 to 40 vdc)	VOLTS indicator
GC0155F	A-C bus frequency	380 to 420 cps (400 cps)		INVERTER caution light
GC0201V	Battery No. 1 voltage	0 to 40 vdc (28 vdc) (R)	20 to 40 vdc	VOLTS indicator
GC0202V	Battery No. 2 voltage	0 to 40 vdc (28 vdc) (R)	20 to 40 vdc	VOLTS indicator
GC0203V	Battery No. 3 voltage	0 to 40 vdc (28 vdc) (R)	20 to 40 vdc	VOLTS indicator
GC0204V	Battery No. 4 voltage	0 to 40 vdc (28 vdc) (R)	20 to 40 vdc	VOLTS indicator
GC0205V	Battery No. 5 voltage	0 to 40 vdc (28 vdc) (R)	20 to 40 vdc	VOLTS indicator
GC0206V	Battery No. 6 voltage	0 to 40 vdc (28 vdc) (R)	20 to 40 vdc	VOLTS indicator
GC0301V	Commander's bus voltage	0 to 40 vdc (28 vdc) (R)	20 to 40 vdc	VOLTS indicator
GC0302V	LM Pilot's bus voltage	0 to 40 vdc (28 vdc) (R)	20 to 40 vdc	VOLTS indicator
GC1201C	Battery No. 1 current	0 to 60 amperes (R)	0 to 120 amperes ÷ 2	AMPS indicator
GC1202C	Battery No. 2 current	0 to 60 amperes (R)	0 to 120 amperes ÷ 2	AMPS indicator
GC1203C	Battery No. 3 current	0 to 60 amperes (R)	0 to 120 amperes ÷ 2	AMPS indicator
GC1204C	Battery No. 4 current	0 to 60 amperes (R)	0 to 120 amperes ÷ 2	AMPS indicator
GC1205C	Battery No. 5 current	0 to 120 amperes (R)	0 to 120 amperes	AMPS indicator
GC1206C	Battery No. 6 current	0 to 120 amperes (R)	0 to 120 amperes	AMPS indicator
GC3501T	Battery No. 1 temperature	0° to +200° F		None
GC3502T	Battery No. 2 temperature	0° to +200° F		None
GC3503T	Battery No. 3 temperature	0° to +200° F		None
GC3504T	Battery No. 4 temperature	0° to +200° F		None
GC3505T	Battery No. 5 temperature	0° to +200° F		None
GC3506T	Battery No. 6 temperature	0° to +200° F		None

ELECTRICAL POWER SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-40. Electrical Power Subsystem - Telemetry Measurements (cont)

Code	Description	Telemetry Range (Nominal)	Display Range	Crew Display
GC3511X	Battery No. 1 overtemperature	Contact closure		BATTERY caution light (See GC9961U.)
GC3512X	Battery No. 2 overtemperature	Contact closure		BATTERY caution light (See GC9962U.)
GC3513X	Battery No. 3 overtemperature	Contact closure		BATTERY caution light (See GC9963U.)
GC3514X	Battery No. 4 overtemperature	Contact closure		BATTERY caution light (See GC9964U.)
GC3515X	Battery No. 5 overtemperature	Contact closure (normal MFC closed)		BATTERY caution light (See GC9965U.)
GC3516X	Battery No. 6 overtemperature	Contact closure (normal MFC closed)		BATTERY caution light (See GC9966U.)
GC4301X	Battery No. 1 overcurrent	Contact closure		BATTERY caution light (See GC9961U.)
GC4302X	Battery No. 2 overcurrent	Contact closure		BATTERY caution light (See GC9962U.)
GC4303X	Battery No. 3 overcurrent	Contact closure		BATTERY caution light (See GC9963U.)
GC4304X	Battery No. 4 overcurrent	Contact closure		BATTERY caution light (See GC9964U.)
GC4305X	Battery No. 5 overcurrent	Contact closure		BATTERY caution light (See GC9965U.)
GC4306X	Battery No. 6 overcurrent	Contact closure		BATTERY caution light (See GC9966U.)
GC4321X	Battery No. 1 reverse-current	Contact closure		BATTERY caution light (See GC9961U.)
GC4322X	Battery No. 2 reverse-current	Contact closure		BATTERY caution light (See GC9962U.)
GC4323X	Battery No. 3 reverse-current	Contact closure		BATTERY caution light (See GC9963U.)

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-40. Electrical Power Subsystem - Telemetry Measurements (cont)

Code	Description	Telemetry Range (Nominal)	Display Range	Crew Display
GC4324X	Battery No. 4 reverse-current	Contact closure		BATTERY caution light (See GC9964U.)
GC4325X	Battery No. 5 reverse-current	Contact closure		BATTERY caution light (See GC9965U.)
GC4326X	Battery No. 6 reverse-current	Contact closure		BATTERY caution light (See GC9966U.)
GC4361X	Battery No. 1 high-voltage tap	Contact closure (R)		SE BAT 1 talk-back (gray)
GC4362X	Battery No. 1 low-voltage tap	Contact closure (R)		SE BAT 1 talk-back (white)
GC4363X	Battery No. 2 high-voltage tap	Contact closure (R)		SE BAT 2 talk-back (gray)
GC4364X	Battery No. 2 low-voltage tap	Contact closure (R)		SE BAT 2 talk-back (white)
GC4365X	Battery No. 3 high-voltage tap	Contact closure (R)		CDR BAT 3 talk-back (gray)
GC4366X	Battery No. 3 low-voltage tap	Contact closure (R)		CDR BAT 3 talk-back (white)
GC4367X	Battery No. 4 high-voltage tap	Contact closure (R)		CDR BAT 4 talk-back (gray)
GC4368X	Battery No. 4 low-voltage tap	Contact closure (R)		CDR BAT 4 talk-back (white)
GC4369X	Battery No. 5 on Commander's bus	Contact closure (R)		BAT 5 BACK UP CDR FEED talkback
GC4370X	Battery No. 6 on Commander's bus	Contact closure (R)		BAT 6 NORMAL CDR FEED talkback
GC4371X	Battery No. 5 on LM Pilot's bus	Contact closure (R)		BAT 5 NORMAL SE FEED talkback
GC4372X	Battery No. 6 on LM Pilot's bus	Contact closure (R)		BAT 6 BACK UP SE FEED talkback
GC9961U (See note.)	Battery No. 1 malfunction (O/C, O/T, or R/C)	Contact closure (R)		BATTERY caution light and BAT FAULT component caution light
GC9962U (See note.)	Battery No. 2 malfunction (O/C, O/T, or R/C)	Contact closure (R)		BATTERY caution light and BAT FAULT component caution light

ELECTRICAL POWER SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-40. Electrical Power Subsystem - Telemetry Measurements (cont)

Code	Description	Telemetry Range (Nominal)	Display Range	Crew Display
GC9963U (See note.)	Battery No. 3 malfunction (O/C, O/T, or R/C)	Contact closure (R)		BATTERY caution light and BAT FAULT compo- nent caution light
GC9964U (See note.)	Battery No. 4 malfunction (O/C, O/T, or R/C)	Contact closure (R)		BATTERY caution light and BAT FAULT compo- nent caution light
GC9965U (See note.)	Battery No. 5 malfunction (O/C, O/T, or R/C)	Contact closure (R)		BATTERY caution light and BAT FAULT compo- nent caution light
GC9966U (See note.)	Battery No. 6 malfunction (O/C, O/T, or R/C)	Contact closure (R)		BATTERY caution light and BAT FAULT compo- nent caution light
<p style="text-align: center;">NOTE</p> <p>Each battery malfunction telemetry signal is a composite of the individual overtemperature, overcurrent, and reverse-current telemetry signals for that particular battery.</p>				

2.6 ENVIRONMENTAL CONTROL SUBSYSTEM.

2.6.1 INTRODUCTION.

The Environmental Control Subsystem (ECS) provides a habitable environment for two astronauts for a maximum of 48 hours while the LM is separated from the CSM, and permits the astronauts to decompress and repressurize the cabin up to four times. It also controls the temperature of electronic equipment and provides water for drinking, cooling, fire fighting, and food preparation.

The major portion of the ECS is in the cabin. Part of the equipment-cooling loop and two oxygen tanks are in the aft equipment bay. Two water tanks are in the upper midsection. A third (larger) oxygen tank and a third (larger) water tank are in the descent stage. (See figures 2-115 and 2-116.) Power for the ECS is supplied from the Electrical Power Subsystem. The ECS (figure 2-117) comprises an atmosphere revitalization section (ARS), an oxygen supply and cabin pressure control section (OSPCCS), a water management section (WMS), and a heat transport section (HTS).

2.6.1.1 Atmosphere Revitalization Section.

The ARS is a closed-loop recirculation system that cools and ventilates the pressure garment assemblies (PGA's); maintains a desirable level of carbon dioxide in the atmosphere; removes odors, noxious gases, and excessive moisture; enables control of the temperature of oxygen flow to the PGA's and the cabin; and, if required, automatically isolates the PGA's from the system.

Oxygen circulation is maintained by centrifugal fans. Heating and cooling is accomplished by passing the oxygen through heat exchangers where heat is either surrendered to or picked up from the coolant from the HTS. Mechanical water separators are used to remove excess moisture during the cooling phase.

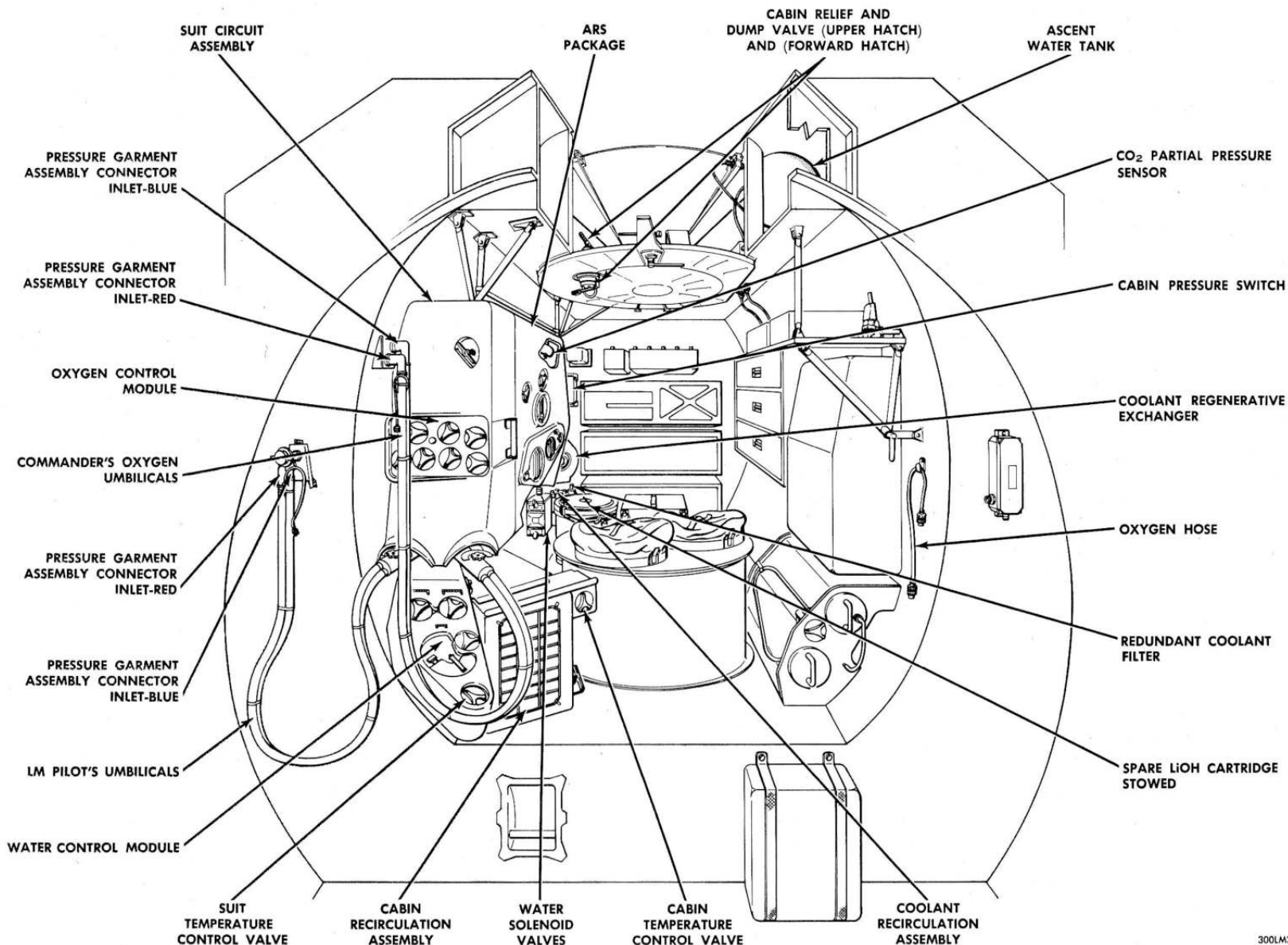
2.6.1.2 Oxygen Supply and Cabin Pressure Control Section.

The OSPCCS stores gaseous oxygen and maintains cabin and suit pressure by supplying oxygen to the ARS. This replenishes losses due to crew metabolic consumption and cabin or suit leakage. There are two oxygen supplies; one in the descent stage provides oxygen for use during the descent and lunar stay phases of the mission, and one in the ascent stage for use during the ascent and rendezvous phases of the mission. All valves, filters, and regulators required by the OSPCCS are located on the oxygen control module. Two automatic pressure relief and dump valves, one in each hatch, are provided to protect the cabin from overpressurization. These are three-position valves; in one position they provide for depressurizing the cabin, in the normal position they provide relief capability, and in the last position the relief capability is overridden.

2.6.1.3 Water Management Section.

The WMS supplies water for drinking, cooling, and food preparation; for refilling the PLSS cooling water tank; and for pressurization of the secondary coolant loop of the HTS. It also provides for delivery of water from ARS water separators to HTS sublimators and from the water tanks to ARS and HTS sublimators.

The water tanks are pressurized before launch to maintain the required pumping pressure in the tanks. The descent stage tank supplies most of the water required until staging. After staging, water is obtained from the ascent storage tanks, water from ARS water separators is used in the sublimators. A self-sealing PLSS DRINK disconnect delivers water for drinking and food preparation.



300LM3-172-1

Figure 2-115. Environmental Control System - Component Location (Sheet 1 of 3)

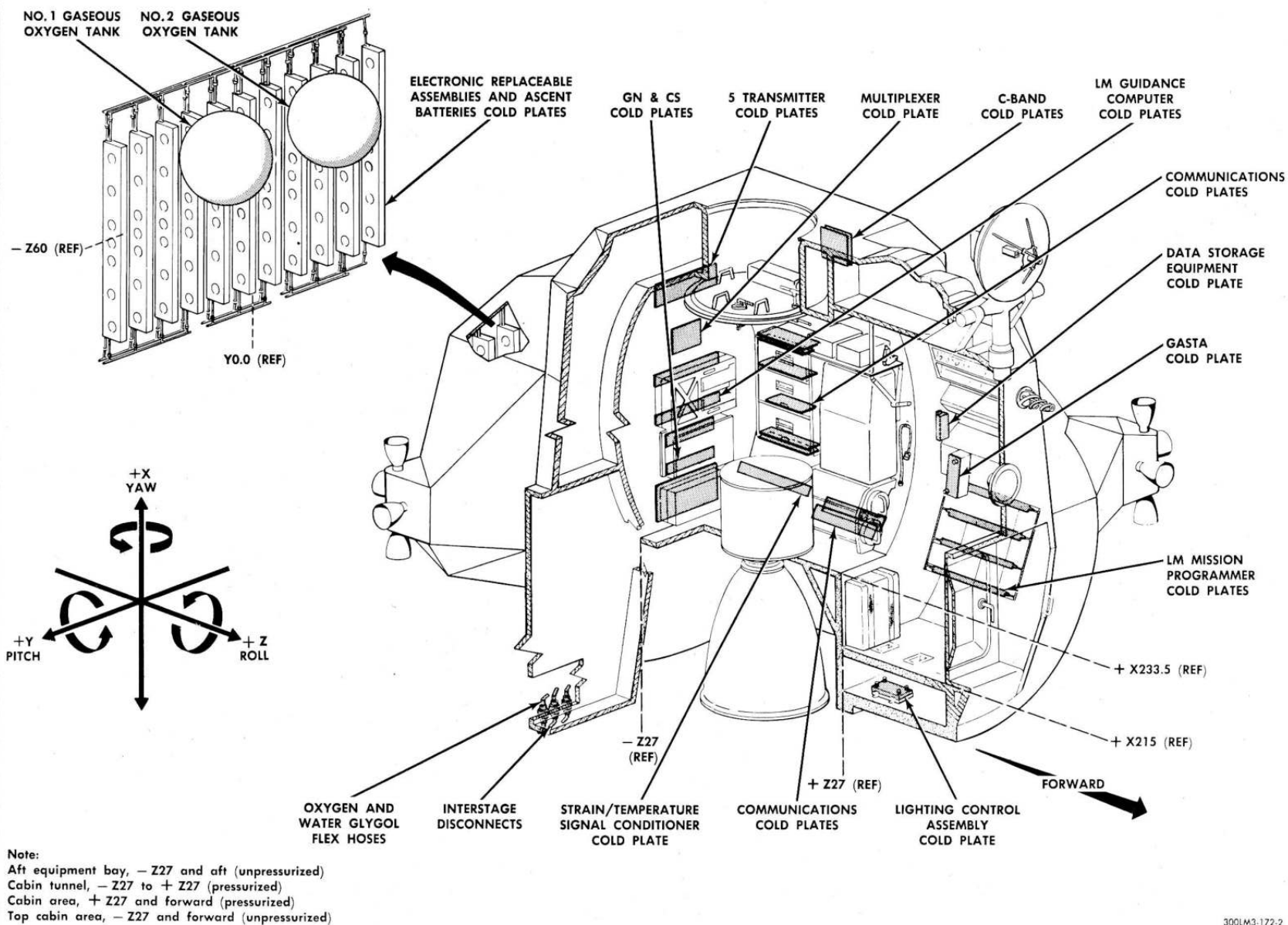
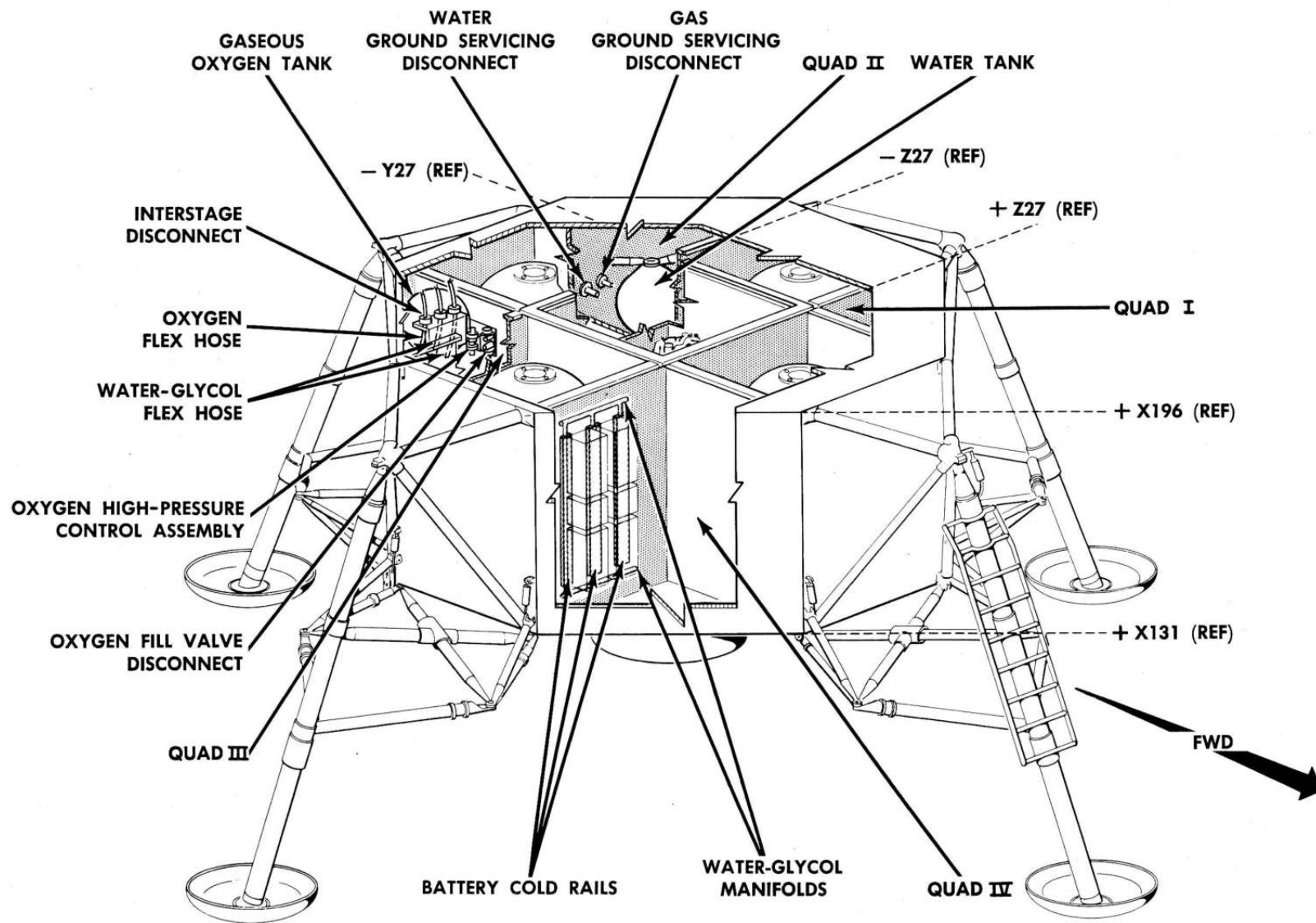


Figure 2-115. Environmental Control System - Component Location (Sheet 2 of 3)



300LM3-173

Figure 2-115. Environmental Control System - Component Location (Sheet 3 of 3)

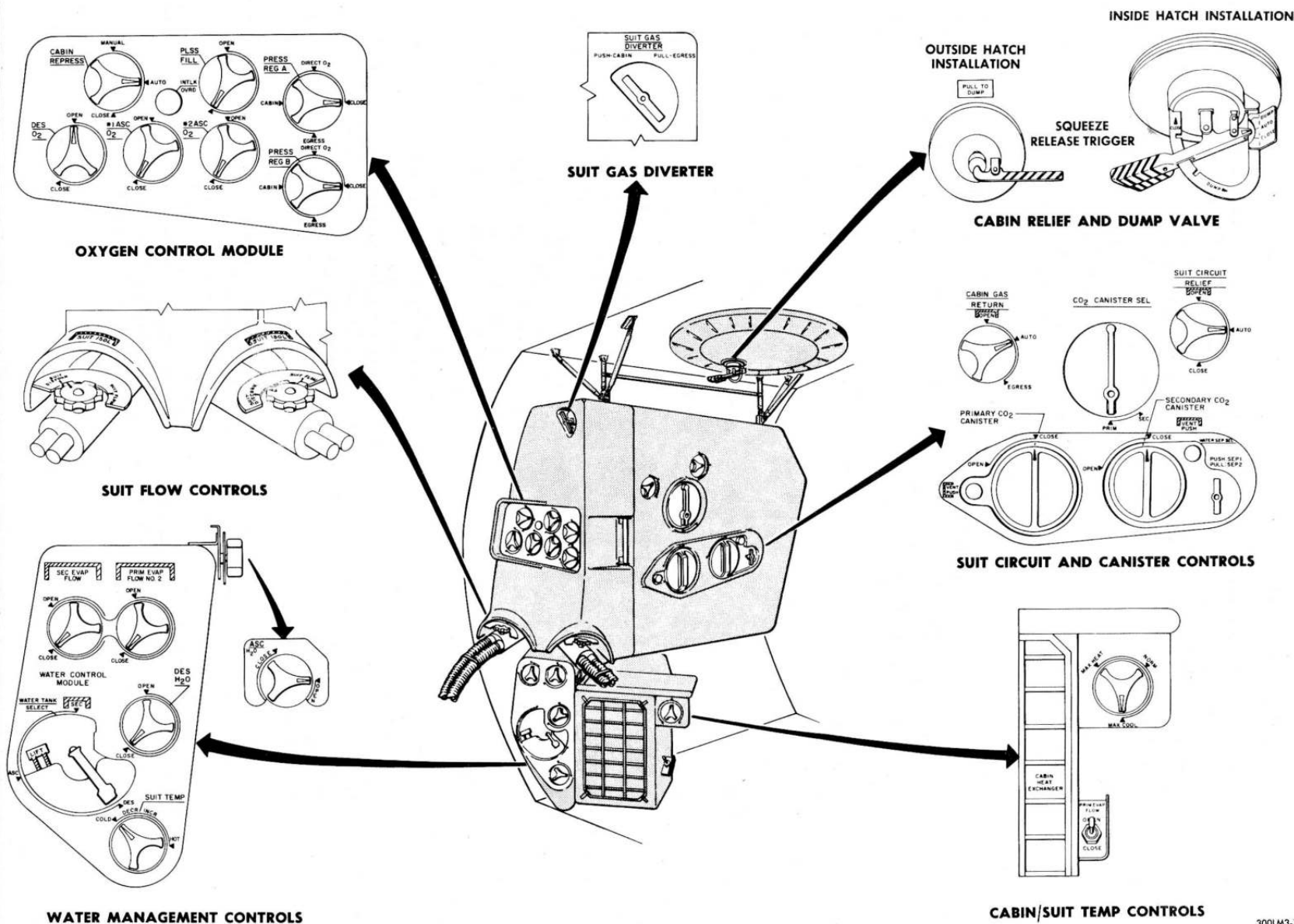


Figure 2-116. Environmental Control Subsystem - Aft Bulkhead Controls

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

2.6.1.4 Heat Transport Section.

The HTS consists of a primary coolant loop and a secondary coolant loop. A water-glycol solution circulates through each loop. The primary loop provides temperature control for batteries, electronic equipment that requires active thermal control, and for the oxygen that circulates through the cabin and PGA's. The batteries and electronic equipment are mounted on cold plates and rails through which coolant is routed to remove waste heat.

The cold plates used for equipment that is required for mission abort contains two separate coolant passages; one for the primary loop and one for the secondary loop. The secondary coolant loop, which is used only if the primary loop is inoperative, serves only these cold plates.

In-flight waste heat rejection from both coolant loops is achieved by the primary and secondary water evaporators which are vented overboard. A coolant pump recirculation assembly contains all the HTS coolant pumps and associated check and relief valves. Coolant flow from the assembly is directed through parallel circuits to the cold plates for the electronic equipment and the oxygen-to-glycol heat exchanger in the ARS.

2.6.2 FUNCTIONAL DESCRIPTION.

The functional description of each of the four major ECS sections is supported by a functional flow diagram which, to reduce complexity, does not contain electrical circuitry. Figure 2-118 shows all ECS electrical circuits, and all ECS interfaces with the Electrical Power and Instrumentation Subsystems.

2.6.2.1 Atmosphere Revitalization Section. (See figure 2-119.)

The ARS is a closed-loop recirculation system that cools, heats, dehumidifies, deodorizes, and replenishes oxygen used within the PGA's and cabin. With the suit isolation (SUIT ISOL) valve set to SUIT DISCONN, the SUIT GAS DIVERTER valve set to CABIN, and the CABIN GAS RETURN check valve open, conditioned oxygen flows to the cabin (bypassing the PGA's) and discharge oxygen returns from the cabin to the recirculation system. With the SUIT ISOL valve set to SUIT FLOW and the SUIT GAS DIVERTER valve set to EGRESS, conditioned oxygen flows through the PGA supply umbilical and discharge oxygen flows through the PGA return umbilical to the recirculation system. The flow from the cabin and the PGA's is routed to the CO₂ removal canisters.

A reference pressure, tapped from the recirculation system below the PGA's is fed to the OSCPCS to modulate pressure in the two oxygen demand regulators that provide makeup oxygen to the ARS. The suit circuit relief valve protects the PGA's against overpressurization, by venting to cabin ambient. The valve operates automatically in response to suit loop pressure, but can be opened and closed manually. Normally, the valve is set to AUTO; when set to OPEN, the suit loop is vented regardless of suit pressure.

The CABIN position of the suit gas diverter valve is used during pressurized-cabin operation, to permit the recirculation system to circulate enough cabin gas to maintain carbon dioxide and humidity levels. When the cabin is unpressurized, or in an emergency when cabin pressure is lost, pulling the valve handle selects the EGRESS position to isolate the PGA's from the cabin. The EGRESS position is used for all pressurized-PGA operations. An electrical override automatically repositions the valve from CABIN to EGRESS when cabin pressure drops below 4.15 ± 0.15 psia.

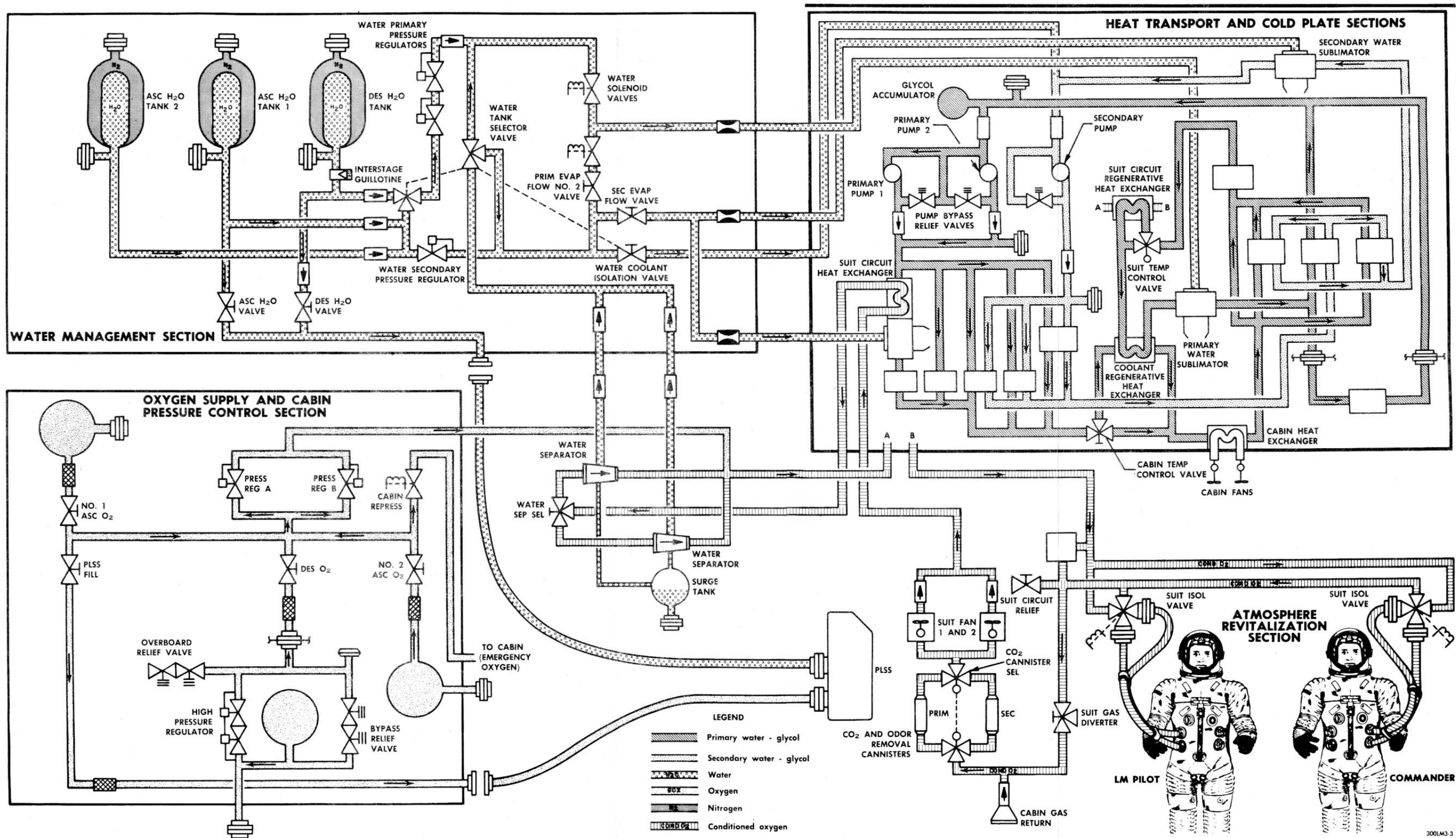


Figure 2-117. Environmental Control Subsystem - Functional Flow Diagram

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

With the suit gas diverter valve set to CABIN, cabin discharge oxygen is returned to the recirculation system through the cabin gas return valve. Setting the CABIN GAS RETURN to AUTO, enables cabin pressure to open the valve. When the cabin is depressurized, spring pressure closes the valve, preventing suit pressure loss. The valve can be manually overridden to the OPEN and EGRESS (closed) positions.

Conditioned oxygen is tapped from the recirculation assembly upstream of the PGA inlets. The oxygen is fed to the CO₂ partial pressure sensor which, utilizing an optical-mechanical sensing system and an electronic computer and signal conditioner, provides a voltage to the PART PRESS CO₂ indicator.

The primary and secondary carbon dioxide (CO₂) and odor removal canisters are connected to form a parallel loop. The primary canister contains a LM-size cartridge; the secondary canister, a PLSS-size cartridge. A debris trap in the primary canister cover prevents particulate matter from entering the cartridge. A relief valve in the cartridge permits flow to bypass the debris trap if it becomes clogged. Discharge oxygen is routed to the CO₂ and odor removal canisters through the canister selector valve. When the valve is set to PRIM, discharge oxygen flows through the primary canister. The carbon dioxide level is controlled by passing the flow across a bed of LiOH; odors are removed by absorption in activated charcoal. When carbon dioxide partial pressure reaches or exceeds 7.6 mm Hg, as indicated on the PART PRESS CO₂ indicator, the CO₂ component caution light and ECS caution light go on. The CO₂ CANISTER SEL valve is then set to SEC, placing the secondary canister onstream. This lowers the carbon dioxide partial pressure and unlocks the cover on the PRIMARY CO₂ CANISTER. The PRIMARY CANISTER CO₂ VENT pushbutton is pushed to release pressure from the canister before the canister cover is removed. The primary cartridge is replaced, the canister cover is installed, and the CO₂ CANISTER SEL valve is set to PRIM, placing the primary canister back onstream and extinguishing the caution lights. Because of chemical reaction, conditioned oxygen leaves the canisters at higher temperature and humidity levels than when it entered.

From the canisters, conditioned oxygen flows to the suit fan assembly, which maintains circulation in the recirculation system. Only one fan operates at a time. The ECS: SUIT FAN 1 circuit breaker is closed and the SUIT FAN selector switch is set to 1 to initiate suit fan operation. At startup, a fan differential pressure sensor is in the low position (low ΔP), which, through the fan condition signal control, energizes the ECS caution light and SUIT FAN component caution light. The lights remain on until the differential pressure across the operating fan increases sufficiently to cause the differential pressure sensor to move to the normal position. If the differential pressure drops to 6.0 inches of water or less, the lights go on and switchover to fan No. 2 is required. The lights go off when fan No. 2 comes up to speed and builds up normal differential pressure. The SUIT/FAN warning light, ECS caution light, and SUIT FAN component caution light go on if fan No. 2 differential pressure does not reach 8.0 inches of water. The fan check valve permits air to pass from the operating fan without back flow through the inoperative fan.

From the check valve, the conditioned oxygen passes through a sublimator to the cooling heat exchanger. The sublimator cools the oxygen under emergency conditions. Normally, the sublimator is inoperative; it is placed in operation when the secondary evaporator flow (SEC EVAP FLOW) valve of the water control module is opened because a failure in the primary heat transport loop renders the cooling heat exchanger inoperative. Heat transfer to the coolant in the heat exchanger reduces gas temperature and causes some condensation of water vapor, which is removed by mechanical water separators. Pressure tapped from the heat exchanger outlet is fed to the primary and secondary pressure regulators of the WMS to regulate the discharge pressure of the regulators to 0.5 to 1.0 psi above ARS pressure.

The conditioned oxygen is next routed to two, parallel-redundant water separators through the water separator selector (WATER SEP SEL) valve. One separator, selected by pushing (SEP 1) or pulling (SEP 2) the WATER SEP SEL valve handle, is operated

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

at a time. The separator is driven by the flow within the recirculation system. Moisture removed from the oxygen is discharged under a dynamic head of pressure sufficient to ensure positive flow from the separator to the WMS. A water drain carries some water from the separators to a surge (collection) tank outside the recirculation system.

The revitalized oxygen from the water separator is mixed with makeup oxygen from the OSCPCS to maintain system pressure. The mixture flows through the regenerative (heating) heat exchanger, where the temperature is increased, to the suit isolation valves. The suit temperature control (SUIT TEMP) valve on the water control module controls the flow of coolant through the regenerative heat exchanger over a range of 0.0 to 2.0 pounds per minute. Setting the valve to INCR HOT increases oxygen temperature; setting it to DECR COLD reduces the temperature.

If a PGA tears while the SUIT ISOL valves are set to SUIT FLOW, the valves are automatically repositioned to SUIT DISCONN when PGA pressure drops to 3.1 psia. This action isolates the PGA's from the ARS. At the same time, the cabin pressure switch is enabled, setting the CABIN REPRESS and the SUIT DIVGRT valves to CABIN. Oxygen from the OSCPCS is completely diverted from the ARS to the cabin.

2.6.2.1.1

Cabin Recirculation Assembly.

The cabin recirculation assembly cools cabin oxygen by circulating the oxygen through the cabin heat exchanger. During pressurized-cabin operation, the assembly maintains cabin temperature at approximately +75°F.

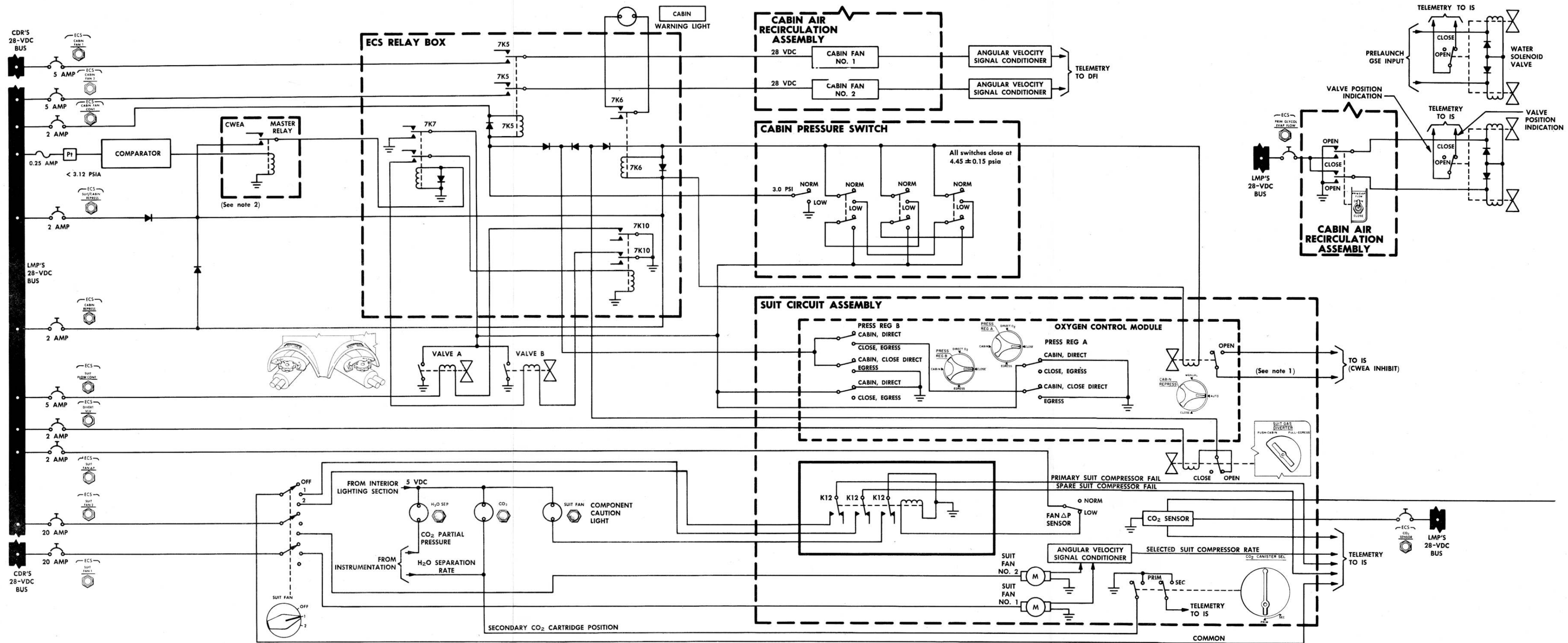
Initially, the assembly fans are turned on by closing the ECS: CABIN FAN 1, CABIN FAN 2, and CABIN FAN CONT circuit breakers and setting the oxygen demand regulators (PRESS REG A and PRESS REG B valves) to CABIN. The CABIN FAN CONT circuit breaker serves the cabin pressure switch and relay. The fans are turned off by setting the oxygen demand regulators to EGRESS or by opening the circuit breakers. The fans operate independently, but simultaneously; each supplies one-half of the maximum required circulation. The fans drive the cabin oxygen directly into the cabin heat exchanger. Cabin temperature is controlled by the cabin temperature control valve of HTS.

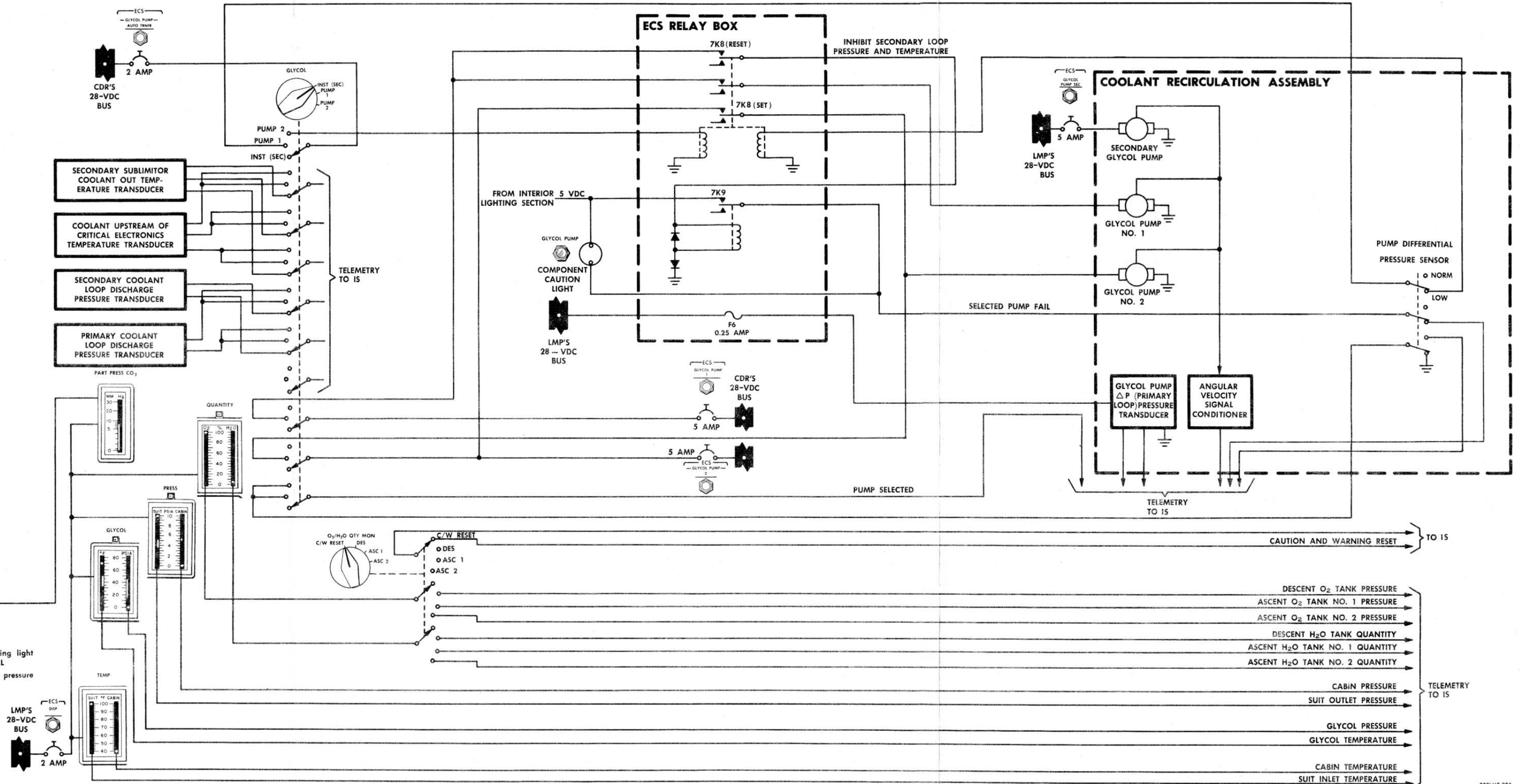
2.6.2.2

Oxygen Supply and Cabin Pressure Control Section. (See figure 2-120.)

The oxygen supply and cabin pressure control section (OSCPCS) stores gaseous oxygen, replenishes the ARS oxygen, and provides refills for the PLSS oxygen storage tank. Before staging, oxygen is supplied from the descent stage oxygen tank. After staging, or if the descent tank is depleted, the ascent stage oxygen tanks supply oxygen to the oxygen control module. The high-pressure assembly in the descent stage, and the oxygen control module in the ascent stage, contain the valves and regulators necessary to control oxygen in the OSCPCS. Two cabin relief and dump valves regulate cabin pressure.

The descent tank pressure, approximately 2,850 psig, is reduced to a level that is compatible with the components of the oxygen control module, approximately 900 psig, by a high-pressure regulator. A series-redundant bypass relief valve, set to operate at a higher pressure than the regulator, protects the descent oxygen tank against over-pressurization if a regulator fails. In addition, a series-redundant overboard relief valve protects the oxygen control module against excessive pressure caused by a defective regulator or by flow through the bypass relief valve. If the pressure on the outlet side of the regulator rises to a dangerous level, a burst disk in the burst diaphragm assembly ruptures and vents the descent tank to ambient. A poppet in the burst diaphragm assembly reseats when tank pressure is reduced to 1,000 psig. Descent oxygen flow through the interstage disconnect is controlled with the descent oxygen shutoff (DES O₂) valve. The valve also acts as a redundant seal to prevent loss of oxygen overboard after staging.





Notes:

1. Circuit inhibits CABIN warning light when valve is set to MANUAL
2. Contacts close with low suit pressure ($<3.12 \pm 0.18$ psia)

Figure 2-118. Environmental Control Subsystem Electrical Schematic Diagram

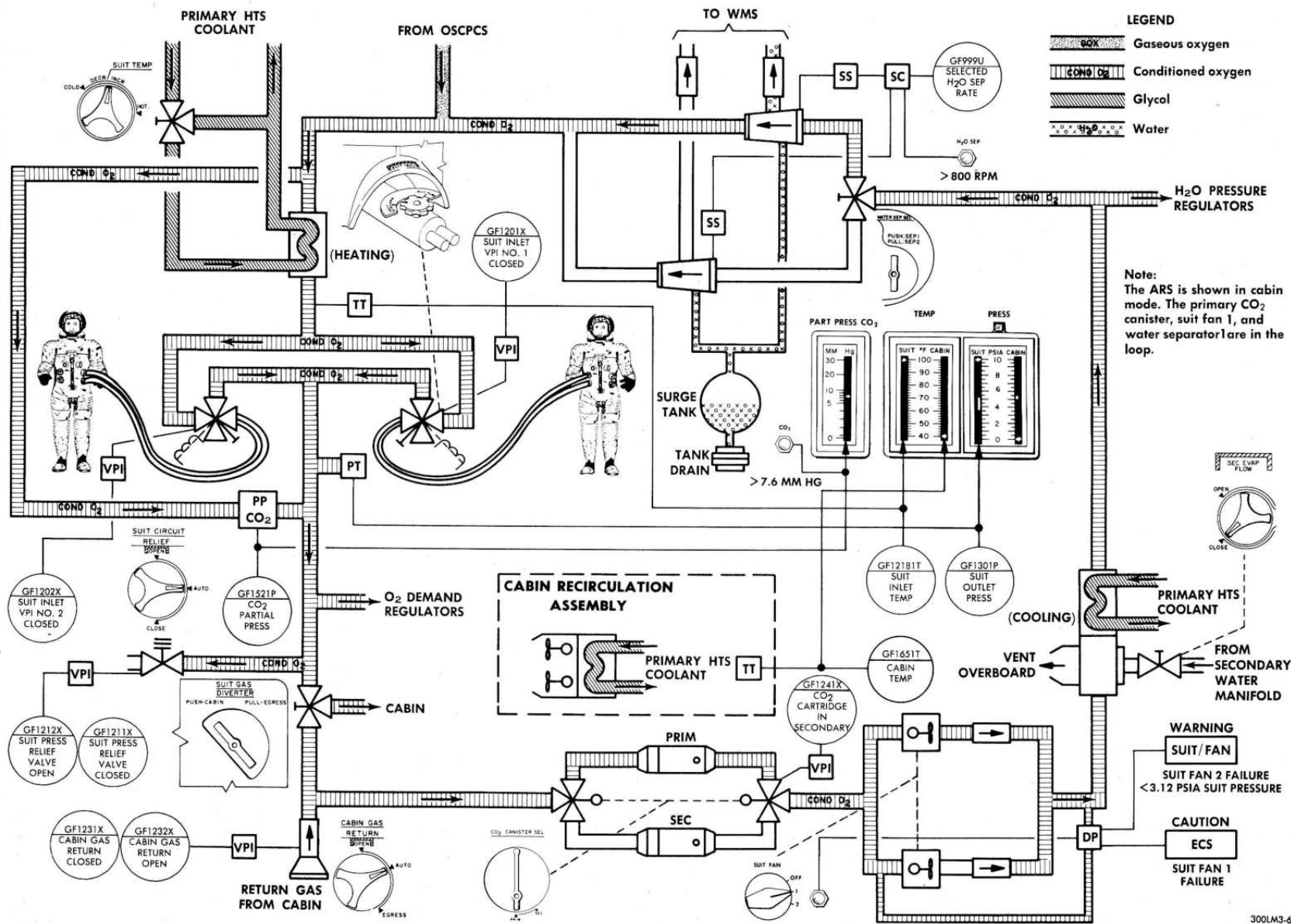


Figure 2-119. Atmosphere Revitalization Section - Functional Flow Diagram

ENVIRONMENTAL CONTROL SUBSYSTEM

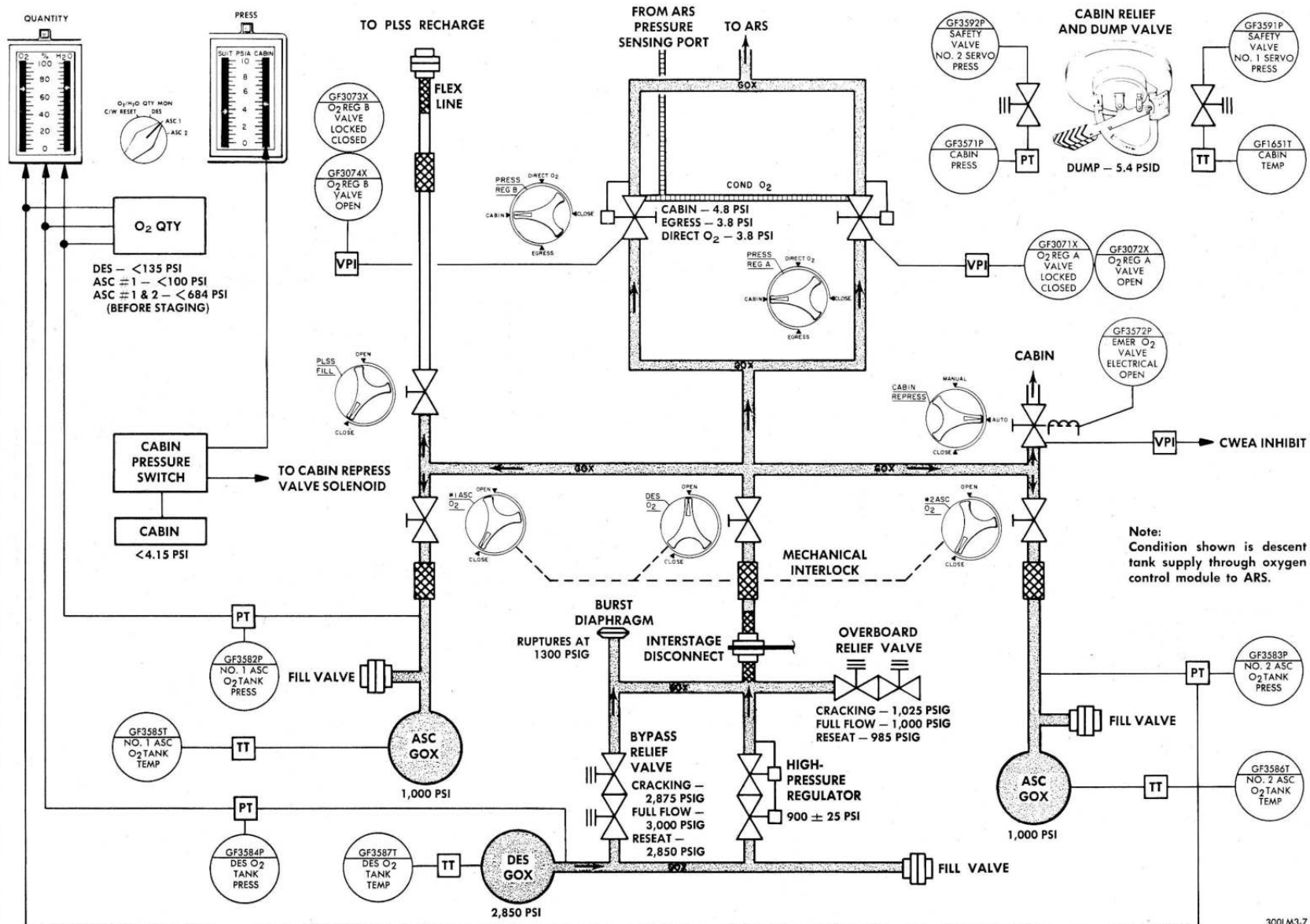


Figure 2-120. Oxygen Supply and Cabin Pressure Control Section - Functional Diagram

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

An absolute pressure transducer in the descent tank feed line generates an output proportional to tank pressure. The output is routed to the IS, where it is conditioned to provide a telemetry signal, a caution indication, and, through the O₂/H₂O QTY MON selector switch (panel 2), a display on the O₂ QUANTITY indicator. When tank pressure drops below 135 psia (approximately 5% of capacity), a signal is routed to the O₂ QTY caution light. Momentarily setting the O₂/H₂O QTY MON selector switch to C/W RESET extinguishes the light.

When ascent stage oxygen is required, the ascent oxygen shutoff (#1 and #2 ASC O₂) valves are used to select their respective tank. A mechanical interlock prevents the valves from being opened unless the descent oxygen shutoff valve is closed. The mechanical interlock may be overridden (if the descent oxygen shutoff valve cannot be closed and the ascent oxygen shutoff valves must be opened) by pressing the INTLK OVRD pushbutton on the oxygen control module. Normally, ascent oxygen tank No 1 is used first.

A pressure transducer in the fuel line of each ascent oxygen tank generates an output that is also conditioned in the IS to provide a telemetry signal, caution indication, and a display on the O₂ QUANTITY indicator. The quantity of oxygen remaining in the tanks is read on the indicator by setting the selector switch to ASC 1 or ASC 2, as applicable. The O₂ QTY caution light goes on if, before staging, the pressure in either ascent oxygen tank is less than 684 psia (less-than-full condition). After staging, the signal that causes this indication is inhibited; instead, the light goes on when pressure in ascent tank No. 1 is less than 100 psia. The caution light is extinguished by setting the selector switch to C/W RESET.

From the oxygen shutoff valves, oxygen is routed to oxygen demand regulators (PRESS REG A and PRESS REG B), a PLSS FILL valve, and a cabin repressurization and emergency oxygen (CABIN REPRESS) valve. The PLSS FILL valve connects to the PLSS oxygen tank through a flexible service hose. A check valve in the PLSS disconnect is opened when the hose is connected. The valve automatically closes when the hose is disconnected. The oxygen demand regulators maintain the pressure to the ARS at a level consistent with normal and purge requirements and prevent higher pressures, which would damage the suit circuit assembly. Both regulators are manually controlled with a four-position handle; both are ordinarily set to the same position. The CABIN position is selected during normal pressurized-cabin operations, to provide oxygen at 4.8 ± 0.2 psia. Setting the regulators to EGRESS maintains suit circuit pressure at 3.8 ± 0.2 psia during egress and unpressurized-cabin operations. The DIRECT O₂ position provides an unregulated flow of oxygen, at approximately 3.8 pounds per hour, into the suit circuit. The CLOSE position shuts off all flow through the regulator. In the CABIN and EGRESS positions, the regulator is internally modulated by a reference pressure from the suit circuit. The demand regulators are redundant; either one can fulfill the ARS oxygen requirements.

If both demand regulators are set to CABIN or DIRECT O₂ and cabin pressure drops to 4.15 ± 0.15 psia, the cabin pressure switch energizes the solenoid of the cabin repressurization and emergency oxygen valve. Oxygen flows through the valve into the cabin. If cabin pressure builds up to 4.45 ± 0.15 psia, the cabin pressure switch deenergizes the valve solenoid, shutting off the oxygen flow. The valve can maintain cabin pressure at 3.5 psia for at least 2 minutes following a 0.5-inch-diameter puncture of the cabin. It responds to signals from the cabin pressure switch during pressurized operation and to a suit pressure sensor during unpressurized operation. Manual override capabilities are provided.

The two cabin relief and dump valves are manually and pneumatically operated. They prevent excessive cabin pressure and permit deliberate cabin decompression. The valves automatically relieve cabin pressure when the cabin-to-ambient differential reaches 5.4 psi. When set to AUTO, the valves can be opened manually with their external handle. Each valve can dump cabin pressure from 5.0 to 0.08 psia in 180 seconds without cabin inflow. In addition to relieving positive pressure, the valves relieve a negative cabin pressure condition. The valves are normally set to AUTO.

ENVIRONMENTAL CONTROL SUBSYSTEM

To egress from the LM, the oxygen demand regulators are set to EGRESS, turning off the cabin fans and closing the SUIT GAS DIVERTER valve; the CABIN GAS RETURN valve is set to EGRESS; the CABIN REPRESS valve is set to CLOSE; and cabin pressure is dumped by setting the CABIN RELIEF AND DUMP VALVE(s) to DUMP. The CABIN warning light goes on. A bacteria filter on the cabin side of the cabin relief and dump valve in the forward hatch removes 95% of all bacteria larger than 0.5 micron from the dumped oxygen. When repressurizing the cabin, the CABIN RELIEF AND DUMP VALVE(s) is set to AUTO, the CABIN REPRESS valve is set to AUTO, the PRESS REG A and PRESS REG B valves are set to CABIN, the SUIT GAS DIVERTER valve handle is pushed in, and the CABIN GAS RETURN valve is set to AUTO. The CABIN warning light goes off.

2.6.2.3

Water Management Section. (See figure 2-121.)

The WMS stores water for metabolic consumption, evaporative cooling, and PLSS water tank refill. It controls the distribution of this stored water and the water reclaimed from the ARS by the water separators. Reclaimed water is used only for evaporative cooling, in the ECS water sublimators. Water is stored in a tank in the descent stage and two identical smaller tanks in the upper midsection of the ascent stage. All three tanks are bladder-type vessels, which are pressurized with nitrogen before launch. The controls for the WMS are grouped together on the water control module located to the right rear of the LM Pilot's station.

Water from the descent stage water tank is fed through check valves to the water control module and, through the descent water (DES H₂O) valve, to the PLSS H₂O DISCONNECT. Water quantity is determined by a Water Quantity Measuring Device, which senses the temperature/pressure ratio of the tank-pressurizing nitrogen, computes the volume of the water, and generates an output analogous to that volume. The output is displayed on the H₂O QUANTITY indicator (panel 2) after the O₂/H₂O QTY MON selector switch is set to DES. If the quantity of water in the tank drops to 16% ± 3%, the WATER QTY caution light goes on. When the DES H₂O valve is set to OPEN, high-pressure water is available for drinking, food preparation, PLSS fill, and fire extinguishing.

When the vehicle is staged, the descent interstage water feed line is severed, and water is supplied from the ascent stage water tanks. Water quantity in each ascent stage tank is measured and displayed in the same manner as descent water quantity; the O₂/H₂O QTY MON switch is set to ASC 1 or ASC 2, as required. The WATER QTY caution light goes on when a less-than-full condition exists in either tank or when the tank water levels are unequal. Water from ascent stage water tank No. 1 is fed to the PLSS H₂O DISCONNECT through the ascent water (ASC H₂O) valve for drinking, food preparation, PLSS fill, and fire extinguishing.

Water from the three water tanks enters the water tank selector (WATER TANK SELECT) valve which consists of two water diverting spools. Setting the valve to DES or ASC determines which tank is on-line.

When using the descent tank, water is supplied to the primary manifold (which consists of the primary pressure regulators and a check valve) by setting the WATER TANK SELECT valve to DES. The water flows through the series primary pressure regulators which control water discharge pressure in response to suit circuit gas reference pressure, at 0.5 to 1.0 psi above this gas pressure. With the PRIM EVAP FLOW switch set to OPEN, the water is routed through the water solenoid valve to the primary sublimator. Discharge water from the water separator is routed through the secondary spool of the selector valve and joins the water from the primary pressure regulators. Setting the selector valve to ASC routes water from the ascent tanks through the primary pressure regulators and, with the PRIM EVAP FLOW switch set to OPEN, through the solenoid valve to the primary sublimator. Flow of water from the water separators is not changed by the selection of the ASC position. If the primary pressure regulators fail, an alternate path to the primary sublimator is provided by setting the primary

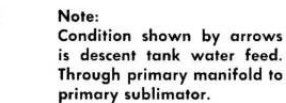


Figure 2-121. Water Management Section - Functional Flow Diagram

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

evaporator flow No. 2 (PRIM EVAP FLOW #2) valve to OPEN. Water then flows directly from the ascent water tanks through the secondary pressure regulator, the primary evaporator flow No. 2 valve, and the normally open solenoid valve to the primary sublimator.

Under emergency conditions (failure of the primary HTS loop), water from the ascent tanks is directed through the secondary manifold (secondary pressure regulator) to the secondary sublimator and the suit circuit sublimator by setting the SEC EVAP FLOW valve to OPEN. Discharge water from the water separators is also directed to the sublimator. Water is diverted to the secondary HTS loop to provide a head of pressure for its pump. To divert the water, the finger latch on the WATER TANK SELECT valve is lifted and the valve is set to SEC. This action punctures the coolant isolation valve and starts the water flow to the secondary HTS loop.

2.6.2.4 Heat Transport Section. (See figure 2-122)

The HTS consists of two closed loops (primary and secondary) through which a water-glycol mixture is circulated to cool the suit circuits, cabin atmosphere, and electronic equipment. When necessary, the primary loop is also a heat source for the cabin atmosphere. Heat is removed by absorption and is radiated to space by sublimation.

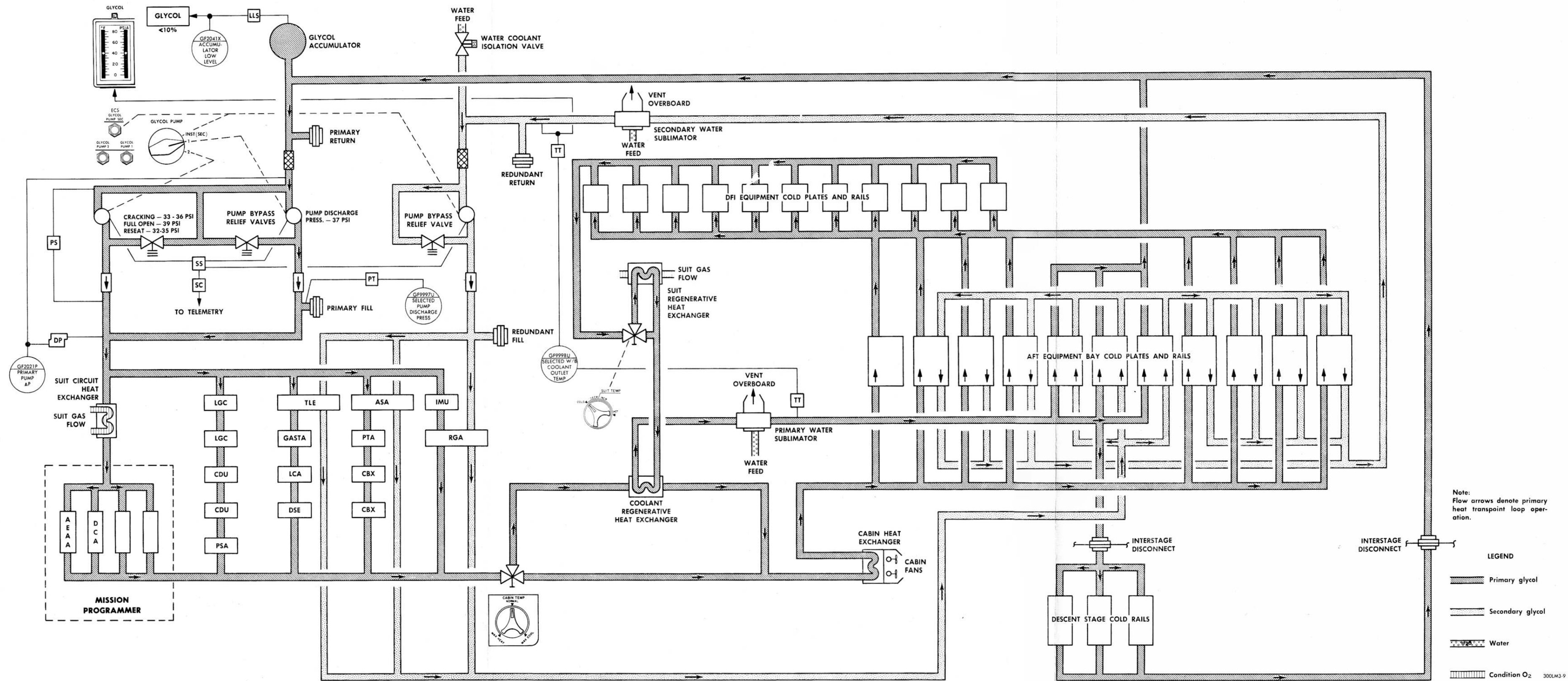
2.6.2.4.1 Primary Coolant Loop.

The loops are charged with coolant at GSE fill points and are then sealed. Pumps, comprising a recirculation assembly, force the coolant through the loops. The glycol accumulator maintains a constant head of pressure (5.5 to 8 psi, depending on coolant level) at the inlets of the primary loop glycol pumps to prevent cavitation. Coolant temperature at the inlets is approximately +40°F. The accumulator also replaces coolant lost through subsystem leakage. A microswitch in a low-level sensor trips when only 10% of coolant volume remains in the accumulator. When tripped, the switch provides a telemetry signal and causes the GLYCOL caution light (panel 2) to go on.

The coolant is routed to the pumps through a filter which has a bypass to maintain flow if the element becomes clogged. Each pump increases coolant pressure by 30 psia. They are started by closing the ECS: GLYCOL PUMP 1 and 2 circuit breakers and setting the GLYCOL selector switch to PUMP 1 or PUMP 2. If the operating pump does not develop a minimum differential pressure (ΔP) of 4.0 psi, the ΔP sensor generates a signal to energize the ECS caution light and the GLYCOL component caution light. Selecting the other pump deenergizes the lights when the onstream pump develops minimum ΔP . If both pumps fail, the secondary loop is activated by setting the WATER TANK SELECT valve to SEC, setting the GLYCOL pump switch to INST (sec), and closing the ECS: GLYCOL PUMP SEC circuit breaker. Automatic transfer of primary pump operation is initiated by closing the ECS: GLYCOL AUTO TRNFR circuit breaker and setting the selector switch to PUMP 1. When transfer is necessary, the caution lights go on, the transfer is accomplished, and the caution lights go off. Pump motor speed sensor outputs are conditioned and telemetered.

If primary loop pressure exceeds 33 psi, the pump bypass relief valve opens and routes the coolant back to the pump inlet, relieving the pressure. The valves start to open at 33 psi, are fully open at 34.6 psi, and reseal at 32 psi. Check valves prevent coolant from feeding back through an inoperative pump.

Part of the coolant leaving the recirculation assembly flows to the suit circuit heat exchanger to cool some of the suit circuit gas of the ARS. The flow out of the heat exchanger is routed to the LM mission programmer. The remainder of the coolant flows to electronic equipment within the cabin. The two flow paths then converge and the coolant is directed to the cabin temperature control valve.



The cabin temperature control valve varies the flow rate to the coolant regenerative heat exchanger to regulate and maintain the temperature of the coolant entering the cabin heat exchanger. Setting the valve handle to NORM controls the percentage of coolant diverted to the coolant regenerative heat exchanger and to the cabin heat exchanger. Greater flow through the coolant regenerative heat exchanger causes a higher temperature in the cabin heat exchanger. This is caused by that portion of the coolant (flowing through the coolant regenerative heat exchanger) that is heated by the warmer coolant returning from the aft equipment bay cold plates. The valve is adjusted by an element which senses the coolant temperature downstream of the cabin heat exchanger. The operating characteristics (sensed temperature-flow percentage relation) are adjusted by selecting a position within the NORM range. Setting the valve to MAX COOL routes all the coolant directly to the cabin heat exchanger, lowering its temperature. Setting the valve to MAX HEAT routes all the coolant to the coolant regenerative heat exchanger, where the coolant picks up heat from the warmer coolant returning from the aft equipment bay cold plates. The warmer coolant flow can be diverted to the suit circuit regenerative heat exchanger through the suit temperature (SUIT TEMP) control valve to increase ARS gas temperature. The valve varies the coolant flow to the heat exchanger from 0 to 2 pounds per minute. All or part of the warm coolant may be diverted to bypass the heat exchanger. The flow from the heat exchanger, combined with the diverted coolant, passes through the warm side of the coolant regenerative heat exchanger.

The coolant from the warm side of the coolant regenerative heat exchanger is routed to the primary sublimator. The sublimator rejects the heat to space through a steam duct. Deflector plates attached to the duct discharge and prevent the steam from applying thrust to the vehicle. Water is fed to the sublimator at a pressure that exceeds 4.0 psia but is less than 8.0 psia. The water pressure must be less than the suit circuit static pressure plus the head pressure from the water separators to the sublimator. The water regulators, referenced to suit circuit pressure, are in the water feed line to the sublimator. Regulated water pressure varies from 0.5 to 1.0 psid above suit circuit pressure. The sublimator inlet temperature is sensed by a temperature transducer, which provides a telemetry signal. Coolant from the sublimator flows through the ascent and descent battery cold rails, then returns to the accumulator.

Two, self-sealing disconnects upstream and downstream of the glycol pumps permit servicing and operation of the HTS by GSE. Interstage disconnects are installed in coolant lines that connect to the descent stage. Before staging, coolant flows through the ascent and descent stage battery cold rails. After staging, the interstage disconnects separate, the lines are sealed by spring-loaded check valves, and the full coolant flow enters the ascent stage battery cold rails.

2.6.2.4.2 Secondary Coolant Loop.

The secondary (emergency) coolant loop provides thermal control for those electronic assemblies and batteries whose performance is necessary to effect a safe return to the CSM. Cooling is provided by the secondary sublimator.

When the secondary loop is activated, water is routed through the water isolation valve and a filter to the secondary glycol pump, enabling active pressurization of the secondary loop. A pump bypass relief valve relieves excessive pressure by routing coolant back to the pump inlet. A check valve at the discharge side of the glycol pump prevents coolant flow from bypassing the HTS during GSE operation. The coolant from the pump passes through the check valve, to the secondary passages of the cold plates and cold rails of the electronics and batteries cold plate section. Waste heat is absorbed by the coolant. The warm coolant then flows to the secondary sublimator.

The secondary sublimator contains porous plates which reject heat to space. It operates in the same manner as the primary sublimator in the primary coolant loop. Water for the sublimator is provided when the SEC EVAP FLOW valve is set to OPEN. The coolant returns to the pump for recirculation.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

2.6.2.5 Cold Plates and Rails. (See figure 2-122.)

Coolant is continuously circulated through cold plates and cold rails to remove heat from electronic equipment and batteries. Equipment essential for successful mission abort is mounted on cold plates that have two independent coolant passages, one for the primary loop and one for the secondary loop.

2.6.2.5.1 Primary Coolant Loop Cold Plates and Rails.

The cold plates in the primary coolant loop are arranged in four groups: upstream electronics, aft equipment bay, Developmental Flight Instrumentation (DFI) equipment, and batteries.

Coolant from the recirculation assembly flows into five parallel paths that serve the upstream electronics cold plate group. In this group, the LM mission programmer and the data storage equipment (DSEA) are cooled by cold rails; the remainder of the group, by flat cold plates. The cold plates are located in the pressurized and unpressurized areas of the LM. The flow rates through the five parallel paths are controlled by flow restrictors, installed downstream on the LM mission programmer and the power servo assembly (PSA) cold plates. The first upstream electronics flow path cools the suit circuit heat exchanger and the LM mission programmer. The second flow path cools five cold plates mounted on the pressurized side of the equipment tunnel back wall. The third path serves the integrally cooled IMU and the rate gyro assembly (RGA) cold plate, both located in the unpressurized area (on the navigation base). The fourth path cools the abort sensor assembly (ASA), pulse torque assembly (PTA), and the two C-band transponder (CBX) cold plates. All the plates for the fourth path are in the unpressurized area above the cabin; the ASA is on the navigation base (AOT). The fifth path serves the tracking light electronics (TLE), gimbal angle sequencing transformation assembly (GASTA), lighting control assembly (LCA), and DSEA plates: one in the unpressurized area in front of the cabin, a second one in the control and display panel area, a third one below the cabin floor, and another one on the left wall of the cabin.

The aft equipment bay is cooled by eight cold rails; the flow is in parallel. The coolant from the bay flows to the DFI cold plates, on the equipment tunnel left side and rear bulkhead. All DFI cold plates are of the flat type; the flow is parallel through 11 plates.

The batteries are installed on cold rails. The ascent batteries are in the center section of the aft equipment bay; the descent batteries are in the forward right area of the descent stage. During the descent phase, the coolant flow is split between the descent batteries and the ascent batteries; the ascent batteries are not used during this time. When the stages are separated, quick-disconnects break the coolant lines and seal the ends; all coolant then flows through the ascent battery cold rails.

2.6.2.5.2 Secondary Coolant Loop Cold Plates and Rails.

The secondary coolant loop is for emergency use. Only cold plates that have two independent passages (one for the primary loop and one for the secondary loop) are served by this loop.

In the upstream electronics area, the secondary coolant flow is split between three cold plates (RGA, ASA, and TLE) in parallel. The flow rate is controlled by a flow restrictor downstream of the TLE. After these three plates, the secondary loop cools the aft equipment bay cold rails in a series-parallel arrangement. The coolant first flows through three ascent battery cold rails in parallel, then through seven aft equipment bay cold rails in parallel.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

2.6.3 MAJOR COMPONENT/FUNCTIONAL DESCRIPTION.

2.6.3.1 Atmosphere Revitalization Section.

2.6.3.1.1 Recirculation System.

Suit Circuit Relief Valve. The SUIT CIRCUIT RELIEF valve is an aneroid-operated, poppet-type valve that protects the recirculation system against overpressurization. The valve has AUTO, OPEN, and CLOSE positions. Two externally mounted microswitches provide telemetry signals when the OPEN or CLOSE position is selected.

In the AUTO position, the valve responds to pressure sensed by the aneroid, and cracks open at 4.3 to 4.45 psia to relieve the pressure to the cabin. At 4.7 psia, the valve is fully open and flows approximately 7 pph at +90° F. The valve reseats at less than 4.3 psia. In the OPEN position, the valve handle displaces the poppet from the seat to open the valve, regardless of pressure. In the CLOSE position, selected if the valve fails open, the normal poppet is left open, but an auxiliary valve is closed, maintaining pressure.

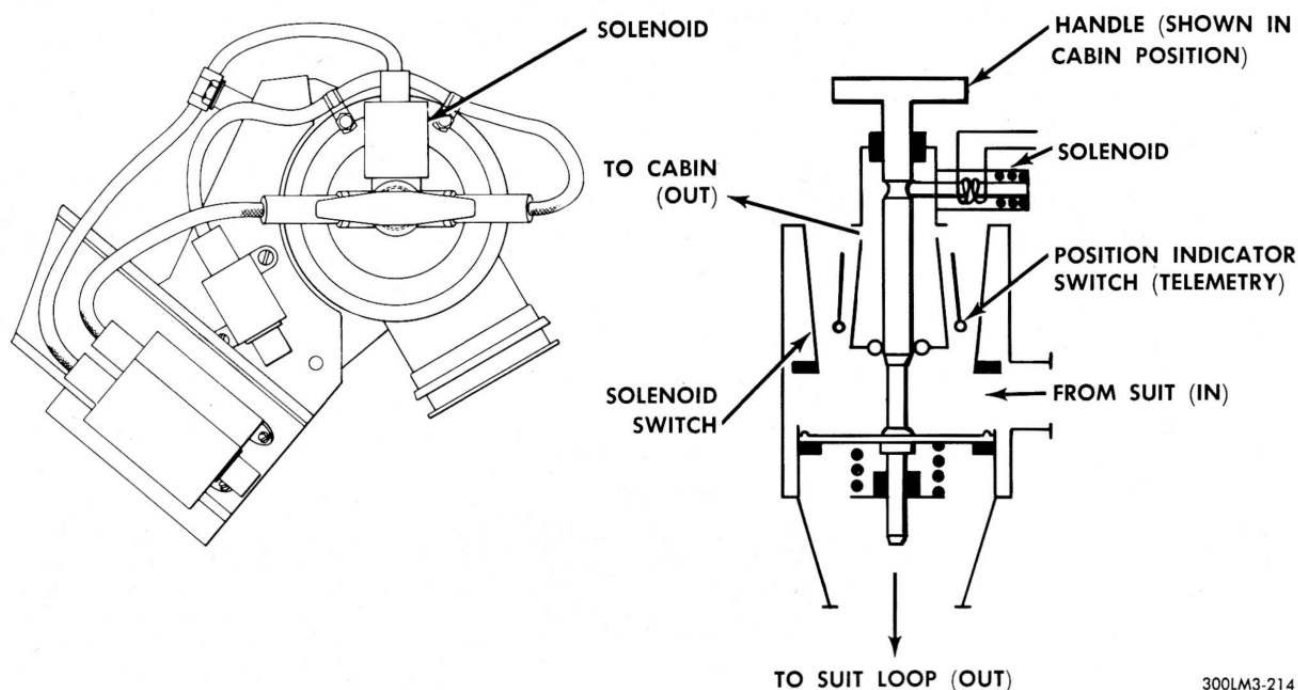
Suit Gas Diverter Valve. (See figure 2-123.) The SUIT GAS DIVERTER valve is a manually operated, two-way valve (one inlet and two outlets) with a solenoid override in one direction. The valve is on the ECS package above the oxygen control module. When the valve handle is pushed in to CABIN position, oxygen is directed into the cabin. The valve is maintained in this position, against main valve spring pressure, by a manually deenergized solenoid latch. Pulling the valve handle to EGRESS position overrides the solenoid latch and permits the valve to reposition to its upper seat, blocking flow to the cabin.

An automatic closed-to-cabin feature is provided. If cabin pressure decays to 4.15±0.15 psia while the valve is set to CABIN, the solenoid latch is energized by the cabin pressure switch, and the main spring returns the valve to the EGRESS position. Electrical power is also supplied to the diverter valve when the PRESS REG A and PRESS REG B valves are set to EGRESS. The diverter valve has a valve-position-indicating switch that provides a telemetry signal when the valve is set to EGRESS.

Cabin Gas Return Check Valve. The CABIN GAS RETURN check valve is a spring-loaded, flapper-type valve. The valve has AUTO, OPEN, and EGRESS (closed) positions. In AUTO position, the valve automatically permits cabin gas to return to the ARS. When the cabin is depressurized, the cabin gas return check valve closes, preventing backflow into the cabin. The OPEN and EGRESS positions provide manual override of the AUTO position. Valve-position-indicating switches provide telemetry signals when the valve is set to OPEN or EGRESS. The switches are enclosed, with EMI suppressors, in metallic housings that provide environmental protection and EMI shielding for each switch.

CO₂ Canister Selector Valve and CO₂ and Odor Removal Canisters. The CO₂ canister selector (CO₂ CANISTER SEL) valve is a dual-flapper-type valve that routes flow through the CO₂ and odor removal canisters. The valve has PRIM and SEC positions. The flapper assembly is connected to a control handle attached to a cable with an interlock, to preclude opening the canisters during use. The flapper assembly floats on a carrier connected to the control handle, to enable a degree of flexibility for proper alignment. One flapper is at the inlet to the canisters; the other, at the outlet.

Both canisters contain a cartridge filled with lithium hydroxide (LiOH) and activated charcoal. The primary canister cover has a debris trap, which may be replaced before, but not during, flight. A relief valve in the cartridge permits flow to bypass the debris trap if it becomes clogged. The canister selector valve is sufficiently leakproof to permit replacement of cartridges, with the cabin unpressurized.



300LM3-214

Figure 2-123. Suit Gas Diverter Valve

The PRIM position permits ARS gas to flow through the primary canister. When replacing a saturated primary cartridge, the CO₂ CANISTER SEL handle is set to SEC. This unlocks the PRIMARY CO₂ CANISTER cover. A relief valve (VENT PUSH) equalizes the pressure of the cabin and the interior of the canister before canister cover removal. A finger latch, part of the canister cover, is released before the cover is rotated to OPEN.

Suit Circuit Fans. Each suit circuit fan is operated by a 28-volt d-c brushless motor. A full radial-type rotor with a vaneless diffuser is used; it moves approximately 24 cfm at 25,000 \pm 500 rpm. A speed sensor, integral with the fan motor, senses motor rotation and develops an input signal to a frequency-to-voltage signal conditioner. Fan operation is controlled by the SUIT FAN selector switch. The fans permit operation at sea level for checkout purposes. An input voltage of 15 vdc is provided for this purpose.

Suit Circuit Sublimator. The suit circuit sublimator has a water inlet and a steam outlet that is vented overboard. Water and ARS gas both make a single pass through the unit, which comprises a stack of modules of several layers of porous plates, water passages, and a coolant passage. The sublimator rejects suit circuit heat to space if the suit circuit heat exchanger is inoperative.

Suit Circuit Heat Exchanger. The suit circuit heat exchanger is a duct-shaped unit of aluminum plate-and-fin construction. It has a single pass for both the coolant and the suit circuit gas and is used as the primary heat sink for the ARS. Heat is transferred to the HTS coolant supplied to the heat exchanger.

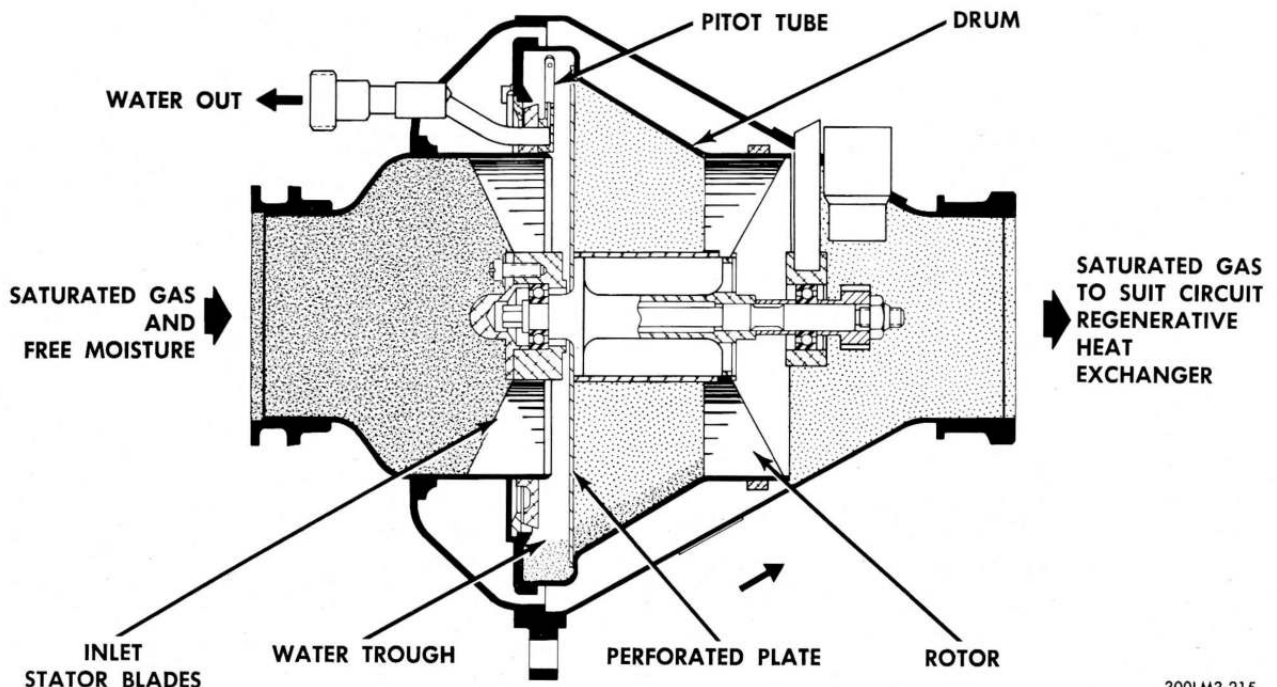
Water Separator Selector Valve. The water separator selector (WATER SEP SEL) valve is a manually operated, flapper-type valve that enables selection of either of two water separators. The valve handle is pushed in for separator No. 1 and pulled for separator No. 2. The internal flapper floats on a carrier, to enable a degree of flexibility for proper alignment purposes. The valve has a position-indicating switch for each water separator for telemetry; it is actuated when either water separator is selected.

Water Separators. (See figure 2-124.) Two water separators are connected in parallel, but only one is used at a time. Saturated gas and free moisture fed into the separator come in contact with the inlet stator blades, which direct the flow onto a rotor at the proper angle. Most of the entrained moisture collects on the rotating perforated plate, which centrifuges the water into a rotating water trough. A stationary pitot tube, placed tangentially to the rotating trough, picks up the removed water and discharges it to the WMS. The pitot pumping action creates a dynamic head of pressure sufficient to ensure positive flow from the water separator to the WMS. Water passing through the perforated plate collects on a rotating conical drum and is fed into the water trough. The oxygen flow drives the rotating parts of the separator.

Each water separator mounts an angular velocity transducer, which is a self-generating magnetic pickup that senses the rotation of the separator shaft. The pickup develops a signal whose frequency is converted to a voltage level with respect to separator rpm, in a signal conditioner unit. A water drain boss on each separator drains the cavity between the rotating drum and the outer shell of the unit. Plumbing attached to each drain boss carries water away from this area, feeds it through flow limiters, and then dumps it into a surge (collection) tank outside the suit circuit.

Suit Circuit Regenerative Heat Exchanger. The suit circuit regenerative heat exchanger is an aluminum plate-and-fin type. Heat from the circulating warm coolant is transferred to the oxygen which makes a single pass through the unit while the coolant makes two passes.

Suit Temperature Control Valve. The suit temperature control (SUIT TEMP) valve is a manually operated diverter valve that controls coolant flow through the suit circuit regenerative heat exchanger. Setting the valve to INCR HOT increases the temperature; setting it to DECR COLD reduces the temperature.



300LM3-215

Figure 2-124. Water Separator

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Suit Isolation Valves. (See figure 2-124A.) The suit isolation (SUIT ISOL) valves are manually operated, two-position valves with automatic override in SUIT FLOW position. In the SUIT FLOW position, the valve opens a port for direct feed to and from the PGA. The SUIT DISCONN position completely isolates the PGA and permits flow through the valve to the recirculation system.

When in SUIT FLOW position, and if a PGA tears, a signal from the emergency sensing circuitry actuates the valve override mechanism, placing the valve in the SUIT DISCONN (bypass) position. This position is retained until the signal is interrupted and the valve is manually reset to SUIT FLOW. If the valve is manually reset to SUIT FLOW before signal interruption, gas flows to the PGA as long as the handle is held in that position. When the handle is released, the valve returns to the SUIT DISCONN position. A valve-position-indicating switch provides a telemetry signal for both positions.

Carbon Dioxide Partial Pressure Sensor. (See figure 2-124B.) The carbon dioxide partial pressure sensor is a single-beam, dual-wavelength, filter photometer, with ratio readout. The sensor operates on the infrared-absorption principle. It measures the amount of infrared energy absorbed by the carbon dioxide in the gas sample that passes through the sensor, by comparing two different wavelengths in the infrared spectrum. (One wavelength is absorbed by carbon dioxide; the other is a reference.) This establishes an amplified ratio signal that is indicated as a d-c voltage proportional to the partial pressure of carbon dioxide in the gas sample.

The sensor has two sections: optics and electronics. The optics section has the infrared energy source (a small tungsten lamp), a collimating lens, a lens that reimages the source on the dual filter, and a lens that reimages the chopped and filtered source image onto the detector target. The electronics section detects and decodes the signal, computes the ratio and, then, reads out a continuous d-c voltage proportional to the partial pressure of carbon dioxide in the gas sample. The sensor provides an electrical signal to the PART PRESS CO₂ indicator and a telemetry signal to indicate the carbon dioxide level in the gas supplied to the astronauts.

2.6.3.1.2

Cabin Recirculation Assembly.

Cabin Heat Exchanger. The cabin heat exchanger is a cross-counter flow, single-pass oxygen, multipass coolant, aluminum plate-and-fin type of heat exchanger, in a welded, sheet-metal housing. The heat exchanger has a self-contained 2.5-pound-capacity reservoir for storage of condensed water, which forms within the heat exchanger during operation. The discharge face of the heat exchanger has wicking that collects the condensed moisture and delivers it to the reservoir. The wicking also provides evaporation of reservoir water when the heat exchanger discharge gas is not saturated.

As flow passes through the heat exchanger, heat is transferred to, or from, the circulating coolant. The coolant flow is regulated by the cabin temperature control valve. A temperature transducer at the cabin heat exchanger outlet senses the coolant temperature and provides a signal to telemetry.

Cabin Fans. Two cabin fans with an interconnecting duct are mounted within a sheet-metal housing attached to the cabin heat exchanger. The fan motors are of the brushless, d-c type; they operate on 28 volts dc with an input power of 62 watts average, 210 watts peak. The fans circulate cabin gas at $+75^{\circ} \pm 5^{\circ}$ F. Each fan can move approximately 5 pounds of air per minute at 13,000 rpm. Fan inlet screens filter out particles that might impair the performance of the cabin recirculation assembly. These screens are replaceable before, but not during, flight. The fans permit operation at sea level for checkout purposes. An input voltage of 15 vdc is provided for this purpose.

(To be supplied)

Figure 2-124A. Suit Isolation Valve

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

(To be supplied)

Figure 2-124B. Carbon Dioxide Partial Pressure Sensor

2.6.3.2 Oxygen Supply and Cabin Pressure Control Section.

2.6.3.2.1 Descent Oxygen Tank.

The descent oxygen tank is in quadrant III of the descent stage. The tank holds 48.01 pounds of oxygen, stored at a pressure of 2,850 psia. The tank provides six PLSS refills at 0.92 pounds each and four cabin repressurizations at 6.6 pounds each. The tanks are filled through high-pressure fill ports, which are capped and lockwired before launch.

2.6.3.2.2 High-Pressure Oxygen Control Assembly.

The major components of the high-pressure oxygen control assembly are a high-pressure oxygen regulator, an overboard relief valve, and a burst diaphragm assembly.

High-Pressure Oxygen Regulator. (See figure 2-124C.) The internally series redundant high-pressure oxygen regulator receives high pressure oxygen from the descent oxygen tank and regulates the pressure to 900 ± 25 psia. If the upstream (primary) regulator sensor fails, the valve fails open, permitting the downstream (secondary) regulator to control outlet pressure. Descent oxygen that enters the regulator is sensed by the primary sensor. As the pressure builds up inside the sensor, it expands and allows the primary valve to move towards its seat, regulating the outlet pressure to the secondary regulator. The secondary regulator operates the same as the primary regulator.

Bypass Oxygen Pressure Relief Valve. The bypass oxygen pressure relief valve protects the descent oxygen tank against overpressurization, by bypassing the high-pressure oxygen regulator. The valve has two series-redundant elements. If tank pressure exceeds relief pressure, the relief valve opens to vent to the downstream side of the high-pressure oxygen regulator. The valve is set to relieve at approximately 3,030 psig.

Overboard Relief Valve. (See figure 2-124D.) The series-redundant overboard relief valve vents oxygen to ambient when the pressure downstream of the high-pressure oxygen regulator reaches 1,025 psig. The valve is fully open at 1,090 psig and reseats at 985 psig at +75° F. System pressure at the first stage relief valve is not relieved overboard, due to the force of the poppet load spring. System pressure is also fed to both capsule sensing elements. When system pressure reaches 1,025 psig, the capsule sensing elements expand, displacing the fail-safe pistons and exerting a force on the belleville lever springs. Belleville-lever-spring motion about the fulcrums opens the poppet valves.

The relief valve has a fail-open feature. If a capsule sensing element leaks, the oxygen is dumped into the leakage chamber. This leakage bleeds overboard; however, its flow rate is restricted by a bleed orifice in the piston. This allows leakage chamber pressure to build up to force the poppet valve open. As the piston is displaced to its full travel, proof-pressure stops and seals make contact, preventing further loss of oxygen overboard. The valve can flow from 0 to 50 pph, at an inlet pressure of 1,100 psig.

Burst Diaphragm Assembly. (See figure 2-124E.) The burst diaphragm assembly opens when the flow from the descent oxygen tank exceeds the relieving capability of the overboard relief valve. An aluminum disk in the inlet port of the burst diaphragm assembly ruptures at a system pressure between 1,300 and 1,400 psig. System pressure causes the diaphragm support to move away from the disk, causing it to rupture. The disk support poppet opens, and vents the descent oxygen tank. The diaphragm assembly permits a minimum flow of approximately 10 pounds per minute. When the descent tank pressure is reduced to 1,000 psia, the disk support poppet reseats to maintain sufficient oxygen for one cabin repressurization up to 1 hour after disk rupture.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

(To be supplied)

Figure 2-124C. High-Pressure Oxygen Regulator

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

(To be supplied)

Figure 2-124D. Overboard Relief Valve

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

(To be supplied)

Figure 2-124E. Burst Diaphragm Assembly Functional Schematic

2.6.3.2.3 Ascent Oxygen Tanks.

Two identical tanks supply all the oxygen required for metabolic consumption and to compensate for cabin and/or suit circuit leakage, oxygen component leakage, and loss due to cabin puncture, subsequent to switchover to ascent consumables. Both tanks are in the aft equipment bay, which is unpressurized. Oxygen flow from either tank is controlled by individual oxygen shutoff valves on the oxygen control module.

2.6.3.2.4 Oxygen Filters.

Filters at the inlets to the oxygen control module and the PLSS disconnect remove particulate matter from the oxygen. Filtering capability is 18 microns nominal and 40 microns absolute.

2.6.3.2.5 Oxygen Control Module. (See figure 2-124F.)

The oxygen control module is mounted on the ECS package which is located to the right rear of the LM Pilot's station. It consists of a cast housing that contains filters, a PLSS oxygen shutoff valve, descent and ascent oxygen shutoff valves, oxygen demand regulators, and a cabin repressurization and emergency oxygen valve. An interlock prevents opening the ascent oxygen shutoff valves until the descent oxygen shutoff valve is closed. An override for this interlock is provided.

PLSS and Oxygen Tank Shutoff Valves. Four positive-action, manually operated shutoff valves control oxygen flow into the oxygen control module. Rotating the valve handle to OPEN displaces a spring-loaded seal. The valves have detents in the OPEN and CLOSE positions; mechanical stops on the handle prevent overtravel.

Oxygen Demand Regulators. (See figure 2-124G.) Two, parallel oxygen demand regulators (PRESS REG A and PRESS REG B) meter oxygen from the tanks to the ARS. Both regulators are manually controlled by individual four-position selector handles. ARS pressure is fed back to an aneroid bellows that actuates a balanced lever system. The levers move a poppet that is biased by spring force. Rotating the valve handle changes the spring force acting on the lever system and establishes different outlet pressure levels. The bellows is evacuated, but kept from collapsing by an internal spring. One end of the bellows is anchored to the regulator housing; the other to the lever system that moves the poppet. When the valve handle is set to EGRESS, the forces exerted on the lever system by the internal springs are such that the poppet is unseated and oxygen flows into the ARS. As pressure rises, the bellows contracts and moves the poppet towards its seated position, throttling the flow to the ARS.

When the valve handle is set to CABIN, the handle shaft lifts the spring seat retainer of the cabin spring, removing its force from the lever system. This opens the poppet and permits pressure to increase to 4.8 ± 0.2 psia. The rising pressure acts on the bellows to maintain the proper pressure level.

Selecting the DIRECT O₂ position lifts the spring seat retainer of the direct O₂ spring off the lever system, fully opening the poppet valve. With an upstream pressure of 900 psia and a temperature of +70° F, one regulator can flow approximately 7.0 pph into the ARS.

In the CLOSE position, the handle shaft bottoms on the lever system driving the poppet onto its seat to terminate flow from that regulator to the ARS.

Each regulator has valve position indicator (VPI) switches, and two functional switches that control electrical circuits in the ECS.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

(To be supplied)

Figure 2-124F. Oxygen Control Module

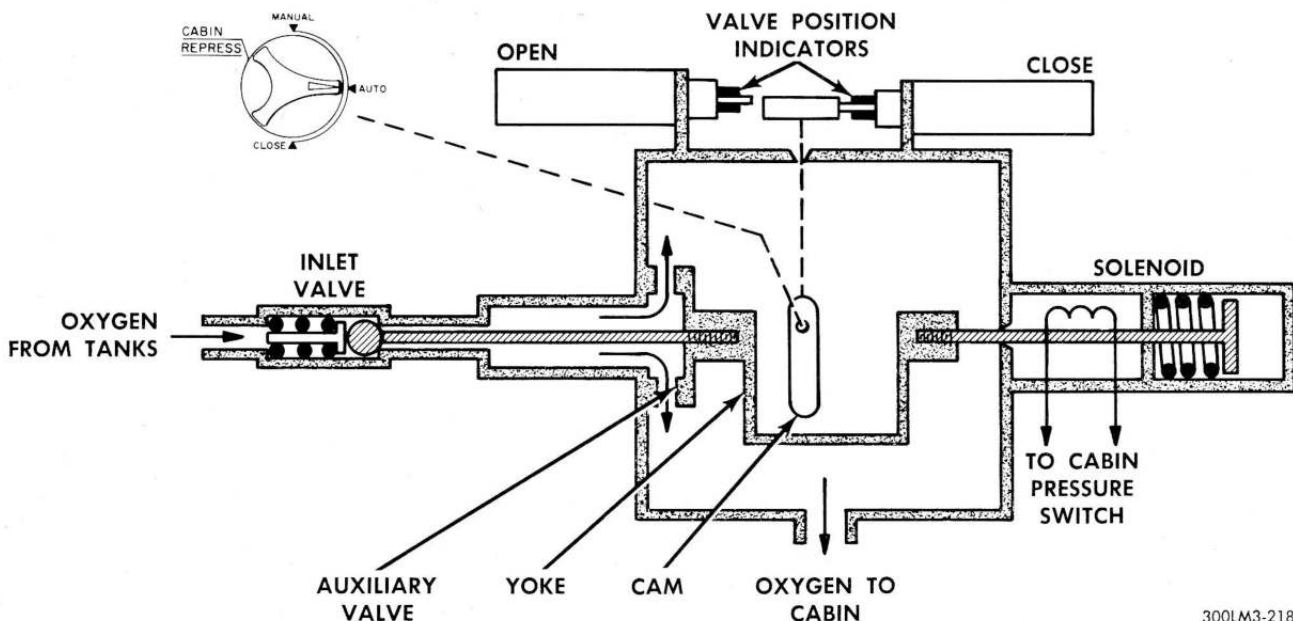
(To be supplied)

Figure 2-124G. Oxygen Demand Regulators Functional Schematic

Cabin Repressurization and Emergency Oxygen Valve. (See figure 2-125.) The cabin repressurization and emergency oxygen (CABIN REPRESS) valve is a solenoid-operated valve with manual override (MANUAL and CLOSE positions). It is used to repressurize the cabin after a deliberate decompression and provides an emergency flow of oxygen if the cabin is punctured. If the cabin is punctured and the diameter of the hole does not exceed 0.5 inch, the valve can maintain cabin pressure at 3.5 psia for at least 2 minutes, allowing the astronauts to return to a closed-suit environment. The cabin repressurization and emergency oxygen valve is controlled by a three-position handle on the oxygen control module. When the AUTO position is selected, valve operation is controlled by the solenoid, which is actuated by the cabin pressure switch. If either oxygen demand regulator is set to CABIN or DIRECT O₂ and cabin pressure drops below 4.15 ± 0.15 psia, the cabin pressure switch energizes the solenoid. This moves the valve yoke to open the inlet valve and permits oxygen from the oxygen manifold to flow through the valve into the cabin area. If cabin pressure rises to 4.45 ± 0.15 psia, the cabin pressure switch deenergizes the solenoid and spring action closes the valve. Setting both oxygen demand regulators to CLOSE or EGRESS disables the circuitry to the solenoid through the cabin pressure switch provided suit-pressure does not fall below 3.12 psia. While the cabin is decompressed, the suit pressure sensor energizes the valve solenoid, provided the valve is set to AUTO. This protects the astronauts against catastrophic failure of the suit circuit while the cabin is unpressurized.

When the MANUAL position is selected, the handle shaft actuates a cam that moves the yoke to open the inlet valve and establish flow to the cabin. When the valve is fully open and in descent mode of operation it can flow 4 ppm regardless of pressure; in ascent mode it can flow 8 ppm at 700 psia.

In CLOSE position the manual close poppet is forced onto its seat shutting off the flow.



300LM3-218

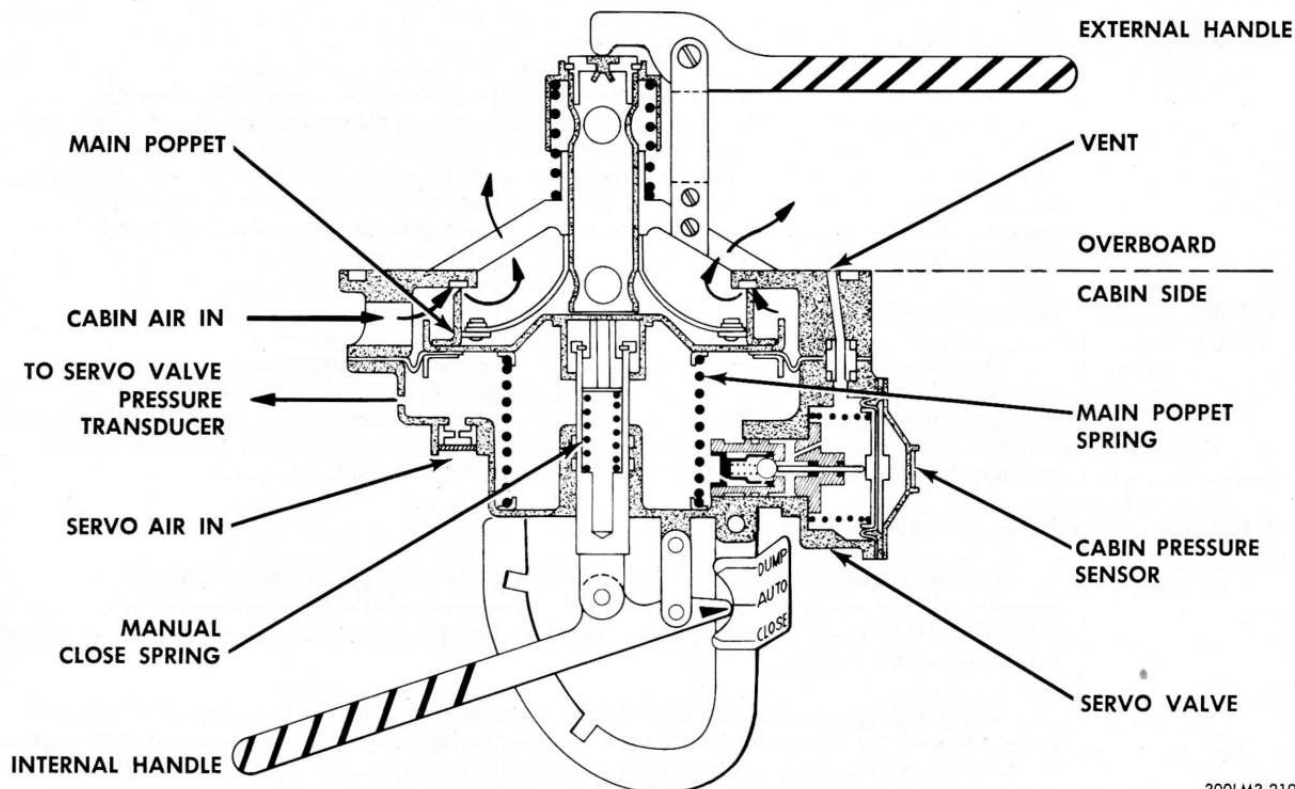
Figure 2-125. Cabin Repressurization and Emergency Oxygen Valve Functional Schematic

2.6.3.2.6 Cabin Relief and Dump Valves. (See figure 2-126.)

A cabin relief and dump valve is installed in each hatch. The valve has a differential-pressure, servo-actuated poppet valve that prevents cabin overpressurization and permits deliberate (manual) dumping of cabin pressure. Each valve is controlled with either of two handles: one, inside the cabin; the other, outside. The inside handles can be used to select three positions (DUMP, AUTO, or CLOSE). The outside handles have only a DUMP position. The forward cabin relief and dump valve has a bacteria filter.

Normally, the cabin relief and dump valves are set to AUTO. In this position, the valves are operated by the servo valve. One side of the servo valve diaphragm is exposed to cabin pressure; the other side of the diaphragm (spring side) is vented overboard. When the cabin-to-ambient pressure differential reaches approximately 5.4 psi, the servo valve diaphragm overcomes the servo spring pressure and unseats the servo valve. This vents the spring side of the main poppet to ambient and causes a pressure drop. Cabin pressure on the surface of the main poppet overcomes the force of the main poppet spring and opens the dump valve. Oxygen is dumped overboard and cabin pressure is reduced to an acceptable value. When the pressure differential is 5.8 psi, one fully open dump valve can dump 11.1 pounds of oxygen per minute overboard. When the valve handle inside the cabin is set to AUTO, the valve can be opened manually from outside.

Setting the internal handle to DUMP unseats the poppet. One valve can then dump the cabin pressure from 5.0 to 0.08 psia in 180 seconds without cabin oxygen inflow



300LM3-219

Figure 2-126. Cabin Relief and Dump Valve Functional Schematic

and without bacteria filter; with filter in 240 seconds. Setting the handle to CLOSE prevents the valve from opening at normal pressures, if the servo valve fails.

A pressure transducer associated with the overhead and forward cabin relief and dump valve provides a telemetry signal to indicate when the valves are relieving cabin pressure. A pressure transducer in the overhead cabin relief and dump valve senses cabin pressure and provides a telemetry signal. A temperature transducer in the forward hatch senses cabin temperature and provides a telemetry signal.

Oxygen Bacteria Filter. A filter on the cabin side of the forward cabin relief and dump valve removes bacteria from the dumped cabin oxygen. The filter can be installed and removed by an astronaut in the cabin. It removes 95% of all bacteria larger than 0.5 microns.

2.6.3.2.7 Cabin Pressure Switch.

The cabin pressure switch monitors cabin pressure and enables electrical signals to control related ECS functions. The switch is an absolute-pressure device that consists of three separate hermetically sealed microswitch capsules. The capsules are set to provide switch closure when cabin pressure decays to approximately 4.15 psia during pressurized-cabin operation. If either oxygen demand regulator is set to EGRESS (this activates two of the three microswitches), the suit gas diverter valve closes, the cabin repressurization and emergency oxygen valve opens, and the CABIN warning light goes on. Increasing cabin pressure to 4.45 ± 0.15 psia opens the cabin pressure switch circuits, closes the cabin repressurization and emergency oxygen valve, deenergizes the CABIN warning light and opens the suit gas diverter valve.

2.6.3.3 Water Management Section.

2.6.3.3.1 Descent Stage Water Tank.

The descent stage water tank is an aluminum tank with an internally mounted standpipe and bladder. The bladder contains the water; the space between the tank and bladder is charged with nitrogen according to a schedule dependent on the load (48.2 psia maximum at +80°F). The nitrogen squeezes the water out of the bladder through the standpipe and into the system. The tank outlet is connected to the water control module. Water from the descent water tank is routed through the WATER TANK SELECT valve by setting it to DES.

2.6.3.3.2 Ascent Stage Water Tanks

The ascent stage water tanks are in the overhead unpressurized portion of the cabin. They are identical with the descent stage water tank, but are smaller. An initial nitrogen charge of 48.2 psia at +80°F is used in each tank. The tank outlets are connected to the water control module. Water from the ascent water tanks is routed through the WATER TANK SELECT valve by setting it to ASC.

2.6.3.3.3 Water Quantity Measuring Devices.

A water quantity measuring device (WQMD) for each of the three water tanks measures the quantity of water in the tank. The analog voltage output of the WQMD is fed to the QUANTITY indicator and is displayed on the H₂O scale as percentage of water remaining in the tanks.

The WQMD measures the quantity of water by first sensing the pressure/temperature ratio of the tank pressurizing gas. This ratio is directly proportional to the mass of the gas. An analog computer then subtracts this mass from the total nitrogen mass in the system, to obtain the nitrogen mass in the water tanks. This value is used to compute the volume of gas in the tanks. Finally, the volume of the gas in the tanks is subtracted from the total tank volume to obtain the total quantity of remaining water.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

The input device of the WQMD is a Wheatstone bridge that senses pressure/temperature (P/T) ratio. The bridge is energized by a bridge amplifier in an analog computer. The analog computer contains a power supply, two amplifiers, and three internal system-calibrating adjustments. The output voltage of the P/T sensor is applied to the output amplifier, which sums this signal with the input reference voltage and provides an analog output (0 to 5 volts) to the QUANTITY indicator. The power supply receives an input voltage from the ECS: DISP circuit breaker.

2.6.3.3.4 Water Control Module. (See figure 2-127.)

The manual controls of the WMS are grouped together on the water control module. The module consists of a cast aluminum manifold in which check valves, shutoff valves, a water evaporator manual feed valve, water coolant isolation valve, water tank selector valve, water control valves, water pressure regulators, evaporator flow valves, and water valves are mounted. All the interconnecting passages, and brackets to mount and support the foregoing components as well as to mount the assembly itself, are an integral part of the cast housing of the module. Each water tank outlet is connected to the module, which diverts the water to selected flow paths.

Descent Water Valve. The descent water (DES H₂O) valve is a manually operated, poppet-type shutoff valve. The valve has OPEN and CLOSE positions. In the OPEN position, the valve provides high-pressure water flow from the descent tank to the water dispenser.

Ascent Water Valve. The ascent water (ASC H₂O) valve, at the top of the water control module, is a manually operated, poppet-type shutoff valve. The valve has OPEN and CLOSE positions. In the OPEN position, the valve provides high-pressure water flow from the ascent tank to the water dispenser.

Check Valves. There are seven check valves in the water control module: one in each tank feed line, one in each discharge line from the ARS water separators, one upstream of the descent water valve, and one downstream of the primary water pressure regulators. The check valves prevent water flow from the module to the water separators, flow from the water hose through the shutoff valve to the descent water tank, and flow from the primary water loop into the secondary water loop.

Water Tank Selector Valve. (See figure 2-128.) The water tank selector (WATER TANK SELECT) valve is a manually operated, three-position, two-spool valve. The two spools (primary and secondary), linked to the valve handle, rearrange the internal ports to establish proper flow paths. The valve has DES, ASC, and SEC positions.

In the DES position, the primary spool establishes a flow path between the descent water tank and the primary water manifold. In the ASC position, the primary spool establishes a flow path between the ascent tanks and the primary water manifold. To select the SEC position, the mechanical handle lock must be released. To release the lock, the finger latch is lifted; this unlatches the ball locks. When the lifting force is removed, the return spring slides the lockpin to the unlocked position and the valve handle can be moved to the SEC position. This action moves the secondary spool, which causes the water coolant isolation valve to be punctured. The secondary spool diverts flow from the ARS water separators to the secondary manifold. In the SEC position, water is routed from the ascent water tanks to the secondary manifold.

Water Pressure Regulators. (See figure 2-129.) Three water pressure regulators are in the WMS. Two are in series in the primary manifold and one is in the secondary manifold. The regulators contain a spring-loaded diaphragm that senses the differential between ARS reference pressure and the downstream water pressure. The diaphragm moves a balanced lever attached to a metering poppet. The water discharge pressure is maintained at 0.5 to 1.0 psi above the reference pressure.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

(To be supplied)

Figure 2-127. Water Control Module

ENVIRONMENTAL CONTROL SUBSYSTEM

Page 2.6-40 Mission LM 3 Basic Date 1 January 1968 Change Date

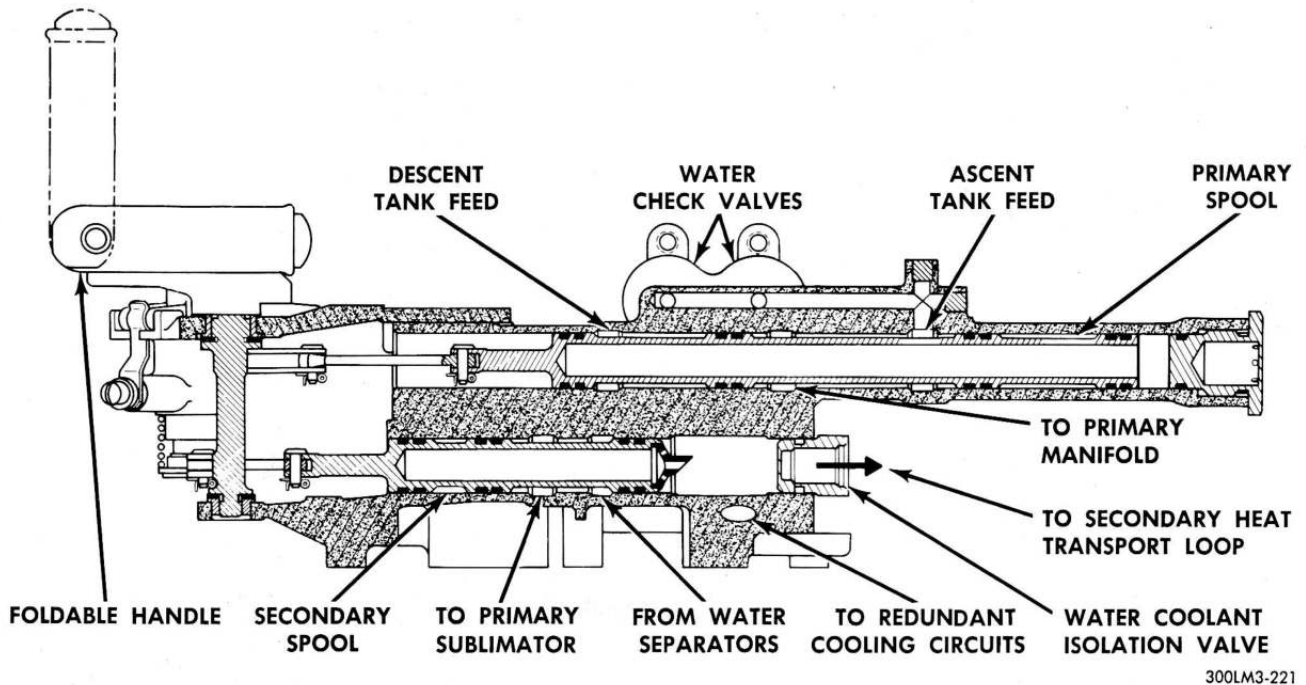


Figure 2-128. Water Tank Selector Valve

Primary Water Evaporator Flow Valve. The primary evaporator flow valve (water solenoid valve) is a poppet-type shutoff valve electrically controlled with a two-position switch (PRIM EVAP FLOW) on the frame of the cabin recirculation assembly. The valve controls water flow to the primary sublimator.

Primary Evaporator Flow Valve No. 2. The primary evaporator flow No. 2 (PRIM EVAP FLOW #2) valve is a manually operated, poppet-type shutoff valve. It has OPEN and CLOSE positions. In the OPEN position, the valve acts as a backup to the primary evaporator flow valve to provide ascent tank water from the secondary water manifold to the primary sublimator.

Secondary Evaporator Flow Valve. The secondary evaporator flow (SEC EVAP FLOW) valve is a manually operated, poppet-type shutoff valve. It has OPEN and CLOSE positions. The valve controls water flow from the secondary water manifold to the secondary sublimator and to the suit circuit sublimator.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

(To be supplied)

Figure 2-129. Water Pressure Regulator

ENVIRONMENTAL CONTROL SUBSYSTEM

2.6.3.4 Heat Transport Section.

2.6.3.4.1 Coolant Accumulator.

The coolant accumulator consists of a two-piece aluminum cylinder that contains a movable spring-loaded piston bonded to a diaphragm. The fluid side contains approximately 47.5 cubic inches of fluid under pressure. The pressure varies, depending on fluid level, from 5.5 to 8 psi. The accumulator maintains a head of pressure on the glycol pump inlets to prevent pump cavitation, and replaces coolant lost through subsystem leakage. The piston moves in response to volumetric changes caused by temperature variations in the primary loop or by leakage. The accumulator spring side is vented to space.

The accumulator has a low-level sensor with a microswitch that trips when only 10% of the coolant volume remains. The switch is mounted on a tube that extends from the top of the accumulator; the tube houses a rod attached to the piston. The switch provides a telemetry signal.

2.6.3.4.2 Primary Coolant Filter.

The primary coolant filter has a filtering capability of 35 microns. It has an integral pressure relief bypass feature that operates at 0.4 psid to maintain coolant flow to the pumps if the filter becomes clogged.

2.6.3.4.3 Coolant Pumps.

The three coolant pumps are identical. Two pumps are connected in the primary loop; the third pump in the secondary loop. The pumps are of the sliding-vane, positive-displacement type; they are driven by 28-volt d-c brushless motors. The motors are of wet or submerged design and are cooled by the recirculating coolant. The pumps receive the coolant at a recirculation rate of approximately 3.7 pounds per minute at +40°F and 7.0-psia pump inlet pressure. The pumps increase coolant pressure by 30 psi (nominal) and operate at approximately 5,200 rpm.

2.6.3.4.4 Cabin Temperature Control Valve. (See figure 2-130.)

The cabin temperature control valve is a diverter valve of sliding-spool construction, with three positions; NORM (automatic), MAX COOL, and MAX HEAT. The NORM position is manually selected and is activated by a wax-filled sensor; all coolant discharged from the cabin heat exchanger is fed across the sensor. The sensor expands and contracts in response to coolant temperature changes and by means of the plunger and spool return spring, repositions the valve spool to obtain the selected coolant and subsequent oxygen temperature. This splits the coolant flow; part goes to the cabin heat exchanger and part to the coolant regenerative heat exchanger. In the MAX COOL (override) position, the spool is positioned to the left, permitting all of the cold coolant to enter the valve and be fed directly to the cabin heat exchanger. In the MAX HEAT (override) position, the spool is repositioned to close the cabin heat exchanger feed port and opens the feed to the coolant regenerative heat exchanger for the hot fluid being returned to the coolant pump inlet from the cold plates. The hot fluid is bypassed to the cabin heat exchanger to perform its heating function.

2.6.3.4.5 Coolant Regenerative Heat Exchanger.

The coolant regenerative heat exchanger is of plate-and-fin construction. It has an inlet and outlet for cold coolant circulation and an inlet and outlet for warm coolant circulation past the coolant core. The cold side is single pass; the warm coolant makes four passes in a cross-counter-flow arrangement.

(To be supplied)

Figure 2-130. Cabin Temperature Control Valve

2.6.3.4.6 Suit Temperature Control Valve.

The suit temperature control valve is a manually operated diverter valve. The amount of warm coolant flowing through the suit circuit regenerative heat exchanger is regulated by the handle which can be turned from HOT to COLD.

2.6.3.4.7 Sublimators.

The porous-plate type sublimators (one in the primary loop and another in the secondary loop) are identical except that the primary sublimator has a larger capacity. Each sublimator has a coolant inlet and outlet, a water inlet, and a steam outlet. Water makes one pass through the unit; coolant makes six passes. For proper sublimator operation, water pressure must exceed 4.0 psia but be less than 8.0 psia. The water pressure must also be less than the suit circuit static pressure plus the head pressure from the water separators to the sublimator.

The unit rejects heat to space by sublimation of ice. Water from the WMS flows through the water passages, into the porous plates, and is exposed to space environment. The vacuum pressure is below the triple point of water; this causes an ice layer to develop within the pores and on the outer surface of the plates. As the hot coolant flows through the sublimator passages, heat transfers from the coolant to the water and to the ice layer. The ice sublimates from the solid state to steam without passing through a liquid state, rejecting its heat load overboard through a plastic duct. The thickness of the ice layer varies with the heat load imposed on the sublimator, resulting in a regulated output temperature over a range of input temperatures.

If the heat load entering the sublimator drops below its low limit, the ice layer expands and may completely fill the water passages. The expanding ice layer may rupture the sublimator. If the heat load is too high, the ice layer melts. If the water pressure is too high, a breakthrough of the ice layer may occur, forcing water through the porous plates. In these cases, heat rejection by the sublimator is greatly reduced because ice is not sublimated. Water consumption is excessive because there is no restraining ice layer.

2.6.3.4.8 Cold Plates.

Electronic equipment that requires active temperature control is cooled by two types of cold plates: flat cold plates and cold rails. The cold plates are installed on the LM structure in a manner that minimizes heat transfer from the structure to the coolant, to avoid a reduction of the coolant cooling capacity. The surrounding structure and equipment may have a temperature range of 0° to +160° F. Cold rails are used in the aft equipment bay for batteries, the LM mission programmer, and the DSEA. The IMU has an integral cooling circuit. All other cold plates are of the flat type. Cold plates for equipment essential for successful mission abort have two independent coolant passages, one for the primary loop and one for the secondary loop.

The flat cold plates are brazed assemblies with inlet and outlet fittings. The coolant flows between two parallel sheets, which are connected by fins for increased heat transfer and structural strength. The internal fin arrangement of these cold plates ensures sufficient flow distribution.

The cold rails are channel-and-tube type of extrusions; the tubular part forms the inside center of the channel. The tube has fins and, at the ends, coolant inlet and outlet fittings. The cold rails are installed in a parallel arrangement, with equal space between the rails to accommodate equipment designed for mounting on cold rails. Each cold rail (except the first and the last one) cools two adjacent rows of equipment.

To increase heat transfer, an interface material is used between the electronic equipment (except the DSEA) and the cold plates. The interface material (silicone rubber with an aluminum oxide additive) is applied in liquid form to the equipment surface before

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

installation and is vulcanized at room temperature after the equipment is mounted. Electronic replaceable assemblies can be installed on, and removed from their cold plates without disturbing the coolant circuit. Repeated removal and installation requires removal of old, and application of new, interface material. The IMU has flexible line connections and quick-disconnects to facilitate IMU replacement, if required.

2.6.4 FAILURE MODES.

The ECS failure modes and the effect on mission capability are given in table 2-41.

Table 2-41. Environmental Control Subsystem - Failure Modes

Failure	Indication	Vehicle Capability
Heat exchanger(s)		
1. Internal leak	Loss of suit circuit cooling	Remaining test objectives are lost.
2. External leak	Same as above	Remaining test objectives are lost. Primary coolant loop is lost and cabin becomes contaminated.
Suit circuit assembly cracked.	SUIT/FAN warning light goes on and SUIT PRESS indicator reads low.	Suit circuit gas goes to cabin, curtailing test objectives. Astronauts can live in cabin environment for some time.
Descent oxygen tank to interface with the oxygen control module (OCM) has ruptured or has external leak.		Some descent testing is lost. Possible explosion and loss of crew.
Interface with OCM has external leak.	Cabin becomes overpressurized and O ₂ QUANTITY indicator reads low.	Descent oxygen may be lost, curtailing some test objectives. Ascent oxygen can be used for some ascent testing.
OCM cracked or ruptured.	O ₂ QTY caution light goes on and O ₂ QUANTITY indicator reads low.	Descent oxygen is lost, curtailing test objectives.
Burst diaphragm ruptured.	O ₂ QTY caution light goes on and QUANTITY indicator reads low.	Test objectives are curtailed.
Oxygen interstage disconnect did not disconnect at staging.	No indication	Possibility of explosion, with loss of crew.
Oxygen interstage disconnect leak before staging.	MSFN will notice pressure and temperature drop.	Loss of descent oxygen causes loss of descent primary test objectives.
Interface between OCM and flex hose has external leak.	O ₂ QTY caution light goes on and O ₂ QUANTITY indicator reads low.	Test objectives are curtailed.
Ascent oxygen tank ruptured or has external leak.	O ₂ QTY caution light goes on and O ₂ QUANTITY indicator reads low.	Possibility of explosion with involving loss of crew; or, loss of some test objectives.
Descent oxygen filter clogged or has external leak.	O ₂ QTY caution light goes on, and O ₂ QUANTITY indicator reads low (for leak).	Loss of descent oxygen curtails test objectives.
DES O ₂ valve jammed on opening or has external leak through stem.	Jammed valve is found during crew operations. O ₂ QUANTITY indicator reads low (for leak).	Loss of descent oxygen curtails test objectives. If valve is jammed in OPEN position, cabin becomes overpressurized; cabin relief and dump valves relieve excess pressure.

ENVIRONMENTAL CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-41. Environmental Control Subsystem - Failure Modes (cont)

Failure	Indication	Vehicle Capability
#1 ASC Q ₂ or #2 ASC O ₂ valve has external leak through stem.	O ₂ QUANTITY indicator reads low.	Some ascent testing is lost. Cabin becomes overpressurized; cabin relief and dump valves relieve excess pressure.
CABIN REPRESS valve failed open or has external leak through stem.	CABIN PRESS indicator reads low.	Remaining test objectives are lost.
PRESS REG A or PRESS REG B valve has external leak through stem.	CABIN PRESS indicator reads low.	Remaining test objectives are lost.
Plumbing between OCM and suit circuit assembly ruptured or has external leak.	CABIN PRESS indicator reads low.	Remaining test objectives are lost. Rupture or leak can become crew safety hazard.
Descent water tank has external leak or is ruptured.	H ₂ O QUANTITY indicator reads low.	Remaining descent testing is lost. If ascent water is used to complete descent tests, ascent testing will be curtailed.
Water control module cracked.	Cabin flooding and H ₂ O QUANTITY indicator reads low.	Cracked water control module (WCM) can cause loss of cooling, overheating of electronics, loss of all test objectives, and possible loss of crew.
WCM interface area has external leak.	Cabin flooding and H ₂ O QUANTITY indicator reads low.	This can cause possible loss of crew or loss of some test objectives.
Ascent water tank has external leak or is ruptured.	H ₂ O QUANTITY indicator reads low.	Some ascent testing is lost.
Descent water check valve has external leak or failed closed.	H ₂ O QUANTITY indicator reads low.	Descent water and some test objectives are lost. Ascent water may be used for descent testing.
Water pressure regulator has external leak or failed closed.	H ₂ O QUANTITY indicator reads low.	Loss of primary water (descent or ascent) curtails test objectives.
Ascent water check valve has external leak or failed closed.	H ₂ O QUANTITY indicator reads low.	Loss of one or both ascent tanks results in possible loss of some test objectives.
WATER TANK SELECT valve leaks and isolation valve has external leak through stem.	Cabin flooding	These leaks can cause loss of all test objectives.
WATER TANK SELECT valve jammed or binds.	Jammed valve is found during crew operations; overheating of cabin and suit circuit assembly.	Descent and/or ascent testing is lost. Water is unavailable for sublimators, drinking, firefighting, and food preparation.

ENVIRONMENTAL CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-41. Environmental Control Subsystem - Failure Modes (cont)

Failure	Indication	Vehicle Capability
Isolation valve aluminum diaphragm has internal leak.	Internal leak will not be found until secondary HTS loop is activated.	This leak can cause loss of all test objectives. Secondary water flow for emergency use is curtailed.
DES H ₂ O valve has external leak through stem. Valve jammed or binds.	H ₂ O QUANTITY indicator reads low. Cabin may flood. Valve jamming or binding is found during crew operations.	Descent testing objectives, drinking water and firefighting capability are lost. Ascent water may be used for some testing, drinking and fire-fighting.
Water solenoid valve did not open (primary sublimator flow).	Temperature in cabin or suit circuit rises.	Water is not available to primary sublimator. PRIM EVAP FLOW #2 valve and alternate water solenoid valve must be used.
PRIM EVAP FLOW switch did not open.	Temperature in cabin or suit circuit rises.	Water is not available to primary sublimator. PRIM EVAP FLOW #2 valve must be used as alternate.
ASC H ₂ O valve has external leak through stem.	H ₂ O QUANTITY indicator reads low. Temperature in cabin or suit circuit rises.	Ascent testing objectives, drinking water, firefighting capability and food preparation are lost.
ECS: PRIM GLYCOL EVAP FLOW circuit breaker failed open.	Temperature in cabin or suit circuit rises.	Mission is curtailed. Water unavailable to primary sublimators, must go to secondary loop. Next failure may constitute crew safety hazard.
Accumulator is ruptured or has external leak.	GLYCOL caution light goes on, GLYCOL temperature indicator reads high, and GLYCOL pressure indicator reads low.	HTS primary loop and PGNS test objectives are lost. Secondary loop must be activated.
Glycol interstage disconnect		
1. Did not disconnect	Vehicle cannot be stage.	1. Mission is curtailed.
2. External leak before staging	Temperature in cabin rises.	2. Primary coolant is lost. Primary test objectives are lost. Secondary coolant loop must be activated.
3. External leak after staging	Temperature in cabin rises.	3. Remaining test objectives are lost or curtailed.
Coolant filter clogged or has external leak.	GLYCOL caution light goes on, due to low-level indication in accumulator.	HTS primary loop is lost. Test objectives are curtailed. Secondary coolant loop must be activated.

ENVIRONMENTAL CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-41. Environmental Control Subsystem - Failure Mode (cont)

Failure	Indication	Vehicle Capability
Primary sublimator cracked or does not operate.	Loss of coolant causes overtemperature condition. GLYCOL caution light goes on, GLYCOL temperature indicator reads high.	HTS primary loop is lost. Test objectives are curtailed. Secondary coolant loop must be activated.
Primary descent cold plate(s) and/or cold rail(s) cracked.	Loss of coolant causes overtemperature condition. GLYCOL caution light goes on and GLYCOL temperature indicator reads high. Cabin may be contaminated.	HTS primary loop is lost. Test objectives are curtailed. Secondary coolant loop must be activated.

2.6.5 PERFORMANCE AND DESIGN DATA.

The performance and design data for the ARS, OSCPS, WMS, and HTS are given in table 2-42. Tables 2-43 through 2-46 have been deleted.

Table 2-42. Environmental Control Subsystem Performance and Design Data

Atmosphere Revitalization Section	
Oxygen partial pressure in atmosphere breathed by astronauts	160 mm Hga (minimum)
Carbon dioxide partial pressure in atmosphere delivered to astronauts	7.6 mm Hga (maximum)
Cabin pressure	4.8 ± 0.2 psia (normal, steady-state)
Suit circuit pressure	
Cabin mode	4.8 ± 0.2 psia (may exceed 5.0 psia during powered flight)
Egress mode	3.8 ± 0.2 psia (4.7 psia maximum during powered flight)
Minimum	3.5 psia
Maximum	9.6 psia and 5.0 psid (with one oxygen demand regulator failed open)
During EMU checkout (measured downstream of PGA's)	8.7 psia (3.7 psig) for 5 minutes
LiOH dust concentration in atmosphere delivered to astronauts	0.02 mg/m ³ (maximum)

ENVIRONMENTAL CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-42. Environmental Control Subsystem Performance and Design Data (cont)

Atmosphere Revitalization Section (cont)	
<p>Leakage</p> <p>ARS external leakage (with CO₂ and odor removal canisters closed, exclusive of PGA's)</p> <p>Suit (one man)</p> <p>Suit inlet temperature range</p> <p>Cabin temperature</p> <p>Relative humidity</p> <p>Suit circuit fan flow</p>	<p>0.01 pound per hour (maximum) at 3.7 psia suit pressure with cabin unpressurized</p> <p>0.035 pound per hour (maximum) with cabin unpressurized</p> <p>With SUIT TEMP control valve in full COLD position, temperature ranges from +38° to 65° F; in full HOT position from +42° to +100° F. Under certain maximum operating conditions suit inlet temperature may exceed +100° F.</p> <p>+55° to +90° F</p> <p>40% to 80%</p> <p>At 4.8 psia - 36.0 pounds per hour At 3.8 psia - 28.4 pounds per hour</p>
Oxygen Supply and Cabin Pressure Control Section	
<p>Suit pressure increase</p> <p>Cabin repressurization and emergency oxygen valve delivery rate</p> <p>Descent mode</p> <p>Ascent mode</p> <p>PLSS refill</p> <p>Oxygen filter flow rate (from oxygen tanks)</p> <p>Suit circuit minimum inflow</p> <p>Cabin volume</p> <p>Oxygen filter efficiency</p>	<p>First 1-psi increase may occur in less than 1 second. Each succeeding 1-psi increase occurs in not less than 8 seconds.</p> <p>4 pounds per minute, regardless of pressure</p> <p>8 pounds per minute at 700 psia</p> <p>0.91 pound/refill at 850 psia or above. Can only be partially filled at lower pressures.</p> <p>7.5 ± 0.2 pounds per hour at 850 psia and +20° F</p> <p>Flow limiters permit sufficient flow to maintain minimum suit circuit pressure of 3.5 psia with suit circuit relief valve failed open and with 550 psia and +130° F at oxygen control module inlet</p> <p>235 cubic feet</p> <p>40 microns absolute</p>

ENVIRONMENTAL CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-42. Environmental Control Subsystem Performance and Design Data (cont)

Oxygen Supply and Cabin Pressure Control Section (cont)	
Dump valve bacteria filter efficiency	Removes 95% of all bacteria larger than 0.5 micron
Cabin-to-ambient pressure differential	5.8 psi (maximum)
Manual cabin pressure dump rate (without oxygen inflow)	One dump valve with bacteria filters from 5.0 psia down to 0.08 psia in 4 minutes (maximum); without filter in 3 minutes. Both valves without filter in 1.5 minutes.
Number of cabin repressurizations	4 at 6.6 pounds each
Cabin repressurization time	≈ 2 minutes
Cabin pressure switch settings	When cabin pressure drops to 4.15 ± 0.15 psia, suit circuit diverter valve closes, cabin repressurization and emergency oxygen valve opens, and CABIN warning light goes on. When cabin pressure increases to 4.45 ± 0.15 psia, cabin repressurization and emergency oxygen valve closes and CABIN warning light goes off. When cabin pressure drops below 3.05 ± 0.05 psia, the cabin fans turn off. When cabin pressure increases to 3.5 ± 0.05 psia, the cabin fans go on.
Descent oxygen tank	
Capacity	48.01 pounds at 2,850 psia and +70°F (residual oxygen: 1.0 pound)
Burst pressure	Approximately 4,500 pounds
Ascent oxygen tanks	
Capacity	2.41 pounds (each tank) at 1,000 psia and 70° F (residual oxygen: 0.24 pound for each tank)
Burst pressure	Approximately 1,500 psia
Gaseous oxygen pressures and temperatures	
Normal pressure (regulated)	900 $\begin{smallmatrix} +60 \\ -25 \end{smallmatrix}$ psia
Normal pressure (unregulated)	50 to 1,000 psia

ENVIRONMENTAL CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-42. Environmental Control Subsystem Performance and Design Data (cont)

Oxygen Supply and Cabin Pressure Control Section (cont)	
Gaseous oxygen pressures and temperatures (cont)	
Maximum pressure	1,100 psia
Minimum pressure	5.0 psia
Normal temperature	0° to +160° F
Maximum temperature	+160° F
Minimum temperature	-200° F
Leakage	
Oxygen supply components	Total external leakage of all oxygen supply components, under maximum operating pressures, does not exceed 0.005 pound per hour of oxygen.
Cabin relief and dump valve	0.005 pound per hour (maximum) for each valve, up to 5.25 psid with increasing or decreasing pressure.
Cabin	0.2 pound per hour (maximum) at 5.0 psia and +75° F
Bypass relief valve	
Full flow pressure	3,030 psig (minimum) at +75° F
Cracking pressure	2,875 psig (maximum) at +75° F
Reseat pressure	2,850 psig (minimum) at +75° F
Overboard relief valve	
Full flow pressure	1,090 psig (maximum) at +75° F
Cracking pressure	1,025 psig (minimum) at +75° F
Reseat pressure	985 psig (minimum) at +75° F
High-pressure regulator	
Outlet pressure with primary and secondary regulators operating normally	At inlet pressure of 1,100 to 3,000 psig and flow of 0.1 to 4.0 pounds per hour, and inlet pressure of 975 to 1,100 psig and flow of 0.1 pound per hour will regulate to:

ENVIRONMENTAL CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-42. Environmental Control Subsystem Performance and Design Data (cont)

Oxygen Supply and Cabin Pressure Control Section (cont)		
<u>Normal downstream regulated pressure (psig)</u>		
Temp ° F	Minimum Pressure	Maximum Pressure
0	875	975
75	875	960
150	860	945
<u>Downstream regulated pressure with a failed open primary regulator (psig)</u>		
Temp ° F	Minimum Pressure	Maximum Pressure
0	875	975
75	875	960
150	860	945
<u>Downstream regulated pressure with a failed open secondary regulator (psig)</u>		
Temp ° F	Minimum Pressure	Maximum Pressure
0	875	975
75	875	960
150	860	945

Water Management Section	
Descent water tank	
Capacity	367 pounds
Initial fill pressure	48.2 psia (maximum) at +80° F
Expulsion efficiency	With initial fill pressure, 98% (minimum) of quantity loaded, down to 100 pounds (minimum)
Pressure upon expulsion of all expellable water	11.0 psia (minimum) at +35° F
Ascent water tanks	
Capacity	47.5 pounds each
Initial fill pressure	48.2 psia (maximum) at +80° F
Expulsion efficiency	With initial fill pressure, 98% (minimum) of quantity loaded, down to 20 pounds (minimum) in each tank
Pressure upon expulsion of all expellable water	11.0 psia (minimum) at +35° F

ENVIRONMENTAL CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-42. Environmental Control Subsystem Performance and Design Data (cont)

Water Management Section (cont)	
External leakage	
Normal mode (exclusive of sublimator in HTS primary loop)	0.700 cc/hr of water (maximum) at 50 psid and +70° F
Redundant mode (exclusive of sublimators in HTS secondary loop)	0.350 cc/hr of water (maximum) at 50 psid and +70° F
Sublimators in HTS primary loop	0.090 cc/hr of water (maximum combined) at 6.5 psid and +70° F
Sublimators in HTS secondary loop	0.090 cc/hr of water at 6.5 psid and +70° F
External-to-internal leakage ground service disconnects	1×10^{-2} scc/hr of helium (maximum each) at internal pressure of 500 microns and in helium ambient of 14.7 psia and +70° F
Pressure regulator discharge pressure	0.5 to 1.0 psi above ARS gas pressure
PLSS refill (each)	9.15 pounds of water
Heat Transport Section	
Coolant	Solution of ethylene glycol and water (35% and 65%, respectively, by weight) with inhibitors (triethanolamino phosphate, to prevent decomposition; sodium mercaptobenzenothiozol, to prevent electrolytic corrosion)
	Approximately 44 pounds of coolant is used in HTS.
Coolant slush point	-3° F
External leakage	
Primary coolant loop	1.215×10^{-4} cc/sec of helium (maximum) at 45 psid and +70° F
Secondary coolant loop	1.0×10^{-4} cc/sec of helium (maximum) at 45 psid and +70° F
Coolant pump pressure rise	30 psi minimum at 32° F and flow rate of 222 pounds per hour
Coolant pump bypass relief valve	
Cracking pressure	33 psi to 36 psi
Full open pressure	39 psi
Reseat pressure	1 psi less than cracking

ENVIRONMENTAL CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-42. Environmental Control Subsystem Performance and Design Data (cont)

Heat Transport Section (cont)	
Coolant temperatures	
Flow into primary sublimator	110° F (maximum)
Flow out of sublimator	29° to 36° F
Flow into secondary sublimator	60.1 (minimum)
Flow out of sublimator	47° F (maximum)
Vacuum fill requirements	HTS withstands internal pressure of 500 microns in sea-level ambient pressure environment.
Primary and secondary coolant filters	
Efficiency	35 microns absolute
Bypass valve operating pressure	0.4 psid
Coolant flow	
Primary coolant loop	222 pounds per hour (minimum)
Secondary coolant loop	222 pounds per hour (minimum)
Cold plates	
Coolant inlet operating temperature	+32° to +100° F
Coolant inlet operating pressure	5 to 45 psia
Coolant inlet operating flow	12 to 85 pounds per hour, depending on cold plates size

2.6.6

OPERATIONAL LIMITATIONS AND RESTRICTIONS.

The operational limitations and restrictions for the ECS are as follows:

- The suit fans and cabin fans must be operated at a reduced voltage of 12 to 15 volts dc in earth ambient pressure, to prevent damage to the motors.
- The glycol pumps must be operating before water from the WMS or water separators is permitted to flow to the sublimators. Sublimator requires minimum heat load to prevent freeze up.
- The HTS must be stabilized at operating temperatures before IMU or LM guidance computer operation, to prevent erroneous and changing operation during temperature cycling resulting in invalid outputs.
- One suit fan must be on when the astronauts are on LM ECS. Atmosphere will not be reconditioned leading to possible loss of consciousness.
- The LiOH cartridge of the primary canister must be replaced with a new cartridge when carbon dioxide partial pressure, as indicated on the PART PRESS CO₂ indicator, reaches 7.6 mm Hg. Carbon dioxide level must be maintained below maximum acceptable partial pressure.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

- The cabin fans must be turned off when cabin pressure drops below 3.8 psia or fans may overspeed and burn up.
- A minimum total heat load of 1,200 Btu/hr must be maintained when the primary water feed is on; otherwise sublimator may freeze and rupture, rendering the primary coolant loop inoperative. The heat loads result from crew activity, LiOH reaction, structural load, and equipment and battery heat loads.
- The temperature of the coolant flow to temperature-critical electronics must not exceed +50°F. Overheating may result and lead to degraded performance of critical equipment.
- A minimum total heat load of 500 Btu/hr must be maintained when the secondary water feed is on; otherwise, the sublimator may freeze and rupture, rendering the HTS inoperative.

2.6.7

TELEMETRY MEASUREMENTS.

The ECS telemetry data are given in table 2-47. "(R)" in the "Telemetry Range" column signifies a real-time telemetry measurement. Real-time telemetry points are shown in figures 2-118, 2-122, 2-126, and 2-129. For DFI telemetry code numbers, refer to table 2-64. For all ECS signals that require conditioning, refer to tables 2-57 and 2-58.

Table 2-47. Environmental Control Subsystem - Telemetry Measurement

Code	Description	Telemetry Range	Display Range	Crew Display
GF1071R	Prime suit compressor rate	14,000 to 30,000 rpm		None
GF1072R	Spare suit compressor rate	14,000 to 30,000 rpm		None
GF1083X	Prime suit compressor failure	Contact closure		None
GF1083X	Prime suit compressor failure			ECS caution light
GF1084X	Spare suit compressor failure	Contact closure		None
GF1084X	Spare suit compressor failure			SUIT FAN warning light
GF1087X	Selected suit compressor failure			SUIT FAN component caution light
GF1111R	H ₂ O separator No. 1 rate	500 to 3,600 rpm		None
GF1112R	H ₂ O separator No. 2 rate	500 to 3,600 rpm		None
GF1191R	Cabin fan No. 1 rate	4,300 to 14,300 rpm		None
GF1192R	Cabin fan No. 2 rate	4,300 to 14,300 rpm		None
GF1201X	Suit No. 1 inlet VPI closed	Contact closure(R)		None
GF1202X	Suit No. 2 inlet VPI closed	Contact closure(R)		None

ENVIRONMENTAL CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-47. Environmental Control Subsystem - Telemetry Measurement (cont)

Code	Description	Telemetry Range	Display Range	Crew Display
GF1211X	Suit pressure relief VPI closed	Contact closure(R)		None
GF1212X	Suit pressure relief VPI open	Contact closure(R)		None
GF1221X	Suit diverter VPI closed	Contact closure(R)		None
GF1231X	Cabin gas return VPI closed	Contact closure(R)		None
GF1232X	Cabin gas return VPI open	Contact closure(R)		None
GF1241X	CO ₂ cartridge in SEC position	Contact closure(R)		None
GF1242X	CO ₂ cartridge in SEC position	Contact closure		CO ₂ component caution light
GF1261P	H ₂ O separator No. 1 Δ P	0 to 1.5 psid		None
GF1262P	H ₂ O separator No. 2 Δ P	0 to 1.5 psid		None
GF1281T	Suit inlet temperature	+ 20° to +120° F (R)		
GF1281T	Suit inlet temperature	+40° to +100° F	+40° to +100° F	SUIT TEMP indicator
GF1291T	Suit No. 1 outlet temperature	+20° to +120° F		None
GF1292T	Suit No. 2 outlet temperature	+20° to +120° F		None
GF1301P	Suit outlet pressure	0 to 10 psia (R)	0 to 10 psia	SUIT PRESS indicator
GF1521P	CO ₂ partial pressure	0 to 30 mm Hg (R)		None
GF1521P	CO ₂ partial pressure			CO ₂ component caution light
GF1521P	CO ₂ partial pressure	7.6 mm Hg		ECS caution light
GF1522P	CO ₂ partial pressure	0 to 30 mm Hg	0 to 30 mm Hg	PART PRESS CO ₂ indicator
GF1651T	Cabin temperature	+20° to +120° F (R)	+40° to +100° F	
GF1651T	Cabin temperature	+40° to +100° F	+40° to +100° F	CABIN TEMP indicator
GF1681T	Suit compressor discharge temperature	0° to +200° F		None
GF1701T	Suit heat exchanger O ₂ outlet	+20° to 120° F		None
GF2011R	Coolant pump No. 1 rate	2,000 to 6,000 rpm		None

ENVIRONMENTAL CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-47. Environmental Control Subsystem - Telemetry Measurement (cont)

Code	Description	Telemetry Range	Display Range	Crew Display
GF2012R	Coolant pump No. 2 rate	2,000 to 6,000 rpm		None
GF2013R	Coolant pump No. 3 rate	2,000 to 6,000 rpm		None
GF2021P	Primary coolant pump ΔP	0 to 50 psid (R)		None
GF2041X	Coolant accumulator fluid low level	Contact closure(R)		None
GF2041X	Coolant accumulator fluid low level	Contact closure		GLYCOL caution light
GF2521T	Main sublimator coolant inlet temperature	0° to +200°F		None
GF2571T	Redundant sublimator coolant outlet temperature	+20° to +120°F		None
GF2621T	Cabin heat exchanger coolant inlet temperature	+20° to +120°F		None
GF2681T	Temperature coolant upstream of critical electronics (GF9998U)	+20° to +120°F		None
GF2741P	Primary pump discharge pressure	0 to 60 psia	0 to 80 psia	GLYCOL pressure indicator
GF2781T	Regenerative heat exchanger coolant outlet temperature (hot)	0° to +200°F		None
GF2841T	Regenerative heat exchanger coolant inlet temperature (hot)	0° to +200°F		None
GF2871T	Cabin heat exchanger coolant outlet temperature	+20° to +120°F		None
GF2921P	Redundant pump discharge pressure (GF9997U)	0 to 60 psia		None
GF2935X	Selected coolant pump failure	Contact closure		ECS caution light
GF2936X	Selected coolant pump failure	Contact closure		GLYCOL PUMP component caution light
GF3071X	PRESS REG A valve locked closed	Contact closure(R)		None
GF3072X	PRESS REG A valve open position	Contact closure(R)		None
GF3073X	PRESS REG B valve locked closed	Contact closure(R)		None
GF3074X	PRESS REG B valve open position	Contact closure(R)		None
GF3571P	Cabin pressure	0 to 10 psia (R)	0 to 10 psia	None

ENVIRONMENTAL CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-47. Environmental Control Subsystem - Telemetry Measurement (cont)

Code	Description	Telemetry Range	Display Range	Crew Display
GF3571P	Cabin pressure	0 to 10 psia	0 to 10 psia	CABIN PRESS indicator
GF3572P	Cabin repressurization and emergency oxygen valve electrically open	Contact closure(R)		None
GF3572P	Cabin repressurization and emergency oxygen valve electrically open.	Contact closure		CABIN WARNING light
GF3582P	No. 1 Ascent oxygen tank pressure	0 to 1000 psia (R)		None
GF3582P	Ascent oxygen tank No. 1 pressure	684/100 psia		O ₂ QTY caution light
GF3582P	Ascent oxygen tank No. 1 pressure	0% to 100%	0% to 100%	O ₂ QUANTITY indicator
GF3583P	Ascent oxygen tank No. 2 pressure	0 to 1,000 psia (R)		None
GF3583P	Ascent oxygen tank No 2 pressure	684 psia		O ₂ QTY caution light
GF3583P	Ascent oxygen tank No. 2 pressure	0 to 854 psia	0% to 100%	O ₂ QUANTITY indicator
GF3584P	Descent oxygen tank pressure	0 to 3,000 psia (R)		None
GF3584P	Descent oxygen tank pressure	135 psia		O ₂ QTY caution light
GF3584P	Descent oxygen tank pressure	0% to 100%	0% to 100%	O ₂ QUANTITY indicator
GF3585T	Ascent oxygen tank No. 1 surface temperature	0° to +200° F (R)		None
GF3586T	Ascent oxygen tank No. 2 surface temperature	0° to +200° F (R)		None
GF3587T	Descent oxygen tank surface temperature	0° to +200° F (R)		None
GF3589P	Selected oxygen supply pressure	0 to 1,400 psia (R)		None
GF3591P	Safety valve No. 1 servo pressure	0 to 25 psia (R)		None
GF3592P	Safety valve No. 2 servo pressure	0 to 25 psia (R)		None
GF4101P	Main water regulator ARS ΔP	0 to 2 psid (R)		None
GF4102P	Redundant water regulator ARS ΔP	0 to 2 psid		None
GF4511T	Main sublimator inlet water temperature	+20° to +160° F (R)		None

ENVIRONMENTAL CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-47. Environmental Control Subsystem - Telemetry Measurement (cont)

Code	Description	Telemetry Range	Display Range	Crew Display
GF4541T	Suit sublimator inlet water temperature	+20° to +160° F		None
GF4561T	Descent tank outlet water temperature	0° to +200° F		None
GF4562T	Ascent tank No. 1 outlet water temperature	0° to +200° F		None
GF4563T	Ascent tank No. 2 outlet water temperature	0° to +200° F		None
GF4581Q	Descent tank water quantity	0% to 100% (R)		
GF4581Q	Descent tank water quantity	15.96%	0% to 100%	WATER QTY caution light
GF4581Q	Descent tank water quantity	0% to 100%	0% to 100%	H ₂ O QUANTITY indicator
GF4582Q	Ascent tank No. 1 water quantity	0% to 100%	0% to 100%	H ₂ O QUANTITY indicator
GF4582Q	Ascent tank No. 1 water quantity	94.78%		WATER QTY caution light
GF4582Q	Ascent tank No. 1 water quantity			WATER QTY caution light
GF4582Q	Ascent tank No. 1 water quantity	0% to 100% (R)	0% to 100%	
GF4583Q	Ascent tank No. 2 water quantity	94.78%		WATER QTY caution light
GF4583Q	Ascent tank No. 2 water quantity			WATER QTY caution light
GF4583Q	Ascent tank No. 2 water quantity	0% to 100% (R)	0% to 100%	H ₂ O QUANTITY indicator
GF8013X	Crossover water solenoid valve open	Contact closure		None
GF8030X	Primary water solenoid valve open	Contact closure		None
GF8507V	Cabin pressure logic out voltage	0 to 28 vdc		None
GF8509V	PRESS REG A and B valve switch test voltage	0 to 28 vdc		None
GF9993U	LiOH select/high CO ₂ advisory	Contact closure		CO ₂ component caution light
GF9995U	Selected suit compressor rate	14,000 to 30,000 rpm		None
GF9997U	Selected pump discharge pressure	0 to 60 psia (R)	0 to 80 psia	None

ENVIRONMENTAL CONTROL SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-47. Environmental Control Subsystem - Telemetry Measurement (cont)

Code	Description	Telemetry Range	Display Range	Crew Display
GF9997U	Selected pump discharge pressure	0 to 80 psia		GLYCOL PRESS indicator
GF9998U	Selected coolant loop temperature	+20° to +120° F (R)	+20° to +120° F	None
GF9998U	Selected coolant loop temperature	+50° F	+49.98° F	GLYCOL caution light
GF9998U	Selected coolant loop temperature	0° to +80° F	0° to + 80° F	GLYCOL TEMP indicator
GF9999U	Selected water separator rate	600 to 3,500 rpm (R)	500 to 3,600 rpm	None
GF9999U	Selected water separator rate	800 rpm		ECS caution light
GF9999U	Selected water separator rate			H ₂ O SEP component caution light
JF8521V	Cabin fan No. 1 voltage	0 to 15 vdc		None
JF8522V	Cabin fan No. 1 voltage	0 to 15 vdc		None
JF8523V	Cabin fan No. 2 voltage	0 to 15 vdc		None
JF8524V	Cabin fan No. 2 voltage	0 to 15 vdc		None
JF8525V	Water solenoid valve voltage	-28 to +28 vdc		None
JF8530V	Primary water solenoid valve voltage	-28 to +28 vdc		None
JF8535V	Suit fan No. 2 voltage	0 to 15 vdc		None
JF8536V	Suit fan No. 1 voltage	0 to 15 vdc		None

ENVIRONMENTAL CONTROL SUBSYSTEM

2.7 COMMUNICATIONS SUBSYSTEM.

2.7.1 INTRODUCTION. (See figure 2-131.)

The Communications Subsystem (CS) provides one of two communications links between LM3 and the Manned Space Flight Network (MSFN) and provides the only link between LM3 and the CSM. The CS described in the following paragraphs provides the communications links during earth-orbital missions. Additional government-furnished communications and instrumentation equipment (Developmental Flight Instrumentation) is included to provide flight qualification data in preparation for lunar missions. The Developmental Flight Instrumentation (DFI) is described in subsection 2.9.

The CS includes all S-band, VHF, and signal-processing equipment necessary to transmit and receive voice and tracking and ranging data, and to transmit telemetry and emergency keying. The CS interfaces with the Electrical Power Subsystem (EPS) for a-c and d-c power requirements and with the Instrumentation Subsystem (IS) for vehicle subsystem data, biomedical data, timing signals, and recording facilities.

Voice communications between the LM and MSFN are provided by the S-band transmitter-receiver assemblies, and between the LM and CSM by VHF transmitter-receiver assemblies. Communication with MSFN via VHF/AM is possible during earth-orbital missions. Telemetry data are transmitted to MSFN via S-band and DFI communications, with DFI being the prime mode. Prime tracking is via C-band (DFI), with the S-band equipment providing a ranging and tracking backup. An additional UHF receiver will be used to receive signals in a modulated serial digital format, for ground control of selected subsystems. This receiver, the digital command assembly (DCA), is part of the LM mission programmer (LMP). The DCA is described in subsection 2.9. The communications links provided by the CS, and their purpose, are listed in table 2-48.

CS

2.7.2 FUNCTIONAL DESCRIPTION.

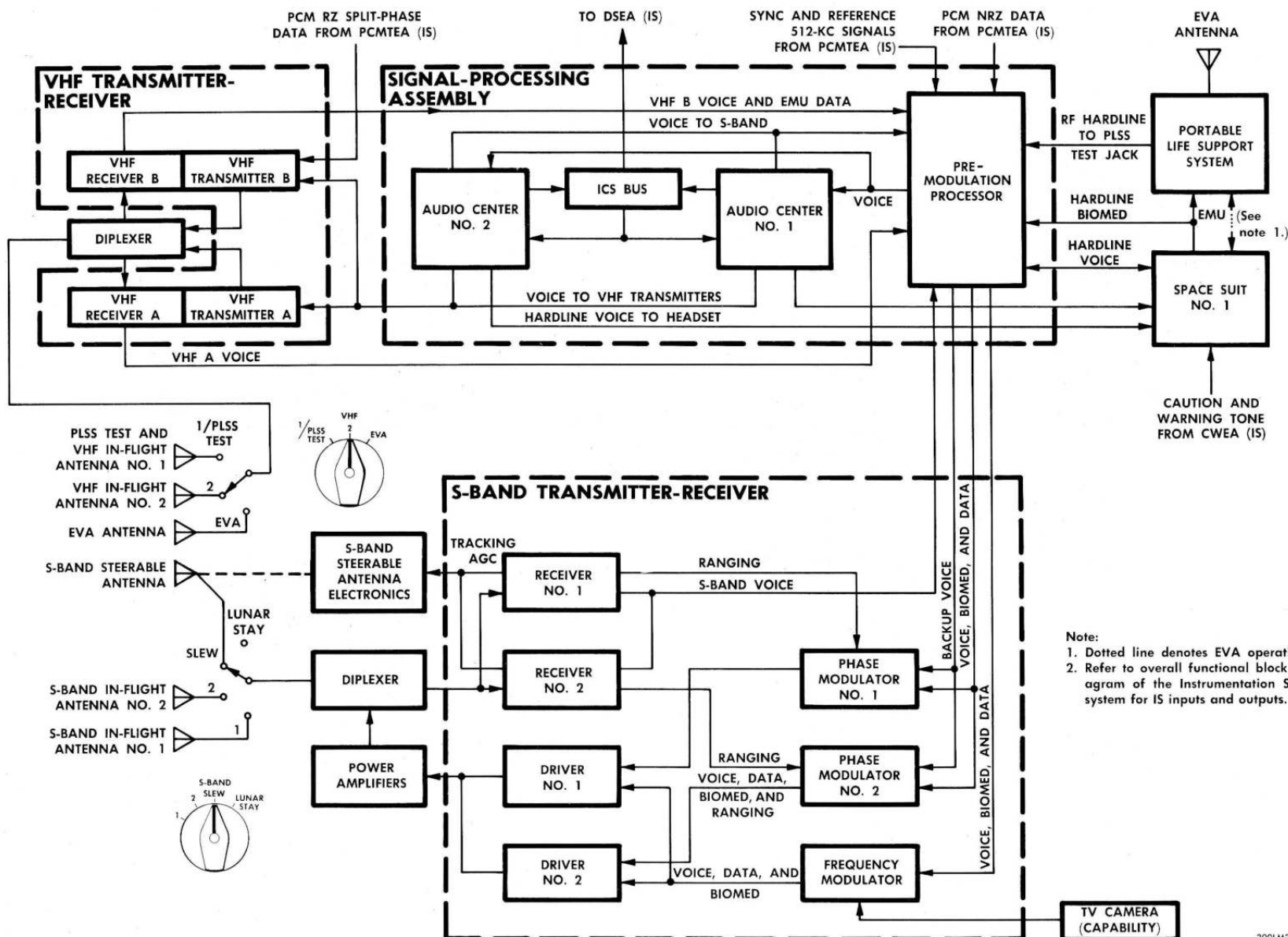
Figure 2-132 shows the voice and data links with related operating frequencies, used for in-flight communications. The DFI communications links (IS) are also included to illustrate total communication capability.

2.7.2.1 Voice Operation.

All voice communications are accomplished through the astronaut's microphone and headset equipment. Voice communication is used between the LM and the CSM; between the LM and MSFN; between the LM, CSM, and MSFN (conference); and between the astronauts.

Each astronaut has an audio center subassembly (part of the signal-processing assembly), which serves as the common acquisition and distribution center for his voice communications. Each astronaut controls audio volume to his headset with his VOLUME thumbwheels (panel 8 or 12). Depending on the selected mode of operation, voice is transmitted to MSFN or the CSM, or stored on tape in the data storage electronics assembly (DSEA) of the IS.

Voice transmission is initiated with any one of four push-to-talk (PTT) switches (one on each of the two electrical umbilicals and two attitude controller assemblies) or the voice-operated relay (VOX) circuit. In addition, a hot-microphone capability exists for intercom only. The PTT switches on the electrical umbilicals can also be used as keying switches for emergency key transmission.



Note:
1. Dotted line denotes EVA operation.
2. Refer to overall functional block diagram of the Instrumentation Subsystem for IS inputs and outputs.

Figure 2-131. Communications Subsystem-Simplified Block Diagram

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-48. Communications Links

Link	Mode	Band	Purpose
MSFN-LM-MSFN	Pseudorandom noise	S-band	Ranging and tracking
LM-MSFN	Voice	S-band, VHF (optional)	In flight communications
LM-CSM	Voice	VHF simplex	In-flight communications
CSM-LM-MSFN	Voice	VHF and S-band	Conference (with LM as relay)
LM-CSM	Low-bit-rate telemetry	VHF (one way)	Record and retransmit to earth
MSFN-LM	Voice	S-band, VHF (optional)	In-flight communications
LM-MSFN	Biomed-PCM telemetry	S-band	In-flight communications
LM-MSFN-CSM	Voice	S-band or VHF	Conference (with earth as relay)
LM-EVA-LM	Voice and data	VHF duplex	EVA direct communications
EVA-LM-MSFN	Voice and data	VHF, S-band	Conference (with LM as relay)
EVA-LM-CSM	Voice and data	VHF duplex	Conference (with LM as relay)
CSM-MSFN-LM-EVA	Voice and data	S-band, VHF	Conference (via MSFN-LM relay)

Two types of voice communication are used in the CS: S-band and VHF. All voice links are line-of-sight (LOS); both ends of the communications path must be in unobstructed line of sight to each other.

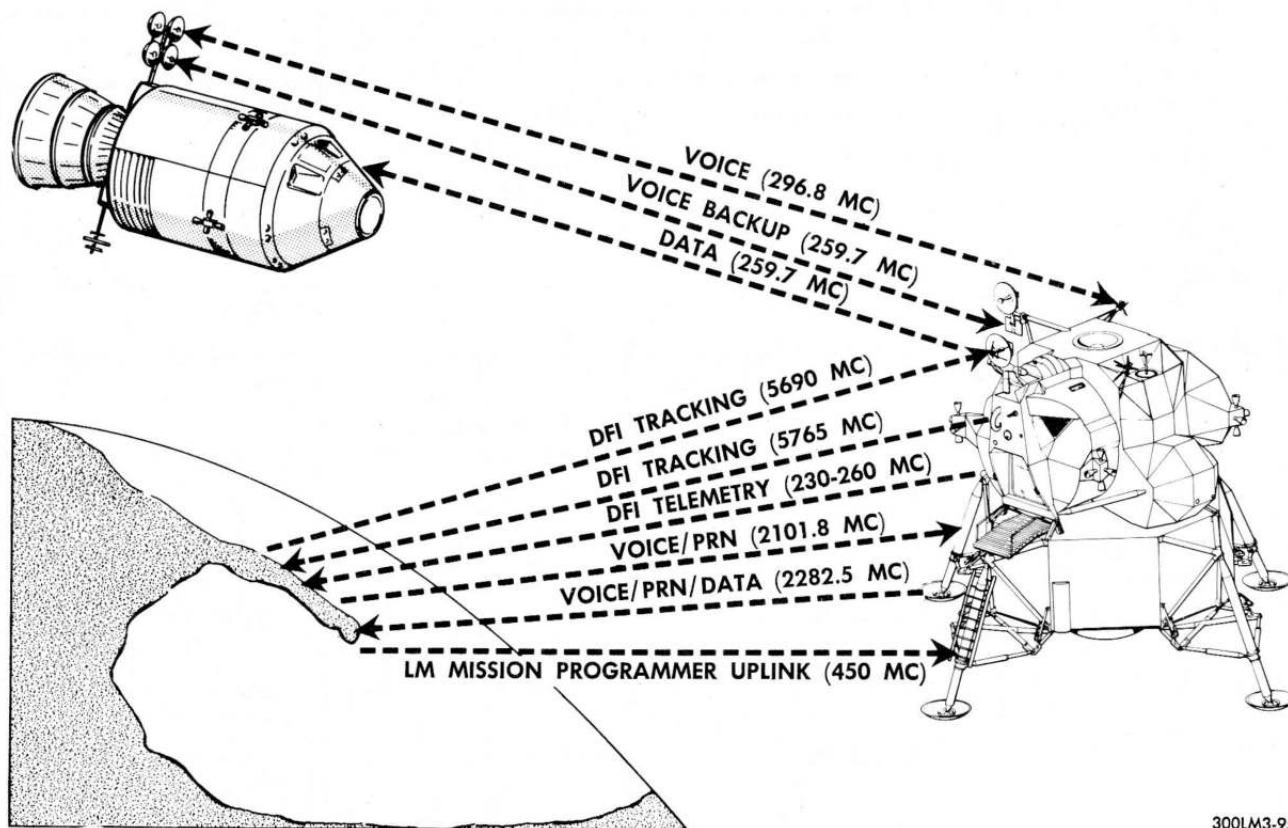
2.7.2.2

DATA OPERATIONS.

LM 3 has transducers that sense physical data from all subsystems and convert the data into electrical outputs acceptable to the DFI or IS. Biomedical (biomed) analog data from sensors worn by the astronauts are also transmitted to MSFN, in pulse-code-modulation (PCM) form. These data are also processed through the IS and DFI.

The IS processes signals supplied by the transducers, converts them to digital form, and routes them serially to the CS for transmission to MSFN or the CSM. These data, in PCM form, are transmitted at one of two data rates: 51,200 bits per second (high bit rate) or 1,600 bits per second (low bit rate). Transmission to MSFN is accomplished via the S-band FM and PM transmitters at either data rate. The PCM data are also transmitted to the CSM via the 259.7-mc transmitter in the CS during loss of LOS between the LM and MSFN, at the low bit rate only. The CSM records these data for retransmission to MSFN, at a later time.

The DFI also provides data transmission to MSFN, via five VHF/FM transmitters during earth-orbital missions.



300LM3-95

Figure 2-132. In-Flight Communications

2.7.2.3

Ranging and Tracking.

LM 3 ranging and tracking equipment enables MSFN to accurately determine the angular position and range of the LM. Two methods are used: C-band tracking (DFI) and S-band tracking.

The S-band transponder is used primarily during deep-space missions; for earth-orbital missions, it is used as backup for the C-band (DFI) transponder. The S-band transponder receives coded pseudo-random noise (PRN) signals from MSFN. These signals are routed to the selected PM transmitter for in-phase-coherence transmission back to MSFN. S-band transmission is at 2282.5 mc; reception at 2101.8 mc.

The tracking and ranging function uses the doppler frequency shift caused by LM high velocity rates, to track the LM. The coded PRN signal transmitted by MSFN is received by a receiver with a phase-locked loop, and retransmitted to MSFN. The retransmitted signal received by MSFN is compared with the originally transmitted signal. Basically, range is determined by the time it takes for the signals to travel from MSFN to the LM and back to MSFN. Once the range has been established accurately by the PRN code, the code is discontinued and range is updated continually by the doppler technique. The phase-locked loop in the LM receiver ensures accuracy of the tracking signals (doppler) by comparing the phase of the received signal with the phase of a local-oscillator output in the detector stage. (See figure 2-135.) The output voltage of the detector, which is proportional to the phase difference between the two signals, is applied to the local oscillator. This signal is applied as a control voltage

to alter the local-oscillator frequency to bring it in phase with the received MSFN signal.

2.7.2.4 Subsystem Operation.

The normal switch and circuit breaker positions for the operational communications modes are listed in table 2-49. If a switch or circuit breaker is not listed for a particular mode, that mode is not influenced by that switch or circuit breaker. The switch positions listed are for prime positions. In some cases, more than one position functions as a prime position; all such positions are indicated.

2.7.3 MAJOR COMPONENT/FUNCTIONAL DESCRIPTION.

The CS is divided into three groups: RF electronic equipment, signal-processing assembly (SPA), and antenna equipment. The items included in each group are listed in table 2-50.

2.7.3.1 RF Electronic Equipment.

The RF electronic equipment includes all subsystem equipment required for transmission and reception of audio, PRN, and telemetry data. The antennas mentioned in the discussion of the RF electronic equipment are covered in paragraph 2.7.3.3. The CS can transmit video, but this function is not used in LM 3.

2.7.3.1.1 S-Band Transmitter-Receiver Assembly. (See figure 2-133.)

The S-band transmitter-receiver assembly provides deep-space and earth-orbital communications between the LM and MSFN. S-band communications consist of voice and PRN transmission from MSFN to the LM, and voice, PRN turnaround, biomed, and subsystem data transmission from the LM to MSFN. The prime function of the S-band transmitter-receiver assembly is to provide deep-space communications. However, it is used during earth-orbital missions as backup for DFI equipment that provides voice, telemetry, and tracking communications, if the LM is within range of MSFN stations equipped for S-band communications.

The S-band transmitter-receiver assembly consists of two identical phase-locked receivers, two phase modulators with driver and multiplier chains, and a frequency modulator. The receivers and phase modulators provide the ranging, voice, emergency-keying, and telemetry transmit-receive functions. The frequency modulator is provided primarily for video transmission, but also accommodates PCM telemetry (subsystem data), biomed, and voice transmission. The frequency modulator does not accommodate PRN data or emergency keying, because PRN data and video use the low end of the baseband generated in the SPA (thereby occupying the same spectrum), and emergency keying is routed only to the PM transmitters. Therefore, the frequency modulator provides limited backup for both phase modulators. The operating frequencies of the S-band equipment are 2282.5 mc (transmit) and 2101.8 mc (receive).

Ranging and tracking is accomplished by phase-modulating the transmit carrier with the PRN ranging code, at MSFN. This signal, detected by the LM S-band receiver, is used to phase-modulate the carrier transmitted to MSFN. MSFN receives the carrier and measures the time that elapsed between transmission of the original signal and reception of the response, thereby obtaining an accurate measurement of range. Once these measurements are established, the range of the LM can be updated continuously at MSFN by a doppler technique.

Table 2-49. Communications Subsystem - General Switch and Circuit Breaker Configuration

Switches and Circuit Breakers	S-Band Voice	PRN Ranging	S-Band Telem- etry	Hard- line- Biomed	S-Band Voice (BU)	Emer- gency Key	TV	High- Power S-Band	S-Band Steerable Antenna	VHF A Sim- plex	VHF B Sim- plex	VHF B Telem- etry	VHF A/B Duplex
Panel 8 (AUDIO)													
S-BAND T/R switch	S-BAND T/R				S-BAND T/R								
ICS T/R switch	ICS T/R									ICS T/R	ICS T/R		ICS T/R
VHF A switch										T/R	OFF		RCV
VHF B switch										OFF	T/R		T/R
RELAY ON switch (See note 1.)	RELAY OFF				(See note 1. Only one RELAY ON switch can be set to RELAY ON at a time.)								
VOX switch (See note 2.)	ICS/ XMTR									ICS/ XMTR	ICS/ XMTR		ICS/ XMTR
AUDIO CONT switch	NORM				NORM					NORM	NORM		NORM
Panel 12 (AUDIO)													
S-BAND T/R switch	S-BAND T/R				S-BAND T/R								
ICS T/R switch	ICS T/R									ICS T/R	ICS T/R		ICS T/R
VHF A switch										T/R	OFF		RCV
VHF B switch										OFF	T/R		
RELAY ON switch (See note 1.)	RELAY OFF				(See note 1. Only one RELAY ON switch can be set to RELAY ON at a time.)								
VOX switch (See note 2.)	ICS/ XMTR									ICS/ XMTR	ICS/ XMTR		ICS/ XMTR
AUDIO CONT switch	NORM				NORM					NORM	NORM		NORM

Table 2-49. Communications Subsystem - General Switch and Circuit Breaker Configuration (cont)

Switches and Circuit Breakers	S-Band Voice	PRN Ranging	S-Band Telemetry	Hard-line Biomed	S-Band Voice (BU)	Emergency Key	TV	High-Power S-Band	S-Band Steerable Antenna	VHF A Simplex	VHF B Simplex	VHF B Telemetry	VHF A/B Duplex
Panel 12 (COMMUNICATIONS)													
MODULATE switch	PM or FM	PM	PM or FM	PM or FM	PM	PM	FM	PM or FM					
XMTR/RCVR switch	PRIM	PRIM	PRIM	PRIM	PRIM	PRIM	PRIM	PRIM					
PWR AMPL switch	OFF	OFF	OFF	OFF	OFF	OFF	OFF	PRIM					
VOICE FUNCTIONS switch	VOICE	VOICE or OFF			VOICE BU	OFF							
PCM FUNCTIONS switch			PCM			KEY							
RANGE FUNCTIONS switch		RANGE			OFF/RESET	OFF/RESET	TV/CWEA ENABLE						
VHF A XMTR switch										ON	OFF		ON
VHF A RCVR switch										ON	OFF		OFF
VHF B XMTR switch										OFF	VOICE	DATA	VOICE
VHF B RCVR switch										OFF	ON	OFF	ON
BIOMED TELEMETRY switch				LEFT or RIGHT	OFF								
PCM TELEMETRY switch			HI or LO									LO	
RECORDER switch (See note 3.)													
Panel 12 (COMMUNICATIONS ANTENNAS)													
VHF selector switch										1/PLSS TEST or 2	1/PLSS TEST or 2	1/PLSS TEST or 2	1/PLSS TEST or 2
S-BAND selector switch	1 or 2	1 or 2	1 or 2	1 or 2	1 or 2	1 or 2	1 or 2	1 or 2	SLEW				

Table 2-49. Communications Subsystem - General Switch and Circuit Breaker Configuration (cont)

Switches and Circuit Breakers	S-Band Voice	PRN Ranging	S-Band Telemetry	Hard-line Biomed	S-Band Voice (BU)	Emergency Key	TV	High-Power S-Band	S-Band Steerable Antenna	VHF A Simplex	VHF B Simplex	VHF B Telemetry	VHF A/B Duplex
Panel 12 (COMMUNICATIONS ANTENNAS) (cont)													
TRACK MODE switch (See note 4.)	OFF	OFF	OFF	OFF	OFF	OFF	OFF		SLEW or AUTO				
PITCH control									-75° to 255°				
YAW control									-75° to 75°				
Circuit Breaker Panel 11													
AC BUS B: S-BD ANT (See note 4.)	Open	Open	Open	Open	Open	Open	Open	Open	Closed				
COMM: SEC S-BD XMTR/RCVR	Open	Open	Open	Open	Open	Open	Open	Open	Open				
COMM: SEC S-BD PWR AMPL (See note 5.)	Open	Open	Open	Open	Open	Open	Open	Open	Open				
COMM: VHF A RCVR										Closed	Open		Closed
COMM: VHF B XMTR										Open	Closed	Closed	Closed
COMM: CDR AUDIO	Closed			Closed	Closed					Closed	Closed		Closed
Circuit Breaker Panel 16													
COMM: SE AUDIO	Closed			Closed	Closed					Closed	Closed		Closed
COMM: VHF A XMTR										Closed	Open		Closed
COMM: VHF B RCVR										Open	Closed		Closed
COMM: PRIM S-BD PWR AMPL (See note 5.)	Open	Open	Open	Open	Open	Open	Open	Closed	Open				
COMM: PRIM S-BD XMTR/RCVR	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed				
COMM: S-BD ANT (See note 4.)	Open	Open	Open	Open	Open	Open	Open	Open	Closed				

Table 2-49. Communications Subsystem - General Switch and Circuit Breaker Configuration (cont)

Switches and Circuit Breakers	S-Band Voice	PRN Ranging	S-Band Telemetry	Head-line Biomed	S-Band Voice (BU)	Emergency Key	TV	High-Power S-Band	S-Band Steerable Antenna	VHF A Sim-plex	VHF B Sim-plex	VHF B Telemetry	VHF A/B Duplex
Circuit Breaker Panel 16 (cont)													
COMM: PMP	Closed		Closed	Closed		Closed	Closed			Closed	Closed	Closed	Closed
COMM: TV		Open			Open	Open	Closed						
COMM: DISP	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed
Push-to-Talk (PTT) Switches (See note 6.)													
Commander's attitude controller assembly PTT switch													
LM Pilot's attitude controller assembly PTT switch													
Commander's electrical umbilical PTT switch						PTT switch used as keyer							
LM Pilot's electrical umbilical PTT switch						PTT switch used as keyer							

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-49. Communications Subsystem - General Switch and Circuit Breaker Configuration (cont)

NOTES:

1. The normal positions for switches on the AUDIO portion of panels 8 and 12 for relay modes, are as follows:

- CSM-LM VHF A simplex, relayed to MSFN via S-band

Panel 8:

RELAY ON switch - RELAY ON
VHF A switch - T/R
VHF B switch - OFF
S-BAND T/R switch - OFF or S-BAND RCV
VOX switch - ICS/XMTR

Panel 12:

RELAY ON switch - RELAY OFF
VHF A switch - OFF or RCV
VHF B switch - OFF
S-BAND T/R switch - S-BAND T/R
VOX switch - ICS/XMTR

- or -

Panel 8:

RELAY ON switch - RELAY OFF
VHF A switch - OFF or RCV
VHF B switch - OFF
S-BAND T/R switch - S-BAND T/R
VOX switch - ICS/XMTR

Panel 12:

RELAY ON switch - RELAY ON
VHF A switch - T/R
VHF B switch - OFF
S-BAND T/R switch - OFF or S-BAND RCV
VOX switch - ICS/XMTR

- EVA-LM VHF A/B duplex, relayed to MSFN via S-band (assuming the remaining astronaut is at the Commander's flight station)

Panel 8:

VOX switch - ICS/XMTR
RELAY ON switch - RELAY ON
VHF A switch - OFF
VHF B switch - OFF
S-BAND T/R switch - OFF
AUDIO CONT switch - BU

Panel 12:

RELAY ON switch - RELAY OFF
VHF A switch - T/R
VHF B switch - RCV
S-BAND T/R switch - S-BAND T/R
VOX switch - ICS/XMTR

- or -

COMMUNICATIONS SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-49. Communications Subsystem - General Switch and Circuit Breaker Configuration (cont)

NOTES:

1. Panel 8:
 (cont)
 - AUDIO CONT switch - NORM
 - RELAY ON switch - RELAY OFF
 - VHF A switch - T/R
 - VHF B switch - RCV
 - S-BAND T/R switch - S-BAND T/R
 - VOX switch - ICS/XMTR
- Panel 12:
 - RELAY ON switch - RELAY ON
 - VHF A switch - OFF
 - VHF B switch - OFF
 - S-BAND T/R switch - OFF
 - VOX switch - ICS/XMTR
2. The Commander's and LM Pilot's VOX switches must be set to ICS/XMTR when combined VHF and S-band equipments are used (relay operation). The ICS position provides hot-microphone capabilities on intercom.
3. The setting of the RECORDER switch does not affect any operational mode setting. The switch may be set to ON when audio transmission to MSFN cannot be accomplished.
4. Normally, the S-band steerable antenna is not used on LM 3.
5. Normally, the S-band power amplifier is not used during this mission.
6. PTT override exists for all VOX modes. In the emergency-keying mode, only one astronaut should key at a time.

Table 2-50. Communications Subsystem - Equipment Groups

Group	Component
RF electronic equipment	S-band transmitter-receiver assembly
	S-band power amplifier
	S-band diplexer and RF switch
	VHF transmitter-receiver assembly
	VHF diplexer and RF switch
Signal-processing assembly	Premodulation processor
	Audio centers
Antenna equipment	S-band in-flight antennas
	S-band steerable antenna
	VHF in-flight antennas

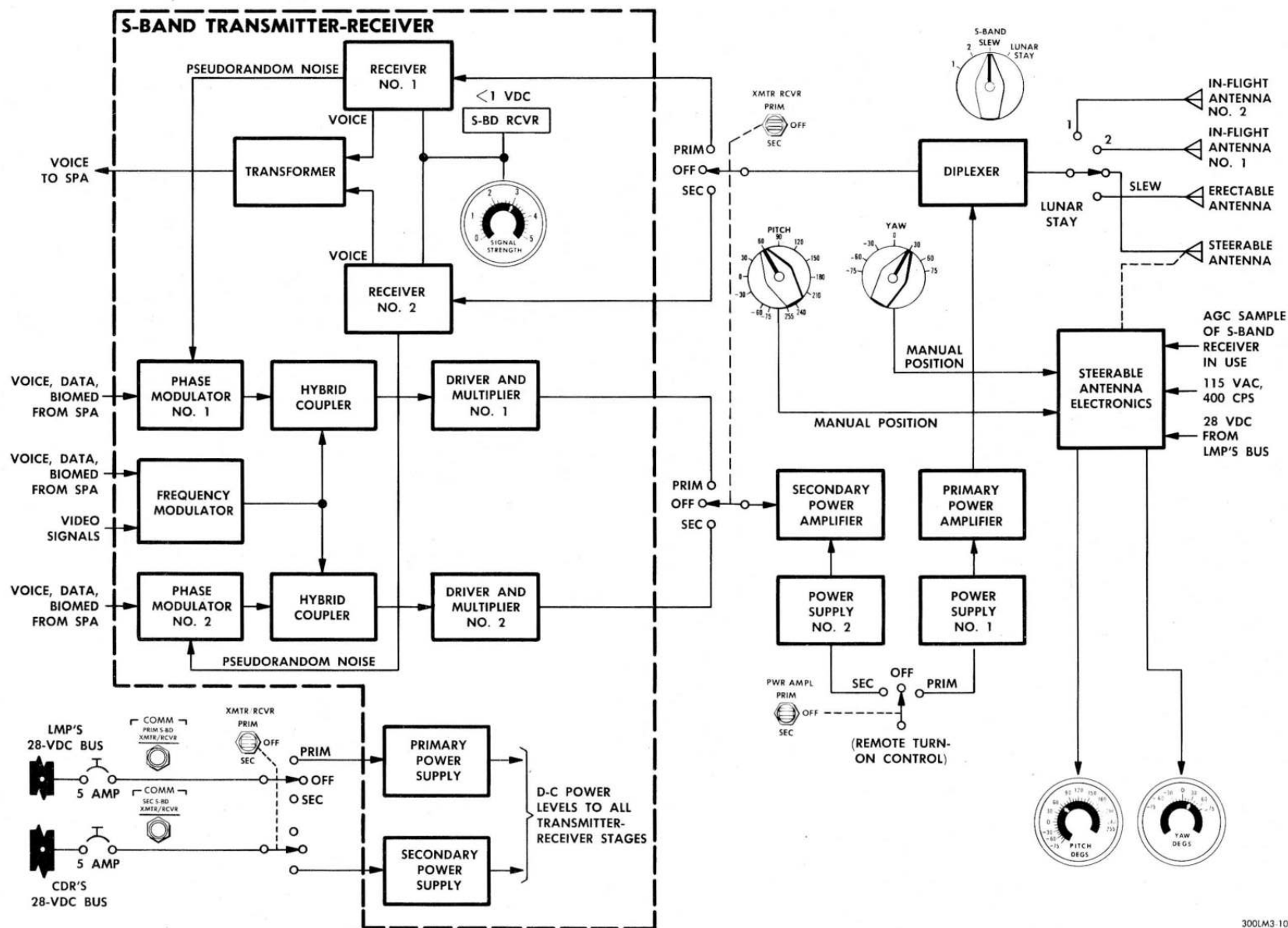


Figure 2-133. S-Band Transmitter-Receiver Assembly - Block Diagram

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

The frequency modulator (figure 2-134) uses a voltage-controlled oscillator (VCO), operating at 76 mc, as the basis of its RF circuit. The FM transmitter is modulated by an input within a 10-cps to 1.5-mc range. A portion of the VCO output is routed through a series of frequency divider networks that reduce the frequency to 9.2 kc. This frequency is compared to the output (also reduced to 9.2 kc) of a 4.7-mc crystal oscillator, in a phase detector. The two inputs to the phase detector are normally 90° out of phase. The phase difference is represented as a voltage at the phase detector output and is used to control VCO frequency stability. The frequency modulator output is then supplied to the selected driver and multiplier chain for transmission through the S-band power amplifier, duplexer, and selected S-band antenna to MSFN.

The phase modulator (figure 2-134) uses the output of the 19-mc VCO in the S-band receiver as the basis of its RF circuit. The VCO output is multiplied to approximately 76 mc in the receiver and routed to the phase modulator, where it is modulated by wide- or narrow-band information supplied from the SPA or by the PRN signal received from MSFN. The 76-mc carrier is then routed through a series of multipliers and drivers, where it is multiplied to the transmit carrier frequency (2282.5 mc).

The prime purpose of the phase modulator during deep-space missions is to provide all in-flight and lunar-stay communications with MSFN. The prime purposes during earth-orbital missions are transmission of voice, backup tracking and ranging, PCM, and biomed data telemetry.

The S-band receivers (figure 2-135) receive voice and coded PRN signals from MSFN. One receiver serves as backup for the normally used unit. The S-band receivers receive a phase-modulated, 2101.8-mc carrier from MSFN. The output of a 19-mc VCO is routed through a chain of multiplier stages, where it is multiplied to 2054.3 mc, and heterodyned with the input carrier to obtain an output frequency of 47.5 mc from the first mixer. The first mixer output is mixed with 38 mc, provided by the VCO through a multiplier stage, yielding a second intermediate frequency of 9.5 mc. The second IF provides several narrow-band outputs, including automatic gain control (AGC) to the first IF, tracking AGC (used to position the steerable antenna), a signal-strength signal to the SIGNAL STRENGTH indicator (panel 12), and AGC-monitoring and static phase error signals that are supplied to the IS, where they are processed for subsequent telemetry transmission. The wide-band signal outputs include voice (routed to the SPA) and the ranging signal (routed to the S-band phase modulator).

A secondary function of the S-band receiver is to provide an output for use as the exciter frequency for the phase modulators. The 19-mc VCO output is routed through a chain of multiplier stages, where it is multiplied to 76 mc for use by the phase modulators.

2.7.3.1.2 S-Band Power Amplifier. (See figure 2-136.)

The S-band power amplifier amplifies the S-band transmitter output when additional transmitted power is required. This assembly consists of two amplitrans, an input and an output isolator (ferrite circulators), and two power supplies, all mounted on a common chassis. The RF circuit is a series interconnection of the isolators and amplitrans. The amplitrans (which are characteristic of saturated, rather than linear, amplifiers) have broad bandwidth, high efficiency, high peak and average power output, but low gain. The normal modes of S-band communications for LM 3 do not require using the S-band power amplifier.

The isolators protect both amplitrans and both S-band transmitter driver and multiplier chains. The isolators exhibit a minimum isolation of 20 db and a maximum insertion loss of 0.6 db.

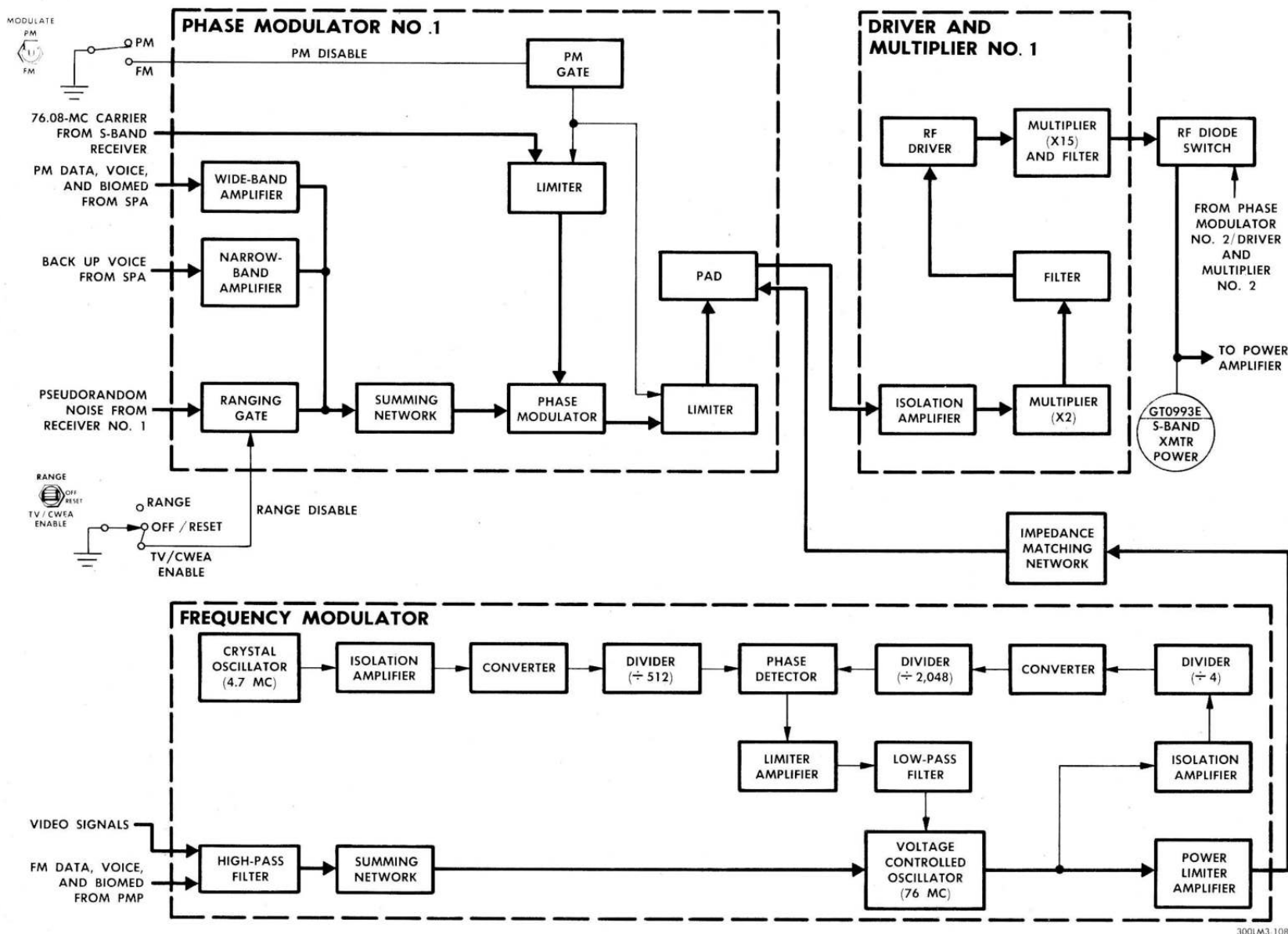
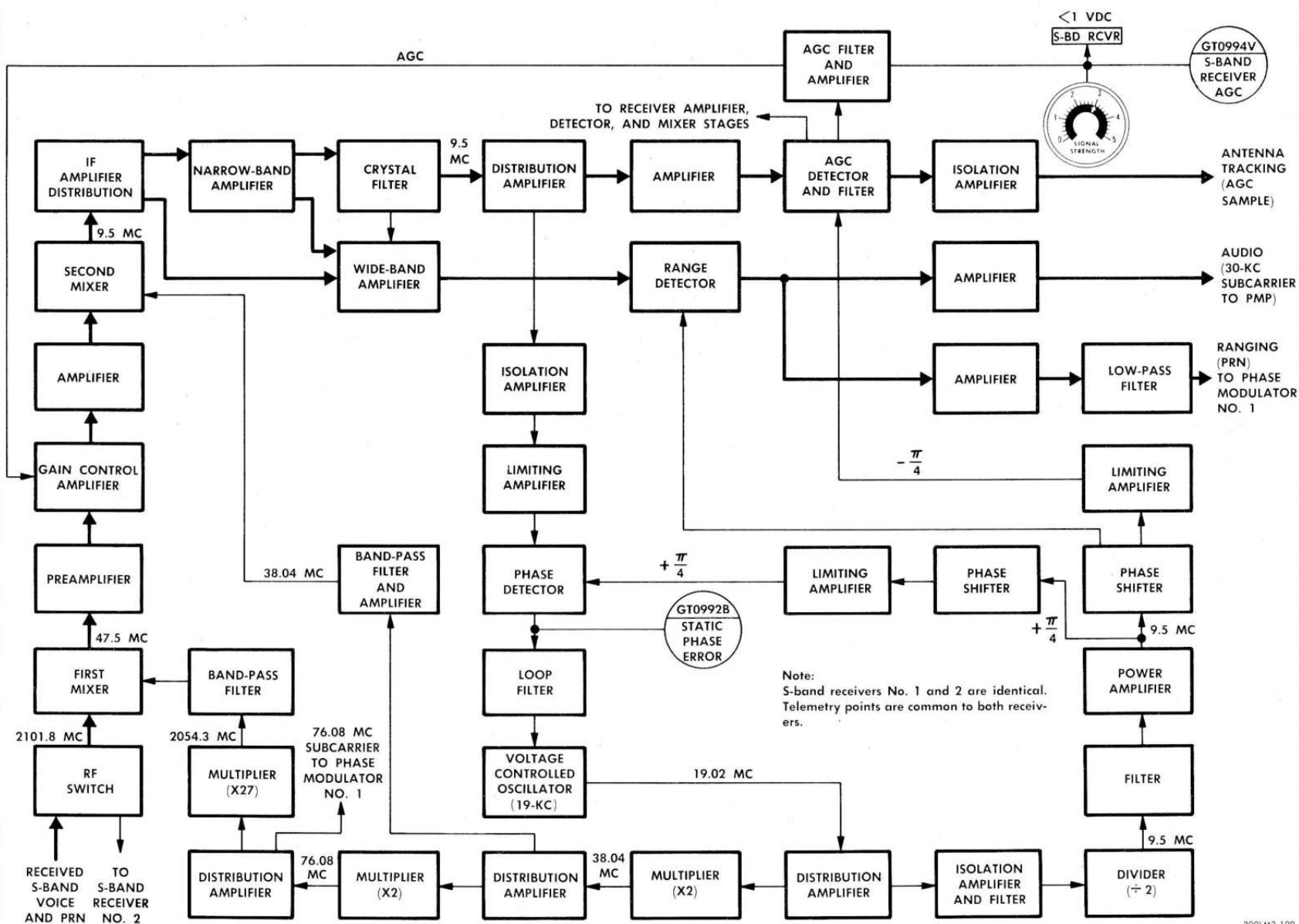


Figure 2-134. S-Band Transmitter - Block Diagram

COMMUNICATIONS SUBSYSTEM



LMA 190-3-LMI 3
 APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

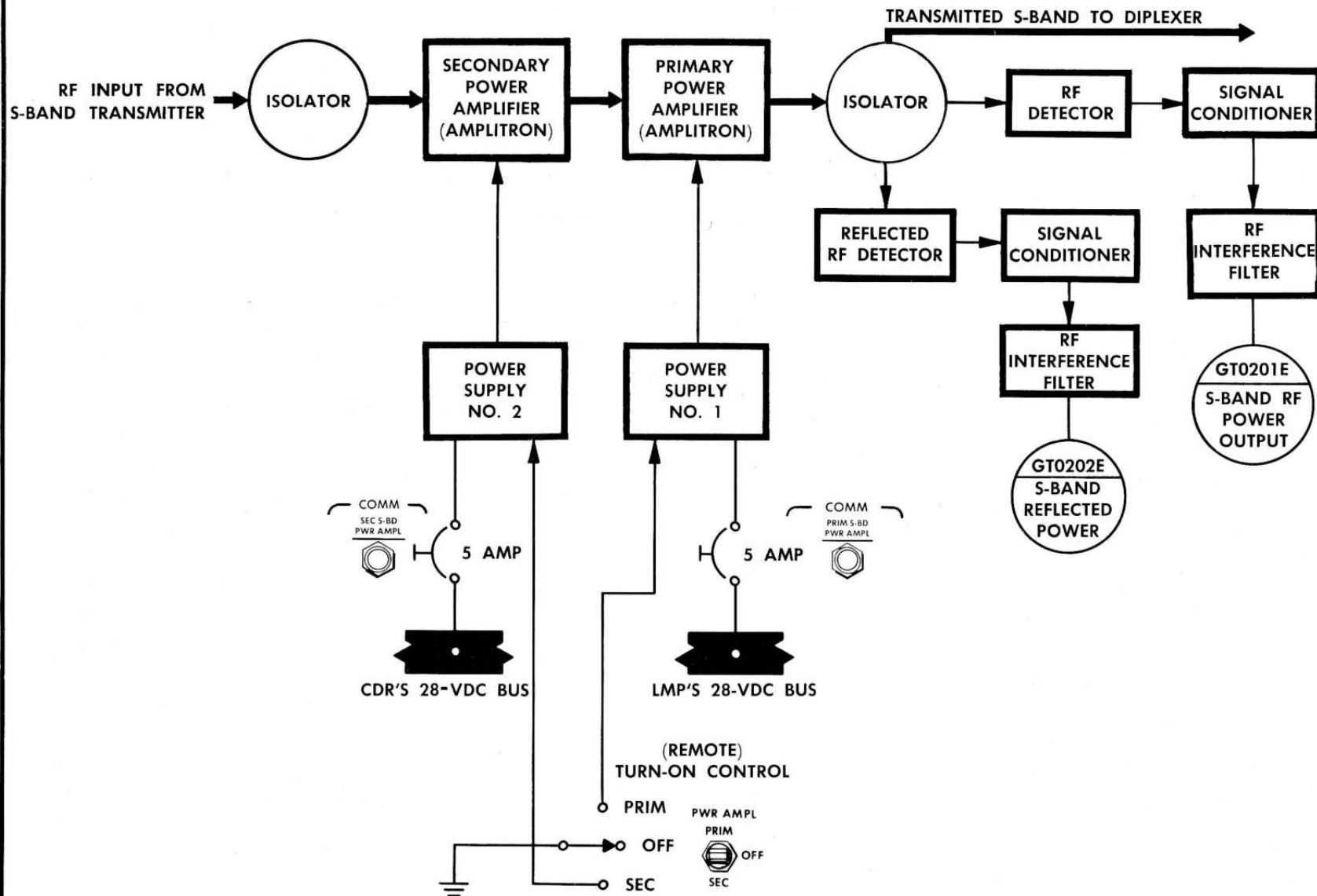


Figure 2-136. S-Band Power Amplifier - Block Diagram

300LM3-110

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Each amplatron is supplied by its own power supply. One amplatron is designated primary; the other, secondary. Only one amplatron can be activated at a time. Selection is made with the PWR AMPL switch (panel 12). When neither amplatron is selected, a feedthrough path through the power amplifier is provided, with an insertion loss of 3.2 db, maximum (feedthrough mode).

When an amplatron is selected, 28 volts dc is supplied to its associated power supply. When 0.75-watt RF power is supplied to the power amplifier input from an S-band transmitter driver and multiplier stage, the minimum output RF power is 18.6 watts through the primary stage or 14.8 watts through the secondary stage at the 2282.5-mc transmit frequency. The slightly degraded power output through the secondary stage is caused by the added attenuation of the primary stage in series with the secondary stage.

2.7.3.1.3 S-Band Diplexer and RF Switch.

The S-band diplexer, connected directly to the output of the S-band power amplifier, permits simultaneous duplex transmission and reception, using one antenna. Insertion loss is 0.9 db (transmit) and 1.3 db (receive).

The S-BAND selector switch on the COMMUNICATIONS ANTENNAS portion of panel 12 enables selection of either S-band in-flight antenna (omnidirectional), the steerable antenna, or the erectable antenna (during lunar stay only). The insertion loss of the switch, in the transmit mode of operation (2282.5 mc), is less than 0.2 db.

2.7.3.1.4 VHF Transmitter-Receiver Assembly. (See figure 2-137.)

The primary functions of the VHF transmitter-receiver assembly are to provide voice communications between the LM and the CSM and, during blackout of transmission to MSFN, to provide low-bit telemetry transmission from the LM to the CSM. This equipment also provides extravehicular astronaut (EVA)/LM voice communications, and reception of EVA biomed and suit data for transmission to MSFN over S-band. During earth-orbital missions, this equipment has the capability to provide voice communications between the LM and MSFN.

The VHF transmitter-receiver assembly consists of two solid-stage superheterodyne receivers, two transmitters, a VHF diplexer, RF antenna selector switch, two in-flight antennas and an EVA antenna (for lunar missions). One transmitter-receiver combination provides a 296.8-mc channel (channel A); the other, a 259.7-mc channel (channel B), for simplex or duplex voice communications. Channel B may also be used to transmit PCM data from the IS at the low bit rate and to receive biomed and suit data from the EVA.

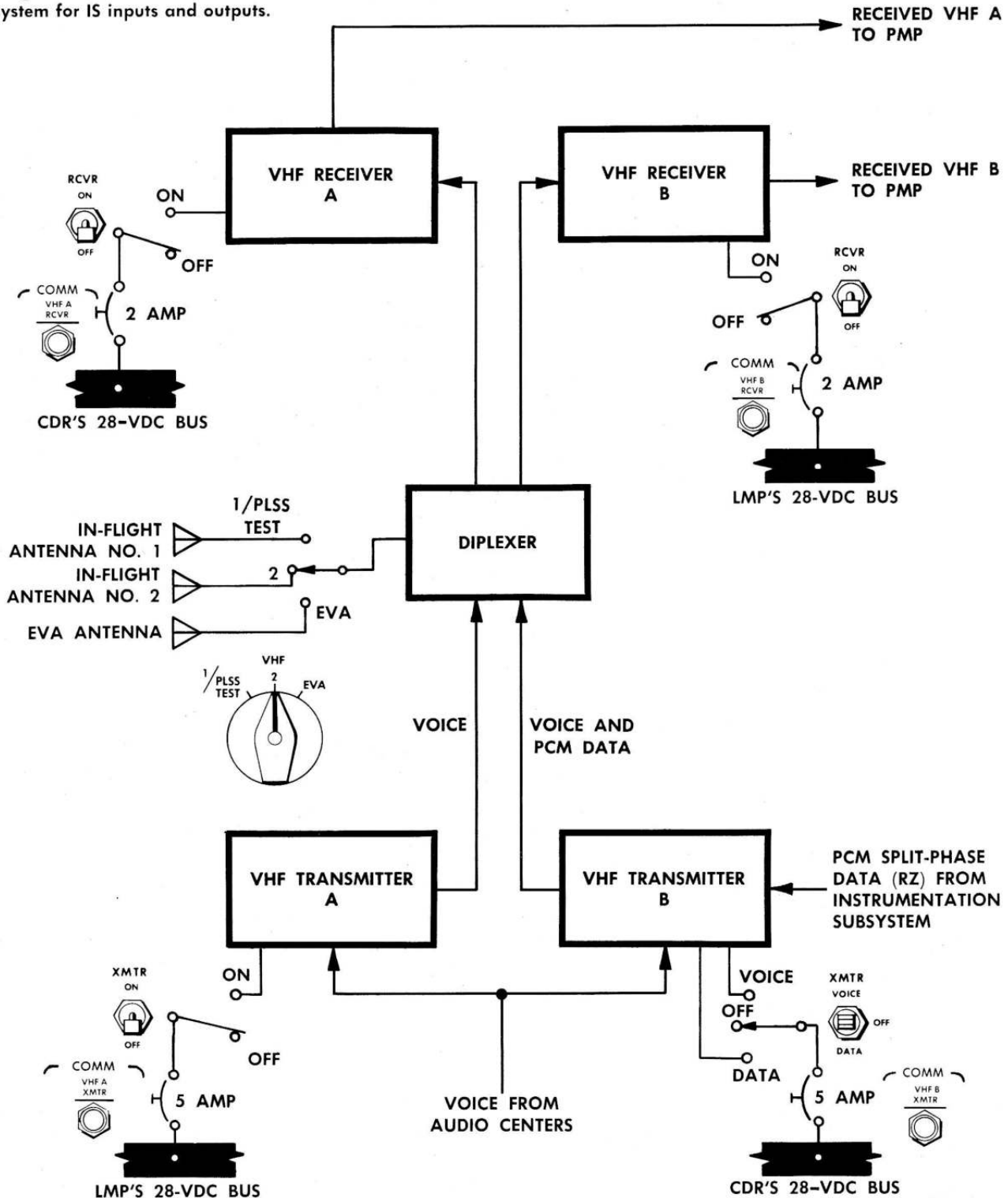
The VHF transmitter (figure 2-138) derives voice modulation and carrier turn-on control signals from the audio centers in the SPA. Carrier turn-on is initiated by the voice-operated relay (VOX) circuit or by operation of the PTT switches. One audio center is connected to the Commander's microphone circuit and to the modulation inputs of the VHF transmitters; the other audio center is similarly connected for the LM Pilot. The input to the channel B transmitter can be switched from voice to PCM transmission by setting the VHF B XMTR switch (panel 12) to DATA. The PCM signals are generated in the pulse-code-modulation and timing electronics assembly (PCMTEA) of the IS. Transmitter outputs are routed to the VHF selector switch (panel 12) and to the antenna via a diplexer that permits simultaneous operation of all VHF transmitters and receivers on a single antenna.

The transmitter uses clipped-speech-type amplitude modulation and delivers a minimum of 10 watts peak and 5 watts average RF power to the diplexer input. Audio input is clipped and amplified by the chain of limiters and amplifiers in the modulator circuit.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Note:

Refer to the overall functional block diagram of the Instrumentation Subsystem for IS inputs and outputs.



300LM3-112

Figure 2-137. VHF Transmitter-Receiver Assembly-Block Diagram

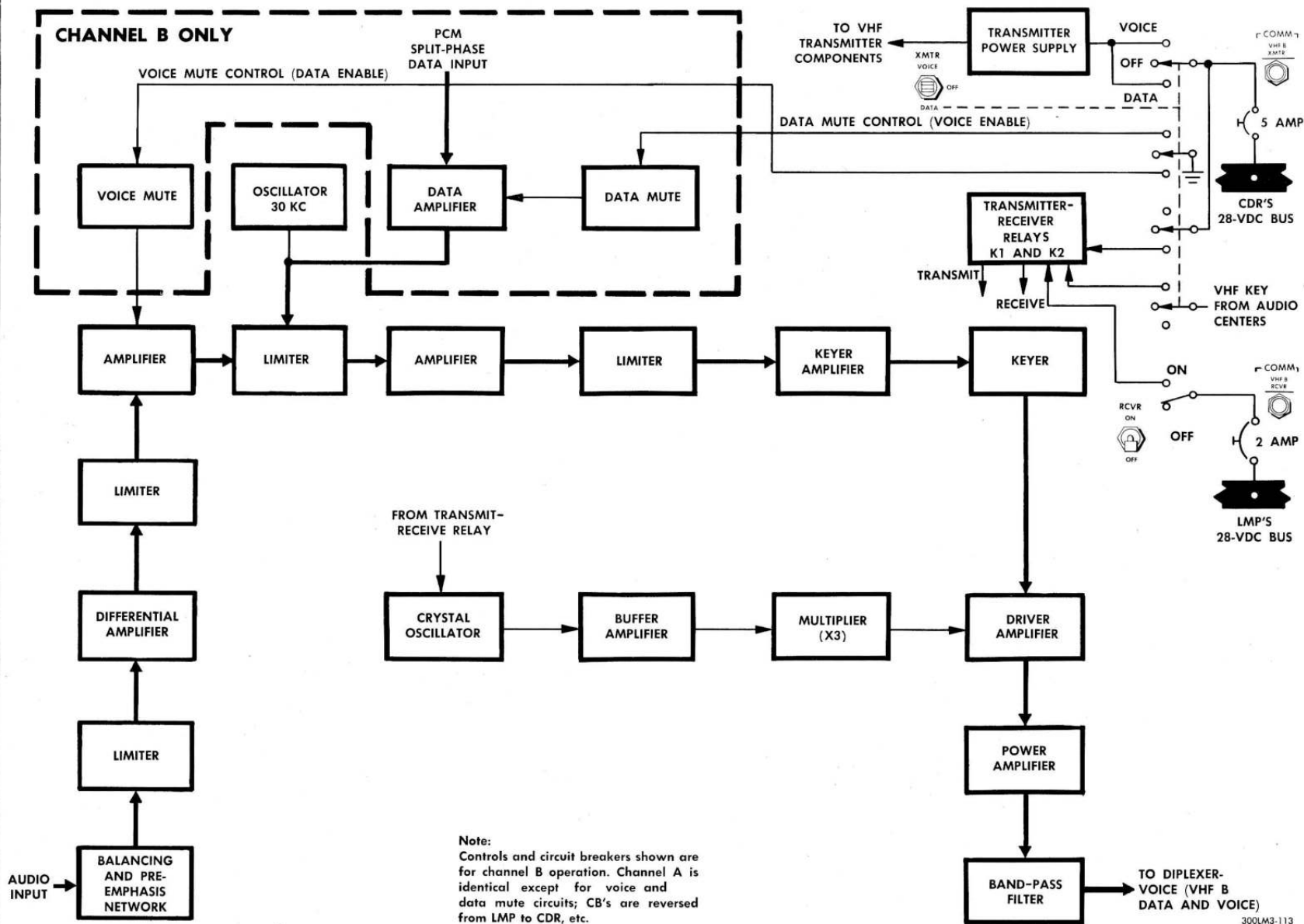


Figure 2-138. VHF Transmitter - Block Diagram

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

After clipping, the input signals appear as square-wave signals, which pulse the key amplifier circuit on and off. The resultant transmitter output is a pulse-shaped RF signal, amplified to the minimum 10-watt peak power. The 30-kc oscillator in the modulator continuously modulates the transmitter signal. This continuous modulation sustains the peak RF power output during pauses in speech, thereby maintaining the LM-CSM link so that the CSM receiver continues to hold its AGC level (remains quiet) during speech-pause periods. A 98.93-mc crystal oscillator is used as the basis of the RF circuit in transmitter A; in transmitter B, an 86.56-mc crystal oscillator is used. The oscillator output frequency is tripled to the carrier frequency and is modulated by the output of the keyed amplifier.

Channel B also provides PCM data transmission. Data inputs are clipped and amplified in the modulator the same as audio signals. This transmitter has a voice-data mute circuit, which is controlled with the VHF B XMTR switch.

The VHF receiver (figure 2-139) is an amplitude-modulation, fixed-tuned, single-conversion superheterodyne receiver that uses carrier-controlled squelch. There are two VHF receivers in the CS. The receivers can receive voice signals at 296.8 and 259.7 mc (channels A and B, respectively) and biomed and suit data from the EVA via channel B. The frequency of a crystal-controlled-oscillator output is multiplied, and mixed with the received VHF signal in the mixer. The heterodyned output is a 30-mc IF signal, which is fed through a 30-mc crystal filter. The filter output is supplied to the AGC-controlled IF amplifiers, amplified, and routed to the premodulation processor (PMP) in the SPA. Squelch is carrier controlled and adjusted by the squelch thumbwheels (panel 12). During earth-orbital missions, AGC signal strength is monitored by sampling the output of the AGC amplifier and routing this signal to the DFI for transmission to MSFN via the DFI transmitters.

2.7.3.1.5 VHF Diplexer and RF Switch.

The VHF diplexer permits simultaneous transmission and reception, using one antenna at two frequencies. During in-flight phases of the mission, the diplexer permits voice transmission over one channel while reception is accommodated over the other channel. The normal LM-CSM communications mode is simplex over channel A; channel B is used for data transmission and voice backup.

The VHF selector switch on the COMMUNICATIONS ANTENNAS portion of panel 12 enables selection of either VHF in-flight antenna (omnidirectional) or the EVA antenna (during lunar stay). The insertion loss of the switch, in the transmit mode of operation (296.8 and 259.7 mc), is less than 0.2 db.

2.7.3.2 Signal-Processing Assembly. (See figure 2-140.)

The SPA is the common acquisition and distribution point for all CS received and transmitted data, except that low-bit-rate, split-phase data is coupled directly to VHF B. It processes all voice and biomed signals and provides the interface between the RF electronics and DSEA and PCMTEA. The SPA consists of an audio center for each astronaut and a premodulation processor.

2.7.3.2.1 Premodulation Processor. (See figure 2-141.)

The premodulation processor (PMP) provides proper signal modulation, mixing, and switching to ensure signal-processing in accordance with the selected mode of operation. The PMP also permits the LM to be used as a relay station between the CSM or EVA and MSFN.

The PMP accepts PCM nonreturn-to-zero (NRZ) data from the PCMTEA at a rate of 51,200 bits per second (high bit rate) or 1,600 bits per second (low bit rate).

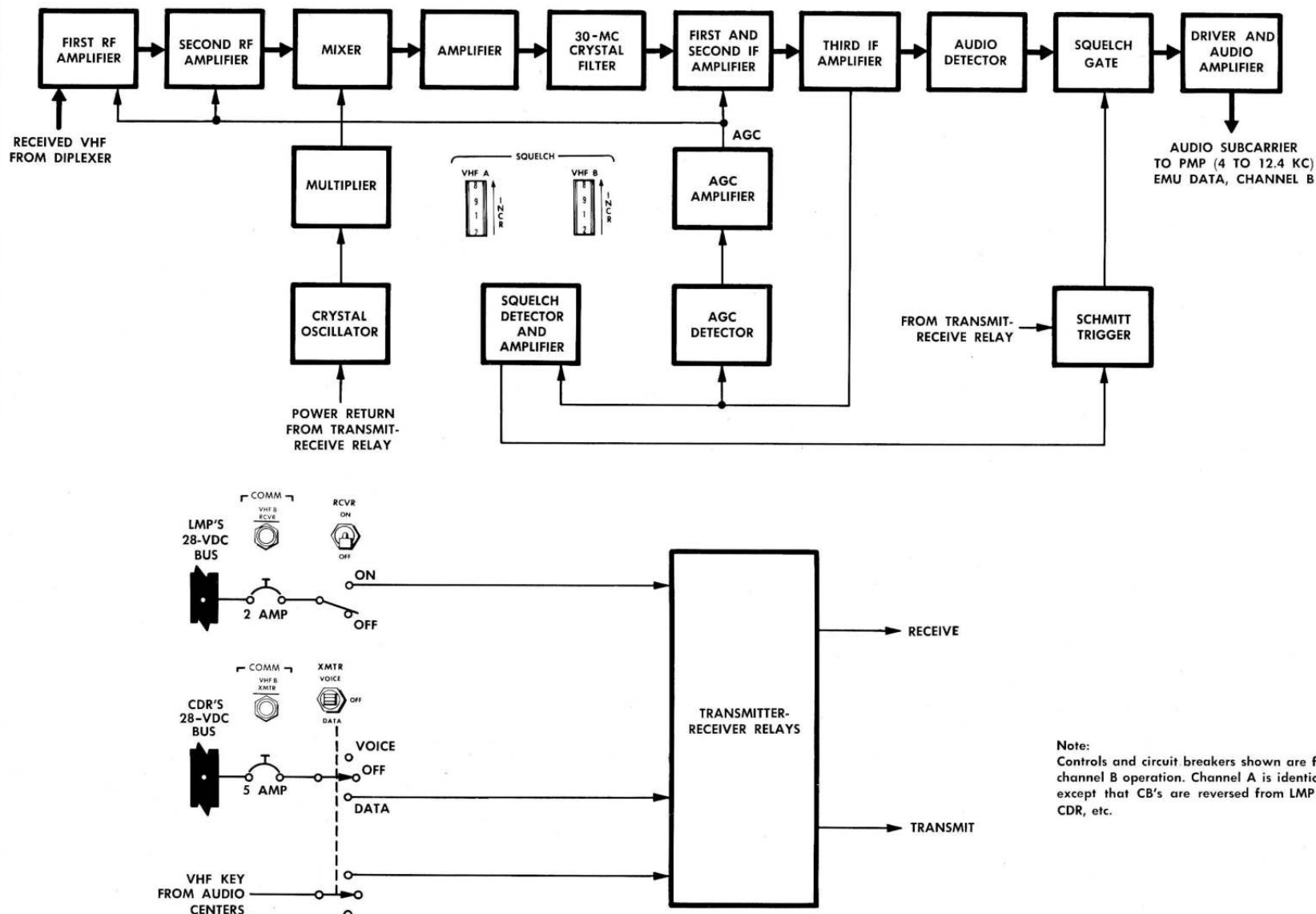


Figure 2-139. VHF Receiver - Block Diagram

The data are routed to a biphase modulator, where the phase of a telemetry subcarrier frequency is controlled. Each logic-level change of the PCM data changes the biphase-modulator output 180° . The biphase-modulator output is supplied to the PM or FM mixing network, depending on the selected mode, where it is combined with other signals processed in the PMP.

Two 512-kc clock signals are provided by the IS to the CS. The 1.024-mc telemetry subcarrier is generated from a 512-kc square wave (reference signal) from the pulse-code-modulation section of the PCMTEA. This 512-kc square wave is routed to a frequency doubler whose output is a 1.024-mc sine wave, phase-referenced to the PCM NRZ data. A 512-kc square wave (sync signal) received by the PMP, from the timing electronics equipment (TE) of the PCMTEA, is supplied to a tuned amplifier that supplies a 512-mc sine wave. This 512-kc signal is added to a 113-kc signal and the result is doubled to provide the 1.25-mc subcarrier. The biphase modulator accepts PCM NRZ data from the IS at the high or low bit rate. The input level of the data is 6 ± 0.5 volts for logic 1; 0 ± 0.5 volt for logic 0. The data modulates the 1.024-mc subcarrier. The biphase-modulator output reflects the change in logic level by a 180° change in subcarrier phase. The modulated subcarrier is routed through a 1.024-mc band-pass filter to the FM or PM mixing network.

Emergency keying is provided in the PMP by gating the 512-kc sync signal generated from the 512-kc square-wave input from the TE, directly on the input line of the S-band phase modulator. The PTT switch on each electrical umbilical serves as the manually operated keyer to gate the output of the key gate circuit on and off.

Voice for S-band transmission is accepted by the PMP via a low-pass filter, which passes 300- to 3,000-cps signals. These voice signals are passed within ± 1 db referenced to 1,000 cps; signals above 4,000 cps are attenuated at least 20 db. The low-pass filter output modulates the 1.25-mc subcarrier or is routed directly to the S-band phase modulator for direct baseband modulation. The modulated 1.25-mc subcarrier is routed through tuned, isolation, and AGC amplifiers and supplied to the PM mixer or FM mixer.

Backup voice transmission is accommodated via S-band by routing the low-pass filter output directly to a speech-processing network. This network provides 24 db of speech clipping, referenced to 3,000 cps, and voice preemphasis of 6 db per octave between 300 and 3,000 cps. The speech-processing network output is supplied directly to the narrow-band PM input of the S-band equipment. This mode is attained by setting the AUDIO CONT switch (panel 8 or 12) to BU and the BIOMED TELEMETRY switch (panel 12) to OFF.

The PMP accepts hardline impedance pneumograph biomed data from each astronaut and, by external control, selects one of these data for S-band transmission. The input is a 0- to 5-volt signal, at 0 to 30 cps. It frequency-modulates a 14.5-kc subcarrier oscillator, with a maximum deviation of 1 kc. The oscillator output is mixed with voice and the composite signal modulates the 1.25-mc subcarrier in the same manner as voice for S-band transmission, or routed directly to the PM or FM mixer for direct baseband modulation.

Received voice signals are routed through the PMP to the microphone and headset volume control circuits in the audio centers. The VHF channel B input has high- and low-pass filters to separate voice and extravehicular mobility unit (EMU) data. The PMP has a discriminator to demodulate the S-band subcarrier. The discriminator output has a bandwidth of 300 to 3,000 cps ± 3 db referenced to 1,000 cps. The output is routed to the audio centers via a low-pass filter and mixer network.

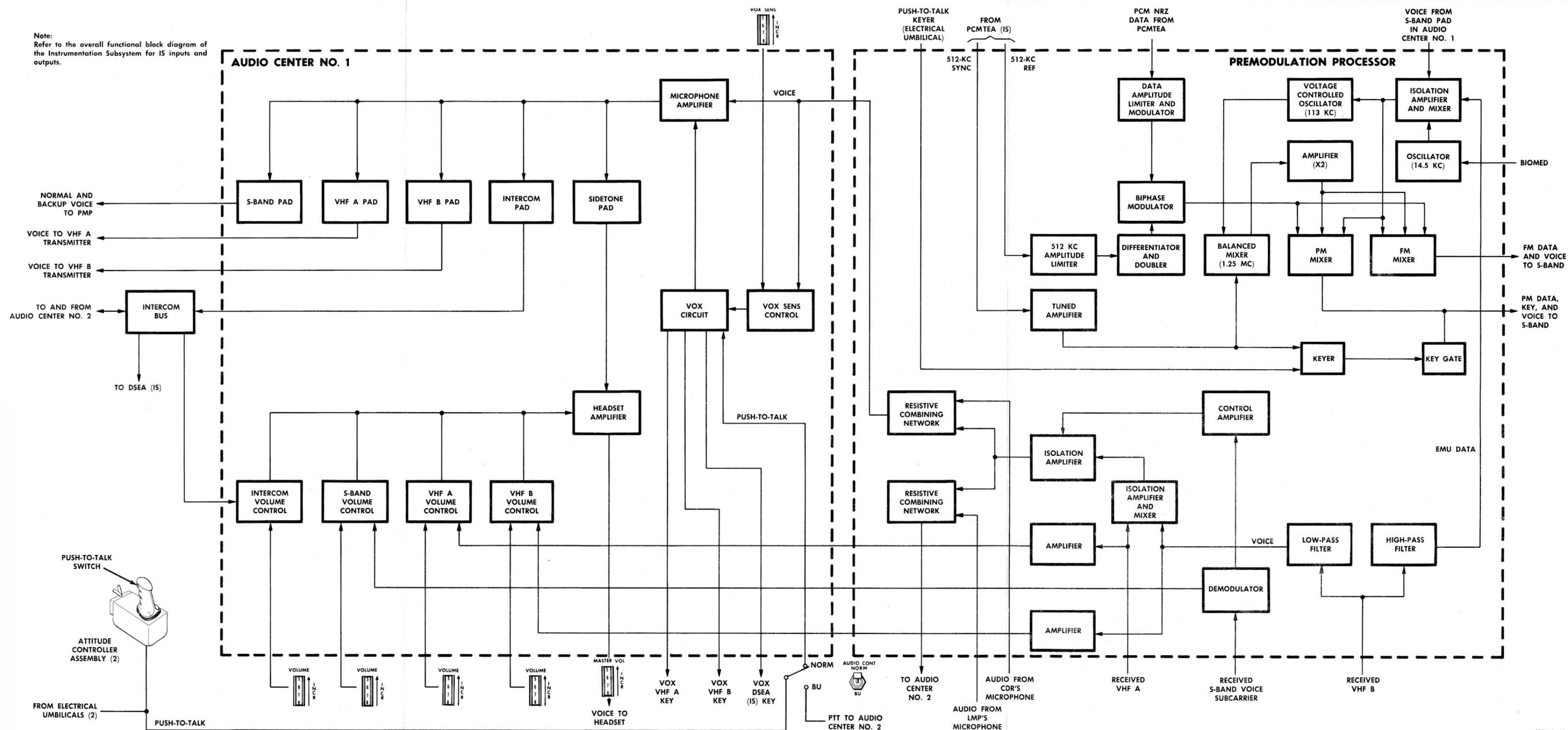


Figure 2-140. Signal-Processing Assembly - Block Diagram

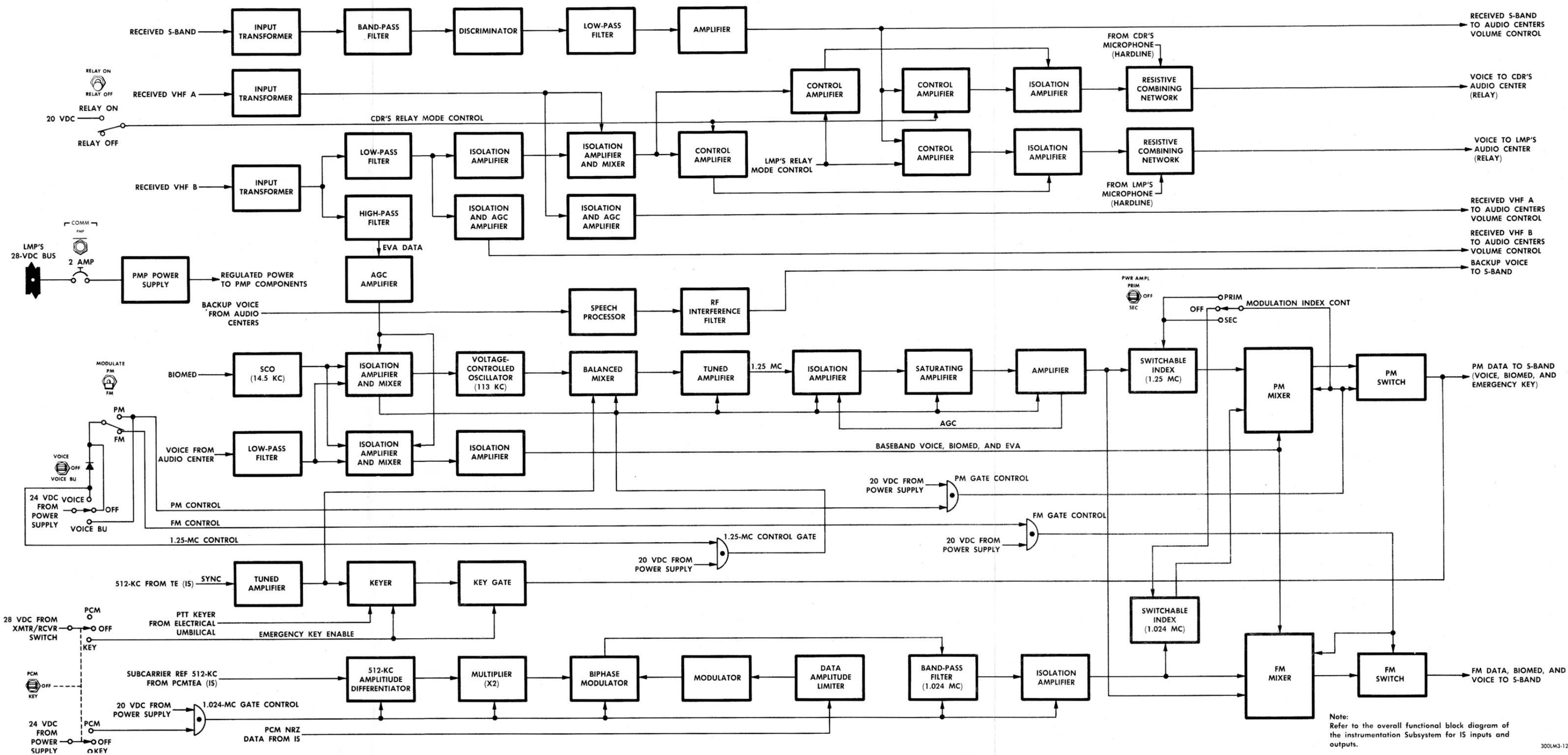


Figure 2-141. Premodulation Processor - Block Diagram

The PM mixing network can process the outputs of the 1.25-mc and 1.024-mc channels (a composite of voice, biomed data, telemetry data, and EMU data). These outputs are then supplied to the selected S-band phase modulator for transmission to MSFN. The FM mixing network can process the outputs of the 1.024-mc data channel and a composite of voice, biomed data, telemetry data, and EMU data, all on the 1.25-mc subcarrier. These outputs are then supplied to the S-band frequency modulator for transmission to MSFN. FM video, PM ranging, backup voice, and emergency key signals are not processed through the mixing networks; they are supplied directly to the proper operational modulator for baseband modulation.

2.7.3.2.2 Audio Centers. (See figure 2-142.)

Two identical audio centers (one for each astronaut) in the SPA provide individual selection, isolation, and amplification of audio signals to and from the CS transmitters and receivers. The audio centers are controlled from the AUDIO portion of panels 8 and 12. Each audio center contains a microphone amplifier, headset amplifier, VOX circuit, diode switches, volume control circuits, and isolation pads. The VOX circuit can control the microphone amplifier by activating it only when required for voice transmission.

Audio signals are routed to and from the VHF A, VHF B, and S-band equipments and the intercommunications (intercom) bus via the audio centers. The intercom bus, common to both audio centers, provides hardline communications between the astronauts. Voice signals to be recorded by the DSEA are taken from the intercom bus.

Inputs and outputs are controlled by the VHF A, VHF B, S-BAND T/R, and ICS T/R (intercom) switches on panels 8 and 12. An associated thumbwheel (volume control) for each switch provides continuous adjustment of the received audio signal. Panels 8 and 12 also have VOX SENS and MASTER VOL thumbwheels. The VOX SENS thumbwheel permits continuous adjustment of the VOX control circuit threshold; the MASTER VOL thumbwheel, continuous adjustment of all audio outputs from the headset amplifier.

Received audio signals are isolated and routed through the volume control circuits, which provide a 35-db range at the output of the headset amplifier. The four inputs (S-band, VHF A, VHF B, and intercom) routed through the headset circuit have minimum isolation of 40 db between any two inputs.

If one audio center fails, the astronaut affected by the malfunction can switch to the other audio center, using the AUDIO CONT switch (panels 8 and 12). With the switch set to NORM, the astronaut is using his own audio center; the BU position switches him to the other audio center.

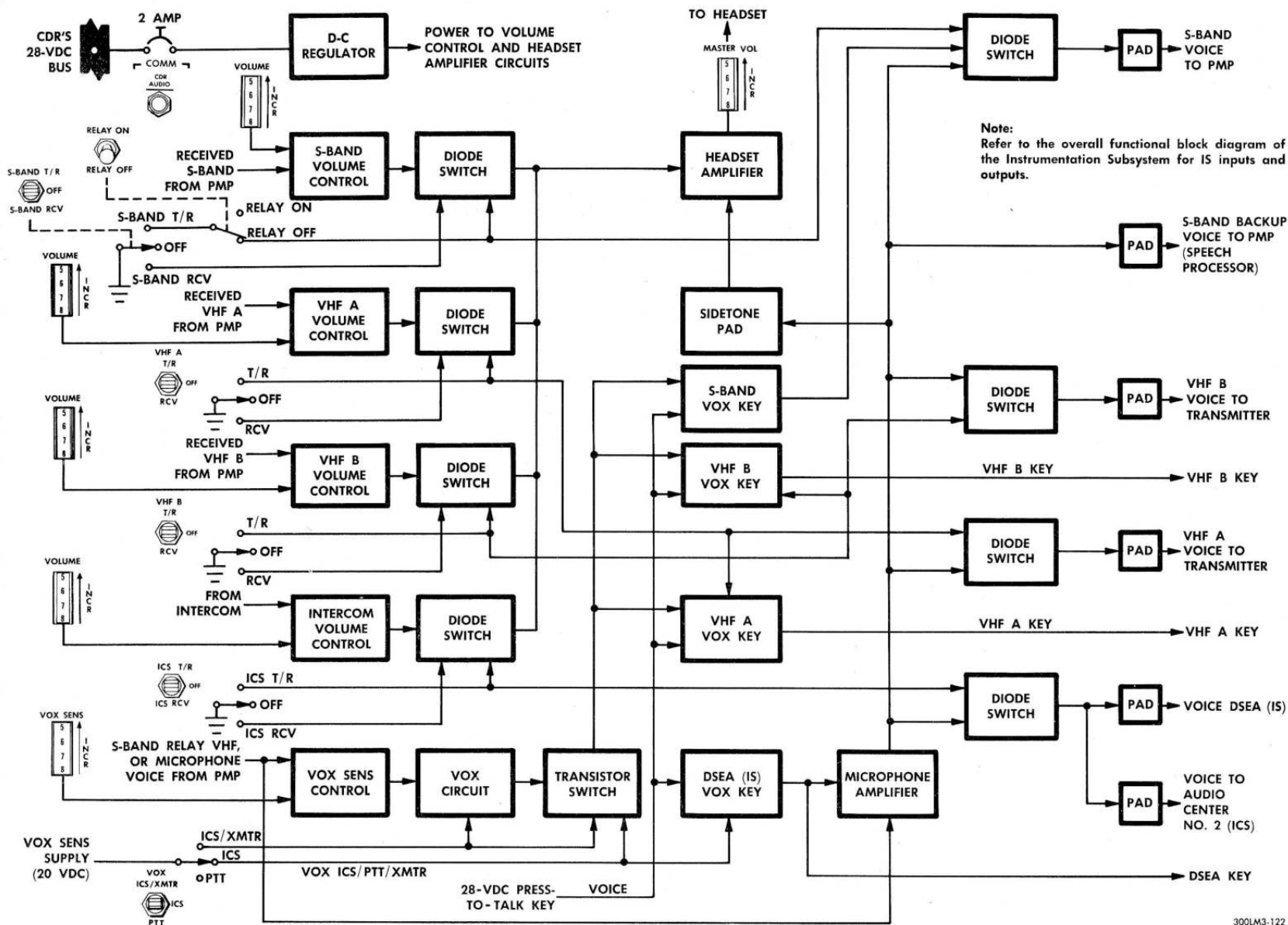
2.7.3.3 Antenna Equipment. (See figure 2-143.)

The CS antenna equipment consists of two S-band in-flight antennas, an S-band steerable antenna, and two VHF in-flight antennas. For lunar missions, a high-gain, lunar-stay antenna for S-band communications and an EVA antenna for EVA-LM VHF communications will be provided. The antennas used in the DFI are covered in subsection 2.9.

2.7.3.3.1 S-Band In-Flight Antennas.

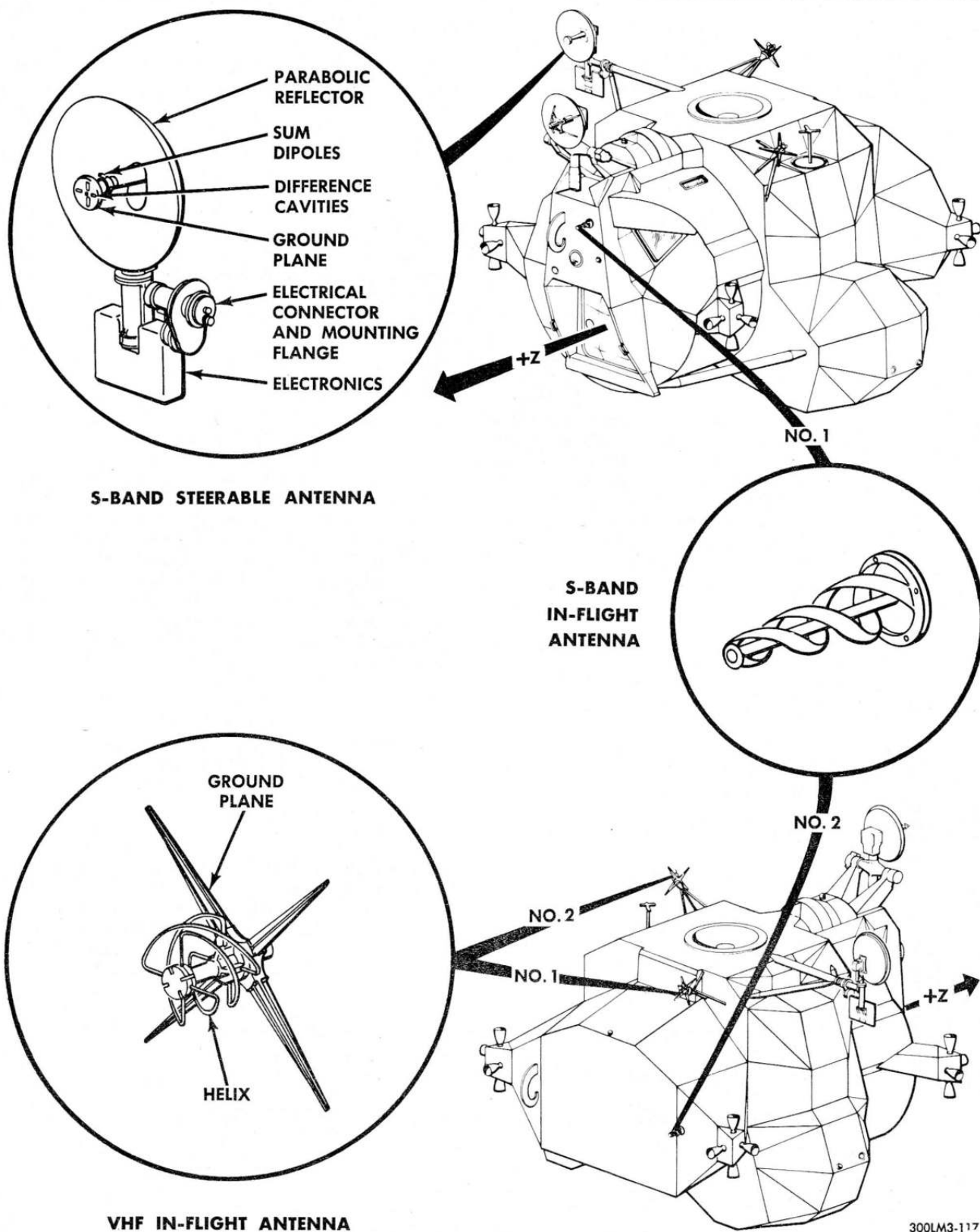
The S-band in-flight antennas are omnidirectional; one is forward and one is aft of the LM. The antennas are right-hand circularly polarized radiators that collectively cover 90% of the sphere at -3 db. They operate at 2282.5 \pm 5 mc (transmit) and 2101.8 mc (receive). These antennas are the primary S-band antennas in LM 3.

COMMUNICATIONS SUBSYSTEM



300LM3-122

Figure 2-142. Audio Center No. 1 - Block Diagram



300LM3-117

Figure 2-143. Communications Subsystem - Antenna Locations

COMMUNICATIONS SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

2.7.3.3.2 S-Band Steerable Antenna. (See figure 2-144.)

The S-band steerable antenna is a 26-inch-diameter parabolic reflector with a point source feed that consists of a pair of cross-sleeved dipoles over a ground plane. The prime purpose of this antenna is to provide deep-space voice and telemetry communications and deep-space tracking and ranging. During earth-orbital missions, the steerable antenna will be checked and will serve as backup to the S-band in-flight antennas.

The S-band steerable antenna provides 150° azimuth coverage and 330° elevation coverage. The antenna can be operated manually or automatically. The manual mode is used for initial positioning of the antenna to orient it within $\pm 12.5^\circ$ (capture angle) of the LOS signal received from the MSFN station. Once the antenna is positioned within the capture angle, it can operate in the automatic mode. Switches and indicators on the COMMUNICATIONS ANTENNAS portion of panel 12 are used to operate the antenna.

When the S-BAND selector switch (panel 12) is set to SLEW (S-band steerable antenna selected) and the TRACK MODE switch (panel 12) is set to AUTO, the antenna is positioned automatically. When in the automatic mode, signals received from a MSFN station cause the steerable antenna electronics to generate error information relative to the angular displacement and direction of the MSFN station LOS with respect to the existing antenna radiation axis. This information is processed and ultimately used to operate two servomotors that drive the antenna. One servomotor is mounted on the LM X-axis; another, on the Y-axis. Angular displacement data are generated by shifting the received signal pattern off the radiation axis in the X-direction and Y-direction, causing a change in strength of the received signal. If the signal strength is increased when the antenna is shifted, the MSFN station LOS is displaced in the shifted direction; otherwise, in the opposite direction. This periodic shifting of the antenna permits generation of servo error signals by sampling the S-band receiver AGC level. The sampled AGC signal is supplied to the steerable antenna electronics sub-assembly and, through X- and Y-axis logic circuits, drives d-c servomotors to position the antenna to obtain the maximum received-signal level.

2.7.3.3.3 VHF In-Flight Antennas.

Two VHF in-flight antennas are used for VHF/AM communications. These are right-hand circularly polarized antennas that operate in the 259.7 to 296.8-mc range. One of these antennas is on each side of the LM, near the top of the structure.

2.7.3.4 Electrical Power Distribution. (See figure 2-145.)

The CS receives primary electrical power from the EPS. The normal d-c voltage requirement is 28 volts, two-wire, negative ground. The required steady-state range is 25 to 31.5 volts; the off nominal range, 20 to 32 volts for periods not exceeding 5 seconds. The CS also requires 110-volt, 400-cps ac for the S-band steerable antenna electronics package.

2.7.4 FAILURE MODES.

The CS failure modes and the effect on mission capability are given in table 2-51.

2.7.5 PERFORMANCE AND DESIGN DATA.

The performance and design data for the CS are given in table 2-52.

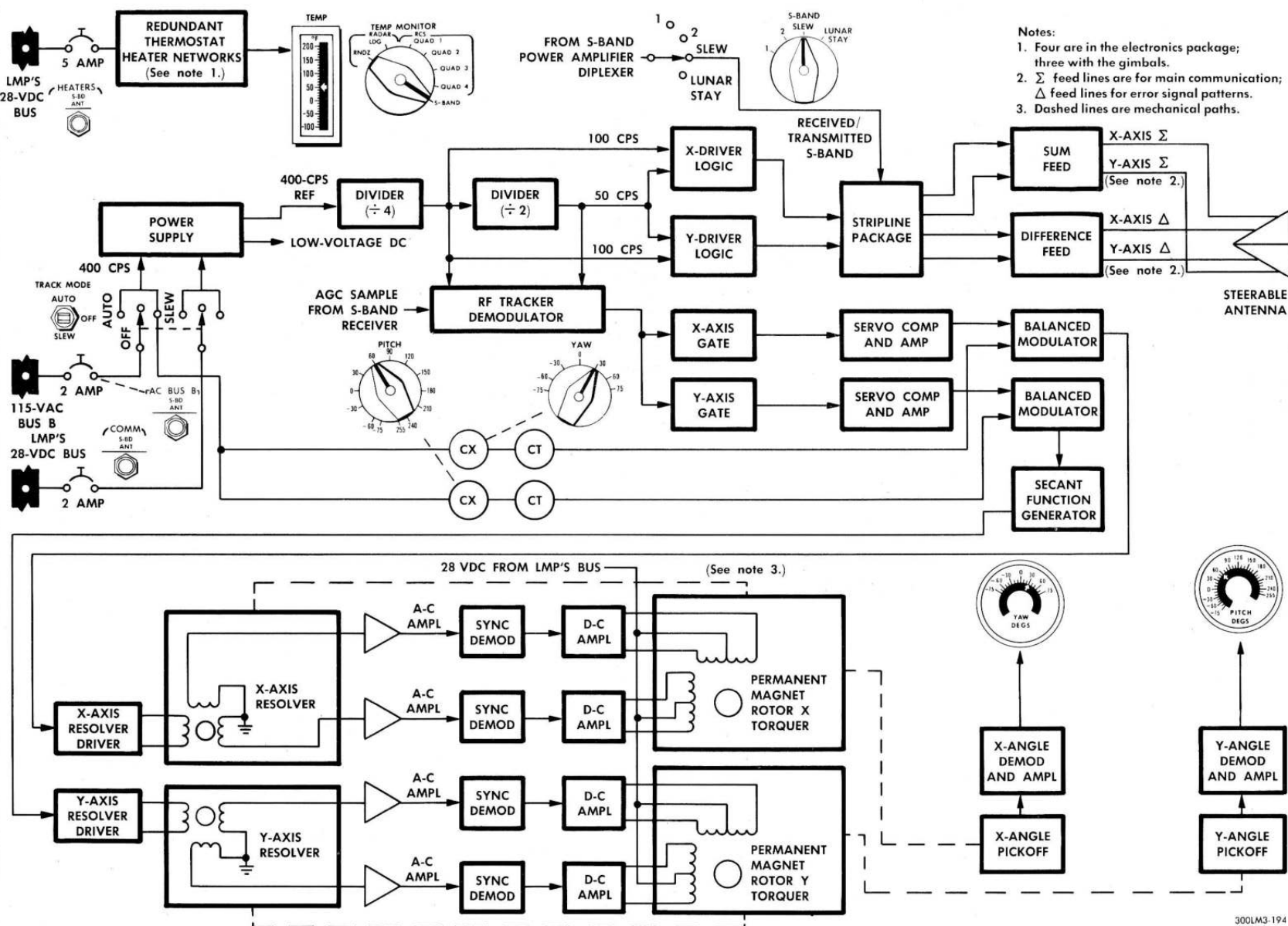


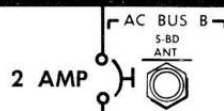
Figure 2-144. S-Band Steerable Antenna-Block Diagram

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Note:

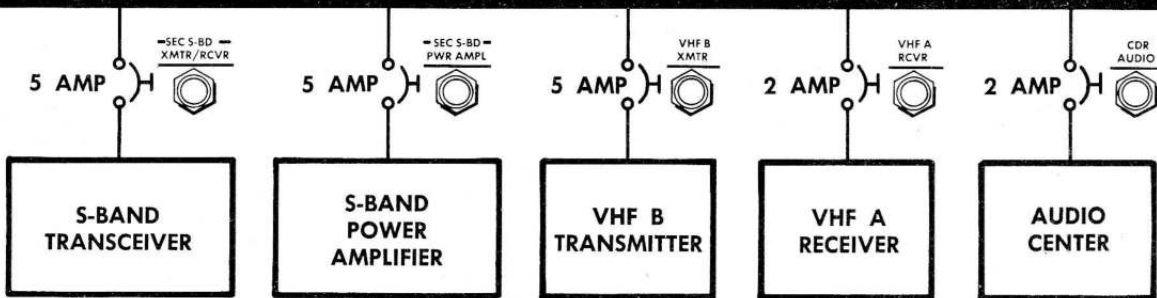
All CS circuit breakers are placarded under COMM identification brackets, unless otherwise indicated.

A-C BUS B 115 VAC, 400 CPS

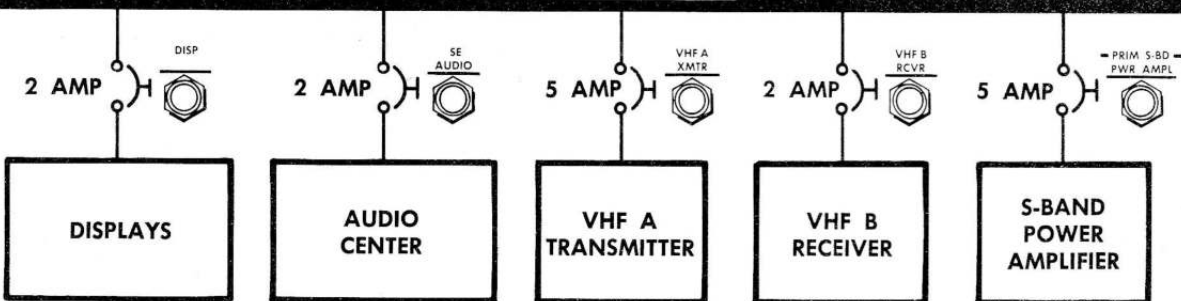


**S-BAND
STEERABLE
ANTENNA**

COMMANDER'S 28-VDC BUS



LM PILOT'S 28-VDC BUS



LM PILOT'S 28-VDC BUS

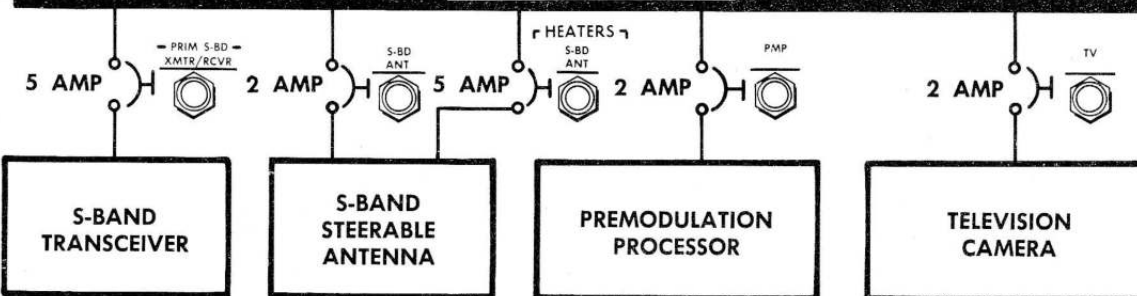


Figure 2-145. Communications Subsystem - Electrical Power Distribution

300LM3-119

COMMUNICATIONS SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-51. Communications Subsystem - Failure Modes

Failure	Indication	Vehicle Capability (See note 3.)
Primary S-band transceiver failed.	Absence of S-band received voice at LM and/or received S-band voice and data at MSFN	Secondary (backup) transceiver must be selected by setting XMTR/RCVR switch (panel 12) to SEC.
S-band transceiver nonredundant elements (power combiner diode switch, PM control lines) failed.	All S-band communication is lost, regardless of transceiver in use.	Evaluation of S-band link is impossible. Voice and data communications to CSM or MSFN may be continued via VHF section. Telemetry to MSFN continues via DFI communications link, with ranging capability via C-band.
Primary S-band power amplifier failed (during mission phases when additional power is required).	Received S-band signal at MSFN is attenuated or absent.	Secondary (backup) power amplifier must be selected by setting PWR AMPL switch (panel 12) to SEC.
S-band diplexer failed.	S-band communication is lost regardless of S-band antenna in use. S-BD RCVR caution light (panel 2) and MASTER ALARM pushbutton lights (panel 1 and 2) go on, and SIGNAL STRENGTH indicator (COMMUNICATIONS ANTENNAS portion of panel 12) reads 0.	Evaluation of S-band link is impossible. Voice and data communications to CSM or MSFN may be continued via VHF section. Telemetry to MSFN continues via DFI communications link, with ranging capability via C-band.
S-band steerable antenna failed.	All S-band communication is lost. S-BD RCVR caution light, MASTER ALARM pushbutton lights, and possibly HEATER caution light (panel 12) go on; SIGNAL STRENGTH indicator reads 0.	Either in-flight backup antenna (No. 1 or 2) (relative to existing vehicle orientation and MSFN LOS) must be selected by setting S-BAND selector switch (COMMUNICATIONS ANTENNAS portion of panel 12) to 1 or 2.
S-band in-flight antenna failed (steerable antenna inoperable).	All S-band communication is lost. S-BD RCVR caution light and MASTER ALARM pushbutton/lights go on, and SIGNAL STRENGTH indicator reads 0.	Other in-flight backup antenna must be selected by setting S-BAND selector switch to 1 or 2. Mission is constrained to vehicle orientation affording LOS with MSFN. (See note 1.)
VHF transmitter and receiver A (normal simplex operation) failed.	Voice communication between LM and CSM is lost.	Transmitter and receiver B must be substituted for transmitter and receiver A with VHF A switches OFF and VHF B switches ON (COMMUNICATIONS portion of panel 12). Data and voice cannot be transmitted simultaneously on VHF B.
VHF A transmitter (normal duplex operation) failed.	Voice communication from LM to EVA is lost.	To retain voice communications, transmitter B must be substituted for transmitter A, and receiver A substituted for receiver B, with VHF A and VHF B switches (COMMUNICATIONS portion of panel 12). EMU data is thereby lost, and EVA must return to LM.

COMMUNICATIONS SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-51. Communications Subsystem - Failure Modes (cont)

Failure	Indication	Vehicle Capability (See note 3.)
VHF B receiver (normal duplex operation) failed.	Voice and EMU data from EVA to LM is lost.	To retain voice communications, receiver A must be substituted for receiver B, and transmitter B substituted for transmitter A, with VHF A and VHF B switches (COMMUNICATIONS portion of panel 12). EMU data is thereby lost, and EVA must return to LM.
VHF diplexer failed.	All VHF communication is lost, regardless of antenna used.	Mission must be constrained. LM must communicate with CSM via MSFN on S-band. EVA must return to LM immediately. (See note 1.)
VHF in-flight antenna failed.	LM-CSM or LM-EVA communication is lost.	Other in-flight antenna must be selected by setting VHF selector switch (COMMUNICATIONS ANTENNAS portion of panel 12) to 1/PLSS TEST or 2. Mission is constrained to vehicle orientation that affords LOS with CSM. EVA must return to LM immediately. (See note 1.)
Audio center No. 1 or 2 (part of SPA) failed.	VHF, S-band, and intercom audio communications control is lost. (See note 2.)	Other audio center must be selected with related AUDIO CONT switch (AUDIO portion of panels 8 and 12) set to BU.
Premodulation processor (PMP) failed.	All or part of S-band and/or VHF communications capability is lost. (See note 2.)	Mission may be constrained severely. (See note 1.) Clipped-speech S-band voice transmission is available as backup mode.
<p style="text-align: center;">NOTES</p> <ol style="list-style-type: none"> 1. Circumstances are dependent on mission phase at time of unit failure. 2. Circumstances are dependent on particular component failures within unit. 3. Where vehicle capability permits redundant equipment to replace malfunctioning equipment, the operating power to the malfunctioning unit must first be removed by opening the related circuit breaker (panels 11 and 16). 		

COMMUNICATIONS SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-52. Communications Subsystem - Performance and Design Data

Equipment	Mode (Status)	Power Requirements		Operating Frequency
		D-C Watts	A-C Watts	
S-band transmitter-receiver	Primary or secondary	36.0	0	
Receiver				2101.8 mc
Transmitter				2282.5 mc
S-band power amplifier and diplexer	Primary or secondary	70.0	0	
S-band steerable antenna				
Electronics	Slew	1.4	27.9	
	Auto	0.7	4.0	
Heaters	On	40.5	0	
VHF A transmitter	Voice	30.0	0	296.8 mc
	Not transmitting	3.5	0	
VHF A receiver	On	1.4	0	296.8 mc
VHF B transmitter	Voice	28.9	0	259.7 mc
	Data	31.7	0	
	Not transmitting	3.5	0	
VHF B receiver	On	1.4	0	259.7 mc
Signal-processing assembly				
Premodulation processor	On	4.3	0	
Audio center (one)	On	4.8	0	
	PTT/keyer	13.2	0	
Biomedical sensors	On	3.0	0	
CS displays	On	3.0	0	
TV camera	On	6.0	0	

2.7.6 OPERATIONAL LIMITATIONS AND RESTRICTIONS.

The operational limitations and restrictions for the CS are covered in paragraphs 2.7.6.1 and 2.7.6.2.

2.7.6.1 Antennas.

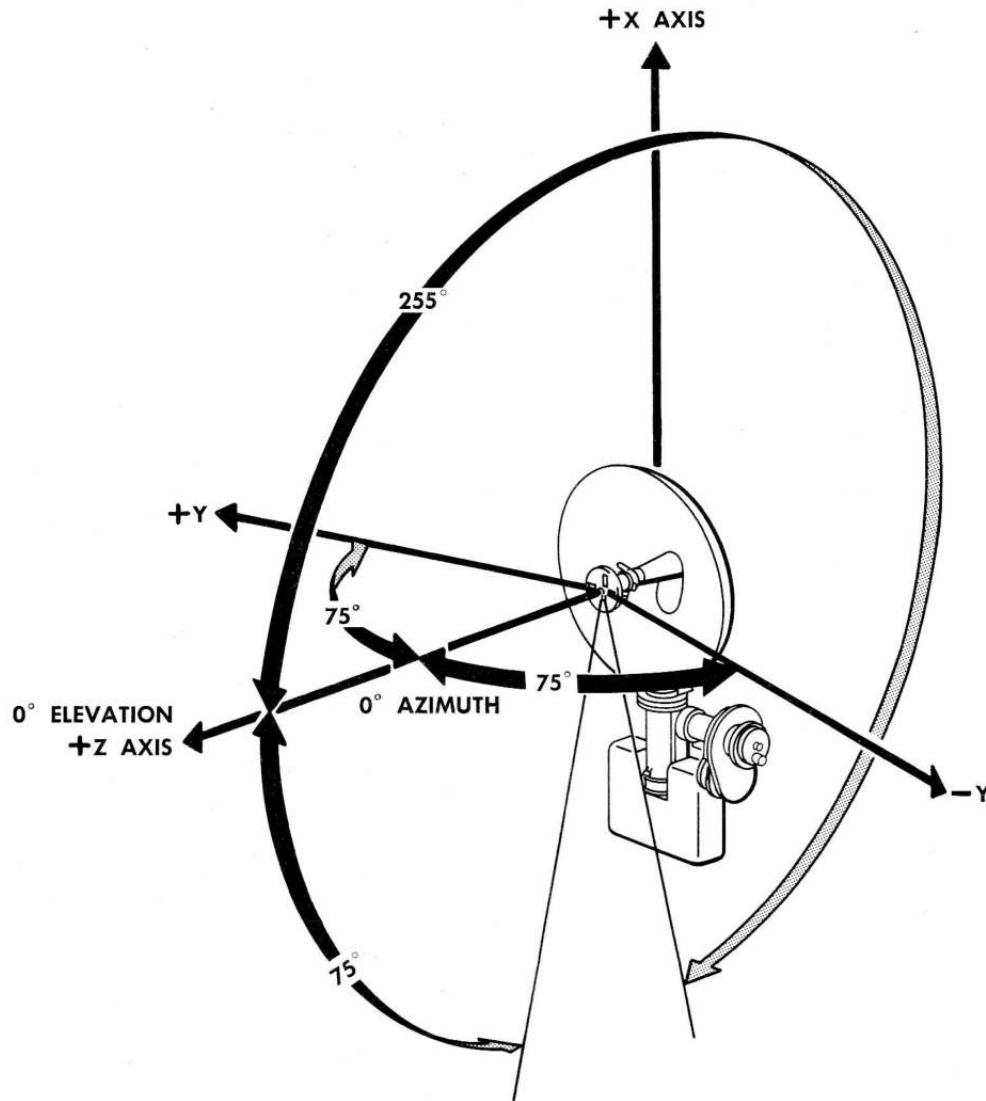
The S-band steerable antenna is mounted on a two-degree-of-freedom gimbal. Elevation (pitch) and azimuth (yaw) are zero when the antenna LOS is parallel to the LM Z-axis, in a positive direction. (See Figure 2-146.) Slewing the antenna toward the +X-axis is positive elevation; slewing the antenna toward the +Y-axis is positive azimuth. For elevation angles between +210° and -20°, the antenna has complete azimuth coverage (+75° to -75°). Elevation angles greater than +210° and less than -20° restrict azimuth coverage because of Reaction Control Subsystem (RCS) thruster shadows. Elevation coverage is restricted to angles between +255° and -75° because of LM structural shadows.

The S-band in-flight antennas cover equivalent overlapping regions. The forward in-flight antenna covers a 170° cone about a line in the X-Z plane 20° above the +Z-axis. The rear antenna covers a 170° cone about a line in the X-Z plane 20° above the -Z-axis.

2.7.6.2 General.

The limitations and restrictions imposed on the CS during the mission are as follows:

- The maximum range of telemetry transmission between the LM and the CSM is 320 nautical miles. Greater ranges will cause loss of telemetry transmission.
- The line-of-sight (LOS) range of the VHF transmitter is limited to 740 nautical miles. Greater ranges will cause loss of VHF communications.
- Once the S-band steerable antenna is unstowed, it cannot be stowed for the remainder of the flight. RCS thruster interaction with the steerable antenna may require the antenna to be re-oriented.
- The S-band steerable antenna provides automatic tracking when its RF axis is aligned to within $\pm 12.5^\circ$ (capture angle) of the MSFN station LOS. Exceeding $\pm 12.5^\circ$ results in an inability to acquire the MSFN signal.
- The maximum S-band steerable antenna tracking velocity is 20°/second.
- The maximum S-band steerable antenna tracking acceleration is 60°/second/second.
- The activation time for the S-band transmitter-receiver is 30 seconds from application of power; 5 seconds, after a change of modulation mode (FM to PM, or PM to FM). If this restriction is not followed, no S-band communication will result until warm-up.
- The warm-up time for the S-band power amplifier is 60 seconds. The recycle time after RF interruption is 20 seconds. If this restriction is not followed, unpredictable communications will result.
- The warm-up time for the S-band steerable antenna electronics is 60 seconds. If this restriction is not followed, no S-band communications will result prior to warm-up.



300LM3-171

Figure 2-146. S-Band Steerable Antenna Gimballing

2.7.7

TELEMETRY MEASUREMENTS.

The CS telemetry data are given in table 2-53. "(R)" in the "Telemetry Range" column signifies a real-time telemetry measurement. Real-time telemetry points are shown in figures 2-134 through 2-136.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-53. Communications Subsystem - Telemetry Measurements

Code	Description	Telemetry Range (Nominal)	Display Range	Crew Display
GTO201E	S-band power amplifier RF power output	0 to 25 watts (18 watts) (R)		None
GTO202E	S-band power amplifier reflected RF power	0 to 25 watts (1.8 watts) (R)		None
GTO224C	S-band power amplifier anode current, power supply No. 1	20 to 30 ma (25 ma)		None
GTO225C	S-band power amplifier anode current, power supply No. 2	20 to 30 ma (25 ma)		None
GTO451H	S-band steerable antenna Y-axis gimbal position	-75° to +255°	-75° to +255°	PITCH indicator (panel 12)
GTO452H	S-band steerable antenna X-axis gimbal position	-75° to +75°	-75° to +75°	YAW indicator (panel 12)
GTO454T	S-band steerable antenna electronics package temperature	-200° to +200° F	-100° to +200° F	TEMP indicator (panel 3) and HEATER caution light (panel 2)
GTO504V	S-band receiver AGC voltage	0 to 4.2 vdc	0 to 5 vdc	SIGNAL STRENGTH indicator (panel 12)
GTO604V	VHF receiver A AGC voltage	0.1 to 0.4 vdc		None
GTO605V	VHF receiver B AGC voltage	0.1 to 0.4 vdc		None
GTO662V	Steerable antenna X-gimbal servo output at 0°	0 or 28 vdc		None
GTO663V	Steerable antenna X-gimbal servo output at 90°	0 or 28 vdc		None
GTO664V	Steerable antenna Y-gimbal servo output at 0°	0 or 28 vdc		None
GTO665V	Steerable antenna Y-gimbal servo output at 90°	0 or 28 vdc		None
GTO992B	S-band transponder static phase error	-15° to +15° (R)		None
GTO993E	S-band transmitter RF power	0.5 to 1 watt (0.75 watt) (R)		None
GTO994V	S-band receiver AGC voltage	0 to 4.2 vdc (R)		None

COMMUNICATIONS SUBSYSTEM

2.8 EXPLOSIVE DEVICES SUBSYSTEM.

2.8.1 INTRODUCTION.

The Explosive Devices Subsystem (EDS) permits the astronauts to operate or enable various LM equipment, using explosive devices. The EDS controls deployment of the landing gear; pressurization of the descent, ascent, and reaction control propellant tanks; venting of descent propellant tanks; and separation of the ascent and descent stages.

There are two separate systems (A and B) in the EDS. (See figure 2-147.) The systems operate in parallel and provide complete redundant circuitry; each system has its own 37.1-volt d-c battery, relays, time-delay circuits (used in staging), fuse-resistors, buses, and explosive cartridges. This redundancy provides additional protection against EDS failures.

Two separate cartridges are provided for each EDS function. Each of the two cartridges uses power from a separate ED bus and can perform its task without the other (redundant) cartridge.

The general location of all components of the EDS is shown in figure 2-148. Electrical power to activate the components in both systems is supplied through circuit breakers on the Commander's circuit breaker panel (11) and the LM Pilot's circuit breaker panel (16). Switches on the EXPLOSIVE DEVICES portion of panel 8 route this power to relays in the ED relay boxes. The relay contacts route ED battery current to explosive-device cartridges located in LM subsystems. These devices perform the EDS functions.

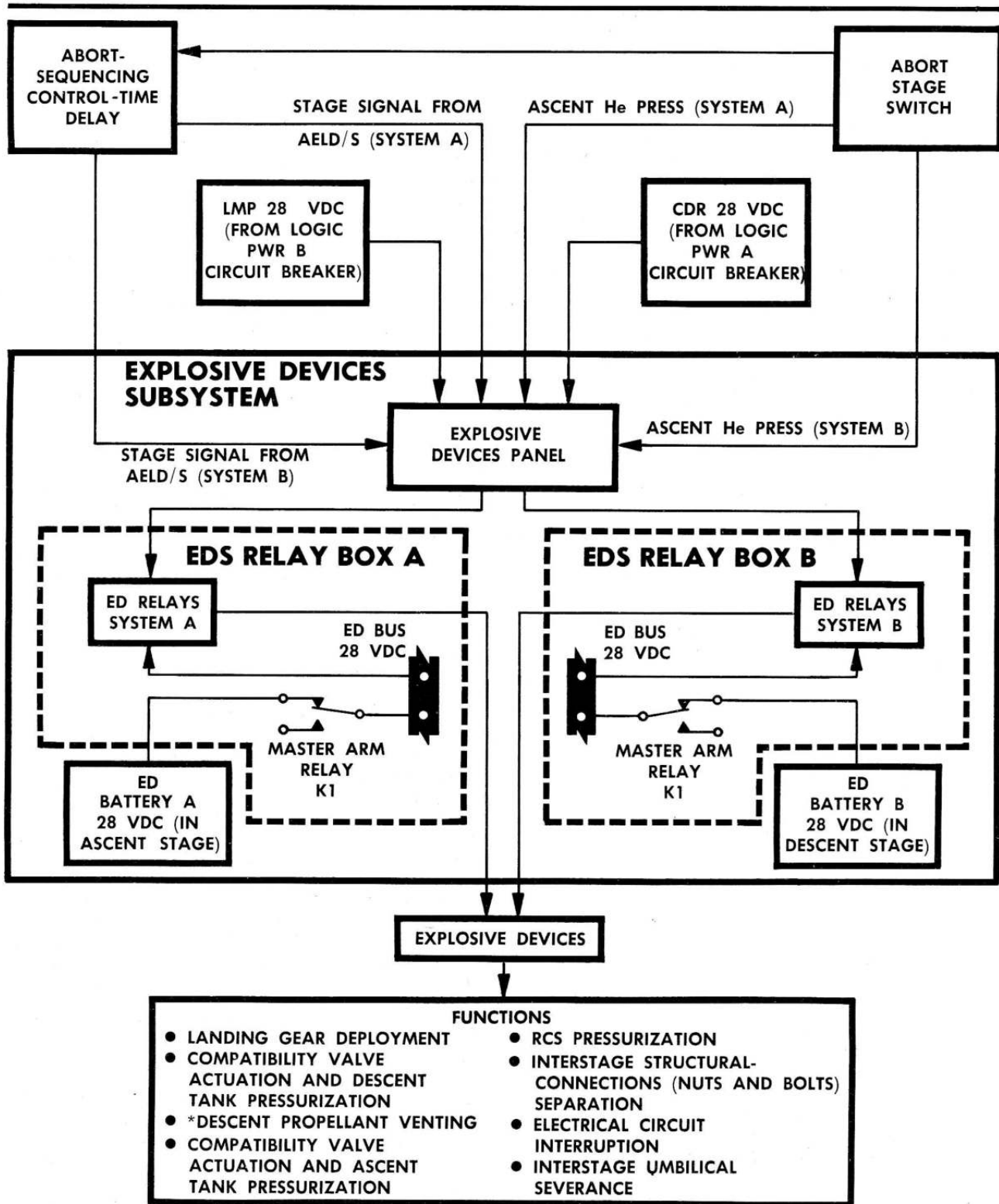
Ascent propellant tank pressurization, and staging (separation of nuts and bolts, electrical circuit interruption, interstage umbilical cable severance), are performed automatically if the ABORT STAGE pushbutton (panel 1) is pressed.

2.8.2 FUNCTIONAL DESCRIPTION. (See figure 2-147.)

EDS systems A and B are operated from the EXPLOSIVE DEVICES portion of panel 8. Each system has a 37.1-volt d-c battery, relay box, and cartridges and the devices they operate. Power (28 volts dc) from the Electrical Power Subsystem (EPS), to actuate the relays in the system A and system B relay boxes is routed through the ED: LOGIC PWR A circuit breaker (panel 11) and the ED: LOGIC PWR B circuit breaker (panel 16), respectively. Firing power for the cartridges is supplied by the ED batteries. When the MASTER ARM switch is set to ON, each battery supplies power to an identical redundant bus in the ED relay boxes, arming the firing circuits and enabling all explosive devices of the LM. The actual firing of any explosive device is controlled by its respective firing switch on panel 8. For descent-tank venting, the DES VENT switch is in conjunction with the FUEL VENT and OXID VENT switches on the DES PROPULSION portion of panel 8.

When the MASTER ARM switch is set to ON, the coils of relays K1 are energized by the Commander's and LM Pilot's bus. Contacts of relays K1 in systems A and B provide a path between each ED battery and its bus. The STAGE SEQ RELAYS SYS A and SYS B component caution lights on the EXPLOSIVE DEVICES portion of panel 8 go on to indicate that systems A and B, respectively, are armed. Telemetry signals GY0201X and GY0202X advise MSFN that systems A and B, respectively, are armed. Once systems A and B are armed, the firing switches can be used to initiate EDS functions. Each switch routes EPS bus voltage to the coils of two relays, one in each relay box. Contacts of these relays route 7.5 to 15 amperes from the ED battery to an associated explosive device. The staging operation is unique to other EDS functions in that it uses a time delay circuit to perform a definite relay sequence operation. Contacts of staging relays connect the ED bus to an RC time-delay circuit in both ED relay boxes and also provides a direct path to relays that operate to perform electrical circuit interruption (deadfacing) and separation of the nuts and bolts that secure the ascent stage to the descent stage.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA



*Two switches on the DES PROPULSION panel are used in conjunction with switches on the EXPLOSIVE DEVICES panel when venting is performed.

300LM3-46

Figure 2-147. Explosive Devices Subsystem - Overall Block Diagram

ASCENT PROPULSION COMPATIBILITY VALVES

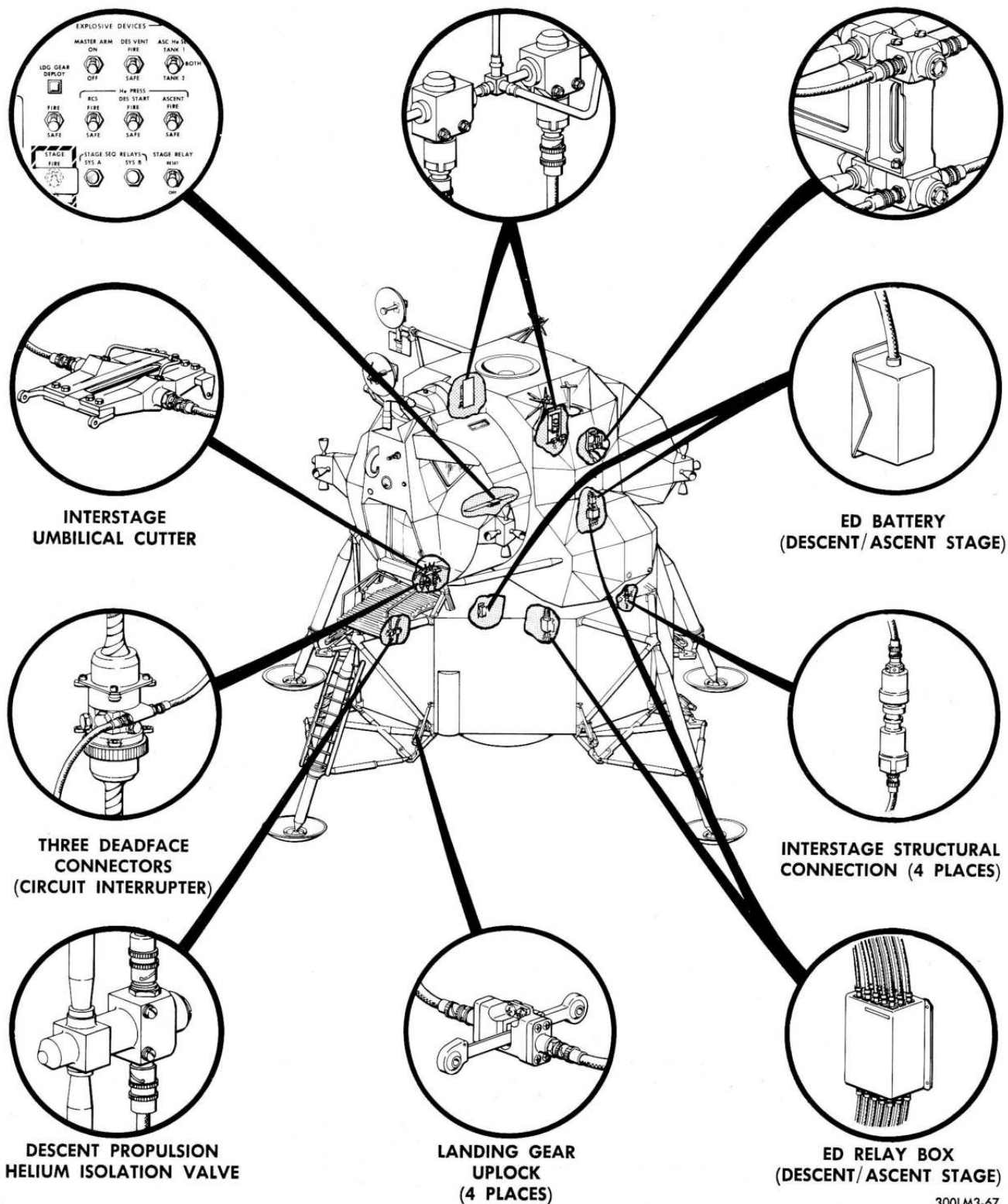


Figure 2-148. Explosive Devices - Component Location

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

The outputs of the time-delay circuit actuate relays to perform interstage umbilical severance. If any of the relays used in the staging operation, or master arm relay K1, operates inadvertently, the SYS A and SYS B component caution lights and the ED RELAYS caution light (panel 2) go on. Additionally, contacts of these relays provide an output (figure 2-149) that is routed to the signal-conditioning electronics assembly (SCEA) in the Instrumentation Subsystem (IS) to provide MSFN with telemetry signals GY0201X and GY0202X (systems A and B, respectively) to monitor the staging sequence.

Contacts of the remaining ED relays (K7 through K15) form a series output that provides MSFN with telemetry signals GY0231X and GY0232X (systems A and B, respectively) to constantly monitor the status of these relays which are used in performing EDS functions. If any one, or combination, of these relays operates inadvertently, their telemetry signal does not distinguish which relay or relays are at fault. If the master arm relays or the staging relays operate inadvertently, the SYS A and/or SYS B component caution lights and the ED RELAYS caution light go on. Use of the STAGE RELAY switch and staging relay telemetry signals GY0123X and GY0124X (system A and B, respectively) distinguishes which relay is at fault.

The outputs from the stage sequence relays to the SCEA units are in parallel. The SCEA outputs are fed to the caution and warning electronics assembly (CWEA) and to the pulse-code-modulation and timing electronics assembly (PCMTEA) in the IS. If one of the SCEA outputs fail, the remaining output is not affected and allows the stage sequence relays to be continuously monitored.

When the MASTER ARM switch or the ABORT STAGE pushbutton (panel 1) is used, an inhibit signal is routed to a CWEA AND gate; the ED RELAYS caution light remains off.

2.8.3

MAJOR COMPONENT/FUNCTIONAL DESCRIPTION.

The redundant circuits and components of the EDS operate simultaneously, as two independent systems (A and B). Either system can perform the EDS functions. Each function is completed before initiation of the next function. The EDS functions are performed in the following sequence:

- Reaction Control Subsystem (RCS) propellant tank pressurization
- Landing gear deployment
- Descent propellant prepressurization
- Descent propellant tank venting
- Ascent propellant pressurization
- Interstage Nut-and-bolt separation and ascent stage deadfacing (occur simultaneously)
- Interstage umbilical severance

2.8.3.1

Explosive Devices.

All explosive devices and components, except the circuit interrupters, can be installed at the launch site late in the LM assembly and prelaunch activity. These devices are actuated by explosive cartridge assemblies. Each cartridge contains a single bridgewire Apollo standard initiator (SBASI), which is a common-use item throughout the LM and is a GFE item. To prevent erroneous installation, cartridges with different outputs have different threads. The connectors on the SBASI are specially indexed and the connectors that mate with the SBASI are not used for any other purpose anywhere in the LM. Twisted, shielded pairs of firing lines provide protection against RF energy.

EXPLOSIVE DEVICES SUBSYSTEM

300LM3-236

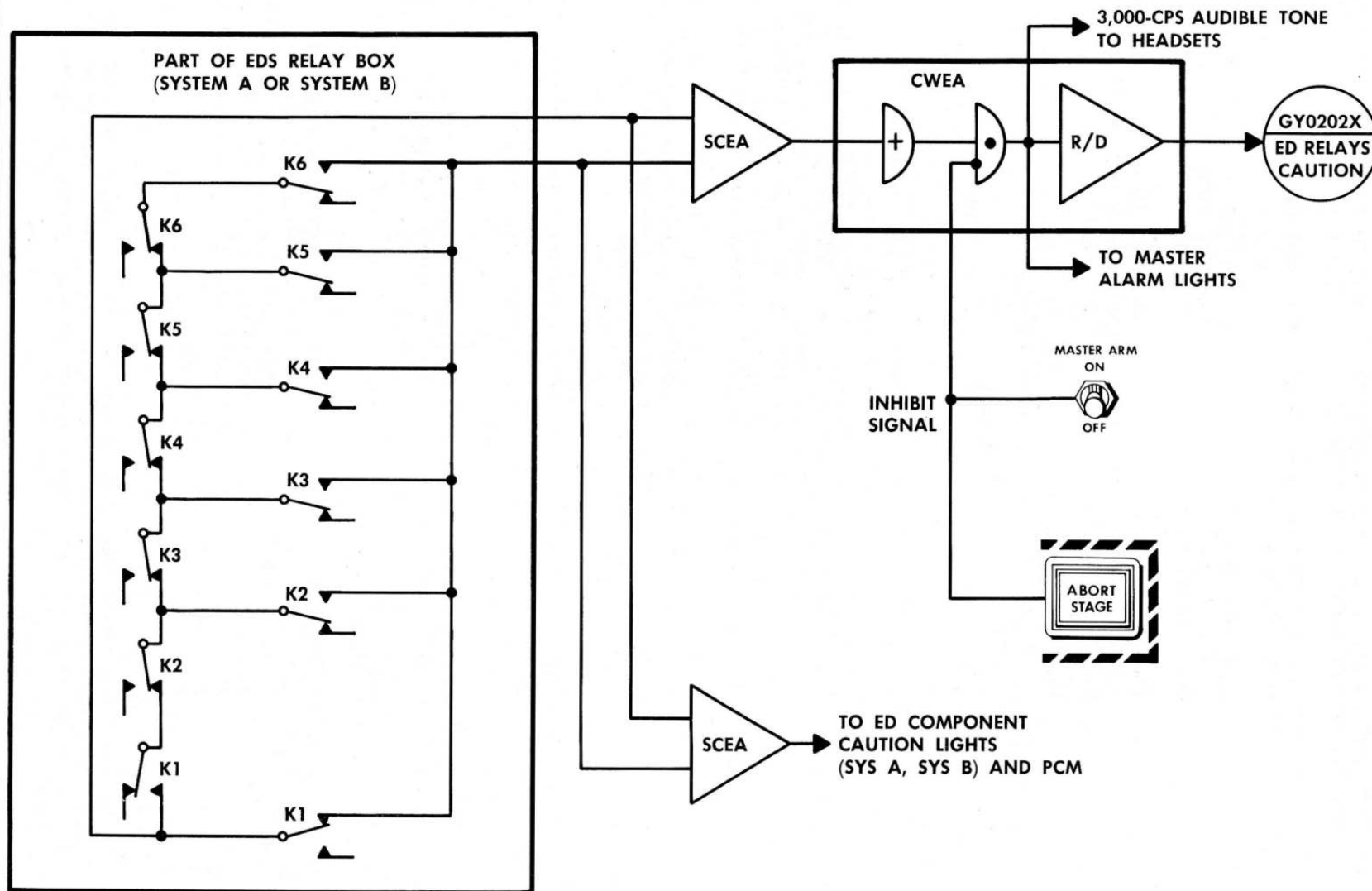


Figure 2-149. Stage Sequence (Relays K2 Through K6) Monitoring - Simplified Schematic Diagram

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

All cartridge assemblies are hermetically sealed to protect the explosive materials against ground and mission environment.

The following explosive devices and components separately, or in various combinations, perform the EDS functions:

- Single Bridgewire Apollo Standard Initiator (SBASI). The SBASI's are fired by ED battery power; they initiate all explosive cartridges and devices required during this mission.
- End Detonator cartridge (EDC). The EDC's are used to detonate all high-explosive charges in the LM landing gear uplock device and the interstage umbilical cutter assembly.
- Pressure cartridges.
 - Electrical circuit interrupter (ECI) cartridges
 - RCS valve cartridges
 - Propulsion valve cartridges
 - Nut cartridges
 - Bolt cartridges
- Helium Isolation Valve and Compatibility Valve. These valves are similar and operate in the same manner; they are used singly or in pairs, depending on the function (RCS, ascent, or descent propellant tank pressurization). Each RCS explosive valve is actuated by a single cartridge. (Redundant valves are used.) Each ascent helium isolation valve and the descent helium isolation and compatibility valves are actuated by two cartridges. There are two ascent fuel and two ascent oxidizer compatibility valves. In each case, one contains two cartridges and the other a single cartridge.
- Circuit Interrupter. Circuit interrupters terminate all signal and power leads that are live at time of staging or that could become live due to activation of a circuit, between the ascent and descent stages. These devices are actuated within 25 milliseconds after stage command is received. They are actuated by either of two cartridges.
- Explosive Nut and Bolt. The ascent and descent stage structures are joined by four explosive nuts and four explosive bolts, each with a single cartridge. Within 20 milliseconds after receipt of the stage command, the four structural tie points are released.
- Guillotine (cable cutter). Dual modes are designed for the guillotine. Either blade can sever an umbilical 35% greater than the actual umbilical within 100 milliseconds after receipt of the stage command at the relay box. Manifolds ensure that both blades receive the fire signal if a failure occurs in one of the modes.
- Landing Gear Uplock. Two independent EDC's are used in each of the four uplocks. A shock wave, generated when the EDC's are fired, acts on the base ends of the two uplock cutting blades. The blades are driven through the connecting strap from opposite directions, severing the strap and deploying the gear. Either blade can sever a strap 35% greater in cross-sectional area than the strap used.

2.8.3.2

Circuitry.

The ED logic circuits are protected by circuit breakers and the firing circuits by current-limiting fuses. Circuit breakers route the power needed to energize the ED relays. Additionally, they protect wiring against deterioration caused by faults or overloads.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

ED circuits are the only electrical load connected to the ED power bus; they do not receive power from the EPS logic bus. The EPS logic bus is used to energize the ED relay coils. The explosive devices switch (panel 8) used determines which relay coil is energized. Relay contacts then route ED battery power (battery A and battery B) from the redundant ED buses to the devices (or cartridges) to perform a specific function. The staging circuitry (unique to the rest of the ED circuits) includes a time-delay circuit that energizes relays in a definite sequence to perform ascent and descent stage separation.

The time delays minimize the possibility of initiating a function before termination of a specific time delay. All ED firing circuits and the EPS staging logic circuits are shielded. Both systems are electrically and physically isolated from one another and the wiring is routed separately wherever possible. The circuits are not grounded; logic and instrumentation ground returns are separated and in no way cause the ED circuits to become grounded.

EDS design is fail-safe in all respects. There are no mechanical or electrical crossovers, except for the mechanical actuation in the ED switches. Failure to arm or operate one EDS system (A or B) does not prevent performance of a function. Redundant wiring is used where loss of a single lead could prevent initiation or control of a function.

All initiators are protected against electromagnetic interference and static electricity by means of a ground loop circuit. The cartridge assemblies are connected to the ED negative bus at all times, until the circuit is fired. When the circuit is fired, the control relay is energized and 37.1 volts dc (ED bus voltage) is routed to the initiators in the cartridge assemblies. A fuse-resistor, in series with the circuit (between the pyro bus and control relay), protects the initiator bridgewire circuit and ED batteries against overloads. The fuse-resistors are rated at 20 amperes for 100 milliseconds, with 1-ohm resistance.

2.8.3.3

MASTER ARM Switch.

The MASTER ARM switch consists of two SPDT switch modules with a common two-position, lever-locking toggle mechanism in the OFF and ON positions. Before performing any EDS functions, this switch must be set to ON. If the ED RELAYS caution light and the SYS A or SYS B component caution light (MSFN telemetry code GY0201X or GY0202X) go on due to the MASTER ARM switch failing in the ON position, or its relay K1 for one system (A or B) closing inadvertently, the affected EDS system should be deactivated by opening the ED: LOGIC PWR A or ED: LOGIC PWR B circuit breaker. A subsequent EDS failure may jeopardize crew safety.

Setting the MASTER ARM switch to ON applies 28 volts dc from EPS systems A and B to the set coils of latching control relays K1 (in systems A and B). Contacts of K1 connect the ED batteries (A and B) to both ED buses, arming the EDS and enabling performance of any function. (See figure 2-150.) The buses are also armed by pressing the ABORT STAGE pushbutton; this bypasses the MASTER ARM switch and is used when staging is performed with automatic ascent engine firing.

Setting the MASTER ARM switch to OFF, deenergizes the ED buses. This position applies 28 volts dc from EPS systems A and B to the reset coils of relays K1 and breaks the circuit between the ED batteries and ED buses.

2.8.3.3.1

STAGE SEQ RELAYS SYS A and SYS B Component Caution Lights.

The STAGE SEQ RELAYS SYS A and SYS B component caution lights are yellow advisory lights. When the MASTER ARM switch is set to ON, both lights go on to signify that both ED buses (systems A and B) are armed and ready to perform an EDS function, and contacts of relays K1 route an inhibit signal to the ED RELAYS caution light. (See figure 2-149.) When the ABORT STAGE pushbutton is pressed, its circuitry bypasses the MASTER ARM switch and provides an inhibit signal to the ED RELAYS caution light.

300LM3-77

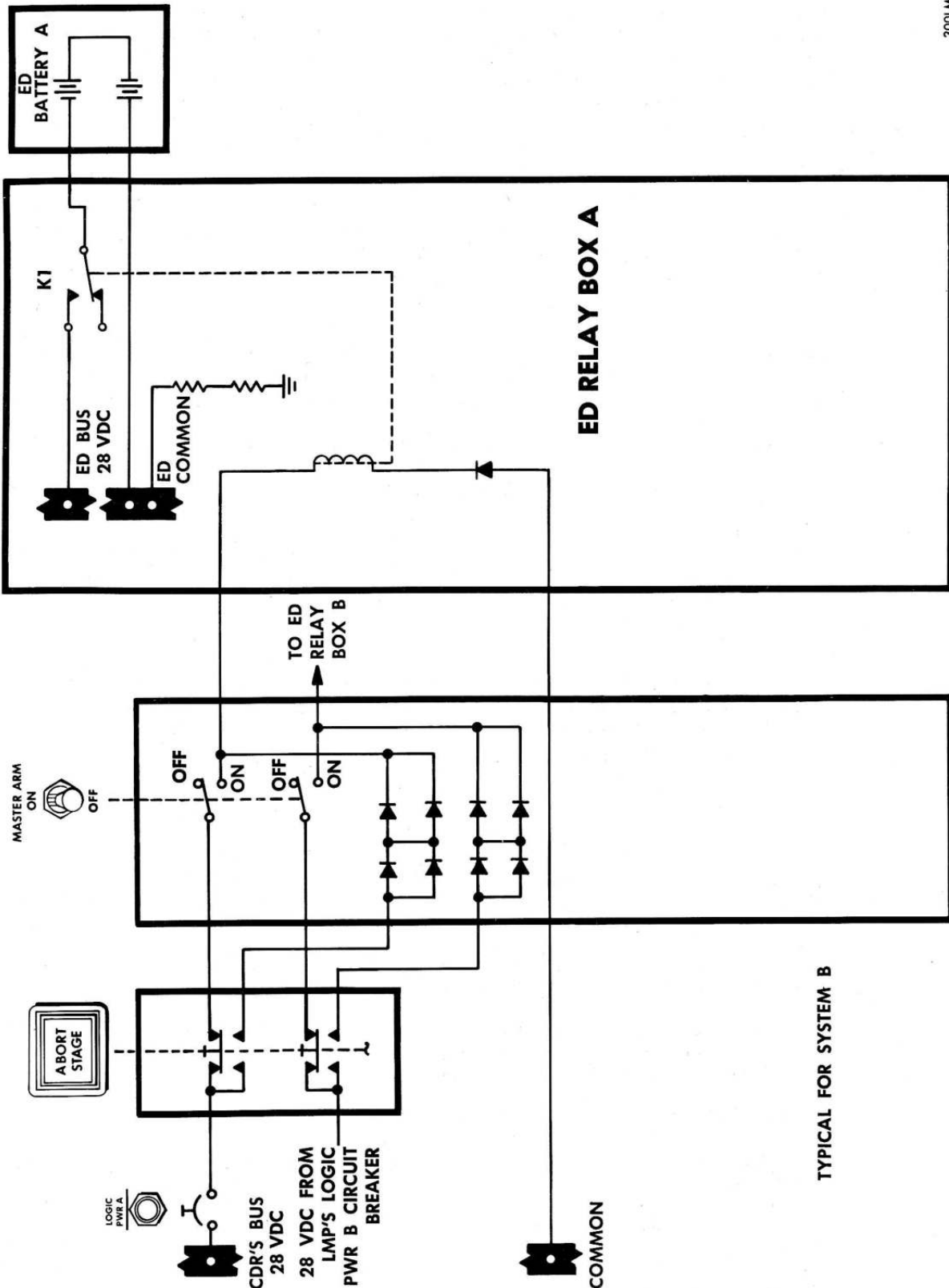


Figure 2-150. Bus-Arming Control - Simplified Schematic Diagram

However, if K1 malfunctions, its contacts route a signal to light the ED RELAYS caution light and, depending on which EDS system has the malfunctioning relay, the SYS A or SYS B component caution light. If any one or combination of relays K1 through K6 malfunction, the ED RELAYS caution light and the SYS A or SYS B (depending on which EDS system failed) component caution light go on. Relay K2 can be reset by momentarily holding the STAGE RELAY switch to RESET. If the SYS A or SYS B (as applicable) component caution light goes off, K2 temporarily failed. If the light remains on, the failure is due to K1, or K3 through K6. The MASTER ARM switch must not be actuated. The defective EDS system must be deactivated by opening (pulling) the ED:LOGIC PWR A or ED:LOGIC PWR B circuit breaker for EDS system A or B, respectively.

2.8.3.4 Initiators. (See figure 2-151.)

The initiators in the EDS cartridges are SBASI's. They provide a high power-to-weight ratio, require low energy to initiate, are compact, and have a high degree of reliability.

Most EDS functions use two cartridges; one is redundant. The ascent propulsion compatibility valves use single cartridges and dual cartridges. (Refer to paragraph 2.8.3.10.) When 3.5 amperes (minimum) is applied to the initiator bridgewire for a few milliseconds, heat is generated. The heat fires the initiator. Each initiator is controlled by separate, independent contacts of the firing relays. Power to fire the initiators is supplied by the ED batteries.

2.8.3.5 ED Batteries.

The LM uses two 20-cell silver oxide-zinc batteries to provide power to both EDS systems to fire the initiators. One battery is in the ascent stage and one is in the descent stage. (See figure 2-148.) Normal operation of either battery provides adequate electrical power for EDS operation. Each battery is rated at 37.1 volts dc (open-circuit voltage), 0.75 ampere-hour; it can produce 75 amperes for 36 seconds. The output voltage of each battery can be monitored periodically on panel 14. Setting the POWER/TEMP MON switch to ED/OFF, and the ED VOLTS switch to BAT A, provides an indication of the output voltage of ED battery A on the VOLTS indicator. Setting the ED VOLTS switch to BAT B provides an indication of the output voltage of ED battery B.

The batteries use potassium hydroxide, one-half saturated, as electrolyte. The battery case is constructed of plastic. Excess pressure in the batteries is vented into the descent and ascent stages at 30 ± 5 psig.

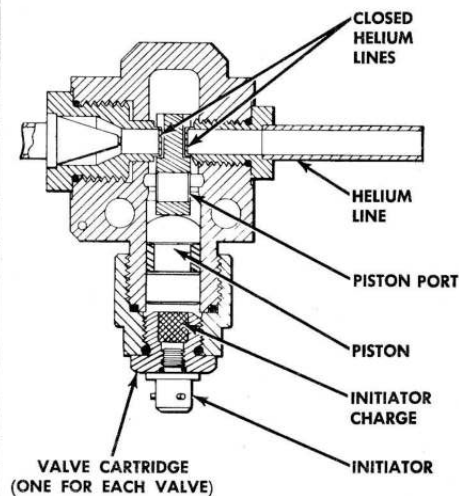
2.8.3.6 Explosive Devices Relay Boxes.

One ED relay box is in the ascent stage; the other one, in the descent stage. (See figure 2-148.) Latching and nonlatching relays are used in the EDS.

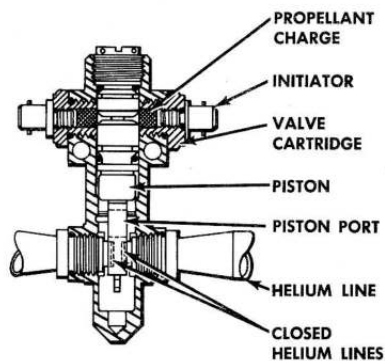
The latching relays, used to control the bus-arming and staging sequence, consist of two coils (set and reset) with associated contacts. The set coil, when energized, initiates circuit operation; the reset coil, when energized, stops circuit operation. The contacts are latched set or reset, depending on the coil pulsed.

The nonlatching relays, used in control and fire circuits, consist of one coil with associated nonlatching contacts. The contacts maintain their normally open or closed position and do not change state until the coil is energized. The contacts remain in the changed state only while the coil is energized.

Fuse-resistors in the ED relay boxes limit the current applied to the initiator bridgewire and provide overcurrent protection for the ED batteries. Each firing circuit uses one fuse-resistor in series with the initiator bridgewire.

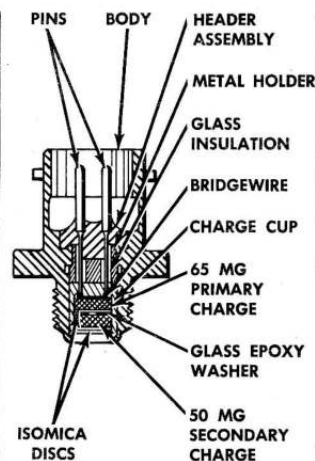


RCS HELIUM ISOLATION VALVE

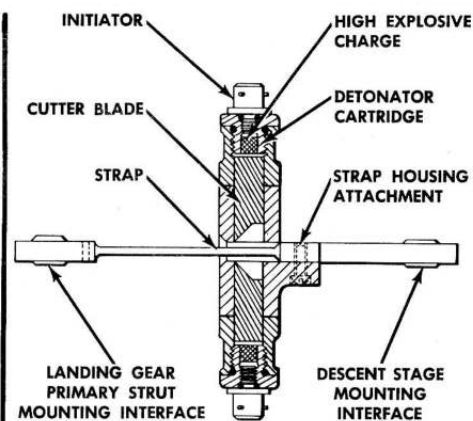


Note:
When the cartridges are fired, the piston travels downward and shears the closed helium lines. The piston port moves into position.

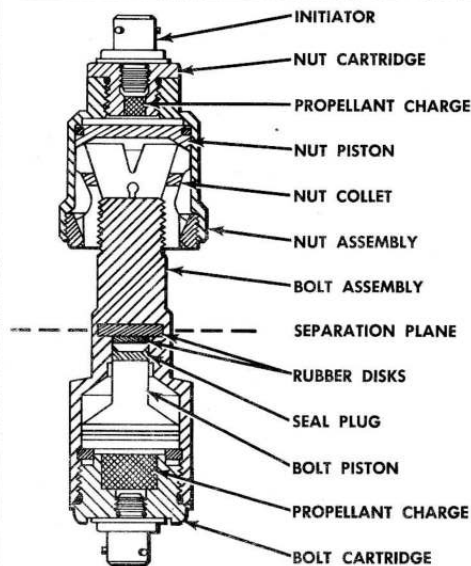
HELIUM ISOLATION VALVE OR COMPATIBILITY VALVE



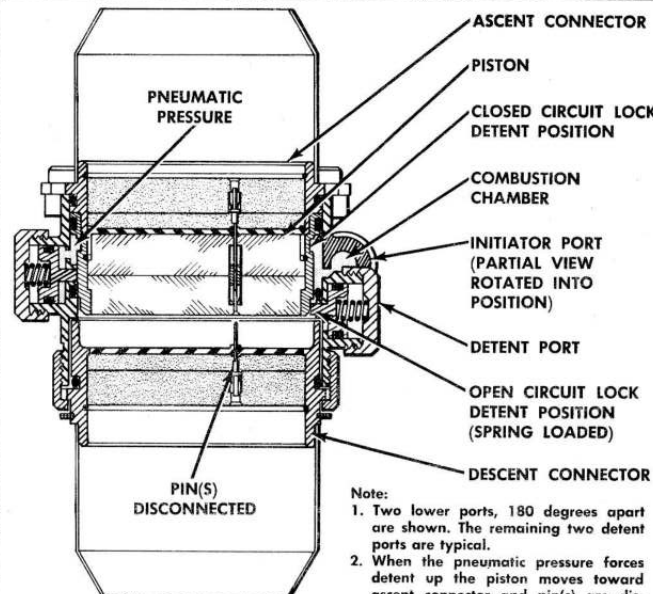
SINGLE BRIDGEWIRE APOLLO STANDARD INITIATOR



LANDING GEAR UPLOCK AND CUTTER ASSEMBLY

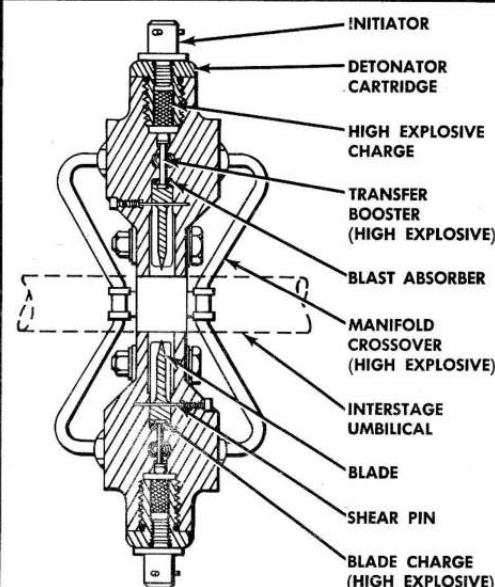


INTERSTAGE STRUCTURAL CONNECTION NUT AND BOLT ASSEMBLY



CIRCUIT INTERRUPTER

Note:
1. Two lower ports, 180 degrees apart are shown. The remaining two detent ports are typical.
2. When the pneumatic pressure forces detent up the piston moves toward ascent connector and pin(s) are disconnected. The detent then locks in the open circuit lock detent position.



CABLE CUTTER ASSEMBLY

300LM3-81

Figure 2-151. Explosive Devices

EDS systems A and B use RC time-delay circuits, in the ED relay boxes, when the staging sequence is performed. Refer to paragraph 2.8.3.9.

2.8.3.7

Landing Gear Uplock and Cutter Assembly. (See figure 2-151.)

The landing gear, stowed in the retracted position at launch, remains retracted until after the astronauts enter the LM. The LDG GEAR DEPLOY switch is used to deploy the landing gear. The switch is a two-position switch, with a lever-locking mechanism for the SAFE position.

An uplock device, with two EDC's, restrains each of the four landing gear legs. Each EDC is controlled and fired by two separate control and fire circuits in parallel. (See figure 2-152.) Firing either EDC in the landing gear uplock results in landing gear leg deployment. Setting the MASTER ARM switch to ON arms the ED buses. Momentarily holding the LDG GEAR DEPLOY switch to FIRE routes power from EPS systems A and B to the coils of relays K8 and K8A in both ED systems. Contacts of these relays route ED battery power to the eight landing gear uplock EDC's. When all four landing gear assemblies have been deployed, EPS power (28 volts dc) is routed through closed contacts of eight switches (one on each side of each landing gear assembly) to provide a gray LDG GEAR DEPLOY talkback display. (See figure 2-153.) The eight switch closures provide MSFN with a combined telemetry signal (GM5000U) for monitoring landing gear deployment.

Firing an EDC generates shock and pressure that act on the base end of the uplock cutting blade. The blade severs a strap connecting the landing gear strut with the LM descent stage, and the landing gear is permitted to deploy. The operation response time of the uplock is approximately 20 milliseconds, after 3.5 amperes (minimum) of direct current is applied to the EDC.

2.8.3.8

Descent Propellant Tank Prepressurization.

An ambient helium isolation valve (figure 2-151) is used in conjunction with two compatibility valves (each downstream of its respective quad check valve in the descent stage) when prepressurizing the descent engine propellant tanks. The valves are normally closed. Setting the MASTER ARM switch to ON and momentarily holding the DES START He PRESS switch to FIRE, routes power from EPS systems A and B to the coil of relays K14 in both EDS systems. (See figure 2-154.) Contact of K14 simultaneously routes ED battery power to the cartridges in the ambient helium isolation valve, allowing ambient helium to flow to the descent engine propellant tank compatibility valves. Momentarily holding the DES PRPLNT ISOL VLV switch to FIRE routes EPS power to the coil of relays K15 in both EDS systems. Contacts of K15 route ED battery power to open the compatibility valves. Ambient helium flows freely to the descent engine fuel and oxidizer tanks, pressurizing them.

Firing either cartridge in a valve generates gases in the valve explosion chamber at extremely high rates. The gases drive a piston downward to shear a closure disk in the pressure line. This opens the valves to permit helium from the descent helium tank to pressurize the propellant tanks. The valves remain open and cannot be closed because, at the end of its stroke, the piston is forced into the valve housing and the piston port in each valve is permanently aligned with the pressure line plumbing. The increase in propellant tank pressure is observed on the FUEL and OXID PRESS indicator (panel 1); the drop in ambient helium tank pressure, on the HELIUM indicator (panel 1). Ambient helium prepressurization permits fuel to flow through the fuel heat exchanger before cryogenic helium flow through the helium heat exchanger is initiated.

When the START pushbutton (panel 5) is pressed to command the descent engine to fire, relay K9 in both ED relay boxes receives a signal, after a 1.3-second delay, from the control electronic section (CES) of the Guidance, Navigation, and Control Subsystem. Contacts of K9 route ED battery power to the cryogenic helium isolation valve, opening the valve. Helium from the cryogenic helium storage tank pressurizes the descent propellant tanks in place of the expended ambient helium. The astronauts are alerted to descent helium pressure malfunctions by the DES REG warning light (panel 1). (Refer to table 2-61.)

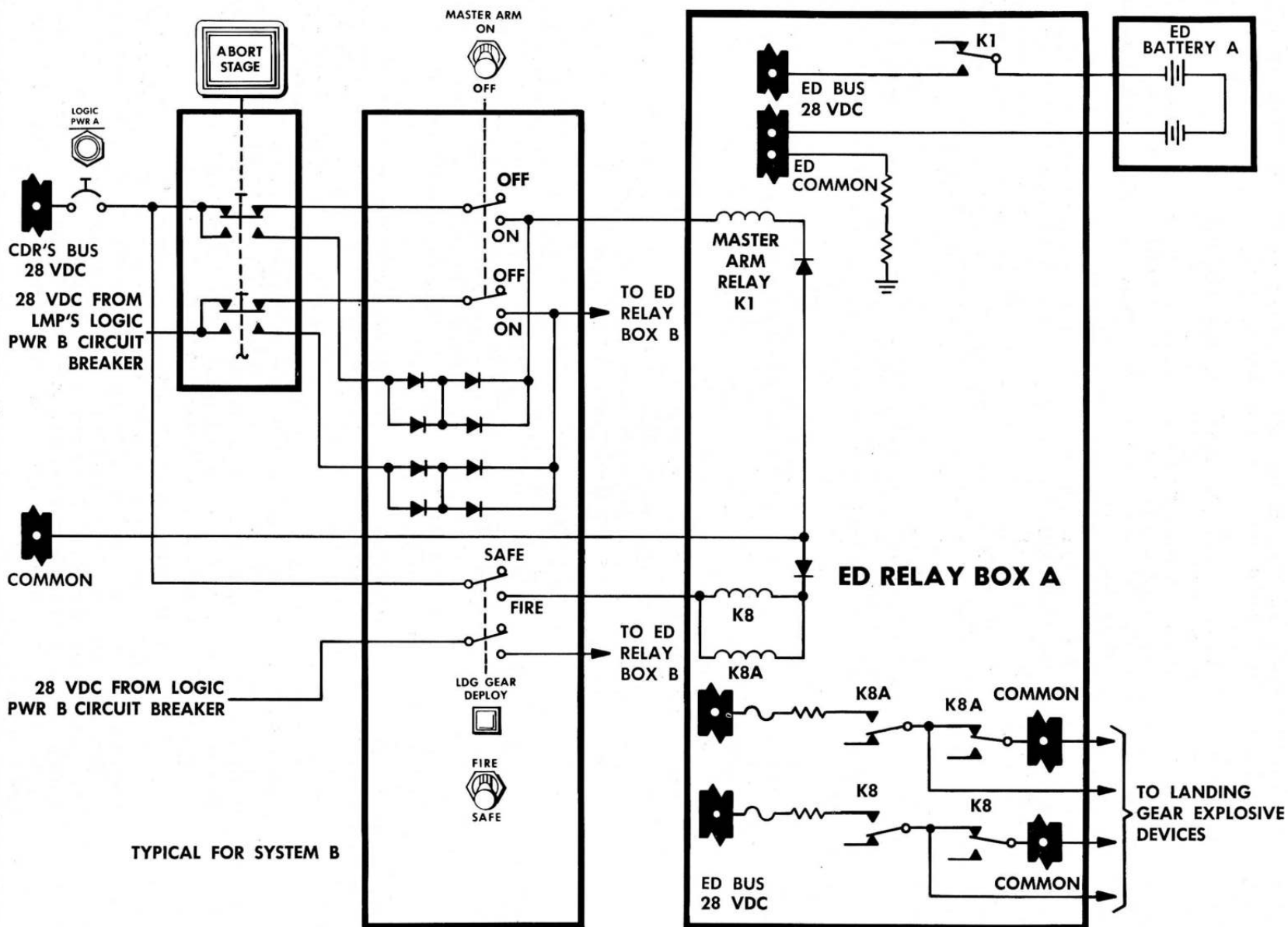


Figure 2-152. Landing Gear Deployment - Simplified Schematic Diagram

300LM3-75

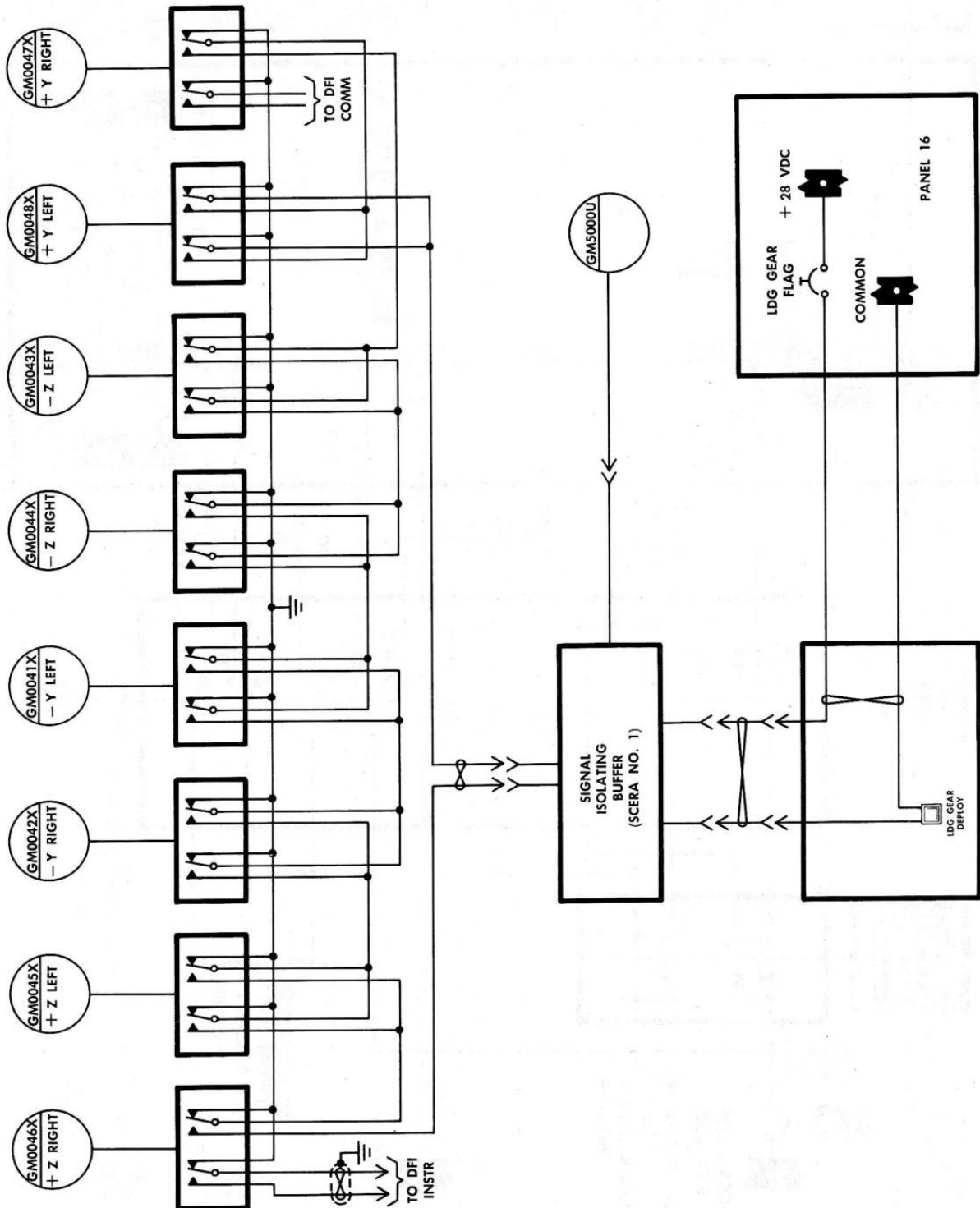


Figure 2-153. Landing Gear Switches - Simplified Schematic Diagram

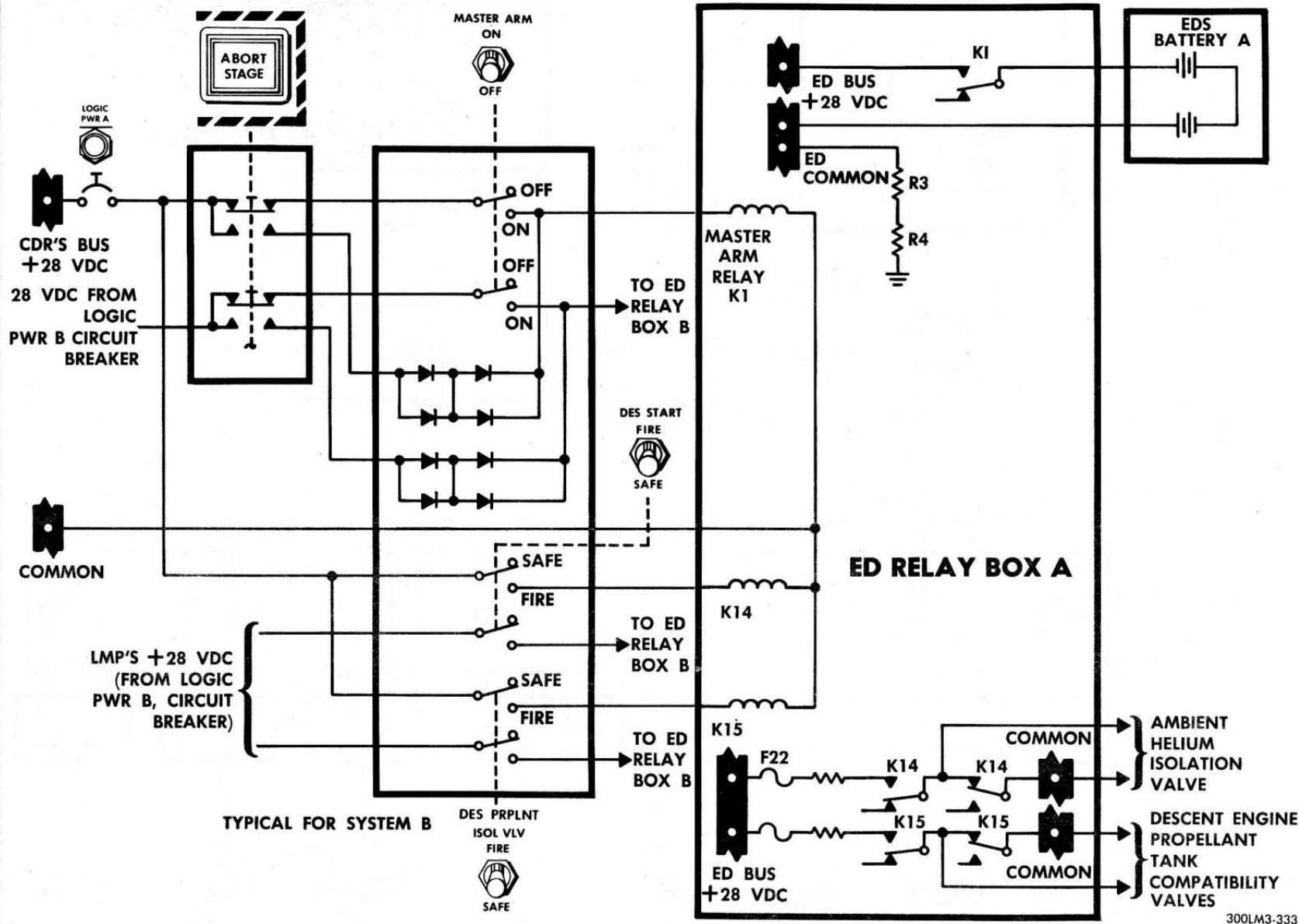


Figure 2-154. Descent Propellant Tank Prepressurization - Simplified Schematic Diagram

2.8.3.9

Stage-Separation Components.

Stage separation requires simultaneous action of the circuit interrupters (dead-facing) and separation of the interstage structural connections (nuts and/or bolts). Following this action, umbilical severance (cable cutting) takes place. This is accomplished by cartridges fired by operation of the STAGE switch or the ABORT STAGE pushbutton, or by an automatic signal from the ascent engine latching device (AELD). The ABORT STAGE pushbutton or the AELD signal provides automatic ascent engine firing after separation. The STAGE switch (not nominally used), initiates the same staging sequence, but does not provide automatic ascent engine firing.

Setting the MASTER ARM switch to ON and the STAGE switch to FIRE applies 28 volts dc from EPS systems A and B to the set coils of latching relays K2. (See figure 2-155.) Contacts of K2 connect the ED stage-sequencing circuits (RC time-delay circuits) to the ED buses, passing current through normally closed contacts of relay K3. This energizes relays K5 and K5A (separation of nuts and bolts) and relays K6 (dead-facing). Relays K3 and K4 do not operate immediately, due to the time-delay circuitry. A time delay is necessary to ensure removal of all power from the interstage umbilical before it is cut. After a 50-millisecond time delay (during which the nuts and bolts separate), capacitor C1 is fully charged. Transistor Q2 conducts and applies ED bus voltage to energize K3. The normally open contacts of K3 close and the bus voltage is applied to another time-delay circuit (transistors Q3 and Q4). This circuit has the same RC time constant; Q4 applies bus voltage to the coil of K4 (guillotine relay), completing stage separation. The staging sequence can also be initiated with a 28-volt d-c signal from the ascent engine latching device segment logic in the CES, by pressing the ABORT STAGE pushbutton. This signal bypasses the STAGE switch. The normally open and closed contacts of K3 ensure that the deadface relay has removed electrical power from the umbilical before the guillotine detonators are fired.

2.8.3.9.1

Interstage Structural Connections. (See figure 2-151.)

The LM uses four nuts and bolts as interstage structural connections. These nuts and bolts are separated explosively for stage separation. Each nut and bolt has its own cartridge; firing either cartridge separates the stages. The nut cartridges are fired by EDS system B; the bolt cartridges by EDS system A. When one or both cartridges are fired, gases that drive a piston within the nut and/or bolt assemblies are generated. This results in bolt fracture and nut separation. If the nut does not separate from the bolt, bolt fracture, alone, results in stage separation. Reaction time for complete nut and bolt separation is approximately 15 milliseconds.

Power for the firing control circuit is controlled by the stage-sequencing circuitry (ED time-delay circuit) in the ascent and descent stages. This circuitry provides proper sequencing of the LM staging operations.

2.8.3.9.2

Interstage Umbilical Cutters (Guillotine). (See figure 2-151.)

The guillotine consists of two cutter subassemblies that sever the interstage electrical umbilical during stage separation. Each cutter assembly consists of an EDC, a transfer booster, a blade charge, and a blade. The transfer booster in each cutter assembly is connected by two manifold crossovers (shielded mild detonating cord), one on each side of the guillotine housing. The manifold crossovers provide for sympathetic ignition needed to operate both blades if one EDC does not fire.

The cutter assembly blades are held safe with shear pins that ensure that the interstage umbilical will not be cut without a positive fire signal to the control circuit. Firing the detonator and explosive blade charge generates a shock wave that drives the cutting blades through the interstage umbilical. The blades sever the umbilical, cutting all electrical wires and the descent water tank supply hardline between the ascent and descent stages. Loss of the ascent water tank supply is prevented by check valves in the ascent stage plumbing. Reaction time for cutter assembly operation is approximately 5 milliseconds, after 3.5 amperes (minimum) of direct current is applied to the initiator bridgewire.

Notes:

1. The remaining contacts of the ABORT STAGE switch route the signal to the CES. The CES routes a stage command back to the EDS.
2. This signal bypasses the ASCENT He PRESS switch; it is routed to relays K10, K11 and K12 through the ASC He SEC switch, for automatic arming and ascent pressurization.

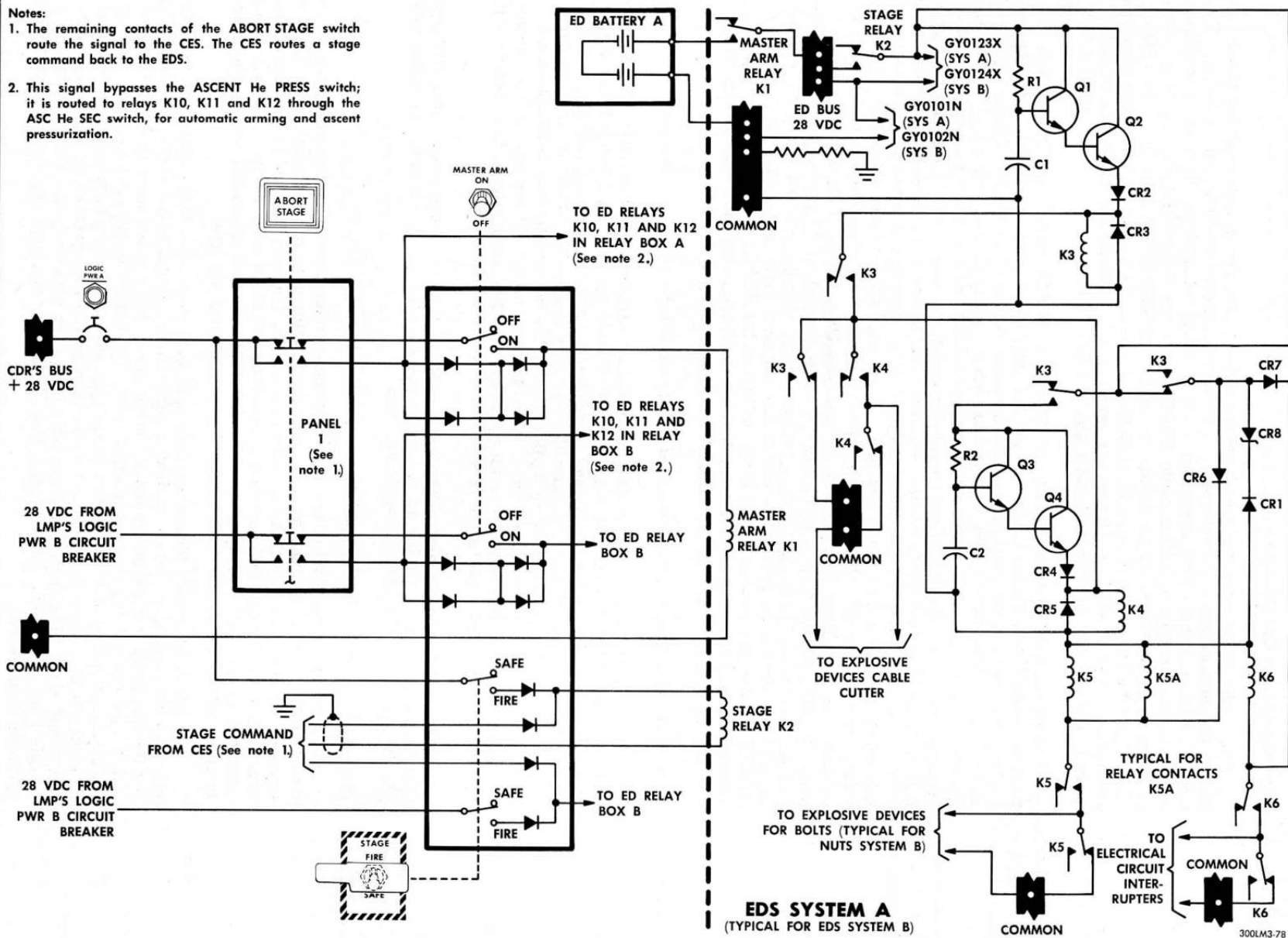


Figure 2-155. Stage Sequence - Simplified Schematic Diagram

2.8.3.9.3 Circuit Interrupters (Deadface Connectors). (See figure 2-151.)

Three circuit interrupters are in the ascent stage. (See figure 2-148.) They are in front of the ascent stage tank thermal shielding, immediately above quadrant IV of the descent stage. Each circuit interrupter has two cartridges. Each cartridge can cause the circuit interrupter to operate. Using two cartridges for each circuit interrupter provides redundancy to ensure that the electrical power between the ascent and descent stages is terminated before umbilical severance.

The circuit interrupter cartridges are energized during the staging operation. When energized, the cartridges cause a pressure buildup in the circuit interrupter combustion chamber. As pressure builds up in the chamber, two initial lock detents move to their open positions, freeing the piston assembly and permitting its movement when its actuation pressure is reached.

When the pressure in the combustion chamber is sufficient to overcome pin and O-ring friction, the piston assembly moves to the open-circuit position, disconnecting the pins of the electrical connectors. Spring-loaded final lock detent pins automatically drop into slots in the piston and retain the piston in the open-circuit position.

Circuit interruption removes all electrical power from the interstage umbilical lines before the umbilical is severed. (See figure 2-156 for a functional block diagram of circuit interruption.)

The stage-sequencing circuits (paragraph 2.8.3.9.4) control circuit interrupter operation. If one cartridge fired by the control circuit malfunctions, the other cartridge, fired by the redundant control circuit performs the function; normally, both cartridges fire. Approximately 240 electrical conductors are routed through each circuit interrupter. The interrupter pin connections are normally closed; they are opened by firing the cartridge. Operation response time of the circuit interrupters is approximately 20 milliseconds.

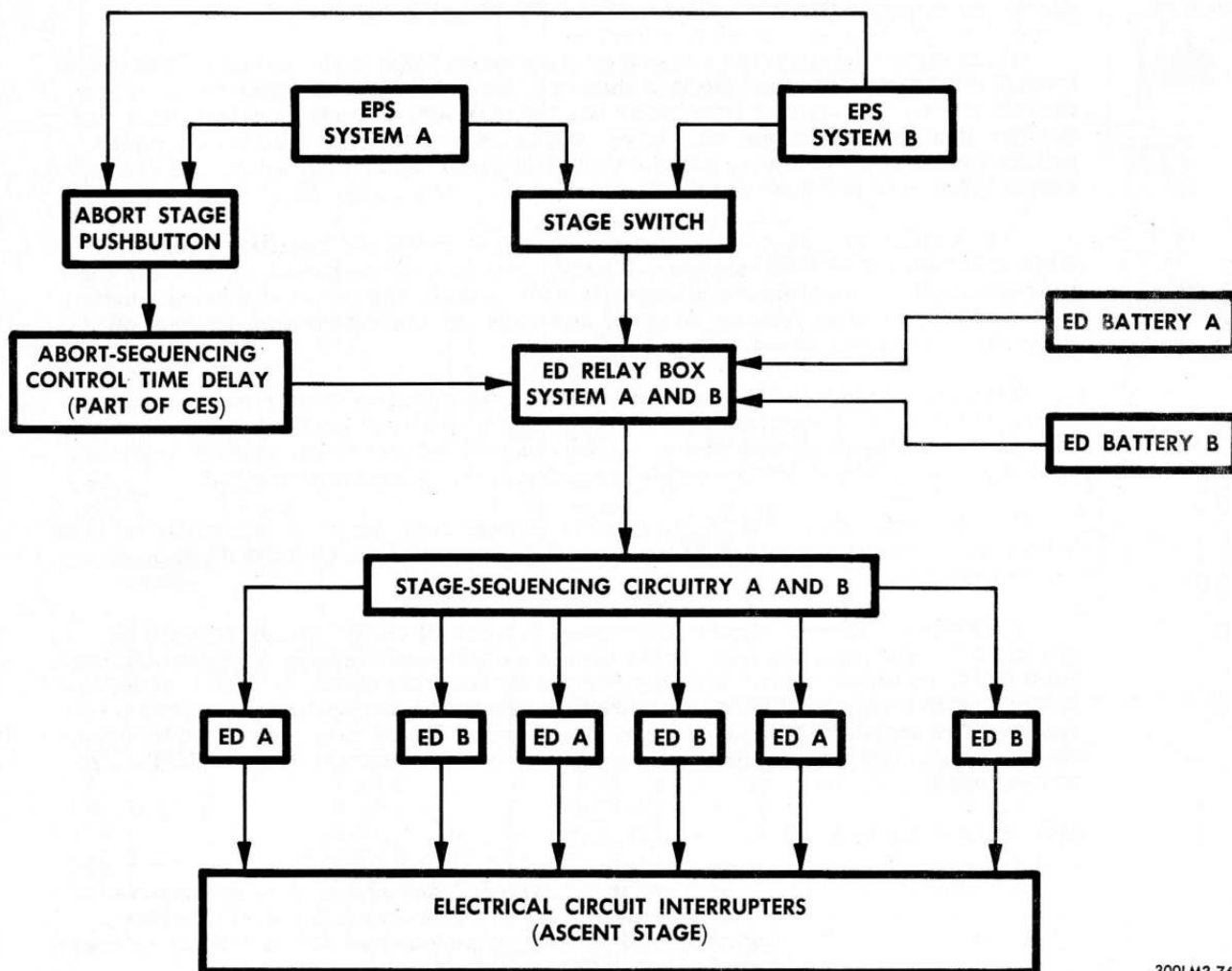
2.8.3.9.4 Stage-Sequencing Circuits.

The stage-sequencing circuits are in the system A and system B relay boxes in the ascent and descent stages. The time-delay circuitry (paragraph 2.8.3.9) provides proper sequencing of the staging operation, using transistorized RC time-delay networks.

2.8.3.10 Ascent Propellant Tank Pressurization. (See figure 2-157.)

Two helium isolation valves (figure 2-151), each with two cartridges and two sets of parallel redundant fuel and oxidizer compatibility valves, are used when pressurizing the ascent engine propellant tanks. One fuel and oxidizer compatibility valve use two cartridges; the other fuel and oxidizer compatibility valve, a single cartridge. The valves are in the ascent stage. (See figure 2-148.) The ASC He SEL switch provides the astronauts with the option of using either one or both helium tanks to pressurize the system.

The valves are normally closed; they open when the cartridges are fired, depending on the setting of the ASC He SEL switch. In addition, the control relays for the helium isolation and the compatibility valves can be energized with a direct signal from the ABORT STAGE pushbutton, which bypasses the ASCENT He PRESS switch. The ASCENT He PRESS switch consists of two SPDT switch modules, actuated by a common two-position, lever-locking toggle mechanism that has a maintain in the SAFE position and momentary in the FIRE position. Normally, the ASC He SEL switch is set to BOTH so that both helium tanks are used for ascent propellant tank pressurization. Setting the MASTER ARM switch to ON and momentarily holding the ASCENT He PRESS switch to FIRE routes 28 volts dc from EPS systems A and B to the coils of control relays K10 and/or K11, depending upon the setting of the ASC He SEL switch, and to relay K12A. Contacts of these relays route ED battery power to the helium isolation valve cartridges and compatibility valve cartridges.



300LM3-76

Figure 2-156. Electrical Circuit Interrupter - Functional Block Diagram

Firing the cartridges (one cartridge is sufficient to accomplish the task) generates gases in the valve chamber. The gases drive a piston, shearing the closed helium pressure line(s). This opens the valve to permit helium from the ascent helium tank(s) to pressurize the propellant tanks. Like the valves used for descent propellant tank pressurization, they remain open; they cannot be closed. The astronauts are alerted to ascent helium pressure malfunctions by the ASC PRESS warning light (panel 1). (Refer to table 2-61.)

2.8.3.10.1

Ascent Helium Tank Select Switch.

The ASC He SEL switch is a three-position switch with lever-locking mechanism in all positions. Setting the switch to TANK 1 routes 28 volts dc to the coils of control relays K10. Contacts of K10, which are in series with cartridges used for helium tank No. 1, close. Setting the switch to BOTH routes 28 volts dc to the coils of control relays K10 and K11; the relay contacts close. This completes the circuits to fire cartridges for helium tank No. 1 and 2. Setting the switch to TANK 2 routes 28 volts dc to the coils of control relays K11. Contacts of K11, which are in series with cartridges used for helium tank No. 2, close. When the ABORT STAGE pushbutton is pressed, only the helium tanks or tank selected with the ASC He SEL switch will have open valves.

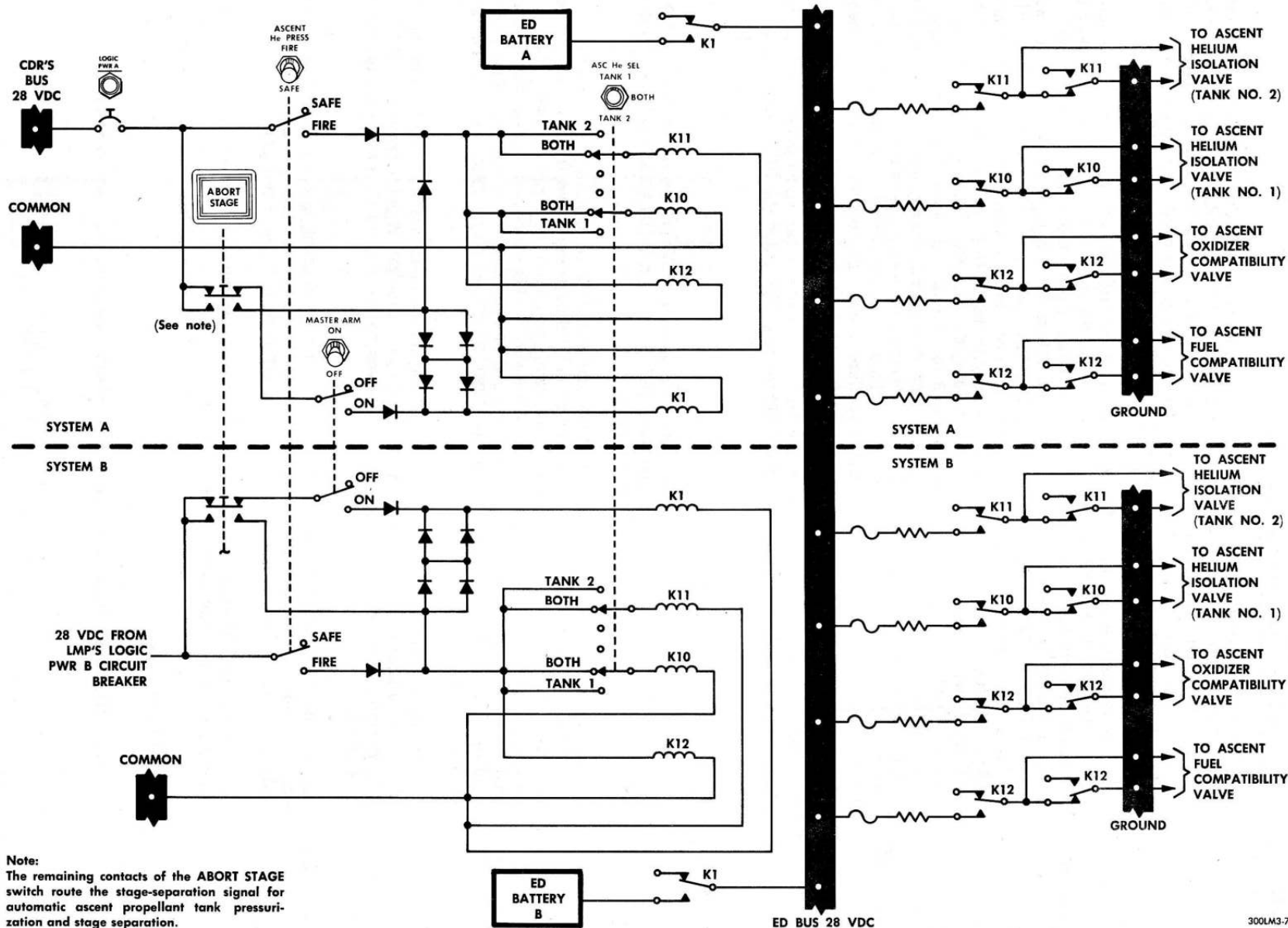


Figure 2-157. Ascent Propellant Tank Pressurization - Simplified Schematic Diagram

2.8.3.11

RCS Propellant Tank Pressurization.

Helium isolation valves in the ascent stage (figure 2-148) are used when pressurizing the RCS propellant tanks. Two helium, two fuel, and two oxidizer tanks are used in the RCS. Each helium tank pressurizes one fuel and one oxidizer tank. Two redundant helium isolation valves, in parallel in the RCS plumbing, are used in conjunction with each helium tank. Each valve has one cartridge and is fired by one of the EDS systems.

The valves are normally closed; their firing circuits are controlled by relays actuated by the RCS He PRESS switch. Except for the switch and relays used, the power to initiate pressurization is routed as shown for landing gear deployment. (See figure 2-152.) Relays K8 and K8A are replaced with relays K7; the LDG GEAR DEPLOY switch, with the RCS He PRESS switch. The RCS He PRESS switch consists of two SPDT switch modules, actuated by a common two-position, lever-locking toggle mechanism that has a maintain in the SAFE position and a momentary in the FIRE position. Setting the MASTER ARM switch to ON and momentarily holding the RCS He PRESS switch to FIRE routes 28 volts dc from EPS systems A and B to the coils of relays K7. Energizing either of these two relays completes the circuit between the cartridges in the helium isolation valves and the ED buses. Firing the cartridges causes gases to drive a piston, shearing the closed helium pressure line. This opens the valves to permit helium from the RCS helium tank to pressurize the propellant tanks. The valves remain open; they cannot be closed.

The astronauts are alerted to RCS helium line pressure and tank pressure malfunctions by the RCS A REG and the RCS B REG warning lights and the RCS caution light (table 2-61).

2.8.3.12

Descent Propellant Tank Venting.

The descent propellant tanks are vented with the DES VENT switch on the EXPLOSIVE DEVICES portion of panel 8 and the FUEL VENT and OXID VENT switches on the DES PROPULSION portion of the same panel.

Setting the MASTER ARM switch to ON and momentarily holding the DES VENT switch to FIRE routes 28-volts d-c power from EPS systems A and B to the coils of relays K13. Energizing either of these two relays completes the circuit between the cartridges in the fuel and oxidizer vent valves and the ED buses. Actuating these valves enables venting the descent propellant tanks and remaining descent helium. The solenoid-operated vent valves actuated by the FUEL VENT and OXID VENT switches actually effect the venting.

Setting the FUEL VENT switch to OPEN opens the descent fuel valve to vent the fuel tanks; the talkback above the switch provides a gray display. A pulse from the FUEL VENT switch opens or closes the solenoid valves, depending on the switch setting (OPEN or CLOSE).

Setting the OXID VENT switch to OPEN opens the descent oxidizer valve to vent the oxidizer tanks; the talkback above the switch provides a gray display. Like the fuel valve, this valve can be closed by setting the OXID VENT switch to CLOSE.

For a detailed discussion of the descent propellant tank venting operation refer to the Main Propulsion Subsystem (subsection 2.3).

2.8.4

FAILURE MODES.

The EDS failure modes and effects on mission capability are given in table 2-54.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-54. Explosive Devices Subsystem - Failure Modes

Failure	Indication	Vehicle Capability
LDG GEAR DEPLOY switch	Barber-pole LDG GEAR DEPLOY flag, or MSFN telemetry	Landing gear assemblies cannot be deployed. This failure does not affect subsequent testing. Mission is compromised to extent that control characteristics are changed.
One or more landing gear explosive devices fire prematurely	CSM visual inspection	If this failure occurred before SLA separation, the LM may not be able to separate and the mission aborted. If the failure occurred after SLA separation, landing gear deployment is not affected. Remaining landing gear assemblies can be deployed. However, until all landing gear assemblies are deployed, mission is compromised to extent that control characteristics are changed.
RCS He PRESS switch	With TEMP/PRESS MON selector switch (panel 2) set to He, helium tank pressure, as indicated on A and B PRESS indicators (panel 2), does not drop. With selector switch set to PRPLNT, propellant tank pressures do not increase.	Ascent propellant can be used to perform RCS maneuvers, by setting CRSFD switch (panel 2) to OPEN. The ascent engine must be on for these maneuvers.
ASCENT He PRESS switch	Ambient helium tank pressure, as indicated on HELIUM indicator (panel 1), does not drop and fuel and oxidizer tank pressure, as indicated on FUEL and OXID PRESS indicators (panel 1), does not increase from previous reading.	Supercritical helium can be used to test descent engine. If this attempt fails due to freezing, descent engine testing is eliminated.
ASCENT He PRESS switch	Helium tank pressure, as indicated on HELIUM indicator, does not drop and fuel and oxidizer tank pressure, as indicated on FUEL and OXID PRESS indicator, does not increase from previous reading.	This failure does not prevent ascent propellant tank pressurization. Pressurization can be accomplished by opening STAB/CONT: ABORT STAGE circuit breakers (panels 11 and 16) and pressing ABORT STAGE pushbutton.
ASC He SEL switch	In the BOTH position the indications are identical to ASCENT He PRESS switch failure. If the TANK 1 position fails the helium tank pressure as indicated on HELIUM indicator for tank No. 1 does not drop. If the TANK 2 position fails the HELIUM indicator for tank No. 2 does not drop.	This is a multiple-pole switch. If entire switch failed ascent propellant tank pressurization is impossible and ascent engine testing is eliminated. If the TANK 1 or TANK 2 position fails the mission is curtailed for ascent engine burns.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-54. Explosive Devices Subsystem - Failure Modes (cont)

Failure	Indication	Vehicle Capability
MASTER ARM switch	STAGE SEQ RELAYS SYS A and SYS B component caution lights do not go on, or MSFN telemetry.	In emergency, STAB/CONT:ABORT STAGE circuit breaker can be opened and ABORT STAGE push-button pressed. However, this action automatically pressurizes ascent propellant tanks if they have not been pressurized.
DES PRPLNT ISOL VLV switch	Fuel and oxidizer tank pressure, as indicated on FUEL and OXID PRESS indicators (panel 1), does not increase from previous reading.	If this failure occurs the descent propulsion compatibility valves do not open. This eliminates descent engine testing.
DES VENT switch	Will not be detected until the FUEL VENT and OXID VENT switches on DES PROPULSION portion of panel 8 are used. Refer to Main Propulsion Subsystem for details.	Refer to Main Propulsion Subsystem for details.
STAGE switch	Descent and ascent stages do not separate, or MSFN telemetry.	Normally this switch is not used for staging. Automatic signal from LGC (through the AELD) is used. ABORT STAGE pushbutton can also be used.
Electrical circuit interrupter cartridge fires prematurely	Loss of descent power including one ED battery. This is observed on the VOLTS meter on ELECTRICAL POWER panel (14).	Descent testing will be eliminated.
Cable cutter cartridge fires prematurely	Loss of descent power.	Possible loss of mission.
Nut/Bolt cartridge fires prematurely	None	This does not prevent actuating the remaining nuts and bolts when staging is to be performed.

2.8.5 PERFORMANCE AND DESIGN DATA.

The performance and design data for the EDS are given in table 2-55.

Table 2-55. Explosive Devices Subsystem - Performance and Design Data

Battery	
Height	3.03 inches
Width	2.75 inches
Length	6.78 inches
Weight (each, filled)	3.50 pounds

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-55. Explosive Devices Subsystem - Performance and Design Data (cont)

Electrical requirements	
Inputs	
From EPS (Commander's and LM Pilot's buses)	28 volts dc
From control electronics section (AELD)	28 volts dc
In preceding text and in preceding table, "AELD" is used.	
From ED batteries (systems A and B)	37.1 volts dc (open-circuit voltage)
	35.0 volts dc (minimum)
Outputs	
To initiators (in cartridge assemblies)	3.5 amperes for 10 milliseconds (minimum)
ED relay boxes	7.5 to 15.0 amperes dc (for at least 10 milliseconds)
Resistance	
Initiators	1.05 \pm 0.10 ohms
Electrical circuit interrupter	Approximately 0.2 ohm with 30-millivolt open-circuit voltage and maximum 10- microampere short-circuit current
Fuse-resistors	1.0 ohm with 20.0 amperes (for 100 milliseconds)

2.8.6

OPERATIONAL LIMITATIONS AND RESTRICTIONS.

The operational limitations and restrictions for the EDS are as follows:

- The landing gear legs must be deployed before the descent engine is fired. In the stowed position, the legs are in the path of the descent engine plume; descent engine firing would damage them.
- The RCS He PRESS switch should not be actuated until quadrant temperatures exceed +60° F. Thermally, the RCS engine values lag the indicated quadrant temperatures and the propellant may contact the valves while they are at their critical low temperature.
- The ASCENT He PRESS switch should not be actuated longer than 24 hours before use. The ascent pressurization valves are designed to operate for only 24 hours after exposure to propellant vapors. Exceeding this limit may cause ascent valve failure.
- The DES START He PRESS and DES PRPLNT ISOL VLV switches should not be actuated longer than 3.5 days before use. The descent pressurization valves are designed to operate for only 3.5 days after exposure to propellant vapors. Exceeding this limit may cause descent valve failure.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

2.8.7

TELEMETRY MEASUREMENTS.

The EDS telemetry data are given in table 2-56.

Table 2-56. Explosive Devices Subsystem - Telemetry Measurements

Code	Description	Telemetry Range (Nominal)	Display Range	Crew Display
GY0050X	Abort commanded	0 or 28 vdc (R)		None
GY0101N	System A continuity	0.5 to 2.0 ohms		None
GY0102N	System B continuity	0.5 to 2.0 ohms		None
GY0123X	Staging relay K2 closed (system A)	Contact closure		STAGE SEQ RELAYS SYS A component caution light and ED RELAYS caution light
GY0124X	Staging relay K2 closed (system B)	Contact closure		STAGE SEQ RELAYS SYS B component caution light and ED RELAYS caution light
GY0201X	ED SYS A relay trans- fer (K1 through K6)	Contact closure		STAGE SEQ RELAYS SYS A component caution light and ED RELAYS caution light
GY0202X	ED SYS B relay trans- fer (K1 through K6)	Contact closure		STAGE SEQ RELAYS SYS B component caution light and ED RELAYS caution light
GY0231X	System A EDS relays K7 through K15	Contact closure		None
GY0232X	System B EDS relays K7 through K15	Contact closure		None
GY0701V (GY0703U)	EDS system A battery voltage	0 to 40 vdc (36 vdc)	0 to 40 vdc	VOLTS meter (panel 14)
GY0702V (GY0703U)	EDS system B battery voltage	0 to 40 vdc (36 vdc)	0 to 40 vdc	VOLTS meter (panel 14)
GY0703U	Selected EDS battery voltage (POWER/TEMP MON switch, panel 14)	20 to 40 vdc	20 to 40 vdc	VOLTS meter (panel 14)
GM5000U	Landing gear deployment	Contact closure		LDG DEPLOY flag

EXPLOSIVE DEVICES SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

2.9 INSTRUMENTATION SUBSYSTEM.

2.9.1 INTRODUCTION.

The Instrumentation Subsystem (IS) monitors the LM subsystems during manned missions, performs in-flight checkout, prepares LM status data for transmission to MSFN, provides timing frequencies and correlated data for LM subsystems, and stores voice and time-correlation data. In addition, during the lunar mission, the IS performs lunar surface checkout and provides scientific instrumentation for lunar experiments. This subsystem discussion includes a discussion of the Developmental Flight Instrumentation (DFI) used during this mission. The DFI is required for flight qualification of the LM; it is not required for the lunar mission.

The IS consists of subsystem sensors, a signal-conditioning electronics assembly (SCEA), pulse-code-modulation and timing electronics assembly (PCMTEA), caution and warning electronics assembly (CWEA), and a data storage electronics assembly (DSEA). The DFI consists of subsystem sensors, signal-conditioning equipment, a constant-bandwidth modulation assembly, three proportional-bandwidth modulation assemblies, four 90-segment time-division multiplexers, three double-pole three-segment vibration commutators, power control and distribution equipment, five VHF/FM transmitters, and a C-band transponder.

Each IS assembly receives operating power from the Electrical Power Subsystem (EPS) through associated circuit breakers. The SCEA receives most of the LM subsystem status signals from sensors located in the subsystems. The signals are then routed to the CWEA for monitoring malfunctions, displays, and/or the PCMTEA for telemetry.

The DFI receives operating power from the EPS through two redundant circuit breakers. The C-band power is applied by setting the C-BAND PWR switch (panel 11) to ON. Like the IS, the DFI receives subsystem data. The data are transmitted to MSFN for checkout of equipment that will not require checkout on the lunar mission.

2.9.2 FUNCTIONAL DESCRIPTION.

2.9.2.1 Instrumentation Subsystem. (See figure 2-158.)

The IS accepts data, such as temperature, valve position, pressure, switch position, voltage, and current, from other subsystems through subsystem sensors. The sensors convert physical data to analog and digital (discrete event functions) signals that are routed to the SCEA for voltage level conditioning. If conditioning is not required, the signals are routed directly to the PCMTEA and CWEA. The SCEA conditions the sensor inputs and feeds outputs of high-level analog (0 to 5 volts dc) or digital (4 to 6 volts dc for logic 1; 0 to 0.5 volt dc for logic 0) data to the PCMTEA, CWEA, and displays. To activate the IS, the INST: SIG CONDR 2, PCM/TE, CWEA, and SIG SENSOR circuit breakers (panel 16) and the AC BUS A: TAPE RCDR and INST: SIG CONDR 1 circuit breakers (panel 11) must be closed.

The conditioned signals supplied by the SCEA to the PCMTEA and the signals routed directly from the sensors to the PCMTEA are changed to serial digital form for transmission to MSFN at one of two bit rates: 1,600 bits per second (low rate) or 51,200 bits per second (high rate). Subcarrier frequencies, time reference signals, and sync pulses are generated in the PCMTEA and supplied to other subsystems that require them for proper operation.

Analog and digital signals supplied from the SCEA to the CWEA are constantly compared to internally generated limits and monitored on display panels. On detecting an out-of-limit condition, the CWEA provides output signals to energize the associated indicator, two MASTER ALARM pushbutton/lights, and a tone generator. Malfunction (out-of-limit condition) indicators consist of warning and caution lights (panels 1 and 2, respectively). The warning lights indicate malfunctions that jeopardize astronaut safety

IS

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

and require immediate action. The caution lights indicate malfunctions that do not require immediate action.

The DSEA provides voice-recording capability. The audio signal is supplied from the astronaut's bus in the Communications Subsystem (CS) to the DSEA, where it is recorded along with time reference signals (mission elapsed time) from the PCMTEA. Ten hours of recording time is provided in the DSEA. The tape cannot be played back by the DSEA; this must be performed with ground equipment.

2.9.2.2 Developmental Flight Instrumentation.

The DFI consists of equipment required for flight qualification of the LM during earth-orbital missions. It provides detection, signal conditioning, and transmission of subsystem data. During earth-orbital missions, the prime mode of ranging and tracking is accomplished via the C-band transponders in the DFI communications section. In addition to transmitting subsystem data detected and processed by the DFI instrumentation section, one of the five VHF/FM transmitters transmits subsystem data acquired by the IS.

2.9.3 MAJOR COMPONENT/FUNCTIONAL DESCRIPTION.

The IS consists of sensing equipment located in other LM subsystems, and four electronic assemblies that prepare subsystem data for transmission to MSFN, generate timing frequencies and correlated timing data, and store voice.

The IS consists of the following:

- Sensors - sense physical data (temperature, valve and switch positions, pressure, voltage, current, water quantity, and stage-separation distance).
- Signal-conditioning electronics assembly - conditions subsystem transducer (sensor) signals and events to proper voltage levels.
- Pulse-code-modulation and timing electronics assembly - prepares subsystem-status signals for transmission and provides timing frequencies and mission-elapsed-time data to subsystems.
- Caution and warning electronics assembly - generates signals that illuminate appropriate caution and warning lights and activate two MASTER ALARM pushbutton/lights and a tone generator.
- Data storage electronics assembly - stores audio and time-correlation data (mission elapsed time) on tape.

The instrumentation section of the DFI consists of the following:

- Sensors - sense physical data (temperature, valve position, pressure, voltage, and current).
- Strain/temperature signal conditioners - condition DFI transducer (sensor) signals to proper voltage levels.
- Commutators - sample most DFI data and provide serial return-to-zero (RZ) output data.
- Modulation packages - route DFI signals to the communications section, for telemetry.
- Signal-conditioning box - conditions signals and serves as a junction box.
- Power control and distribution equipment - Routes 28 4-volt d-c LM power to operate DFI equipment.

INSTRUMENTATION SUBSYSTEM

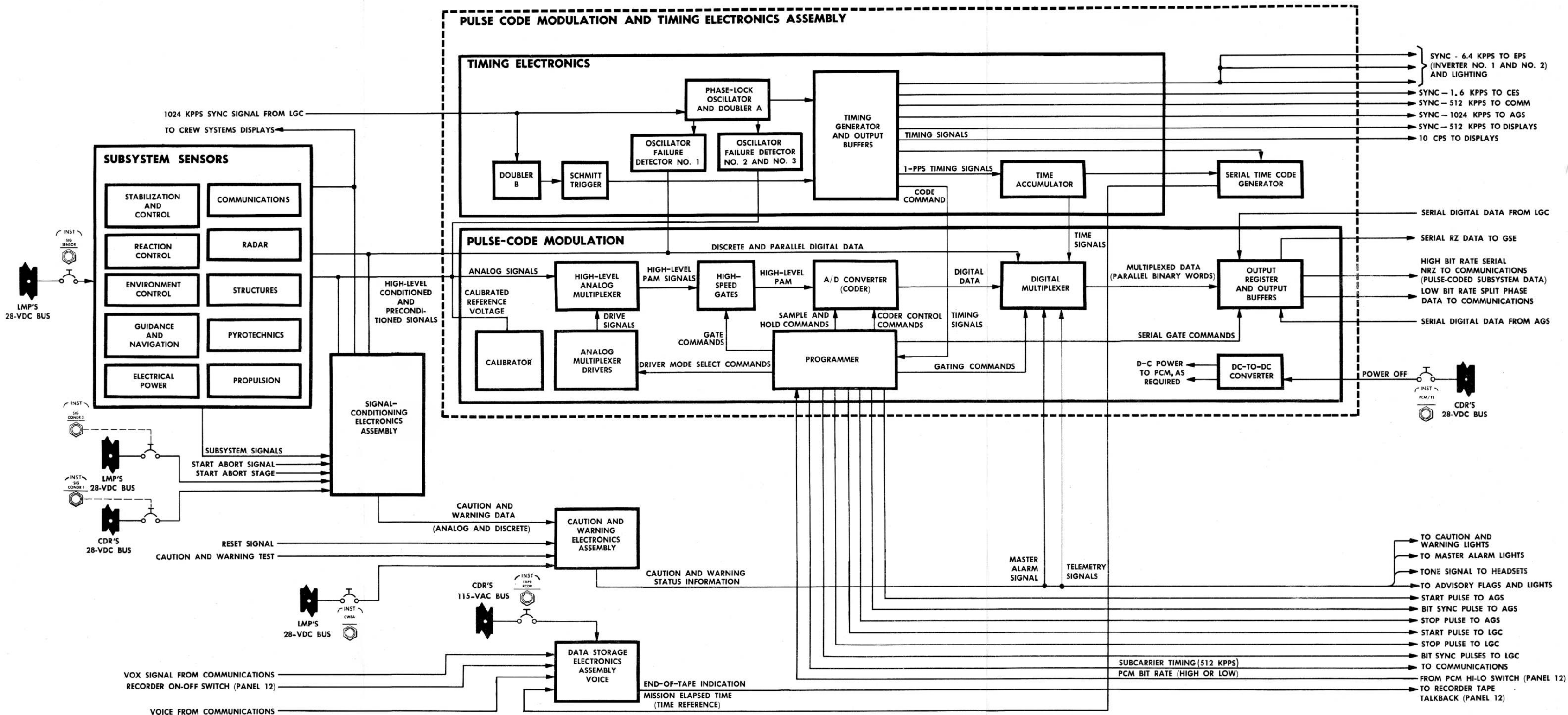


Figure 2-158. Instrumentation Subsystem - Overall Functional Block Diagram

The communications section of the DFI consists of the following:

- VHF/FM transmitters - Four transmitters transmit DFI data; one processes IS data.
- Five-channel multiplexer - used in conjunction with any one of the VHF transmitters.
- Diplexer— connects ground control of the LM mission programmer (LMP) and the five-channel multiplexer to a DFI whip antenna system.
- SLA VHF antenna - transmits LM data and receives commands from time of earth launch until LM separation from the SLA.
- LM VHF antenna - transmits LM data after SLA separation and receives LMP commands from MSFN.
- C-band transponders A and B - provide radar tracking during LM near-earth orbits.

2.9.3.1

Sensing Equipment.

The IS sensors continuously check the status of other subsystems by sensing temperature, valve and switch positions, pressure, voltage, current, water and propellant quantity, and stage-separation distance. These sensed data are changed into electrical signals (digital or analog) compatible with the requirements of the SCEA or PCMTEA.

2.9.3.2

Signal-Conditioning Electronics Assembly.

The SCEA converts all unconditioned subsystem and transducer (sensor) signals and events to proper voltage levels required by the PCMTEA, CWEA, and displays. The unconditioned signals are fed through amplifiers, attenuators, ac-to-dc converters, analog and discrete isolating buffers, frequency-to-dc converters, resistance-to-dc converters, and phase-sensitive demodulators to provide the proper output voltages. These seven basic SCEA subassemblies are in each electronic replaceable assembly (ERA-1 and ERA-2) that makes up the SCEA. Each ERA has capacity for 21 plug-in subassemblies (conditioning units) and provides the interface connections between other LM subsystems and the IS subassemblies. (Refer to tables 2-57 and 2-58 for conditioned and preconditioned interfacing signals.) These assemblies provide conditioned digital and analog data. Digital data (discrete event functions) outputs appear as a 4- to 6-volt d-c level for logic 1 or "on"; as a 0- to 0.5-volt d-c level, for logic 0 or "off." Discrete signals to be monitored by displays are in the form of solid-state switch closures. Analog data varies from 0 to 5 volts dc. Each ERA contains circuits that route signals to IS assemblies. In tables 2-57 and 2-58, the number in parentheses, following the conditioning unit number, designates the units location in ERA-1 or ERA-2. The displays in parentheses are located on the corresponding subsystem panel, except where otherwise noted. The warning and caution arrays are located at the top of panels 1 and 2, respectively.

2.9.3.2.1

D-C Amplifiers.

Each d-c amplifier (501-1) receives unipolar or bipolar analog voltage inputs and provides four single-channel outputs. The unipolar inputs range from 0 to 5 volts dc; they are conditioned to a 0- to 5-volt d-c full-scale output. Bipolar inputs range from -2.5 volts to +2.5 volts dc. At the negative level, the offset is adjusted for a zero output. At the positive level, the gain is adjusted for a 5-volt output. When operating in a unipolar mode, the output is directly proportional to the input; the maximum input signal produces a 5-volt d-c output. In a bipolar mode, the maximum negative input (-2.5 volts dc) produces a zero output; the maximum positive input (+2.5 volts dc) produces a 5-volt output. Zero input produces a +2.5-volt d-c output.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-57. ERA-1 - Conditioned and Preconditioned Interfacing Signals

Signal Nomenclature and Telemetry Code No.	From (Subsystem)	To (Conditioning Unit)	Output	To (IS Assembly and Display)
Automatic thrust command voltage - GH1331	GN&CS (control electronics section)	502-2 (15)		
		Circuit No. 1	0 to 5.0 vdc (0 to 12.0 vdc) 0% to 100%	PCMTEA Display (CMD THRUST indicator)
Manual thrust command voltage - GH1311		Circuit No. 2	0 to 5.0 vdc (0 to 14.6 vdc) 0% to 100%	PCMTEA Display (CMD THRUST indicator)
Abort sensor assembly voltage - GI3215	GN&CS	Circuit No. 4	10.8 to 13.2 vdc	CWEA (AGS warning light)
Inverter bus voltage-GC0071	EPS	503-2 (17)		
		Circuit No. 1	4.48 to 5.0 vdc (112 to 125 vrms)	CWEA (INVERTER caution light) (For PCMTEA and display, refer to 504-1 (18) circuit No. 2.)
Spare - Z6016		Circuit No. 2	0 to 5 vdc	PCMTEA
Rate gyro assembly pickoff excitation (0.8 kc) voltage - GH1405	GN&CS (control electronics section)	Circuit No. 3	4.19 to 4.84 vdc (26.0 to 30 vrms)	CWEA (CES AC warning)
Inverter bus frequency - GC0155	EPS	504-1 (18)		
		Circuit No. 1	0 to 5 vdc (380 to 420 cps)	PCMTEA (For CWEA, refer to 505-1(16) circuit No. 1.)
Inverter bus voltage - GC0071		Circuit No. 2	0 to 5 vdc (105 to 125 vrms)	PCMTEA, display (VOLTS indicator) (For CWEA, refer to 503-2 (17) circuit No.1.)
Commander's bus-GC0301		Circuit No. 3	0 to 5 vdc (0 to 40 vdc) 26.5 to 40 vdc	PCMTEA and display (VOLTS indicator) CWEA (DC BUS warning light)
Main water regulator ΔP - GF4101		Circuit No. 4	0 to 5 vdc (0 to 2 psid)	PCMTEA
Helium tank No. 2 pressure - GP0002	MPS (ascent propulsion section)	504-1(19)		
		Circuit No. 1	0 to 5 vdc (0 to 4,000 psia)	PCMTEA and display (HELIUM indicator)
		Preconditioned	3.74 to 5.0 vdc (2,994 psia)	CWEA (ASC PRESS warning light)

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-57. ERA-1 - Conditioned and Preconditioned Interfacing Signals (cont)

Signal Nomenclature and Telemetry Code No.	From (Subsystem)	To (Conditioning Unit)	Output	To (IS Assembly and Display)
Helium regulator outlet manifold pressure - GQ3018	MPS (cont) (descent propulsion section)	504-1(19)		
		Circuit No. 2	0 to 5 vdc (0 to 300 psia)	PCMTEA
		Precon- ditioned	3.65 to 4.32 vdc (220 to 260 psia)	CWEA (DES REG warning light)
Fuel isolation valve inlet pres- sure - GP1501	MPS (ascent propulsion section)	Circuit No. 3	0 to 5 vdc (0 to 250 psia)	PCMTEA
		Precon- ditioned	2.4 to 5.0 vdc (120 to 250 psia)	CWEA (ASC PRESS warning light)
Oxygen isolation valve inlet pres- sure - GP1503		Circuit No. 4	0 to 5 vdc (0 to 250 psia)	PCMTEA
		Precon- ditioned	2.4 to 5.0 vdc (120 to 250 psia)	CWEA (ASC PRESS warning light)
Suit outlet pres- sure - GF1301	ECS	504-1 (5)		
		Circuit No. 1	0 to 5 vdc (0 to 10 psia)	PCMTEA
		Precon- ditioned	1.56 to 5.0 vdc (3.2 to 10 psia)	CWEA (SUIT/FAN warning light)
CO ₂ Partial pres- sure - GF1521		Circuit No. 1	0 to 10 psia	Display (SUIT PRESS indicator)
		Circuit No. 2	0 to 5 vdc (0 to 30 mm Hg)	PCMTEA
		Precon- ditioned	2.27 to 5.0 vdc (13.8 to 30 mm hg)	CWEA (ECS caution light)
Selected water separator rate - GF9999		Circuit No. 3	0 to 5 vdc (500 to 3,600 rpm)	PCMTEA
		Precon- ditioned	More than 1530 rpm	CWEA (ECS caution light)
Selected S-band receiver AGC voltage - GT0994		Circuit No. 4	0 to 5 vdc	PCMTEA
		Precon- ditioned		CWEA
Helium tank A pressure - GR1101	RCS	504-1 (6)		
		Circuit No. 1	0 to 5 vdc (0 to 3,500 psia)	PCMTEA

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-57. ERA-1 - Conditioned and Preconditioned Interfacing Signals (cont)

Signal Nomenclature and Telemetry Code No.	From (Subsystem)	To (Conditioning Unit)	Output	To (IS Assembly and Display)		
Helium tank B pressure - GR1102	RCS (cont)	504-1 (6) (cont)				
		Preconditioned	More than 1,700 psia	CWEA (RCS caution light)		
		Circuit No. 1	0 to 3,500 psia	Display (A PRESS indicator)		
		Circuit No. 2	0 to 5 vdc (0 to 3,500 psia)	PCMTEA		
		Preconditioned	More than 1,700 psia	CWEA (RCS caution light)		
		Circuit No. 2	0 to 3,500 psia	Display (B PRESS indicator)		
		Circuit No. 3	0 to 5 vdc (0 to 350 psia)	PCMTEA		
		Preconditioned	165 to 205 psia	CWEA (RCS A REG warning light)		
		Circuit No. 3	0 to 350 psia	Display (A PRESS indicator)		
		Circuit No. 4	0 to 5 vdc (0 to 350 psia)	PCMTEA		
		Preconditioned	165 to 205 psia	CWEA (RCS B REG warning light)		
		Circuit No. 4	0 to 350 psia	Display (B PRESS indicator)		
Helium regulator A output pressure - GR1201	ECS	504-1 (7)				
		Circuit No. 1	0 to 5 vdc (0 to 1,000 psia)	PCMTEA		
		Preconditioned	95 to 684 psia	CWEA (O ₂ QTY caution light)		
		Circuit No. 1	0 to 854 psia	Display (O ₂ QUANTITY indicator)		
		Circuit No. 2	0 to 5 vdc (0 to 1,000 psia)	PCMTEA		
		Preconditioned	95 to 684 psia	CWEA (O ₂ QTY caution light)		
		Circuit No. 2	0 to 854 psia	Display (O ₂ QUANTITY indicator)		
		Circuit No. 3	0 to 5 vdc (0% to 100%)	PCMTEA		
		Helium regulator B output pressure-GR1202	ECS	504-1 (7)		
				Circuit No. 1	0 to 5 vdc (0 to 1,000 psia)	PCMTEA
				Preconditioned	95 to 684 psia	CWEA (O ₂ QTY caution light)
				Circuit No. 1	0 to 854 psia	Display (O ₂ QUANTITY indicator)
Circuit No. 2	0 to 5 vdc (0 to 1,000 psia)			PCMTEA		
Preconditioned	95 to 684 psia			CWEA (O ₂ QTY caution light)		
Circuit No. 2	0 to 854 psia			Display (O ₂ QUANTITY indicator)		
Circuit No. 3	0 to 5 vdc (0% to 100%)			PCMTEA		
Ascent oxygen tank No. 1 pressure - GF3582	ECS			504-1 (7)		
				Circuit No. 1	0 to 5 vdc (0 to 1,000 psia)	PCMTEA
				Preconditioned	95 to 684 psia	CWEA (O ₂ QTY caution light)
				Circuit No. 1	0 to 854 psia	Display (O ₂ QUANTITY indicator)
		Circuit No. 2	0 to 5 vdc (0 to 1,000 psia)	PCMTEA		
		Preconditioned	95 to 684 psia	CWEA (O ₂ QTY caution light)		
		Circuit No. 2	0 to 854 psia	Display (O ₂ QUANTITY indicator)		
		Circuit No. 3	0 to 5 vdc (0% to 100%)	PCMTEA		
		Ascent oxygen tank No. 2 pressure - GF3583	ECS	504-1 (7)		
				Circuit No. 1	0 to 5 vdc (0 to 1,000 psia)	PCMTEA
				Preconditioned	95 to 684 psia	CWEA (O ₂ QTY caution light)
				Circuit No. 1	0 to 854 psia	Display (O ₂ QUANTITY indicator)
Circuit No. 2	0 to 5 vdc (0 to 1,000 psia)			PCMTEA		
Preconditioned	95 to 684 psia			CWEA (O ₂ QTY caution light)		
Circuit No. 2	0 to 854 psia			Display (O ₂ QUANTITY indicator)		
Circuit No. 3	0 to 5 vdc (0% to 100%)			PCMTEA		
Descent tank water quantity - GF4581	ECS			504-1 (7)		
				Circuit No. 1	0 to 5 vdc (0 to 1,000 psia)	PCMTEA
				Preconditioned	95 to 684 psia	CWEA (O ₂ QTY caution light)
				Circuit No. 1	0 to 854 psia	Display (O ₂ QUANTITY indicator)
		Circuit No. 2	0 to 5 vdc (0 to 1,000 psia)	PCMTEA		
		Preconditioned	95 to 684 psia	CWEA (O ₂ QTY caution light)		
		Circuit No. 2	0 to 854 psia	Display (O ₂ QUANTITY indicator)		
		Circuit No. 3	0 to 5 vdc (0% to 100%)	PCMTEA		

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-57. ERA-1 - Conditioned and Preconditioned Interfacing Signals (cont)

Signal Nomenclature and Telemetry Code No.	From (Subsystem)	To (Conditioning Unit)	Output	To (IS Assembly and Display)
Selected ED battery voltage EDS GY-0703U	ECS (cont)	504-1 (7) (cont)		
		Precon-ditioned	More than 0.8 vdc	CWEA (WATER QTY caution light)
		Circuit No. 3	0% to 100%	Display (H ₂ O QUAN-TITY indicator)
		Circuit No. 4	0 to 5 vdc	EPS display (VOLTS indicator)
		Precon-ditioned	0 to 5 vdc	
		504-1 (8)		
		Circuit No. 1	0 to 5 vdc (0% to 100%)	PCMTEA
		Precon-ditioned	More than 95%	CWEA (WATER QTY caution light)
		Circuit No. 1	0% to 100%	Display (H ₂ O QUAN-TITY indicator)
		Circuit No. 2	0 to 5 vdc (0% to 100%)	PCMTEA
Ascent tank No. 1 water quantity - GF4582	MPS (ascent propulsion section)	Precon-ditioned	More than 95%	CWEA (WATER QTY caution light)
		Circuit No. 1	0% to 100%	Display (H ₂ O QUAN-TITY indicator)
		Circuit No. 2	0 to 5 vdc (0% to 100%)	PCMTEA
		Precon-ditioned	More than 95%	CWEA (WATER QTY caution light)
		Circuit No. 2	0% to 100%	Display (H ₂ O QUAN-TITY indicator)
		Circuit No. 3	0 to 5 vdc (0 to 300 psia)	PCMTEA
		Precon-ditioned	Less than 220 psia	CWEA (ASC HI REG caution light)
		Circuit No. 4	0 to 5 vdc (0 to 4,000 psia)	PCMTEA
		Precon-ditioned	More than 3,000 psia	CWEA (ASC PRESS warning light)
		Circuit No. 4	0 to 4,000 psia	Display (HELIUM indicator)
Regulator outlet manifold pressure - GP0025	GN&CS	504-2 (2)		
		Circuit No. 1	4 to 6 vdc (on) 0 to 0.5 vdc (off)	CWEA (RCS TCA warning light) and PCMTEA
Helium tank No. 1 pressure - GP0001				
Jet No. B2U driver output - GH1426				

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-57. ERA-1 - Conditioned and Preconditioned Interfacing Signals (cont)

Signal Nomenclature and Telemetry Code No.	From (Subsystem)	To (Conditioning Unit)	Output	To (IS Assembly and Display)
	GN&CS (cont)	504-2 (2) (cont)		
Jet No. B2U driver output - GH1427		Circuit No. 2	4 to 6 vdc (on) 0 to 0.5 vdc (off)	CWEA (RCS TCA warning light) and PCMTEA
Jet No. A2A driver output - GH1428		Circuit No. 3	4 to 6 vdc (on) 0 to 0.5 vdc (off)	CWEA (RCS TCA warning light) and PCMTEA
Jet No. B2L driver output - GH1429		Circuit No. 4	4 to 6 vdc (on) 0 to 0.5 vdc (off)	CWEA (RCS TCA warning light) and PCMTEA
Jet No. A1U driver output - GH1430		Circuit No. 5	4 to 6 vdc (on) 0 to 0.5 vdc (off)	CWEA (RCS TCA warning light) and PCMTEA
Jet No. B1D driver output - GH1431		Circuit No. 6	4 to 6 vdc (on) 0 to 0.5 vdc (off)	CWEA (RCS TCA warning light) and PCMTEA
Jet No. B1L driver output - GH1433		Circuit No. 7	4 to 6 vdc (on) 0 to 0.5 vdc (off)	CWEA (RCS TCA warning light) and PCMTEA
Jet No. A1F driver output - GH1432		Circuit No. 8	4 to 6 vdc (on) 0 to 0.5 vdc (off)	CWEA (RCS TCA warning light) and PCMTEA
	EDS			
Abort commanded-GY0050		Circuit No. 9	4 to 6 vdc (on) 0 to 0.5 vdc (off)	CWEA (inhibit signal) and PCM
Spare - Z6002		Circuit No. 10	4 to 6 vdc (on) 0 to 0.5 vdc (off)	CWEA and PCMTEA
	GN&CS	504-2 (3)		
Deadband select (wide) - GH1603	(control electronics section)	Circuit No. 1	4 to 6 vdc (on) 0 to 0.5 vdc (off)	PCMTEA
Ascent engine arm (from panel 2) - GH1230		Circuit No. 2	4 to 6 vdc (on) 0 to 0.5 vdc (off)	PCMTEA
Thrust chamber pressures - GR5041-GR5046		Circuits No. 3 through 8	4 to 6 vdc (on) 0 to 0.5 vdc (off)	PCMTEA CWEA (RCS TCA)
Descent engine arm - GH1348		Circuit No. 9	4 to 6 vdc (on) 0 to 0.5 vdc (off)	PCMTEA
X-translation override - GH1893		Circuit No. 10	4 to 6 vdc (on) 0 to 0.5 vdc (off)	PCMTEA

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-57. ERA-1 - Conditioned and Preconditioned Interfacing Signals (cont)

Signal Nomenclature and Telemetry Code No.	From (Subsystem)	To (Conditioning Unit)	Output	To (IS Assembly and Display)
AEA test mode fail - GI3232	GN&CS (abort guidance section)	504-2 (4)		
		Circuit No. 1	4 to 6 vdc (on) 0 to 0.5 vdc (off)	CWEA (AGS warning light)
Spare - Z6001	GN&CS (control electronics section)	Circuit No. 2	4 to 6 vdc (on) 0 to 0.5 vdc (off)	CWEA
Jet No. B4U driver output - GH1418		Circuit No. 3	4 to 6 vdc (on) 0 to 0.5 vdc (off)	CWEA (RCS TCA warning light) and PCMTEA
Jet No. B4F driver output - GH1420		Circuit No. 4	4 to 6 vdc (on) 0 to 0.5 vdc (off)	CWEA (RCS TCA warning light) and PCMTEA
Jet No. A4D driver output - GH1419		Circuit No. 5	4 to 6 vdc (on) 0 to 0.5 vdc (off)	CWEA (RCS TCA warning light) and PCMTEA
Jet No. A4R driver output - GH1421		Circuit No. 6	4 to 6 vdc (on) 0 to 0.5 vdc (off)	CWEA (RCS TCA warning light) and PCMTEA
Jet No. A3U driver output - GH1422		Circuit No. 7	4 to 6 vdc (on) 0 to 0.5 vdc (off)	CWEA (RCS TCA warning light) and PCMTEA
Jet No. B3D driver output - GH1423		Circuit No. 8	4 to 6 vdc (on) 0 to 0.5 vdc (off)	CWEA (RCS TCA warning light) and PCMTEA
Jet No. B3A driver output - GH1424		Circuit No. 9	4 to 6 vdc (on) 0 to 0.5 vdc (off)	CWEA (RCS TCA warning light) and PCMTEA
Jet No. A3R driver output - GH1425		Circuit No. 10	4 to 6 vdc (on) 0 to 0.5 vdc (off)	CWEA (RCS TCA warning light) and PCMTEA
		504-2 (11)		
Thrust chamber pressure No. B4U - GR5031	RCS	Circuit No. 1	4 to 6 vdc (on) 0 to 0.5 vdc (off)	PCMTEA and CWEA (RCS TCA warning light)
Thrust chamber pressure - GR5033-GR5040		Circuit No. 2	4 to 6 vdc (on) 0 to 0.5 vdc (off)	PCMTEA and CWEA (RCS TCA warning light)
		504-1 (12)		
Main propulsion valves A closed - GR9609		Circuit No. 1	4 to 6 vdc (on) 0 to 0.5 vdc (off)	CWEA (RCS A REG warning light inhibit signal) (For PCM and display, refer to circuit No. 8.)

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-57. ERA-1 - Conditioned and Preconditioned Interfacing Signals (cont)

Signal Nomenclature and Telemetry Code No.	From (Subsystem)	To (Conditioning Unit)	Output	To (IS Assembly and Display)
Main propulsion valves B closed - GR9610	RCS (cont)	504-1 (12) (cont)		
		Circuit No. 2	4 to 6 vdc (on) 0 to 0.5 vdc (off)	CWEA (RCS B REG warning light inhibit signal) (For PCM and display, refer to circuit No. 10.)
Spare - Z6014		Circuit No. 3	4 to 6 vdc (on) 0 to 0.5 vdc (off) 0 to 0.5 vdc (on) 28 vdc (off)	PCMTEA Display
Spare - Z6017		Circuit No. 4	4 to 6 vdc (on) 0 to 0.5 vdc (off) 0 to 0.5 vdc (on) 28 vdc (off)	PCMTEA Display
Spare - Z6018		Circuit No. 5	4 to 6 vdc (on) 0 to 0.5 vdc (off) 0 to 0.5 vdc (on) 28 vdc (off)	CWEA Display
	MPS (ascent propulsion section)			
Helium primary line solenoid valve closed - GP0318		Circuit No. 6	4 to 6 vdc (on) 0 to 0.5 vdc (off) 0 to 0.5 vdc (on) 28 vdc (off)	PCMTEA Display (ASCENT He REG 1 talkback)
Helium secondary line solenoid valve closed - GP0320		Circuit No. 7	4 to 6 vdc (on) 0 to 0.5 vdc (off) 0 to 0.5 vdc (on) 28 vdc (off)	PCMTEA Display (ASCENT He REG 2 talkback)
Main propulsion valves A closed - GR9609		Circuit No. 8	4 to 6 vdc (on) 0 to 0.5 vdc (off) 0 to 0.5 vdc (on) 28 vdc (off)	PCMTEA (For CWEA, refer to circuit No. 1.) Display SYS A MAIN SOV talkback)
Spare - Z6013		Circuit No. 9	4 to 6 vdc (on) 0 to 0.5 vdc (off) 0 to 0.5 vdc (on) 28 vdc (off)	CWEA Display
Main propulsion valves B closed - GR9610		Circuit No. 10	4 to 6 vdc (on) 0 to 0.5 vdc (off) 0 to 0.5 vdc (on) 28 vdc (off)	PCMTEA (for CWEA, refer to circuit No. 2.) Display (SYS B MAIN SOV talkback)
ED SYS A relay transfer-GY0201	EDS	Circuit No. 11	4 to 6 vdc (on) 0 to 0.5 vdc (off) 0 to 0.5 vdc (on) 28 vdc (off)	PCMTEA Display (SYS A component caution light) CWEA (ED RELAYS caution light)

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-57. ERA-1 - Conditioned and Preconditioned Interfacing Signals (cont)

Signal Nomenclature and Telemetry Code No.	From (Subsystem)	To (Conditioning Unit)	Output	To (IS Assembly and Display)
ED SYS B relay transfer - GY0202	EDS (cont)	Circuit No. 12	4 to 6 vdc (on) 0 to 0.5 vdc (off) 0 to 0.5 vdc (on) 28 vdc (off)	PCMTEA Display (SYS B component caution light) CWEA (ED RELAYS caution light)
Thrust chamber assembly solenoid valve A4 closed - GR9661	RCS	504-4 (13)		
Thrust chamber assembly solenoid valve B4 closed - GR6962		Circuit No. 1	4 to 6 vdc (on) 0 to 0.5 vdc (off) 0 to 0.5 vdc (on) 28 vdc (off)	PCMTEA (For CWEA, refer to 504-5, location 14.) Display (SYSTEM A QUAD 4 talkback)
Thrust chamber assembly solenoid valve A3 closed - GR9663		Circuit No. 2	4 to 6 vdc (on) 0 to 0.5 vdc (off) 0 to 0.5 vdc (on) 28 vdc (off)	PCMTEA (For CWEA, refer to 504-5, location 14.) Display (SYSTEM B QUAD 4 talkback)
Thrust chamber assembly solenoid valve B3 closed - GR9664		Circuit No. 3	4 to 6 vdc (on) 0 to 0.5 vdc (off) 0 to 0.5 vdc (on) 28 vdc (off)	PCMTEA (For CWEA, refer to 504-5, location 14.) Display (SYSTEM A QUAD 3 talkback)
Thrust chamber assembly solenoid valve A2 closed - GR9665		Circuit No. 4	4 to 6 vdc (on) 0 to 0.5 vdc (off) 0 to 0.5 vdc (on) 28 vdc (off)	PCMTEA (For CWEA, refer to 504-5, location 14.) Display (SYSTEM B QUAD 3 talkback)
Thrust chamber assembly solenoid valve B2 closed - GR9666		Circuit No. 5	4 to 6 vdc (on) 0 to 0.5 vdc (off) 0 to 0.5 vdc (on) 28 vdc (off)	PCMTEA (For CWEA, refer to 504-5, location 14.) Display (SYSTEM A QUAD 2 talkback)
Thrust chamber assembly solenoid valve A1 closed - GR9667		Circuit No. 6	4 to 6 vdc (on) 0 to 0.5 vdc (off) 0 to 0.5 vdc (on) 28 vdc (off)	PCMTEA (For CWEA, refer to 504-5, location 14.) Display (SYSTEM B QUAD 2 talkback)
Thrust chamber assembly solenoid valve B1 closed - GR9668		Circuit No. 7	4 to 6 vdc (on) 0 to 0.5 vdc (off) 0 to 0.5 vdc (on) 28 vdc (off)	PCMTEA (For CWEA, refer to 504-5, location 14.) Display (SYSTEM A QUAD 1 talkback)
		Circuit No. 8	4 to 6 vdc (on) 0 to 0.5 vdc (off) 0 to 0.5 vdc (on) 28 vdc (off)	PCMTEA (For CWEA, refer to 504-5, location 14.) Display (SYSTEM B QUAD 1 talkback)

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-57. ERA-1 - Conditioned and Preconditioned Interfacing Signals (cont)

Signal Nomenclature and Telemetry Code No.	From (Subsystem)	To (Conditioning Unit)	Output	To (IS Assembly and Display)
Landing gear legs deployed - GM5000	EDS	504-4 (13) (cont) Circuit No. 9	4 to 6 vdc (on) 0 to 0.5 vdc (off) 0 to 0.5 vdc (on) 28 vdc (off)	PCMTEA Display (LDG GEAR DEPLOY talkback)
RCS/ASC interconnect A not closed - GR9611	RCS	Circuit No. 10	4 to 6 vdc (on) 0 to 0.5 vdc (off) 0 to 0.5 vdc (on) 28 vdc (off)	PCMTEA Display (SYSTEM A ASC FUEL talkback)
RCS/ASC interconnect B not closed - GR9612	RCS	Circuit No. 11	4 to 6 vdc (on) 0 to 0.5 vdc (off) 0 to 0.5 vdc (on) 28 vdc (off)	PCMTEA Display (SYSTEM B ASC FUEL talkback)
Manifold crossfeed valves not closed - GR9613	RCS	Circuit No. 12	4 to 6 vdc (on) 0 to 0.5 vdc (off) 0 to 0.5 vdc (on) 28 vdc (off)	PCMTEA Display (CRSFD talkback)
Thrust chamber assembly solenoid valves A4, B4, A3, B3, A2, B2, A1 and B1 closed - GR9661 through GR9668	RCS	504-5 (14) Circuits No. 1 through 8, respectively	4 to 6 vdc (on) 0 to 0.5 vdc (off)	CWEA (RCS TCA warning light inhibit signals)
System A relays K7 through K15 closed - GY-0231	EDS	Circuit No. 9	4 to 6 vdc (on) 0 to 0.5 vdc (off)	PCMTEA
System B relays K7 through K15 closed - GY0232	EDS	Circuit No. 10	4 to 6 vdc (on) 0 to 0.5 vdc (off)	PCMTEA
SYS A relay transfer - GY0201	EDS	Circuit No. 11	4 to 6 vdc (on) 0 to 0.5 vdc (off)	PCMTEA Display (SYS A component caution light) CWEA (ED RELAYS caution light)
SYS B relay transfer - GY-0202	EDS	Circuit No. 12	4 to 6 vdc (on) 0 to 0.5 vdc (off)	PCMTEA Displays (SYS B component caution light) CWEA (ED RELAYS caution light)

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-57. ERA-1 - Conditioned and Preconditioned Interfacing Signals (cont)

Signal Nomenclature and Telemetry Code No.	From (Subsystem)	To (Conditioning Unit)	Output	To (IS Assembly and Display)
Frequency inverter bus - GC0155	EPS	505-1 (16) Circuit No. 1	2.25 to 2.75 vdc (398 to 402 cps)	CWEA (INVERTER caution light) (For PCMTEA, refer to 504-1 (18) circuit No. 1.)
Frequency abort sensor assembly - GI3233	GN&CS (abort guidance section)	Circuit No. 2	0.63 to 4.38 vdc (385 to 415 cps)	CWEA (AGS warning light)
Spare - Z6015		Circuit No. 3	0 to 5 vdc 380 to 420 cps	PCMTEA
Fuel tank No. 1 fuel bulk tempera- ture - GQ3718	MPS (descent propulsion section)	506-3 (9) Circuit No. 1	0 to 5 vdc (+20° to +120° F) +40° to +100° F	PCMTEA Display (FUEL TEMP indicator)
Fuel tank No. 2, fuel bulk tempera- ture - GQ3719		Circuit No. 2	0 to 5 vdc (+20° to +120° F) +40° to +100° F	PCMTEA Display (FUEL TEMP indicator)
Fuel tank, fuel bulk temperature - GP0718	(ascent propulsion section)	Circuit No. 3	0 to 5 vdc (+20° to +120° F) +40° to +100° F	PCMTEA Display (FUEL TEMP indicator)
Oxidizer tank, oxidizer bulk temperature - GP1218		Circuit No. 4	0 to 5 vdc (+20° to +120° F) +40° to +100° F	PCMTEA Display (OXID TEMP indicator)
Selected coolant loop temperature - GF9998	ECS	506-3 (10) Circuit No. 1	0 to 5 vdc (+20° to +120° F) more than +50° F 0° to +80° F	PCMTEA CWEA (GLYCOL caution light) Display (GLYCOL temperature indicator)
Abort sensor assembly temper- ature - GI3301	GN&CS (abort guidance section)	Circuit No. 2	0 to 5 vdc +20° to +200° F	PCMTEA
Oxidizer tank No. 1, oxidizer bulk temp- erature - GQ4218	MPS (descent propulsion section)	Circuit No. 3	0 to 5 vdc (+20° to +120° F) +40° to +100° F	PCMTEA Display (OXID TEMP indicator)

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-57. ERA-1 - Conditioned and Preconditioned Interfacing Signals (cont)

Signal Nomenclature and Telemetry Code No.	From (Subsystem)	To (Conditioning Unit)	Output	To (IS Assembly and Display)
	MPS (cont)			
Oxidizer tank No. 2, oxidizer bulk temperature - GQ4219		Circuit No. 4	0 to 5 vdc (+20° to +120° F) +40° to +100° F	PCMTEA Display (OXID TEMP indicator)
	RCS			
		506-3 (20)		
Quad cluster 3 - GR6002		Circuit No. 1	0 to 5 vdc (+20° to +200° F) 2.75 to 4.725 vdc (+119° to +190° F) +20° to +200° F	PCMTEA CWEA (HEATER caution light) Display (TEMP indicator, panel 3)
Quad cluster 2 - GR6003		Circuit No. 2	0 to 5 vdc (+20° to +200° F) 2.75 to 4.725 vdc (+119° to +190° F) -100° to +200° F	PCMTEA CWEA (HEATER caution light) Display (TEMP indicator, panel 3)
Quad cluster 1 - GR6004		Circuit No. 3	0 to 5 vdc (+20° to +200° F) 2.75 to 4.725 vdc (+119° to +190° F) -100° to +200° F	PCMTEA CWEA (HEATER caution light) Display (TEMP indicator, panel 3)
Quad cluster 4 - GR6001		Circuit No. 4	0 to 5 vdc (+20° to +200° F) 2.75 to 4.725 vdc (+119° to +190° F) -100° to +200° F	PCMTEA CWEA (HEATER caution light) Display (TEMP indicator, panel 3)
		506-3 (21)		
Suit inlet temperature - GF1281		Circuit No. 1	0 to 5 vdc (+20° to +120° F) +40° to +100° F	PCMTEA and display (SUIT TEMP indicator)
Cabin temperature - GF1651		Circuit No. 2	0 to 5 vdc (+20° to +120° F) +40° to +100° F	PCMTEA and display (CABIN TEMP indicator)
	GN&CS			
	(radar section)			
Rendezvous radar temperature - GN7723		Circuit No. 3	0 to 5 vdc (-200° to +200° F) -50° to +150° F -100° to +200° F	PCMTEA CWEA (HEATER caution light) Display (TEMP indicator, panel 3)
Landing radar antenna temperature - GN7563		Circuit No. 4	0 to 5 vdc (-200° to +200° F) -15° F to +150° F -100° to +200° F	PCMTEA CWEA (HEATER caution light) Display (TEMP indicator, panel 3)

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-58. ERA-2 - Conditioned and Preconditioned Interfacing Signals

Signal Nomenclature and Telemetry Code No.	From (Subsystem)	To (Conditioning Unit)	Output	To (IS Assembly and Display)
Descent oxygen tank pressure - GF3584	ECS	501-1 (8)		
		Circuit No. 1	2.22 vdc (135 psia)	CWEA (O ₂ QTY caution light)
	EPS	Circuit No. 2	0 to 5 vdc (0 to 3,000 psia) 0 to 2,730 psia (0 to 100%) 0.5 vdc	PCMTEA Display (CO ₂ QUAN- TITY indicator) (For CWEA, refer to 501-1 (8) circuit No. 1.)
		Circuit No. 3	4.3 to 5.0 vdc	CWEA (CES DC warning light)
		Circuit No. 4	0 to 5 vdc	PCMTEA and display (VOLTS indicator) (For CWEA, refer to 502-2 (15) circuit No. 4.)
		502-2 (15)		
		Circuit No. 1	3.50 to 4.33 vdc	CWEA (PRE AMPS caution light)
		Circuit No. 2	3.50 to 4.33 vdc	CWEA (PRE AMPS caution light)
		Circuit No. 3	3.94 to 4.81 vdc	CWEA (AGS warning light)
		Circuit No. 4	3.31 to 5.0 vdc	CWEA (DC BUS warning light) (For PCMTEA and display, refer to 501-1(8) circuit No. 4.)
		502-2 (16)		
		Circuit No. 1	0 to 5 vdc	PCMTEA and display (VOLTS indicator)
4.3 vdc supply - GH1408	EPS	Circuit No. 2	0 to 5 vdc	PCMTEA and display (VOLTS indicator)
LM Pilot's bus voltage - GC0302		Circuit No. 3	0 to 5 vdc	PCMTEA and display (VOLTS indicator)
Primary -4.7 volts dc - GH1488		Circuit No. 4	0 to 5 vdc	PCMTEA and display (VOLTS indicator)
Backup -4.7 volts dc - GH1489		502-2 (17)		
Abort-sensor assembly +28 vdc - GI3214		Circuit No. 1	0 to 5 vdc	PCMTEA and display (VOLTS indicator)
LM Pilot's bus voltage - GC0302		Circuit No. 1	0 to 5 vdc	PCMTEA and display (VOLTS indicator)
Battery No. 1 voltage - GC0201		Circuit No. 2	0 to 5 vdc	PCMTEA and display (VOLTS indicator)
Battery No. 2 voltage - GC0202		Circuit No. 3	0 to 5 vdc	PCMTEA and display (VOLTS indicator)
Battery No. 3 voltage - GC0203		Circuit No. 4	0 to 5 vdc	PCMTEA and display (VOLTS indicator)
Battery No. 4 voltage - GC0204		502-2 (17)		
Battery No. 5 voltage - GC0205		Circuit No. 1	0 to 5 vdc	PCMTEA and display (VOLTS indicator)

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-58. ERA-2 - Conditioned and Preconditioned Interfacing Signals (cont)

Signal Nomenclature and Telemetry Code No.	From (Subsystem)	To (Conditioning Unit)	Output	To (IS Assembly and Display)
	GN&CS			
X-translation command voltage - GH1240	(control electronics section)	Circuit No. 2	0 to 5 vdc	PCMTEA
Y-translation command voltage - GH1241		Circuit No. 3	0 to 5 vdc	PCMTEA
Z-translation command voltage - GH1242		Circuit No. 4	0 to 5 vdc	PCMTEA
	EPS	502-2 (18)		
Battery No. 6 voltage - GC0206		Circuit No. 1	0 to 5 vdc	PCMTEA and display (VOLTS indicator)
	GN&CS			
Roll logic input error voltage - GH1249	(control electronics section)	Circuit No. 2	0 to 5 vdc	PCMTEA
Yaw logic input error voltage - GH1247		Circuit No. 3	0 to 5 vdc	PCMTEA
Pitch logic input error voltage - GH1248		Circuit No. 4	0 to 5 vdc	PCMTEA
		502-2 (19)		
+15-vdc supply - GH1406		Circuit No. 1	4.12 to 4.71 vdc	CWEA (CES DC warning light)
-15-vdc supply - GH1407		Circuit No. 2	4.12 to 4.71 vdc	CWEA (CES DC warning light)
+6.0-vdc supply - GH1493		Circuit No. 3	3.86 to 4.71 vdc	CWEA (CES DC warning light)
-6.0-vdc supply - GH1494		Circuit No. 4	3.86 to 4.71 vdc	CWEA (CES DC warning light)
		503-2 (7)		
Rate gyro assem- bly spin motor line A-B voltage - GH1401		Circuit No. 1	3.83 to 4.83 vdc	CWEA (CES AC warning light)
Rate gyro assem- bly spin motor line B-C voltage - GH1402		Circuit No. 2	3.83 to 4.83 vdc	CWEA (CES AC warning light)

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-58. ERA-2 - Conditioned and Preconditioned Interfacing Signals (cont)

Signal Nomenclature and Telemetry Code No.	From (Subsystem)	To (Conditioning Unit)	Output	To (IS Assembly and Display)
Rate gyro assembly spin motor line C-A voltage - GH1403	GN&CS (cont)	503-2 (7) (cont) Circuit No. 3	4.32 to 5.0 vdc	CWEA (CES AC warning light)
Spare - Z6571	GN&CS (radar section)	504-3 (2) Circuit No. 1	4 to 6 vdc (on) 0 to 0.5 vdc (off)	PCMTEA and CWEA
Spare - Z6572		Circuit No. 2	4 to 6 vdc (on) 0 to 0.5 vdc (off)	PCMTEA and CWEA
Landing radar range data defective - GN7521		Circuit No. 3	4 to 6 vdc (on) 0 to 0.5 vdc (off)	PCMTEA and CWEA (LDG RDR caution light)
Landing radar velocity sensor data defective - GN7557		Circuit No. 4	4 to 6 vdc (on) 0 to 0.5 vdc (off)	PCMTEA and CWEA (LDG RDR caution light)
Rendezvous radar, no track indication - GN7621		Circuit No. 5	4 to 6 vdc (on) 0 to 0.5 vdc (off)	PCMTEA and CWEA (RNDZ RDR caution light)
Low fuel tank level - GP0908	MPS (ascent propulsion section)	Circuit No. 6	4 to 6 vdc (on) 0 to 0.5 vdc (off)	PCMTEA and CWEA (ASC QTY caution light)
Low oxidizer tank level - GP1408		Circuit No. 7	4 to 6 vdc (on) 0 to 0.5 vdc (off)	PCMTEA and CWEA (ASC QTY caution light)
Spare - Z6560		Circuit No. 8	4 to 6 vdc (on) 0 to 0.5 vdc (off)	PCMTEA and CWEA
Low propellant liquid level - GQ4455	(descent propulsion section)	Circuit No. 9	4 to 6 vdc (on) 0 to 0.5 vdc (off)	PCMTEA and CWEA (DES QTY warning light)
Ascent engine on/off to PROP - GH1260	GN&CS (control electronics section)	Circuit No. 10	4 to 6 vdc (on) 0 to 0.5 vdc (off)	PCMTEA
Abort guidance section warmup - GI3305	(abort guidance section)	Circuit No. 11	4 to 6 vdc (on) 0 to 0.5 vdc (off)	PCMTEA
Spare - Z6550		Circuit No. 12	4 to 6 vdc (on) 0 to 0.5 vdc (off)	PCMTEA and CWEA

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-58. ERA-2 - Conditioned and Preconditioned Interfacing Signals (cont)

Signal Nomenclature and Telemetry Code No.	From (Subsystem)	To (Conditioning Unit)	Output	To (IS Assembly and Display)
Primary guidance and navigation section - GG9003	GN&CS	504-3 (3) Circuit No. 1	4 to 6 vdc (on) 0 to 0.5 vdc (off)	PCMTEA and CWEA (PGNS caution light)
Prime suit compressor failure - GF1083	ECS	Circuit No. 2	4 to 6 vdc (on) 0 to 0.5 vdc (off)	PCMTEA and CWEA (ECS caution light)
Low-level coolant accumulator fluid - GF2041		Circuit No. 3	4 to 6 vdc (on) 0 to 0.5 vdc (off)	PCMTEA and CWEA (GLYCOL caution light)
Descent engine on - GH1301	GN&CS (control electronics section)	Circuit No. 4	4 to 6 vdc (on) 0 to 0.5 vdc (off)	PCMTEA
Guidance select switch (AGS) - GH1621		Circuit No. 5	4 to 6 vdc (on) 0 to 0.5 vdc (off)	PCMTEA
Spare suit compressor failure - GF1084	ECS	Circuit No. 6	4 to 6 vdc (on) 0 to 0.5 vdc (off)	PCMTEA and CWEA (SUIT/FAN warning light)
Emergency oxygen valve pressure indicator open - GF3081		Circuit No. 7	4 to 6 vdc (on) 0 to 0.5 vdc (off)	PCMTEA and CWEA (CABIN warning light)
Emergency oxygen valve electrically open - GF3572		Circuit No. 8	4 to 6 vdc (on) 0 to 0.5 vdc (off)	PCMTEA and CWEA (CABIN warning light)
Pitch trim failure - GH1323		Circuit No. 9	4 to 6 vdc (on) 0 to 0.5 vdc (off)	PCMTEA and CWEA GDA/RCCA caution light)
Roll trim failure - GH1330		Circuit No. 10	4 to 6 vdc (on) 0 to 0.5 vdc (off)	PCMTEA and CWEA GDA/RCCA caution light)
LM guidance computer warning - GG9001	GN&CS (primary guidance and navigation section)	Circuit No. 11	4 to 6 vdc (on) 0 to 0.5 vdc (off)	PCMTEA and CWEA (LGC warning light)
Inertial subsystem warning - GG9002		Circuit No. 12	4 to 6 vdc (on) 0 to 0.5 vdc (off)	PCMTEA and CWEA (ISS warning light)

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-58. ERA-2 - Conditioned and Preconditioned Interfacing Signals (cont)

Signal Nomenclature and Telemetry Code No.	From (Subsystem)	To (Conditioning Unit)	Output	To (IS Assembly and Display)
	EPS	504-4 (4)		
Battery No. 1 high-voltage tap - GC4361		Circuit No. 1	4 to 6 vdc (on) 0 to 0.5 vdc (off) 0 to 0.5 vdc (on) 28 vdc (off)	PCMTEA Display (SE BAT 1 talkback)
Battery No. 1 low-voltage tap - GC4362		Circuit No. 2	4 to 6 vdc (on) 0 to 0.5 vdc (off) 0 to 0.5 vdc (on) 28 vdc (off)	PCMTEA Display (SE BAT 1 talkback)
Battery No. 2 high-voltage tap - GC4363		Circuit No. 3	4 to 6 vdc (on) 0 to 0.5 vdc (off) 0 to 0.5 vdc (on) 28 vdc (off)	PCMTEA Display (SE BAT 2 talkback)
Battery No. 2 low-voltage tap - GC4364		Circuit No. 4	4 to 6 vdc (on) 0 to 0.5 vdc (off) 0 to 0.5 vdc (on) 28 vdc (off)	PCMTEA Display (SE BAT 2 talkback)
Battery No. 3 high-voltage tap - GC4365		Circuit No. 5	4 to 6 vdc (on) 0 to 0.5 vdc (off) 0 to 0.5 vdc (on) 28 vdc (off)	PCMTEA Display (CDR BAT 3 talkback)
Battery No. 3 low-voltage tap - GC4366		Circuit No. 6	4 to 6 vdc (on) 0 to 0.5 vdc (off) 0 to 0.5 vdc (on) 28 vdc (off)	PCMTEA Display (CDR BAT 3 talkback)
Battery No. 4 high-voltage tap - GC4367		Circuit No. 7	4 to 6 vdc (on) 0 to 0.5 vdc (off) 0 to 0.5 vdc (on) 28 vdc (off)	PCMTEA Display (CDR BAT 4 talkback)
Battery No. 4 low-voltage tap - GC4368		Circuit No. 8	4 to 6 vdc (on) 0 to 0.5 vdc (off) 0 to 0.5 vdc (on) 28 vdc (off)	PCMTEA Display (CDR BAT 4 talkback)
Battery No. 5 on (Commander's bus) - GC4369		Circuit No. 9	4 to 6 vdc (on) 0 to 0.5 vdc (off) 0 to 0.5 vdc (on) 28 vdc (off)	PCMTEA Display (BAT 5 BACK UP CDR FEED talkback)
Battery No. 6 on (Commander's bus) - GC4370		Circuit No. 10	4 to 6 vdc (on) 0 to 0.5 vdc (off) 0 to 0.5 vdc (on) 28 vdc (off)	PCMTEA Display (BAT 6 NORMAL CDR FEED talkback)
Battery No. 5 on (LM Pilot's bus) - GC4371		Circuit No. 11	4 to 6 vdc (on) 0 to 0.5 vdc (off) 0 to 0.5 vdc (on) 28 vdc (off)	PCMTEA Display (BAT 5 NORMAL SE FEED talkback)

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-58. ERA-2 - Conditioned and Preconditioned Interfacing Signals (cont)

Signal Nomenclature and Telemetry Code No.	From (Subsystem)	To (Conditioning Unit)	Output	To (IS Assembly and Display)
	EPS (cont)	504-4 (4) (cont)		
Battery No. 6 on (LM Pilot's bus) - GC4372		Circuit No. 12	4 to 6 vdc (on) 0 to 0.5 vdc (off) 0 to 0.5 vdc (on) 28 vdc (off)	PCMTEA Display (BAT 6 BACK UP SE FEED talkback)
		504-4 (12)		
Spare - Z6553		Circuit No. 1	4 to 6 vdc (on) 0 to 0.5 vdc (off) 0 to 0.5 vdc (on) 28 vdc (off)	CWEA
Spare - Z6554		Circuit No. 2	4 to 6 vdc (on) 0 to 0.5 vdc (off) 0 to 0.5 vdc (on) 28 vdc (off)	PCMTEA Display
Spare - Z6555		Circuit No. 3	Same as circuit No. 2	Same as circuit No. 2
Spare - Z6556		Circuit No. 4	Same as circuit No. 2	Same as circuit No. 2
Spare - Z6557		Circuit No. 5	4 to 6 vdc (on) 0 to 0.5 vdc (off)	PCMTEA
Spare - Z6558		Circuit No. 6	4 to 6 vdc (on) 0 to 0.5 vdc (off)	PCMTEA
Battery No. 1 malfunction (plus battery fault signal from IS for BAT FAULT component caution light) - GC9961		Circuit No. 7	4 to 6 vdc (on) 0 to 0.5 vdc (off) 0 to 0.5 vdc (on) 5.0 vdc (off)	PCMTEA Display (BAT FAULT component caution light) (For CWEA, refer to 504-5 (13) circuit No. 7.)
Battery No. 2 malfunction (same as circuit No. 7) - GC9962		Circuit No. 8	4 to 6 vdc (on) 0 to 0.5 vdc (off) 0 to 0.5 vdc (on) 5.0 vdc (off)	PCMTEA Same as circuit No. 7 (For CWEA, refer to 504-5 (13) circuit No. 8.)
Battery No. 3 malfunction (same as circuit No. 7) - GC9963		Circuit No. 9	4 to 6 vdc (on) 0 to 0.5 vdc (off) 0 to 0.5 vdc (on) 5.0 vdc (off)	PCMTEA Same as circuit No. 7 (For CWEA, refer to 504-5 (13) circuit No. 9.)
Battery No. 4 malfunction (same as circuit No. 7) - GC9964		Circuit No. 10	4 to 6 vdc (on) 0 to 0.5 vdc (off) 0 to 0.5 vdc (on) 5.0 vdc (off)	PCMTEA Same as circuit No. 7 (For CWEA, refer to 504-5 (13) circuit No. 10.)

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-58. ERA-2 - Conditioned and Preconditioned Interfacing Signals (cont)

Signal Nomenclature and Telemetry Code No.	From (Subsystem)	To (Conditioning Unit)	Output	To (IS Assembly and Display)
Battery No. 5 mal- function (same as circuit No. 7) - GF9965	EPS (cont)	504-4 (4) (cont)		
		Circuit No. 11	4 to 6 vdc (on) 0 to 0.5 vdc (off) 0 to 0.5 vdc (on) 5.0 vdc (off)	PCMTEA Same as circuit No. 7 (For CWEA, refer to 504-5 (13) circuit No. 11.)
Battery No. 6 mal- function (same as circuit No. 7) - GC9966	ECS	Circuit No. 12	4 to 6 vdc (on) 0 to 0.5 vdc (off) 0 to 0.5 vdc (on) 5.0 vdc (off)	PCMTEA Same as circuit No. 7 (For CWEA, refer to 504-5 (13) circuit No. 12.)
CO ₂ secondary cartridge - GF1241		504-5 (5)		
		Circuit No. 1	4 to 6 vdc (on) 0 to 0.5 vdc (off)	PCMTEA
Suit diverter valve position indicator closed - GF1221		Circuit No. 2	Same as circuit No. 1	PCMTEA
Suit pressure relief valve position indi- cator closed - GF1211		Circuit No. 3	Same as circuit No. 1	PCMTEA
Suit pressure relief valve position indicator open - GF1212		Circuit No. 4	Same as circuit No. 1	PCMTEA
Oxygen regulator valve 306A locked closed - GF3071		Circuit No. 5	Same as circuit No. 1	PCMTEA
Oxygen regulator valve 306A open - GF3072		Circuit No. 6	Same as circuit No. 1	PCMTEA
Oxygen regulator valve 306B locked closed - GF3073		Circuit No. 7	Same as circuit No. 1	PCMTEA
Oxygen regulator valve 306B open- GF3074		Circuit No. 8	Same as circuit No. 1	PCMTEA
Cabin gas return valve pressure indicator closed - GF1231		Circuit No. 9	Same as circuit No. 1	PCMTEA
Cabin gas return valve pressure indicator open - GF1232		Circuit No. 10	Same as circuit No. 1	PCMTEA

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-58. ERA-2 - Conditioned and Preconditioned Interfacing Signals (cont)

Signal Nomenclature and Telemetry Code No.	From (Subsystem)	To (Conditioning Unit)	Output	To (IS Assembly and Display)
	ECS (cont)	504-5 (5) (cont)		
Suit inlet valve pressure indicator No. 1 closed - GF1201		Circuit No. 11	Same as circuit No. 1	PCMTEA
Suit inlet valve pressure indicator No. 2 closed - GF1202		Circuit No. 12	Same as circuit No. 1	PCMTEA
	GN&CS	504-5 (13)		
Roll altitude control selector - GH1628	(control electronics section)	Circuit No. 1	4 to 6 vdc (on) 0 to 0.5 vdc (off)	PCMTEA
Pitch attitude control selector - GH1629		Circuit No. 2	Same as circuit No. 1	PCMTEA
	ECS			
Selected coolant pump failure - GF2935		Circuit No. 3	Same as circuit No. 1	CWEA (ECS caution light)
Spare - Z6570		Circuit No. 4	Same as circuit No. 1	PCMTEA
	GN&CS			
Abort guidance section standby condition - GI3306	(abort guidance section)	Circuit No. 5	Same as circuit No. 1	PCMTEA
Yaw attitude con- trol selector - GH1630	(control electronics section)	Circuit No. 6	Same as circuit No. 1	PCMTEA
	EPS			
Battery No. 1 mal- function (plus EPS battery caution signal from IS) - GC9961		Circuit No. 7	Same as circuit No. 1	CWEA (BATTERY caution light) (For PCMTEA and display, refer to 504-4 (12) circuit No. 7.)
Battery No. 2 mal- function (same as circuit No. 7) - GC9962		Circuit No. 8	Same as circuit No. 1	CWEA (BATTERY caution light) (For PCMTEA and display, refer to 504-4 (12) circuit No. 8.)
Battery No. 3 mal- function (same as circuit No. 7) - GC9963		Circuit No. 9	Same as circuit No. 1	CWEA (BATTERY caution light) (For PCMTEA and display, refer to 504-4 (12) circuit No. 9.)

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-58. ERA-2 - Conditioned and Preconditioned Interfacing Signals (cont)

Signal Nomenclature and Telemetry Code No.	From (Subsystem)	To (Conditioning Unit)	Output	To (IS Assembly and Display)
Battery No. 4 mal-function (same as circuit No. 7) - GC9964	EPS (cont)	504-5 (13) (cont)		
		Circuit No. 10	Same as circuit No. 1	CWEA (BATTERY caution light) (For PCMTEA and display, refer to 504-4 (12) circuit No. 10.)
Battery No. 5 mal-function (same as circuit No. 7) - GC9965		Circuit No. 11	Same as circuit No. 1	CWEA (BATTERY caution light) (For PCMTEA and display, refer to 504-4 (12) circuit No. 11.)
Battery No. 6 mal-function (same as circuit No. 7) - GC9966	GN&CS (control electronics section)	Circuit No. 12	Same as circuit No. 1	CWEA (BATTERY caution light) (For PCMTEA and display, refer to 504-4 (12) circuit No. 12.)
Abort stage command - GH1283		504-5 (14)		
		Circuit No. 1	4 to 6 vdc (on) 0 to 0.5 vdc (off)	PCMTEA
Engine fire override - GH1286		Circuit No. 2	Same as circuit No. 1	PCMTEA
Sequence control system automatic mode select - GH1608		Circuit No. 3	Same as circuit No. 1	PCMTEA
Sequence control system attitude hold select - GH1609		Circuit No. 4	Same as circuit No. 1	PCMTEA
Attitude controller assembly out of detent - GH1204		Circuit No. 5	Same as circuit No. 1	PCMTEA
Automatic engine-on command - GH1214		Circuit No. 6	Same as circuit No. 1	PCMTEA
Automatic engine-off command - GH1217		Circuit No. 7	Same as circuit No. 1	PCMTEA
Unbalanced couples - GH1896		Circuit No. 8	Same as circuit No. 1	PCMTEA
Shutoff valves A/B in midposition - GQ7498	MPS (descent propulsion section)	Circuit No. 9	Same as circuit No. 1	PCMTEA

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-58. ERA-2 - Conditioned and Preconditioned Interfacing Signals (cont)

Signal Nomenclature and Telemetry Code No.	From (Subsystem)	To (Conditioning Unit)	Output	To (IS Assembly and Display)
	MPS (cont)			
Shutoff valves C/D in midposition - GQ7499		Circuit No. 10	Same as circuit No. 1	PCMTEA
Solenoid/bipro- pellant valves A mismatch - GQ2997	(ascent propulsion section)	Circuit No. 11	Same as circuit No. 1	PCMTEA
Solenoid/bipro- pellant valves B mismatch - GQ2998		Circuit No. 12	Same as circuit No. 1	PCMTEA
	ECS			
Suit water-sublimator inlet water temper- ature - GF4541		506-2 (6) Circuit No. 1	0 to 5 vdc (+20° to +160° F) +70° F normal	PCMTEA
Suit No. 1 outlet temperature - GF1291		Circuit No. 2	0 to 5 vdc (+20° to +120° F) +80° F normal	PCMTEA
Suit No. 2 outlet temperature - GF1292		Circuit No. 3	0 to 5 vdc (+20° to +120° F) +80° F normal	PCMTEA
Main water-sublimator inlet water tempera- ture GF4511		Circuit No. 4	0 to 5 vdc (+20° to +160° F) +70° F normal	PCMTEA
	RCS			
Helium tank A temperature - GR1121		506-3 (20) Circuit No. 1	0 to 5 vdc (+20° to +120° F) +70° F normal	PCMTEA and display (A TEMP indicator)
Fuel tank A tem- perature - GR2121		Circuit No. 2	0 to 5 vdc (+20° to +120° F) +70° F normal	PCMTEA and display (A TEMP indicator)
Fuel tank B tem- perature - GR2122		Circuit No. 3	0 to 5 vdc (+20° to +120° F) +70° F normal	PCMTEA and display (B TEMP indicator)
	Structures			
Primary leg strut temperature - GM0064		506-3 (21) Circuit No. 1	0 to 5 vdc (-200° to +500° F)	PCMTEA
S-band steerable antenna electronic assembly temper- ature - GT0454	CS	Circuit No. 2	0 to 5 vdc (-100° to +200° F) 1.7 to 4.4 vdc	Display (TEMP indicator, panel 3) CWEA (HEATER caution light)

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-58. ERA-2 - Conditioned and Preconditioned Interfacing Signals (cont)

Signal Nomenclature and Telemetry Code No.	From (Subsystem)	To (Conditioning Unit)	Output	To (IS Assembly and Display)
Helium tank No. 1 temperature - GP0201	MPS (ascent propulsion section)	Circuit No. 3	0 to 5 vdc (-200° to +200° F)	PCMTEA and display (HELIUM indicator)
Helium tank No. 2 temperature - GP0202		Circuit No. 4	0 to 5 vdc (-200° to +200° F) +70° F normal	PCMTEA and display (HELIUM indicator)
Pitch gimbal drive actuator position - GH1313, GH1314	GN&CS (control electronics section)	507-1 (9)		
		Circuit No. 1	0 to 5 vdc	PCMTEA
		Circuit No. 2	Same as circuit No. 1	PCMTEA
Yaw attenuator error - GH1455		Circuit No. 3	Same as circuit No. 1	PCMTEA
Pitch attenuator error - GH1456		Circuit No. 4	Same as circuit No. 1	PCMTEA
		507-1 (10)		
Roll attenuator error - GH1457		Circuit No. 1	0 to 5 vdc (-3.5 to +3.5 vrms)	PCMTEA
Yaw rate gyro signal - GH1461		Circuit No. 2	0 to 5 vdc (-3.5 to +3.5 vrms)	PCMTEA
Pitch rate gyro signal - GH1462		Circuit No. 3	0 to 5 vdc (-3.5 to +3.5 vrms)	PCMTEA
Roll rate gyro signal - GH1463		Circuit No. 4	0 to 5 vdc (-3.5 to +3.5 vrms)	PCMTEA

The inputs are amplified by a variable-gain d-c amplifier and fed to a 1.8-kc modulator. The modulated signal is routed through a transformer, for impedance matching and ground isolation. The signal is then demodulated and fed to a two-stage filter circuit that attenuates the ripple and provides the required bandpass. The d-c signal is then fed to an output amplifier to provide a low output impedance. A zener diode across the amplifier limits the output to ensure that maximum and minimum voltage output limits are not exceeded. A zero offset and gain control is provided so that zero input voltage results in zero output voltage and the proper gain is realized.

2.9.3.2.2 Attenuators.

The attenuators (502-2) accept unipolar or bipolar analog voltage inputs and provide four single-channel outputs. Jumper points within the attenuators provide for operation

of the units in the unipolar or bipolar mode. When operating in the bipolar mode, the attenuator receives input signals with a range of -2.5 to +2.5 volts dc and -20 to +20 volts dc. The maximum negative input corresponds to a zero output; the maximum positive input, to a +5-volt d-c output. Zero input produce a +2.5-volt d-c output. When operating in the unipolar mode, the output is directly proportional to the input. In this mode, analog inputs are between 0 and 5 volts dc (minimum attenuation) and between 0 and 40 volts dc (attenuation of 8, or a gain of 1/8). The maximum input corresponds to a +5-volt d-c output.

The input signal is fed to a gain adjust stage that consists of a voltage divider network. The output of this network is fed to a d-c amplifier and then modulated and passed through an isolation transformer to provide the necessary ground isolation and impedance matching. This signal is then demodulated and fed to a two-stage filter that attenuates the ripple and provides the required bandpass. A zener diode across the amplifier limits the output to ensure that the maximum and minimum voltage output limits are not exceeded.

2.9.3.2.3 AC-to-DC Converters.

Each ac-to-dc converter (503-2) receives sinusoidal a-c input signals with a frequency range of 380 to 840 cps. The converter supplies three single-channel analog output within a range of 0 to 5 volts dc. The outputs are proportional to the average a-c input. Converter gain is adjustable to provide full-scale output (+5 volts dc), corresponding to full-scale inputs of 21, 31, 100, or 150 volts rms.

The input signal is applied to an attenuator that has a gain control for setting full-scale output for maximum input. The attenuator output is fed through an a-c amplifier to a transformer, for impedance matching and ground isolation. A precision rectifier demodulates the signal by converting it to pulsating d-c voltage. A filter changes the pulsating dc to pure dc. A d-c amplifier receives the filter output and provides a low output impedance. A limiter across the amplifier output ensures that the maximum and minimum voltage output limits are not exceeded.

2.9.3.2.4 Analog Signal Isolating Buffer.

The analog signal isolating buffer (504-1) receives 0- to 5-volt d-c input signals, fully isolates them, and provides unity gain (+0%, -0.05%) at its four single-output channels.

The signal is fed through an amplifier to an emitter follower, for impedance matching with the input of a modulator. The modulator feeds the signal to a transformer, for impedance matching and ground isolation. The signal is then demodulated and passed through a 2-cps filter for ripple attenuation and to provide proper bandpass. This signal is fed to a d-c amplifier whose output provides a low impedance. A limiter across the amplifier output ensures that the maximum and minimum voltage output limits are not exceeded.

2.9.3.2.5 Discrete Signal Isolating Buffers.

The discrete signal isolating buffers (504-2, -3, -4, and -5) receive remote switch (solid-state or mechanical) closures and provide either 10 dual-channel, 12 single-channel, or 12 dual-channel output step voltages.

Buffer 504-2 receives signals from grounded sources; it has a floating input to provide isolation. This buffer is turned on when the source supplies a step voltage (4 to 6 volts dc). The buffer has 10 dual channels whose discrete output step voltages (0.0 to 5.0 volts dc) are isolated. In addition to input isolation, each channel has power input transformers for channel-to-channel isolation. These feed output transformers through solid-state switches actuated by the input signal.

Buffers 504-3, -4, and -5 receive signals from floating sources; the negative input terminals are ground to the LM 28-volt power supply to provide isolation. Buffers 504-3 and -4 have 12 dual-channel outputs; buffer 504-5 has 12 single-channel outputs. The dual channels of buffer 504-3 provide 24 discrete output step voltages that are isolated. These voltages range from 4 to 6 volts dc when the buffer is turned on; from 0.0 to 0.5 volt dc, when it is turned off. The dual channels of buffer 504-4 provide 12 discrete output step voltages that are isolated. They range from 4 to 6 volts dc when the buffer is turned on; from 0.0 to 0.5 volts dc when it is turned off. These dual channels also provide 12 solid-state switch closure outputs that are used for talkback or lamp displays. The single-channel outputs of buffer 504-5 provide 12 discrete output step voltages that are isolated. These voltages have the same range as those of buffers 504-3 and -4.

Buffers 504-3, -4, and -5 each consist of a dual-purpose switch and series regulator. Actuating the switch feeds power to a 3-kc square-wave oscillator. One of the oscillator output windings feeds a rectifier filter to provide a sampling of the oscillator output to a reference generator and a voltage-comparison network. This configuration stabilizes the oscillator output; the oscillator input voltage is regulated to make the oscillator insensitive to line voltage fluctuation. Another set of oscillator windings isolates the oscillator from the output circuits.

2.9.3.2.6 Frequency-to-DC Converters.

The frequency-to-dc converters (505-1) receive sinusoidal inputs with frequency variations between 380 and 420 cps and a carrier amplitude of 20 to 130 volts rms. Zero volts dc corresponds to the low limit of the input frequency range; 5 volts dc, to the high limit of the input frequency range.

The input sine wave is limited and changed to peaked pulses in a differentiator circuit. Each positive spike of the differentiator output triggers a one-shot multivibrator whose output controls a solid-state reversing switch. At the low-frequency limit, the stable and unstable states of the multivibrator are equal time periods. Each state of the multivibrator alternately reverses the precision reference voltage on a charging circuit in the converter output. The net charge, being time-dependent, is zero when both time periods are equal. At the high-frequency limit, the stable period is much shorter than the unstable period. This results in a net charge of +5 volts dc.

2.9.3.2.7 Resistance-to-DC Converters.

The resistance-to-dc converters (506-3) sample resistance changes that unbalance a Wheatstone bridge and produce bridge errors of 0.0 to 130 millivolts. These errors produce a 0- to 5-volt d-c output at the four dual output channels of the converters. The resistance changes sampled by the converters are linear with temperature changes, as follows:

<u>Temperature (°F)</u>	<u>Resistance (ohms)</u>
+20 to +120	1,364 to 1,671
+20 to +160	1,364 to 1,793
+20 to +200	1,364 to 1,914
-200 to +200	665 to 1,914
-200 to +500	665 to 2,795

Each converter consists of a bridge circuit, with a precise 2.6 volts applied to one of its legs for bridge excitation. A preregulator output is applied to a precision regulator circuit that comprises two zener circuits: one establishes a 2.6-volt d-c reference from the preregulator supply; the other maintains a 2.6-volt d-c bridge reference from the output of the precision regulator. These voltages are compared by a differential amplifier that adjusts a series circuit in the precision regulator to compensate for voltage fluctuations from the preregulator and load variations in the bridge circuit.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

2.9.3.2.8 Phase-Sensitive Demodulators.

The phase-sensitive demodulators (507-1) receive a-c signal inputs that are compared to a reference a-c input. The signal-input frequency is the same as the reference-input frequency, with a phase relationship of $0^\circ \pm 2^\circ$ or $180^\circ \pm 2^\circ$ between the signal- and reference-input voltages. The relationship between the signal input and the phase of the reference input, and the resultant d-c output is as follows:

<u>Input Voltage (rms)</u>	<u>Phase Angle</u>	<u>D-C Output (volts)</u>
Maximum	180°	0
0.5 maximum	180°	1.25
0.0	$180^\circ/0^\circ$	2.50
0.5 maximum	0°	3.75
Maximum	0°	5.0

The input signal is fed to an attenuator and gain control circuit that permits adjusting the full-scale output to 5 volts dc for an a-c input of 15 and 26 volts. The signal is passed through an a-c amplifier to a demodulator, where the input signal is compared to a reference pulse. The resultant demodulated signal is passed through a filter circuit to provide the required bandpass.

2.9.3.3 Pulse-Code-Modulation and Timing Electronics Assembly.

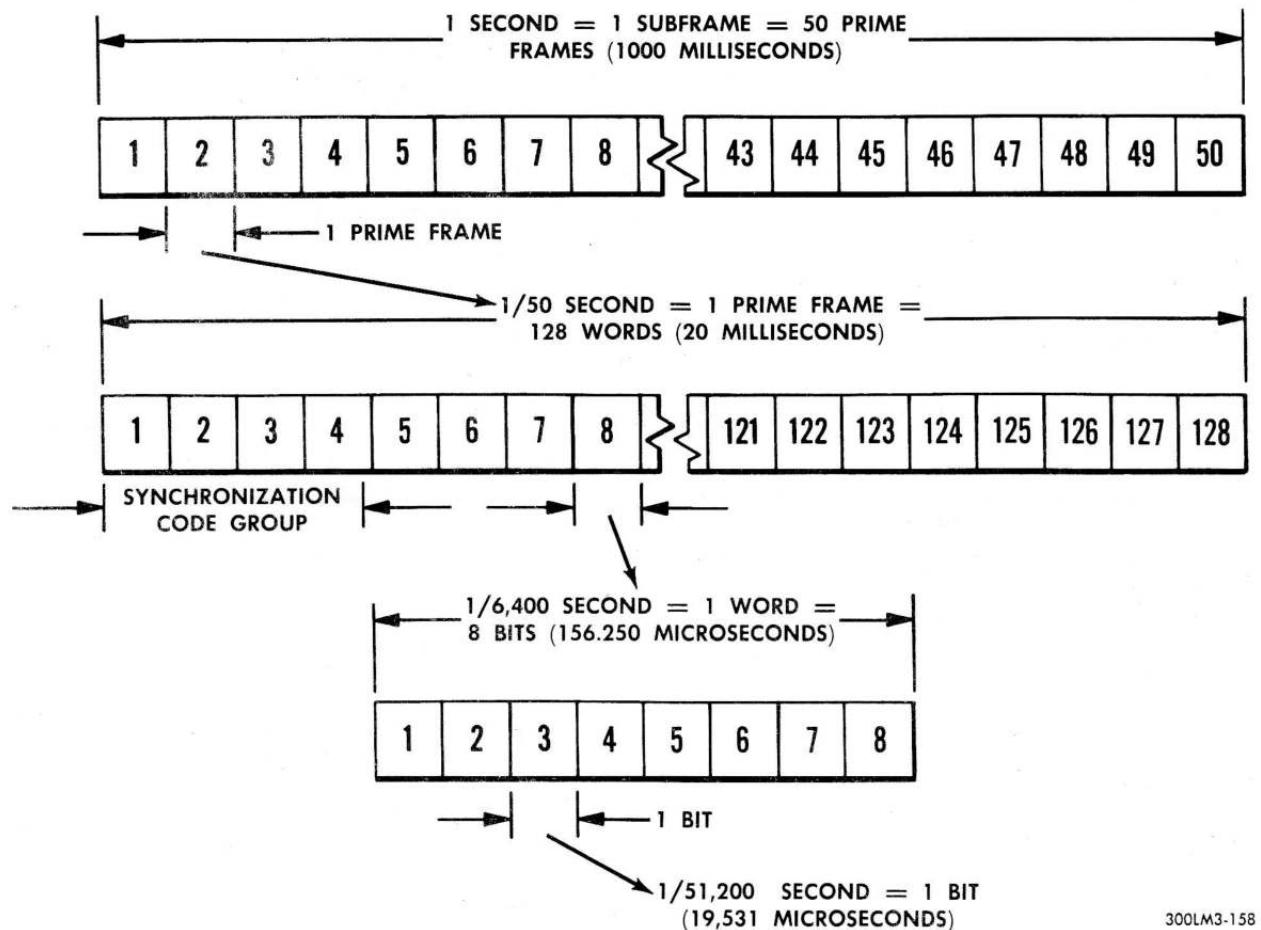
The PCMTEA converts all data inputs generated by the sensors into serial digital output signals. These signals are routed to the CS for transmission to MSFN or the CSM. The PCMTEA consists of pulse-code-modulation equipment that processes subsystem data, and timing electronics equipment that provides timing and synchronizing signals to other LM subsystems. The PCMTEA (figure 2-158) consists of the following:

- Pulse-code-modulation equipment
 - Analog multiplexer drivers
 - High-level analog multiplexer and high-speed gates
 - Analog-to-digital converter (coder)
 - Calibrator
 - Programmer
 - Digital multiplexer
 - Output register and data transfer buffers
 - Power supply
- Timing electronics equipment
 - Phase-locked oscillator and doublers
 - Timing generator
 - Time accumulator and serial time code generator
 - Oscillator failure-detection circuits.

The PCMTEA receives a 1024-kc synchronizing signal and three types of data: high-level analog, parallel digital, and serial digital. Some parallel digital and high-level analog inputs are supplied directly to the PCMTEA from the sensors; others are routed through the SCEA. The SCEA conditions the inputs to voltage levels required by the PCM equipment. The 1024-kc sync signal, from the LM guidance computer (LGC), provides synchronization for the PCMTEA and those subsystems that use outputs from the timing electronics equipment (TE) of the PCMTEA.

Primary control of all units in the PCM equipment is established by the programmer. Using submultiples of the internal or external 1024-kc signals, the programmer provides the basic timing for data sampling and processing. It generates signals for bit, word, prime frame, and subframe timing intervals. (See figures 2-159 and 2-160.)

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA



300LM3-158

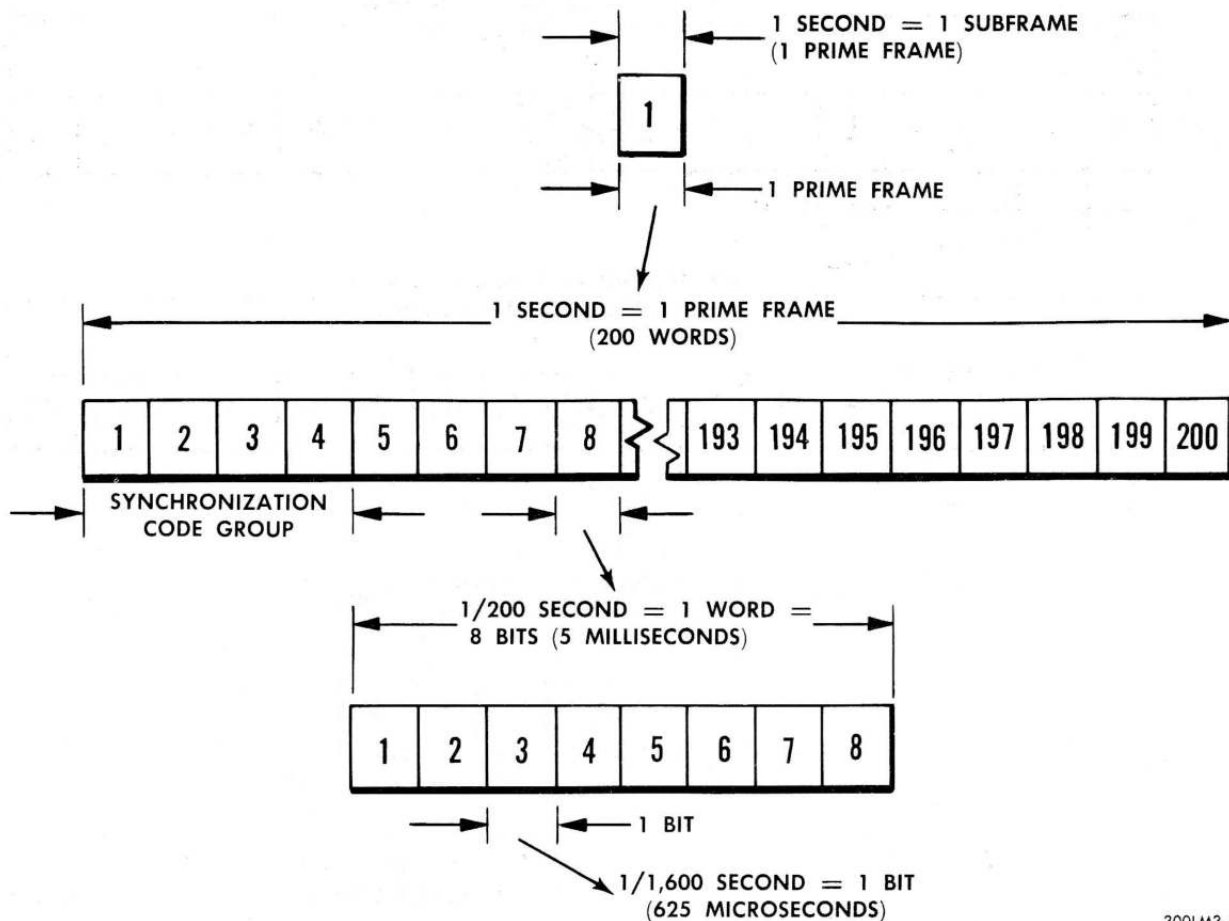
Figure 2-159. Data Format No. 1 (Normal Mode)

External format select signals cause the programmer to generate commands for a fixed, predetermined program of analog and digital data sampling and to sequentially control the sampling operation. The programmer generates synchronization and format identification word patterns and inserts this information into the output serial data stream. It also generates the command and timing signals necessary for synchronizing other LM equipment with the PCMTEA.

The analog multiplexer drivers receive the timing and command signals from the programmer and route the signals to appropriate circuits in the high-level analog multiplexer gates. The analog voltage inputs to these gates are selected at the programmed sampling rate and applied to the high-speed gates. The high-level pulse-amplitude-modulated (PAM) outputs from the high-speed gates are routed to the analog-to-digital converter (coder). The coder produces digitized words that represent the input analog data and supplies the words to the digital multiplexer.

The digital multiplexer gates receive digitized-data signals from the coder and pure digital information from other LM equipment. Gating command signals from the programmer control the sequential operation of the digital multiplexer gates according to a fixed program, producing multiplexed data that consist of parallel binary words.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA



300LM3-159

Figure 2-160. Data Format No. 2 (Reduced Mode)

The parallel binary words are then gated to the output register and data transfer buffers. The output register converts the parallel data to a serial RZ and NRZ-C output. It also receives, from the LGC and the abort guidance section (AGS) of the Guidance, Navigation, and Control Subsystem (GN&CS), serial digital data, which are inserted into the serial output of the PCMTEA.

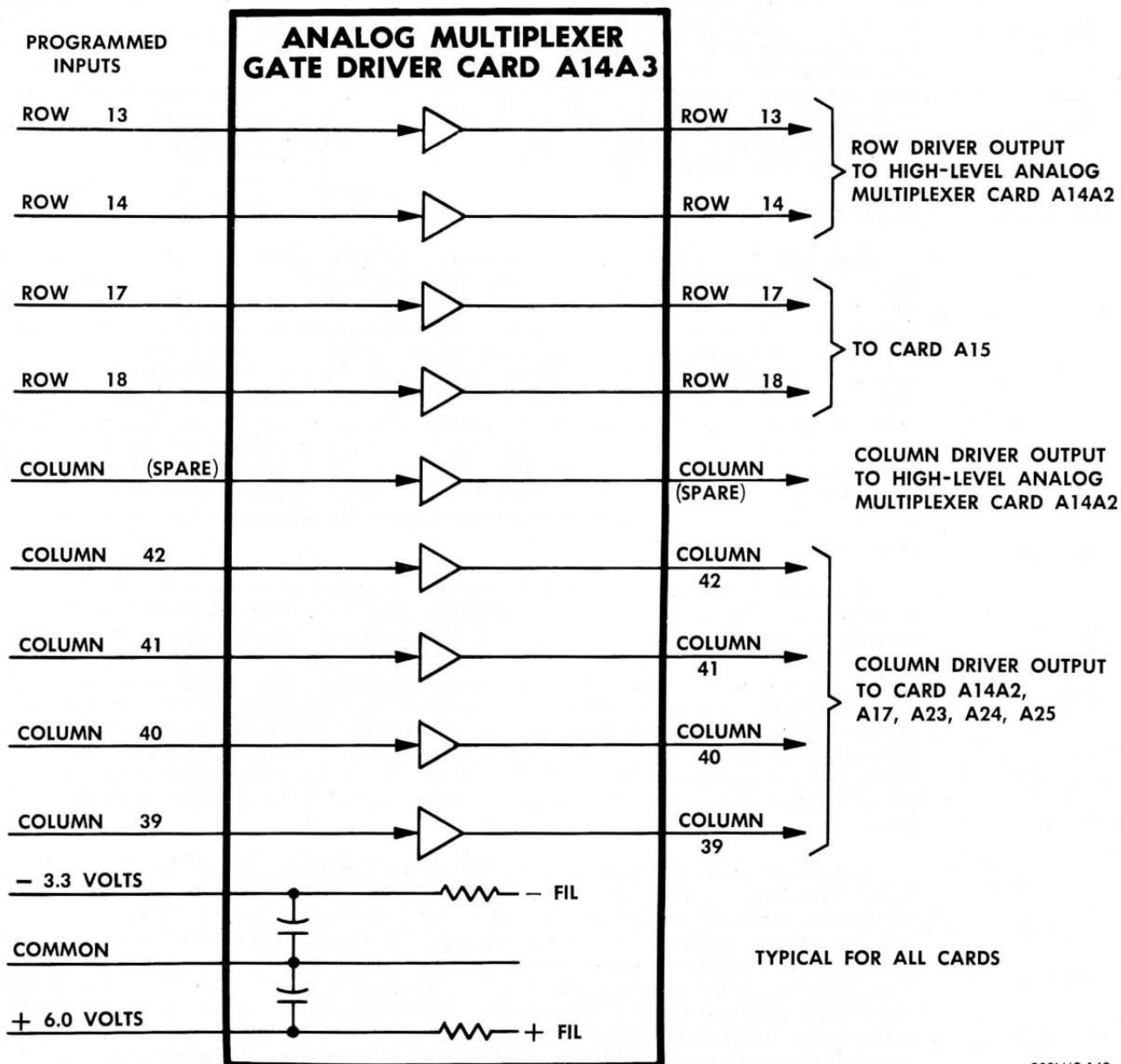
The PCMTEA supplies timing commands and synchronization signals. These signals are provided, by the TE and the programmer, to the data transfer buffers (output buffers), which supply the signals to other LM equipment.

The TE consists of a phase-locked oscillator and doublers, a timing generator, time accumulator, serial time code generator, and three oscillator failure-detection circuits. The TE is redundant in critical areas. A 1024-kc external input from the LGC forces the phase-locked oscillator into synchronism. If the 1024-kc input from the LGC fails, the phase-locked oscillator continues to furnish the necessary timing signals without loss of data. The TE divides the 1024-kc signal into a number of selected subharmonic frequencies, which are routed to the PCM equipment and other LM devices.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

2.9.3.3.1 Analog Multiplexer Gate Drivers. (See figure 2-161.)

Upon command from the programmer, the analog multiplexer gate drivers perform the switching required by the high-level analog gates for sampling the analog inputs. Two basic types of drivers are used: row and column. A row driver is used to activate 6 to 24 gates; a column driver, 7 to 14 gates. A row driver is a compound NPN transistor stage, used in the common-emitter configuration. The row driver is switched on by a positive-going row command from the programmer. Each column driver is a two-stage, direct-coupled amplifier that uses NPN and PNP transistors connected in the common-emitter configuration. Each column driver is switched on by a positive-going column command from the programmer.



300LM3-160

Figure 2-161. Typical Analog Multiplexer Driver Card - Simplified Logic Diagram

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

2.9.3.3.2 High-Level Analog Multiplexer and High-Speed Gates. (See figure 2-162 and 2-163.)

The high-level analog gates sample 277 high-level (0 to 5 volts) analog input channels from LM equipment and generate PAM outputs for each channel input. The pulses occur at the sampling rate of the channel; the amplitude of each pulse represents the analog input at sampling time. The high-level analog gates comprise matrix combinations in an OR-gate arrangement to provide as many as 24 channel inputs per row, with multiple rows forming the desired matrices. Five primary gates in each row use a common sequencer gate. The sequencer gate prevents a shorted primary gate from causing loss of data from more than four primary gates. The shorted gate is not affected and remains on, allowing data to flow continuously. The matrices process the high-level analog inputs and supply four PAM outputs to the high-speed gates. The high-speed gates contain four electronic switches and four associated drivers; they sharply time each pulse in the PAM train. The primary and secondary gates do not turn off sharply; therefore, the trailing edge of each PAM pulse at the input to the sequencer gates gradually trails off to zero. The high-speed gates cut off each pulse sharply before combining all pulses into one serial PAM train. Commands from the programmer to the high-speed gates connect the output of the high-level analog multiplexer to the input of the coder sample and hold circuitry.

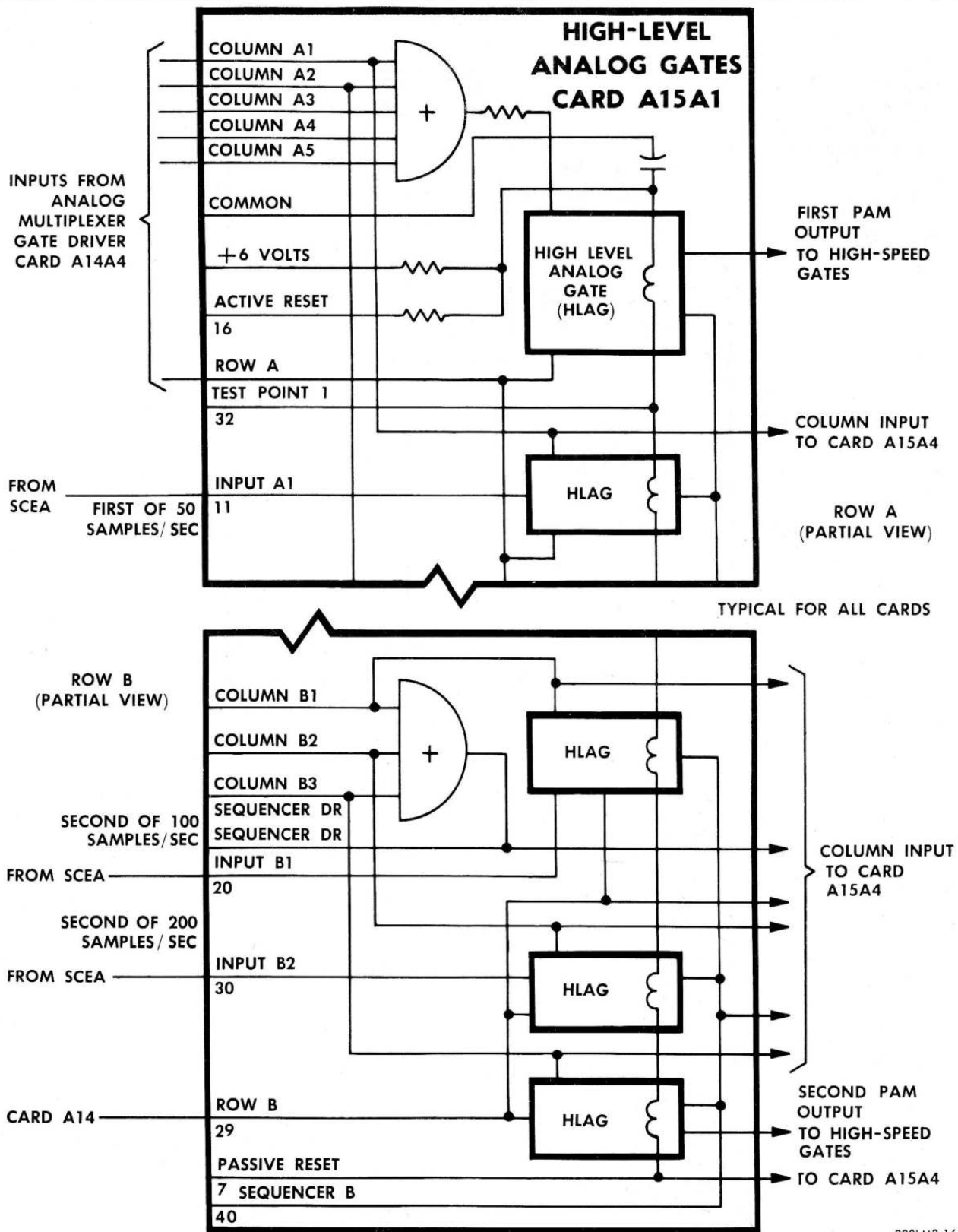
2.9.3.3.3 Analog-to-Digital Converter. (See figure 2-164.)

Controlled by the programmer, the analog-to-digital converter (coder) receives analog high-level PAM inputs from the high-speed gates for sample and hold and charging capacitor output. The coder converts analog input data to digital form. Based upon the commands from the programmer, the coder provides a digital output of eight-bit words to the digital multiplexer. (Refer to paragraph 2.9.3.3.6.) The coder converts the input voltages to an eight-bit binary code: zero volts is coded as binary 00000001 (1_{10}); 5 volts, as binary 11111110 (254_{10}). For each additional 19.7-millivolt input, the binary code is increased by binary 1, until the 5-volt level is obtained. Under-scale voltages (less than zero) are represented as binary 00000000 (0); overscale voltages (more than 5 volts), as binary 11111111 (255_{10}). The sample and hold circuitry of the coder comprises an input buffer amplifier, a charging capacitor with gates, and an output buffer. The output buffer provides the voltage for driving the current-summing junction.

During a 39-microsecond sampling period, the capacitor is charged to the PAM analog input voltage from the high-speed gates. At the end of 39 microseconds, the sampling gate is disabled and the capacitor voltage appears at the output of the sample and hold output buffer. Sample and hold commands from the programmer, coincident with the buffer output, initiate successive approximation cycles. The timing generator is a counter that is matrix driven by an astable multivibrator that operates at approximately 100 kc. The generator provides eight sequential timing pulses to the coder. The pulses have separate inputs to the coder to provide timing for the weighted-current (WC) decisions sensed by the differential amplifier. At the beginning of each timing pulse, a differential query pulse is generated and routed to the differential amplifier gate.

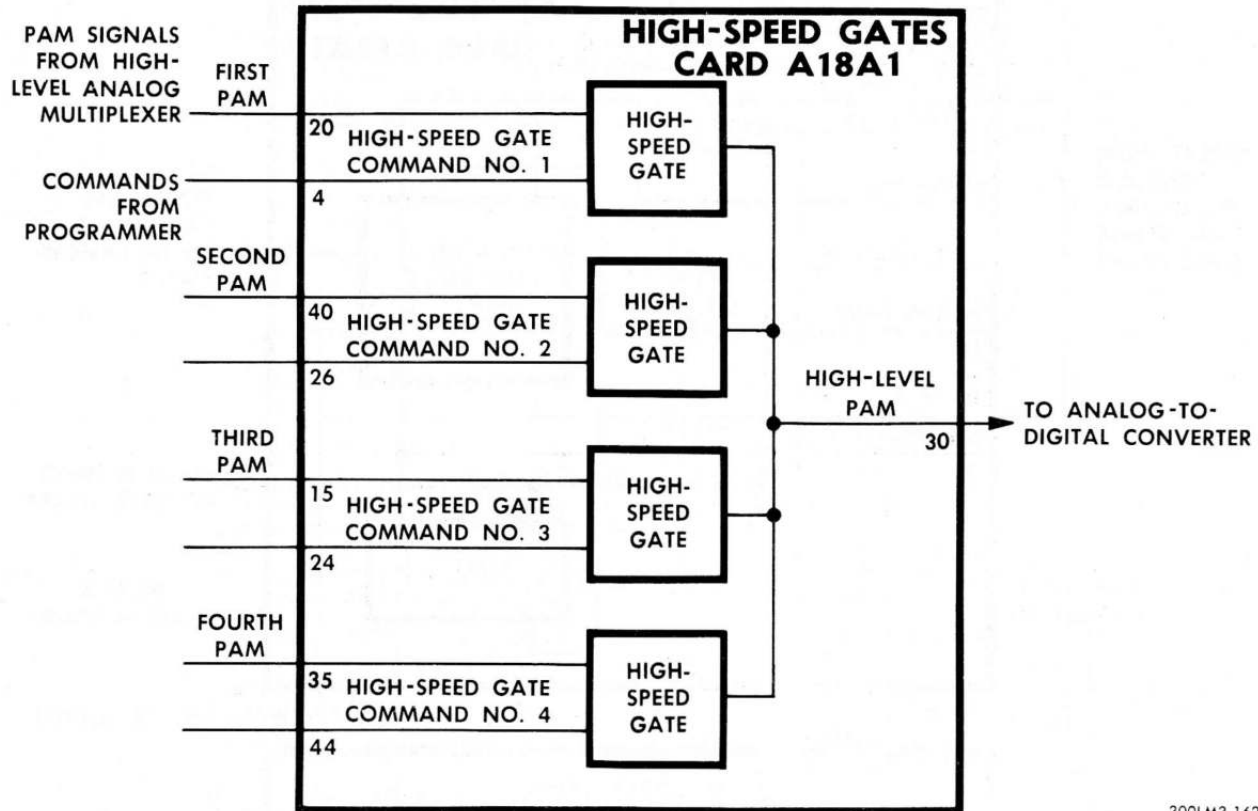
Commands from the programmer reset all WC flip-flops, except the 128-bit flip-flop, to the 0 state. The 128-bit flip-flop is set to a 1 state, providing a path through the 128-bit weighted-current gate (WCG) for the precision half-scale current input generated by the calibrated reference voltage. The PAM sample and hold output and the 128-bit WCG output are summed through their precision resistors and fed to the summing junction. If the resultant current at the junction is positive, the WC was less than the current produced by the PAM voltage. The differential amplifier senses the resultant positive current and applies an input to the differential amplifier gates. Query pulses are coincident with this input. For differential amplifier outputs that represent a resultant positive summing junction current, the query pulses set the differential amplifier flip-flop and provide a 1 output. This 1 output is coincident with timing pulse No. 1 at the input to the 128-bit AND gate. The 1 output from the AND gate is fed to the 128-bit flip-flop, which initially was set to a 1 state. The flip-flop is not reset: the 1 output (128-bit) is stored.

INSTRUMENTATION SUBSYSTEM



300LM3-161

Figure 2-162. High-Level Analog Multiplexer Card - Simplified Logic Diagram



300LM3-162

Figure 2-163. High-Speed Gates - Logic Diagram

The timing pulse input fed to the 128-bit AND gate is also fed to the 64-bit WC flip-flop, setting the 64-bit WCG. Remaining 128-bit current (if any), the 64-bit current, and the PAM analog current are now summed at the summing junction. The differential amplifier again senses the resultant current and accepts or discards the 64-bit WCG output. Discarding occurs when the query pulse prevents the differential amplifier output from gating through to the differential amplifier flip-flop. This provides a zero input at the AND gates; there is no output to the digital multiplexer.

This process continues through timing pulse No. 8, at which time the least significant bit is stored and the WC flip-flops contain a parallel digital representation of a code word. The flip-flop outputs are strobed through digital multiplexer gates to the output register, to be converted to serial NRZ data.

2.9.3.3.4

Calibrator.

The calibrator produces two precision (0.18%) voltage outputs for system calibration. The desired outputs are 85% and 15% of 5 volts (4.25 and 0.750 volts, respectively). The precision voltages are obtained by tapping the desired potentials from the precision resistor network. The 4.25 and 0.750 calibrator voltages may be supplied to the analog gates by external jumpers. The calibrator precision voltages are used in functional loop checks, to determine the operational status of the high-speed gates and the coder.

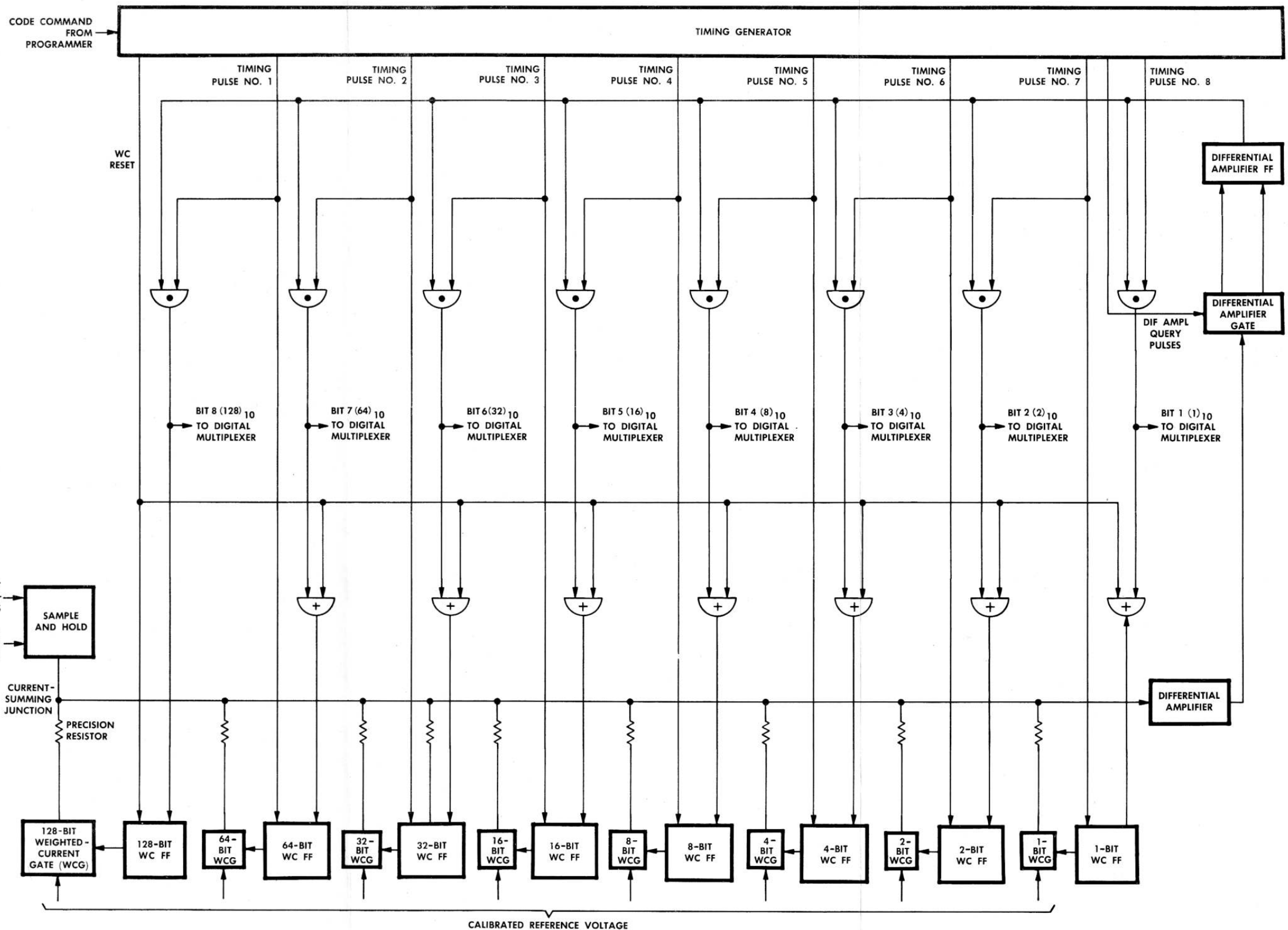


Figure 2-164. Analog-to-Digital Converter (Coder) - Simplified Logic Diagram

2.9.3.3.5 Programmer. (See figure 2-165.)

The programmer establishes the basic timing required for operation of the PCMTEA in the normal (51.2 kilobits per second) or reduced (1.6 kilobits per second) mode, and controls sampling by the PCMTEA. To operate in the normal mode, the TELEMETRY PCM switch (panel 12) is set to HI. To operate in the reduced mode, the switch is set to LO. The programmer functions are as follows:

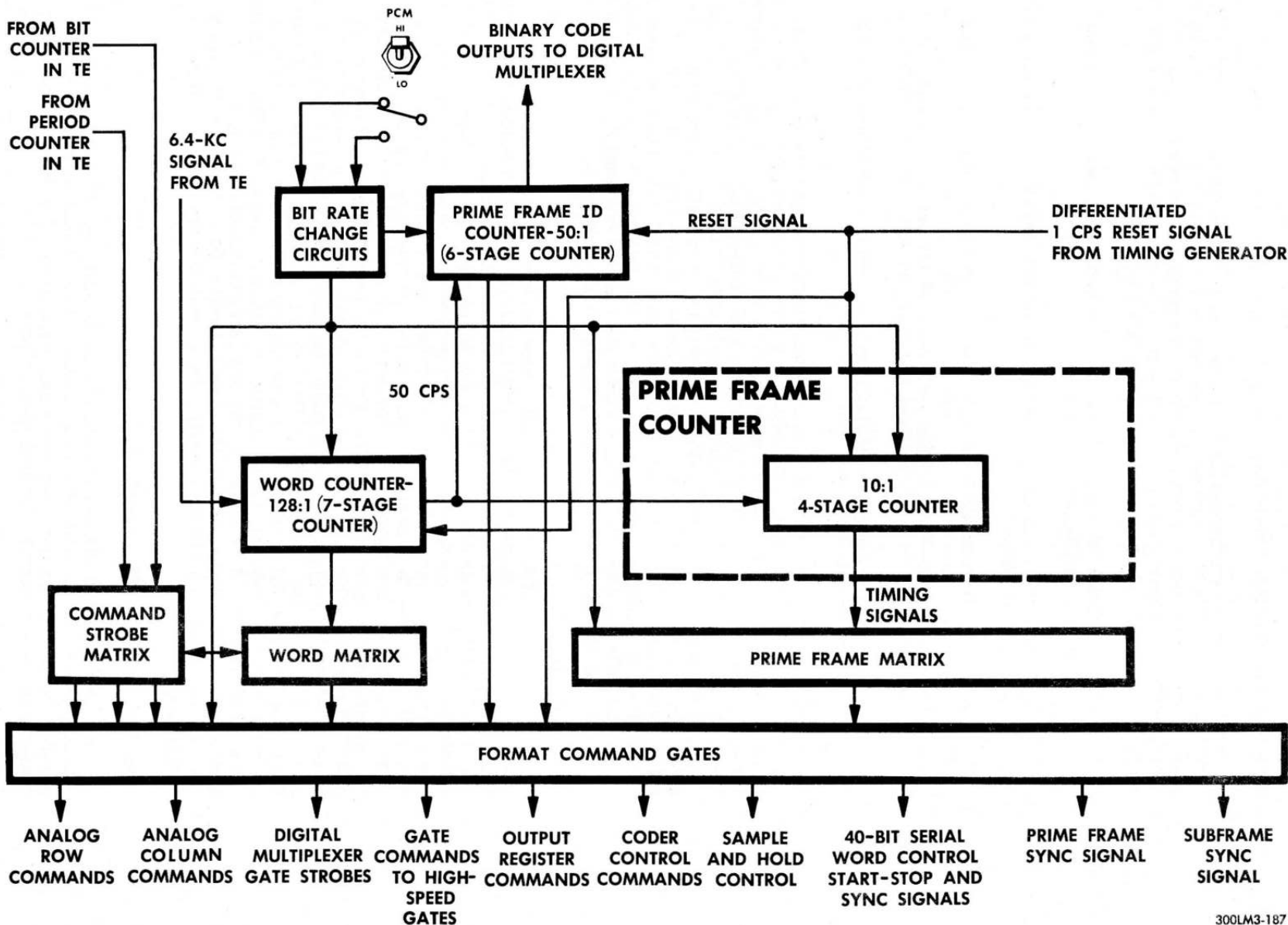
- Establishes the basic intervals for timing periods, bits, words, prime frames, and subframes
- Generates commands for analog and digital sampling in conformance with a fixed program
- Generates commands for coder operation and data transfer operations
- Generates patterns for sync and format identification (ID) words, and the commands for inserting these words into the output of the PCMTEA
- Generates commands and timing signals used to synchronize other LM equipment with the PCMTEA.

The programmer counter matrix is a flexible counter that provides submultiples of the basic 512-kpps clock input. The outputs are subsequently decoded to produce specific timing outputs. The counter logic consists of 17 bistable stages: 7 stages are allotted for a word counter; 6, for a 50-to-1 prime frame ID counter; and 4, for a 10-to-1 prime frame counter. Each stage of the counter is designated by an F number. The prime frame ID counter produces the six binary numbers that identify the prime frames. The counter is cleared at the end of each subframe by the differentiated 1-cps input; it is then stepped through 50 binary states (000001 through 110010). The binary numbers are furnished to the digital multiplexer gates, for insertion into the PCMTEA data. During normal bit-rate operation, the binary numbers are inserted into word No. 4 of the data input. During reduced bit-rate operation, binary 000001 is inserted into word No. 4 of every frame.

Normal and reduced bit-rate ID control logic implements the switchover from normal to reduced bit-rate mode within the programmer. It also produces a command to a digital multiplexer gate, which causes the bit-rate format code to be inserted into the PCMTEA serial train during word No. 5 of prime frame No. 1. This is accomplished by sampling the output of the remotely located bit-rate selector switch and storing this information in two bistables controlled by AND gates. When the normal bit-rate mode is selected to replace the reduced mode, the mode information is stored at reduced word No. 4. (See figures 2-159 and 2-160.) The normal bit-rate ID command is then generated during reduced word No. 200 and the format ID word is inserted into the PCMTEA data at the digital multiplexer gates. Likewise, when the reduced bit-rate mode is selected to replace the normal mode, the mode information is stored at prime frame No. 1, word No. 3. The reduced bit-rate ID command is generated at normal bit-rate word No. 2, prime frame No. 1. Switchover from normal to reduced bit-rate mode can be accomplished only at the start of a subframe. Thus, if a change is made after prime frame No. 1, word No. 3, the remainder of the subframe operates at normal rate. In the next subframe, the reduced bit-rate ID is inserted in the format and the subframe operates at the normal rate. Switchover occurs at the start of the next subframe.

2.9.3.3.6 Digital Multiplexer. (See figure 2-166.)

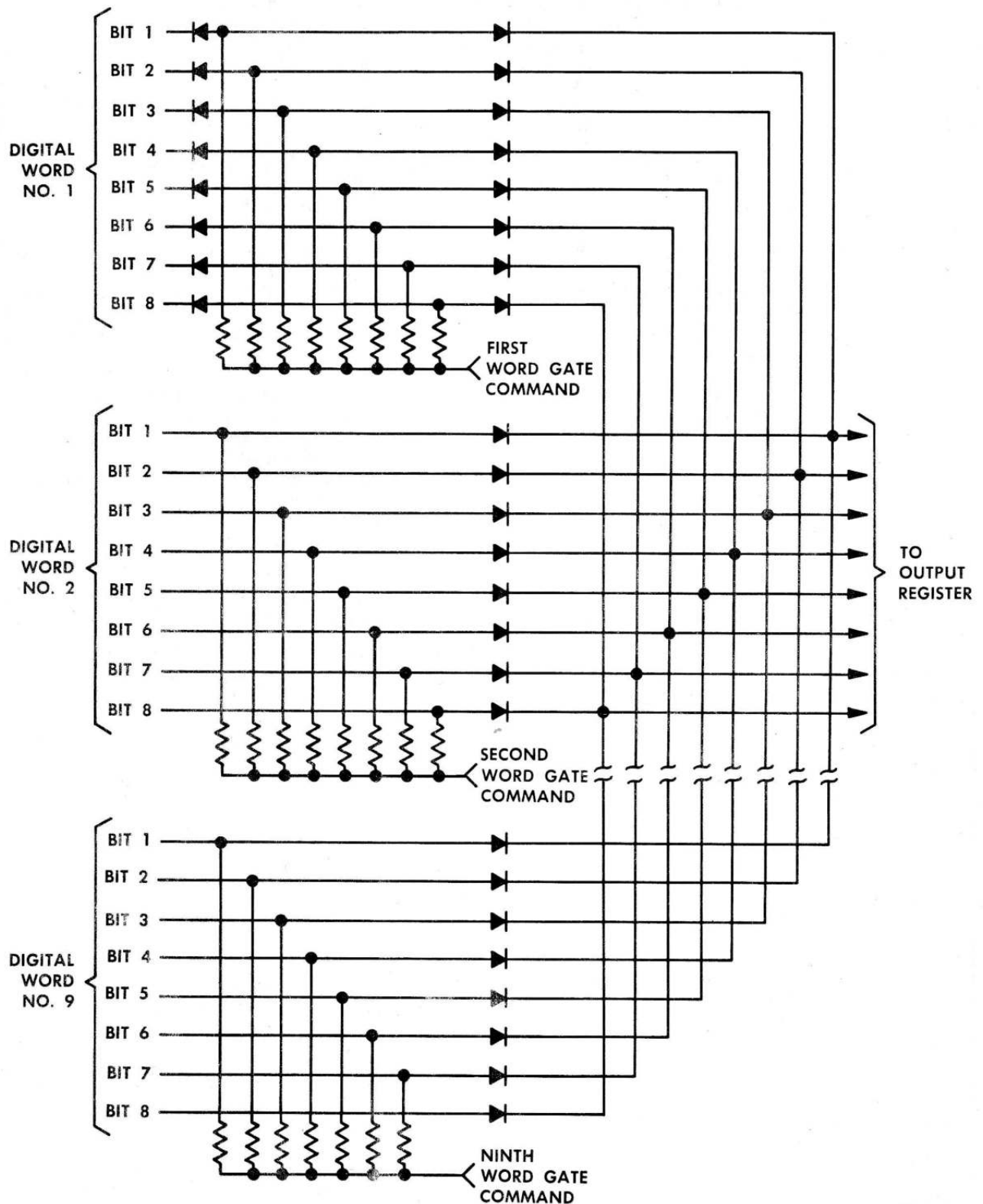
The first number in channel identification is the sampling rate of the channel. The following letter (A or D) signifies analog or digital data. Letter P, S, or H signifies parallel, serial, or high-sampling-rate data, respectively. The last number, letter, or combination thereof identifies the individual channel.



300LM3-187

Figure 2-165. Programmer - Block Diagram (51.2 Kilobits/Sec, Normal Mode; 1.6 Kilobits/Sec, Reduced Mode)

LMA790-3-LM 3
 APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA



300LM3-188

Figure 2-166. Digital Multiplexer - Logic Diagram

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Based upon commands from the programmer, the digital multiplexer gates perform gating functions for digital inputs from the coder, programmer, time accumulator, CWEA, and other LM equipment. Eight-bit binary words, resulting from the coding of the analog channel inputs, are received by the digital multiplexer gates from the coder. From the programmer, the digital multiplexer gates receive four programmed sync words (three 8-bit words and one 2-bit word), six bits of frame ID (frame number), and the format ID word. The digital multiplexer gates also receive multiple digital inputs from other LM equipment: sixty-five 1-bit words (channels 1DPE1 through 1DPE45, 1DP1 through 1DP10, 10DP1, 50DP1, 50DPE1 through 50DPE4, and 100DPE1 through 100DPE4), one 16-bit word (channel 200DEP1), and two 32-bit words (channels 50DP1 and 10DP1). Each of these inputs is gated to the output register on a time-shared basis, in the form of eight-bit words. (The specific multiplexing of these inputs is shown in tables 2-59 and 2-60.) When a digital input consists of more than eight bits, the eight most significant bits of the input word are gated to the output register first, then the eight next most significant bits. Table 2-59 consists of 128 words, which make up one prime frame. Fifty prime frames (1 subframe) are generated in 1 second. Table 2-60 consists of 200 words which make up one frame (equal to one subframe). The frame is generated in 1 second.

The digital multiplexer gating structure consists of nine 8-bit word gates. The binary-weighted outputs of these nine gates are OR gated to eight output lines. Each word gate consists of eight AND structures (one for each bit of input), followed by an isolation diode that is junction OR gated to the weighted output lines. Multiplexing of the word inputs is controlled by inputs from the programmer. When a word is to be gated to the output register, the eight-bit AND structure is strobed by a word command from the programmer. The input word configuration is transferred to the output register through the junction OR gates.

Table 2-59. Word and Channel Assignments - Normal Format (51.2 Kilobits Per Second)

Word No.	Data or Channel
1	Sync 50DP1A
2	Sync 50DP1B
3	Sync 50DP1C
4	Sync and ID 50DP1D
5	F1 (format ID) (1DP1)
	F2 (1AH4), F7 (1AH23), F12 (1AH42), F17 (1AH61),
	F3 (1AH8), F8 (1AH27), F13 (1AH46), F18 (1AH65),
	F4 (1AH12), F9 (1AH31), F14 (1AH50), F19 (1AH69),
	F5 (1AH16), F10 (1AH35), F15 (1AH54), F20 (1AH73),
	F6 (1DP3), F11 (1DP5), F16 (1DP7), F21 (1DP9),
	F22 (1AH80), F23 (1AH84), F24 (1AH88)... F50 (1AH192)
6	200DPE1A
7	200DPE1B
8	100DPE1
9	200AH1
10	200AH2
11	200AH3

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-59. Word and Channel Assignments - Normal Format (51.2 Kilobits Per Second) (cont)

Word No.	Data or Channel
12	200AH4
13	200AH5
14	200AH6
15	200AH7
16	100DPE2
17	100AH1
18	100AH2
19	100AH3
20	100AH4
21	100AH5
22	100AH6
23	100AH7
24	50DPE1
25	100AH8
26	100AH9
27	100AH10
28	100AH11
29	100AH12
30	100AH13
31	100AH14
32	50DPE2
33	F1, F6, F11, F46 (10DP1A)
	F2, F7, F12, F47 (10AH8)
	F3, F8, F13, F48 (10AH18)
	F4, F9, F14, F49 (10AH28)
	F5, F10, F15, F50 (10AH37)
34	F1, F6, F11, F46 (10DP1B)
	F2, F7, F12, F47 (10AH9)
	F3, F8, F13, F48 (10AH19)
	F4, F9, F14, F49 (10AH29)
	F5, F10, F15, F50 (10AH38)

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-59. Word and Channel Assignments - Normal Format (51.2 Kilobits Per Second) (cont)

Word No.	Data or Channel
35	F1, F6, F11, F46 (10DP1C) F2, F7, F12, F47 (10AH10) F3, F8, F13, F48 (10AH20) F4, F9, F14, F49 (10AH30) F5, F10, F15, F50 (10AH39)
36	F1, F6, F11, F46 (10DP1D) F2, F7, F12, F47 (10AH11) F3, F8, F13, F48 (10AH21) F4, F9, F14, F49 (10AH31) F5, F10, F15, F50 (10AH40)
37	F1 (1AH1), F6 (1AH20), F11 (1AH39), F16 (1AH58), F21 (1AH77) F2 (1AH5), F7 (1AH24), F12 (1AH43), F17 (1AH62), F22 (1AH81) F3 (1AH9), F8 (1AH28), F13 (1AH47), F18 (1AH66), F23 (1AH85) F4 (1AH13), F9 (1AH32), F14 (1AH51), F19 (1AH70), F24 (1AH89) F5 (1AH17), F10 (1AH36), F15 (1AH55), F20 (1AH74), F25 (1AH93) F26 (1AH97), F32 (1AH121), F38 (1AH145), F44 (1AH169), F27 (1AH101), F33 (1AH125), F39 (1AH149), F45 (1AH173), F28 (1AH105), F34 (1AH129), F40 (1AH153), F46 (1AH177), F29 (1AH109), F35 (1AH133), F41 (1AH157), F47 (1AH181), F30 (1AH113), F36 (1AH137), F42 (1AH161), F48 (1AH185), F31 (1AH117), F37 (1AH141), F43 (1AH165), F49 (1AH189), F50 (1AH193)
38	200DPE1A
39	200DPE1B
40	100DPE3
41	200AH1
42	200AH2
43	200AH3
44	200AH4
45	200AH5
46	200AH6
47	200AH7
48	100DPE4
49	100AH15
50	100AH16
51	100AH17

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-59. Word and Channel Assignments - Normal Format (51.2 Kilobits Per Second) (cont)

Word No.	Data or Channel				
52	100AH18				
53	100AH19				
54	100AH20				
55	100AH21				
56	100AH22				
57	50AH1				
58	50AH2				
59	50AH3				
60	50AH4				
61	50AH5				
62	50AH6				
63	50AH7				
64	50AH8				
65	F1,	F6,	F11	...	F46 (10AH1)
	F2,	F7,	F12	...	F47 (10AH12)
	F3,	F8,	F13	...	F48 (10AH22)
	F4,	F9,	F14	...	F49 (10AH32)
	F5,	F10,	F15	...	F50 (10AH41)
66	F1,	F6,	F11	...	F46 (10AH2)
	F2,	F7,	F12	...	F47 (10AH13)
	F3,	F8,	F13	...	F48 (10AH23)
	F4,	F9,	F14	...	F49 (10AH33)
	F5,	F10,	F15	...	F50 (10AH42)
67	F1,	F6,	F11	...	F46 (10AH3)
	F2,	F7,	F12	...	F47 (10AH14)
	F3,	F8,	F13	...	F48 (10AH24)
	F4,	F9,	F14	...	F49 (10AH34)
	F5,	F10,	F15	...	F50 (10AH43)
68	F1,	F6,	F11	...	F46 (10AH4)
	F2,	F7,	F12	...	F47 (10AH15)
	F3,	F8,	F13	...	F48 (10AH25)
	F4,	F9,	F14	...	F49 (10AH35)
	F5,	F10,	F15	...	F50 (10AH44)

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-59. Word and Channel Assignments - Normal Format (51.2 Kilobits Per Second) (cont)

Word No.	Data or Channel
69	F1 (1AH2), F6 (1AH21), F11 (1AH40), F16 (1AH59), F21 (1AH78) F2 (1AH6), F7 (1AH25), F12 (1AH44), F17 (1AH63), F22 (1AH82) F3 (1AH10), F8 (1AH29), F13 (1AH48), F18 (1AH67), F23 (1AH86) F4 (1AH14), F9 (1AH33), F14 (1AH52), F19 (1AH71), F24 (1AH90) F5 (1AH18), F10 (1AH37), F15 (1AH56), F20 (1AH75), F25 (1AH94) F26 (1AH98), F33 (1AH126), F40 (1AH154), F47 (1AH182) F27 (1AH102), F34 (1AH130), F41 (1AH158), F48 (1AH186) F28 (1AH106), F35 (1AH134), F42 (1AH162), F49 (1AH190) F29 (1AH110), F36 (1AH138), F43 (1AH166), F50 (1AH194) F30 (1AH114), F37 (1AH142), F44 (1AH170), F31 (1AH118), F38 (1AH146), F45 (1AH174), F32 (1AH122), F39 (1AH150), F46 (1AH178),
70	200DPE1A
71	200DPE1B
72	100DPE1
73	200AH1
74	200AH2
75	200AH3
76	200AH4
77	200AH5
78	200AH6
79	200AH7
80	100DPE2
81	100AH1
82	100AH2
83	100AH3
84	100AH4
85	100AH5
86	100AH6
87	100AH7
88	50DPE3
89	100AH3
90	100AH9
91	100AH10
92	100AH11

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-59. Word and Channel Assignments - Normal Format (51.2 Kilobits Per Second) (cont)

Word No.	Data or Channel
93	100AH12
94	100AH13
95	100AH14
96	50DPE4
97	50DP2
98	F1, F6, F11 ... F46 (10AH5) F2 (1DPE1), F7 (1DPE5), F12 (1DPE9), ... F27 (1DPE21) F3 (1DPE2), F8 (1DPE6), F13 (1DPE10), ... F28 (1DPE22) F4 (1DPE3), F9 (1DPE7), F14 (1DPE11), ... F29 (1DPE23) F5 (1DPE4), F10 (1DPE8), F15 (1DPE12), F20 (1DPE16), F25 (1DPE20), F30 (1DPE25) F32 (1DPE26), F37 (1DPE31), F42 (1DPE36), F47 (1DPE41) F33 (1DPE27), F38 (1DPE32), F43 (1DPE37), F48 (1DPE42) F34 (1DPE28), F39 (1DPE33), F44 (1DPE38), F49 (1DPE43) F35 (1DPE30), F40 (1DPE35), F45 (1DPE40), F50 (1DPE45)
99	F1, F6, F11 ... F46 (10AH6) F2, F7, F12 ... F47 (10AH16) F3, F8, F13 ... F48 (10AH26) F4, F9, F14 ... F49 (10AH36) F5, F10, F15 ... F50 (10AH45)
100	F1, F6, F11 ... F46 (10AH7) F2, F7, F12 ... F47 (10AH17) F3, F8, F13 ... F48 (10AH27) F4 (1DP2), F9 (1DP4), F14 (1DP6), F19 (1DP8), F24 (1DP10) F5, F10, F15 ... F50 (10DPE1) F29 (1DPE24), F34 (1DPE29), F39 (1DPE34), F44 (1DPE39), F49 (1DPE44)
101	F1 (1AH3), F7 (1AH26), F13 (1AH49), F19 (1AH72), F2 (1AH7), F8 (1AH30), F14 (1AH53), F20 (1AH76), F3 (1AH11), F9 (1AH34), F15 (1AH57), F21 (1AH79), F4 (1AH15), F10 (1AH38), F16 (1AH60), F22 (1AH83) F5 (1AH19), F11 (1AH41), F17 (1AH64), F23 (1AH87) F6 (1AH22), F12 (1AH45), F18 (1AH68), F24 (1AH91) F25 (1AH95) F26 (1AH99), F32 (1AH123), F38 (1AH147), F44 (1AH171), F27 (1AH103), F33 (1AH127), F39 (1AH151), F45 (1AH175), F28 (1AH107), F34 (1AH131), F40 (1AH155), F46 (1AH179), F29 (1AH111), F35 (1AH135), F41 (1AH159), F47 (1AH183), F30 (1AH115), F36 (1AH139), F42 (1AH163), F48 (1AH187), F31 (1AH119), F37 (1AH143), F43 (1AH167), F49 (1AH191), F50 (1AH195)

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-59. Word and Channel Assignments - Normal Format (51.2 Kilobits Per Second) (cont)

Word No.	Data or Channel
102	200DPE1A
103	200DPE1B
104	100DPE3
105	200AH1
106	200AH2
107	200AH3
108	200AH4
109	200AH5
110	200AH6
111	200AH7
112	100DPE4
113	100AH15
114	100AH16
115	100AH17
116	100AH18
117	100AH19
118	100AH20
119	100AH21
120	100AH22
121	50DS1A
122	50DS1B
123	50DS1C
124	50DS1D
125	50DS1E
126	50DS2A
127	50DS2B
128	50DS2C

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-60. Word and Channel Assignments - Reduced Format (1.6 Kilobits Per Second)

Word No.	Data or Channel	Word No.	Data or Channel	Word No.	Data or Channel
1	Sync 50 DP1A	32	1AH30	63	1AH59
2	Sync 50 DP1B	33	10DP1A	64	1AH60
3	Sync 50 DP1C	34	10DP1B	65	1AH61
4	Sync 50 DP1D	35	10DP1C	66	1AH62
5	Format 1D (1DP1)	36	10DP1D	67	1AH63
6	1AH5	37	1AH35	68	1AH64
7	1AH6	38	1AH36	69	1AH65
8	1AH7	39	1AH37	70	1AH66
9	1AH8	40	1AH38	71	1AH67
10	1AH9	41	1DP3	72	1AH68
11	1AH10	42	1DP4	73	1DP6
12	1AH11	43	50DPE1	74	1DP7
13	1AH12	44	50DPE2	75	1KP8
14	1AH13	45	1AH42	76	1DP9
15	1AH14	46	10AH9	77	1AH73
16	1AH15	47	10AH14	78	1AH74
17	1AH16	48	10AH16	79	1AH75
18	1AH17	49	1AH46	80	1AH76
19	1AH18	50	10AH19	81	1DP10
20	1AH19	51	10AH24	82	1DPE1
21	1DP2	52	10AH26	83	1DPE2
22	1AH20	53	1AH50	84	1DPE3
23	1AH21	54	10AH29	85	1AH80
24	1AH22	55	10AH34	86	1AH81
25	1AH23	56	10AH36	87	1AH82
26	1AH24	57	1AH54	88	1AH83
27	1AH25	58	10AH38	89	1AH84
28	1AH26	59	10AH43	90	1AH85
29	1AH27	60	10AH45	91	1AH86
30	1AH28	61	1DP5	92	1AH87
31	1AH29	62	1AH58	93	1AH88

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-60. Word and Channel Assignments - Reduced Format (1.6 Kilobits Per Second) (cont)

Word No.	Data or Channel	Word No.	Data or Channel	Word No.	Data or Channel
94	1AH89	125	1AH120	156	1DPE17
95	1AH90	126	1AH121	157	1AH152
96	1AH91	127	1AH122	158	1AH153
97	1AH92	128	1AH123	159	1AH154
98	1AH93	129	1AH124	160	1AH155
99	1AH94	130	1AH125	161	1DPE18
100	1AH95	131	1AH126	162	1DPE19
101	1DPE4	132	1AH127	163	1DPE20
102	1AH97	133	1AH128	164	1DPE21
103	1AH98	134	1AH129	165	1AH160
104	1AH99	135	1AH130	166	1AH161
105	1AH100	136	1AH131	167	1AH162
106	1AH101	137	1AH132	168	1AH163
107	1AH102	138	1AH133	169	1AH164
108	1AH103	139	1AH134	170	1AH165
109	1AH104	140	1AH135	171	1AH166
110	1AH105	141	1DPE13	172	1AH167
111	1AH106	142	1AH137	173	1AH168
112	1AH107	143	1AH138	174	1AH169
113	1DPE5	144	1AH139	175	1AH170
114	1DPE6	145	1AH140	176	1AH171
115	1DPE7	146	1AH141	177	1AH172
116	1DPE8	147	1AH142	178	1AH173
117	1AH112	148	1AH143	179	1AH174
118	1AH113	149	1AH144	180	1AH175
119	1AH114	150	1AH145	181	1DPE22
120	1AH115	151	1AH146	182	1AH177
121	1DPE9	152	1AH147	183	1AH178
122	1DPE10	153	1DPE14	184	1AH179
123	1DPE11	154	1DPE15	185	1AH180
124	1DPE12	155	1DPE16	186	1AH181

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-60. Word and Channel Assignments - Reduced Format (1.6 Kilobits Per Second) (cont)

Word No.	Data or Channel	Word No.	Data or Channel	Word No.	Data or Channel
187	1AH182	192	1AH187	197	1AH192
188	1AH183	193	1DEP23	198	1AH193
189	1AH184	194	1DPE24	199	1AH194
190	1AH185	195	1DPE25	200	1AH195
191	1AH186	196	1DPE26		

The gating structure used for each word gate consists of eight input diodes connected with the collector of a two-stage complementary gate driver and eight isolation diodes. Each junction is OR gated with the same binary-weighted output of eight other word gates. The AND function is controlled by the gate driver output. During non-sampling time, each input diode is reverse biased by a negative voltage on the collector of the final stage of the driver. When data are to be gated to the output register, the gate driver is pulsed by a word command from the programmer. This saturates the gate driver, providing drive to set a 1 into each stage of the output register, corresponding to the digits of the digital word that are 1 (in excess of +3.5 volts) at the input. If a digit is 0 (less than +1.5 volts), the input diode is forward biased and the set current is inhibited.

2.9.3.3.7

Output Register and Data Transfer Buffers. (See figure 2-167.)

The output register receives eight-bit (parallel-by-bit) PCM words from the digital multiplexer gates and converts these data into serial PCM outputs. It also receives 40- and 24-bit serial binary inputs (channels 50DS1 and 50DS2) from other LM equipment and converts these data to PCM outputs. The data transfer buffers accept data from the output register, and inputs from the programmer and TE, to provide the following PCM output signals:

- NRZ data
- RZ data
- Split-phase data
- Data rate timing
- Subframe sync
- Two subcarrier reference signals
- One 40-bit serial start
- Two 40-bit serial stop
- Two 40-bit serial sync
- One 24-bit serial stop
- One 24-bit serial sync.

The output register consists of an eight-stage shift register, a shift pulse driver, and serial data transfer gates. Eight-bit words (bits 1, 2, ... 8) are parallel loaded into the shift register from the digital multiplexer gates, on word command to the gates from the programmer. The word command is active during bit 8 of 8 of each word time that an analog or parallel digital input is sampled. Each binary 1 sets a stage of the shift register. Each stage of the shift register is a conventional, saturating bistable that uses an input driver and negative steering diodes. During the next word time, the word is shifted out at the bit rate, with the most significant bit (bit 8) shifted out first. This is accomplished by shift pulses developed by the shift pulse driver from a bit rate input furnished by the programmer. The final stage of the shift register drives the NRZ, RZ, and split-phase bistables.



Figure 2-167. Output Register

The 40- and 24-bit serial words are also processed by the shift register. These serial words are transferred synchronously from other LM equipment by start, stop, and bit sync pulses furnished by the PCM equipment. Each bit of the words is AND gated at the serial data transfer gates, with the word command from the programmer and furnished as an input to the eighth stage of the shift register. Each bit is subsequently entered into this state and shifted out by the shift pulse as serial PCM data. The 50DS1 and 50DS2 inputs are inserted in words No. 121 through 128 of each prime frame during operation in the normal bit-rate mode. When operating in the reduced bit-rate mode, channels 50DS1 and 50DS2 are not sampled.

The data transfer buffers supply a start pulse one bit time before the beginning of the serial digital readout, 40-bit sync pulses (one each read time), and a stop pulse one bit time after readout of the 40th bit.

2.9.3.3.8 Power Supply.

The PCMTEA power supply (double-thickness card) is a dc-to-dc converter. It converts a +28-volt input to highly regulated outputs for the PCM analog blocks (+20, -20, +10, -10, and +6.3 volts) and the PCM digital blocks (+10, +6, +3.3, and -3.3 volts). The power supply also fulfills the power requirements of the TE.

2.9.3.3.9 Phase-Locked Oscillator and Doublers.

A 1024-kc signal from the LGC is routed to the TE doubler circuits through two parallel paths (primary and secondary). In the secondary path, a 2048-kc signal (doubler circuit output) controls the phase-locked oscillator. This temperature-compensated quartz crystal oscillator continues to operate and drive the timing generator if the 1024-kc input from the LGC fails. Additionally, if the Schmitt trigger output in the primary path fails to drive the timing generator, the phase-locked oscillator provides the redundancy needed for the timing generator to produce synchronizing signals for PCM outputs and other LM subsystems.

2.9.3.3.10 Oscillator Failure-Detection Circuits (No. 1, No. 2 and No. 3).

The three oscillator failure-detection circuits in the TE monitor the status of the phase-locked oscillator in the TE. Failure-detection circuit No. 1 routes digital status data to the digital multiplexer in the PCMTEA. This signal provides MSFN with telemetry signal GL0400 in real time. Failure-detection circuits No. 2 and 3 route analog status data to the high-level analog multiplexer in the PCMTEA. These signals provide MSFN with telemetry signals GL0422 and GL0423 in real time. If the phase-locked oscillator fails, MSFN is cautioned that the TE synchronization output signals to the PCMTEA and other LM subsystems are supplied through the primary input path to the timing generator. In this condition, if the LGC 1024-kc input to the TE fails, the synchronizing output signals from the TE will not appear.

2.9.3.3.11 Timing Generator.

The timing generator is tri-redundant logic that divides the 2048-kpps input signal into 1024- and 512-kpps signals. These synchronizing signals are routed to the AGS and CS, respectively. In addition, the timing generator divides the 512-kpps signal down to 10 pps. The redundant counters provide outputs at 51.2, 6.4, and 1.6 kpps; 10 cps; and 1 pps to the PCM equipment and other LM subsystems. These outputs are buffered; all division is done by integrated circuit bistables.

2.9.3.3.12 Time Accumulator and Serial Time Code Generator.

The time accumulator is a nonredundant device that comprises integrated circuitry that accepts the 10-cps signal from the redundant counters in the timing generator and divides it into the required binary-coded-decimal (BCD) outputs (seconds, minutes, hours, and days). Total recycling occurs at 39 days. An automatic reset circuit resets the time accumulator when power is initially applied to the PCMTEA. The

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

BCD outputs that represent seconds, minutes, hours, and days are fed in parallel to the serial time code generator as a 26-bit time code signal. The 26 bits represent mission elapsed time. The generator output (100 bits per second in NRZ-C format) is routed, with the most significant bit first, to the DSEA for time correlation of recorded voice. The first 24 bits are a synchronization code; the following 26 bits represent mission elapsed time.

2.9.3.4 Caution and Warning Electronics Assembly. (See figure 2-168.)

The CWEA provides the astronauts and MSFN with a continuous rapid check of LM status during manned missions. By continuously monitoring the data supplied by the SCEA, malfunctions are immediately detected. When a malfunction is detected, the CWEA provides signals that light caution lights (panel 2), warning lights (panel 1), and MASTER ALARM pushbutton/lights (one each on panel 1 and 2). A malfunction also activates a 3-kc signal that provides a tone in the astronaut headsets, and supplies the PCMTEA with a telemetry signal. The warning lights (red) indicate malfunctions that jeopardize astronaut safety and require immediate action. The caution lights (yellow) indicate malfunctions that do not necessarily require immediate action.

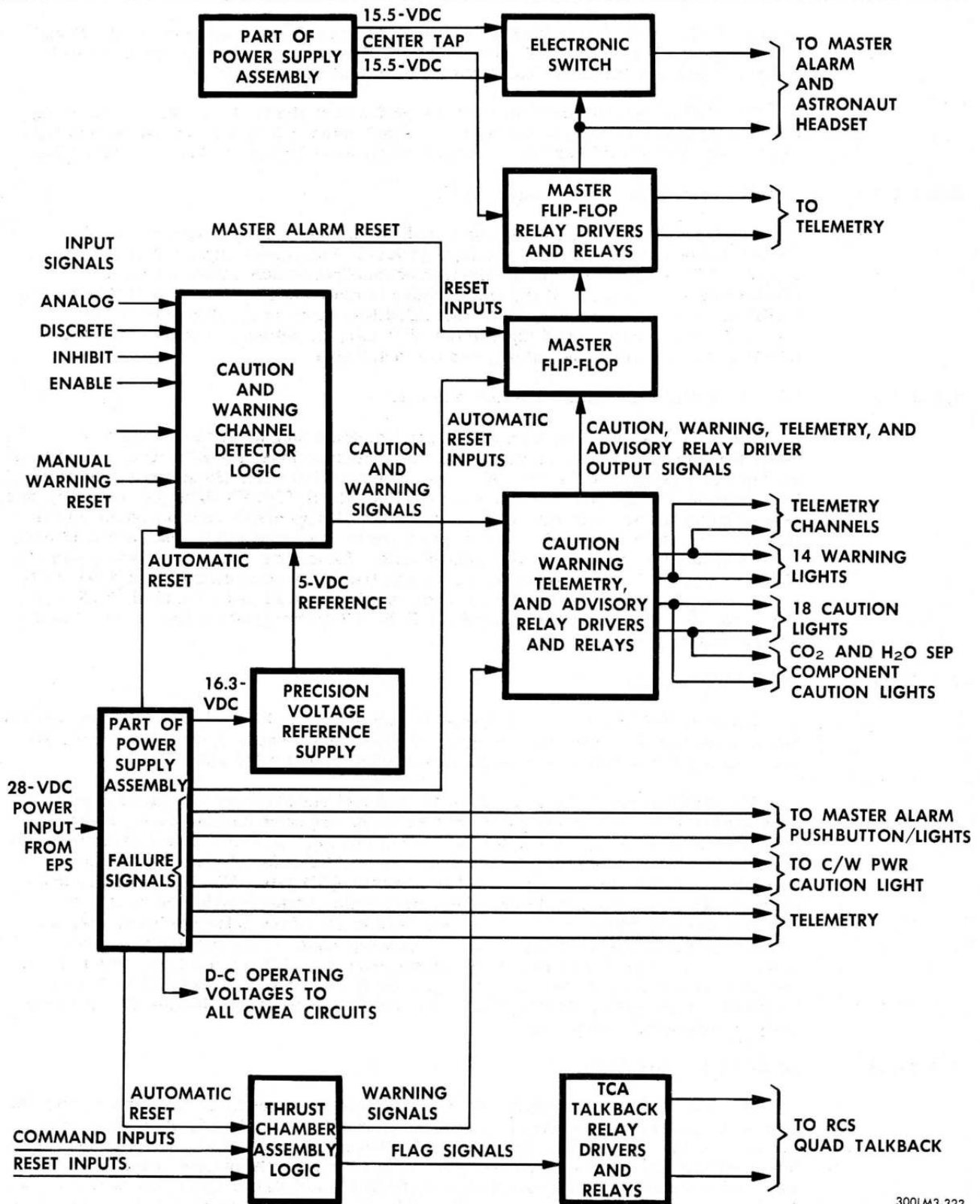
The CWEA compares analog signals (between 0 and 5 volts dc) from the SCEA with preselected internally generated limits supplied by the caution and warning power supply as reference voltage. In addition to the analog inputs, the CWEA receives discrete on-off and contact closure signals. All inputs are applied to detectors (analog and discrete) in the CWEA. The detected signal is routed through logic circuitry, enabling the necessary relay contacts for the caution or warning lights. Simultaneously, the signal is routed to a master flip-flop that energizes a master relay driver, enabling relay contacts. These relay contacts route the signal to light the MASTER ALARM pushbutton/lights and provide the 3-kc tone to the astronaut headsets. Pressing either MASTER ALARM pushbutton/light extinguishes both lights and terminates the tone, but has no effect on the caution or warning lights.

The CWEA channel detector logic also receives automatic reset signals from the power supply assembly, and manual caution and manual warning reset signals from LM sources. The thrust chamber assembly (TCA) logic accepts command input signals that correspond to TCA operation. Automatic resets from the power supply assembly and voltage resets from LM sources are accepted by the TCA logic. TCA outputs are routed simultaneously to a warning relay driver and a talkback relay driver, which operate the RCS TCA warning light and a particular QUAD talkback, depending on quadrant in which the TCA (system A or B) failed. The master flip-flop monitors the output of all caution and warning relay drivers. When one of these relay drivers is energized, the master flip-flop energizes master flip-flop relay drivers. These drivers operate relays whose contacts provide a path to actuate an electronic switch and a telemetry channel. When the electronic switch contacts make, a signal is routed to light both MASTER ALARM lights. Resetting the MASTER ALARM pushbutton/light does not affect a caution, warning, telemetry, advisory lights, or talkbacks. These malfunction indications remain until the cause is eliminated or until the appropriate reset or inhibit signal is applied. The telemetry channel provides MSFN with the malfunction indication. The power supply assembly not only provides operating voltages for the CWEA; it has automatic reset and failure-detection circuits. The automatic reset circuits operate when power is turned on; they reset the master flip-flop and all resettable CWEA logic circuits. Power supply failure is sensed by the failure-detection circuit, which operates relays that cause the MASTER ALARM pushbutton/lights and the C/W PWR caution light to go on and close a telemetry channel. The 16.3-volt d-c output of the power supply assembly provides a regulated voltage to a precision voltage reference supply. This supply provides a precise zener voltage reference for comparing input signal voltages in the CWEA channel detector logic circuits.

For the location of caution and warning lights, refer to section 3. The following paragraphs discuss inputs received by caution and warning lights. For failure modes detected by the CWEA, malfunction limits, and inhibit, enable, and reset signals, refer

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA



300LM3-323

Figure 2-168. Caution and Warning Electronics Assembly - Functional Block Diagram

INSTRUMENTATION SUBSYSTEM

to table 2-61. In designing the CWEA, numbers were used for designating inputs and CWEA lights. The "Input No." column and the "Light No." column provide a cross-reference between the numerical system and official nomenclature.

The CWEA logic circuitry that routes malfunction signals to a caution or warning light consists of high and low comparators, AND gates, OR gates, inverters, and flip-flops. See figure 2-169 for typical logic circuits used for caution and warning lights.

2.9.3.4.1 CABIN Warning Light. (See figure 2-169.)

The CABIN warning light goes on to indicate a lack of oxygen supply. If cabin pressure drops below 4.6 psia, the light goes on. Emergency oxygen input signals, routed to CWEA circuits from the Environmental Control Subsystem (ECS), are received by an AND gate. If the oxygen valve is closed due to electrical difficulty, the CABIN light goes on. Setting the CABIN REPRESS valve on the ECS module, to MANUAL applies an inverted input to the AND gate, disabling it, extinguishing the CABIN light, and restoring cabin pressure to 4.8 psia.

2.9.3.4.2 SUIT/FAN Warning Light. (See figure 2-169.)

The SUIT/FAN warning light goes on to indicate a lack of suit pressure or a faulty fan. The LM has two fans. If fan No. 1 malfunctions, the ECS caution light goes on; fan No. 2 is switched on and, if pressure is restored within 25 seconds, the caution light goes off. If fan No. 2 becomes inoperative, the SUIT/FAN light goes on. The suit pressure and fan No. 2 inputs are routed to a CWEA low-pressure comparator and an OR-gate circuit, respectively. If suit pressure is compared and is less than 3.12 psia, the comparator feeds this signal to the OR gate. Either one or both inputs are gated to energize a relay driver. Relay contacts route the malfunction signal to the SUIT/FAN light. If fan No. 2 fails and suit pressure drops below 3.12 psia, the SUIT/FAN light is extinguished by opening the ECS: SUIT FAN ΔP circuit breaker (panel 16). Cabin oxygen is then used.

2.9.3.4.3 ASC PRESS Warning Light.

The ASC PRESS warning light goes on if pressure in either of the two ascent helium tanks is below 2,773 psia before staging or if blanket pressure in the fuel or oxidizer lines at the bipropellant valves of the ascent stage is below 120 psia.

The CWEA receives helium, oxidizer, and fuel signals from the Main Propulsion Subsystem (MPS). These inputs are routed to low-pressure comparators. If the compared input is less than 2,773 psia (helium tank) or 120 psia (blanket pressure), low-pressure signals are fed through an OR gate to an AND gate. A staged input signal, coincident with the low-pressure input enables the AND gate. The low-pressure malfunction signal is then gated to a relay driver; relay contacts route the malfunction signal to the ASC PRESS light. If the pressure in one of the helium tanks is low, the remaining tank is used; the light goes off upon separation of the descent and ascent stages. Stage separation removes the staged input signal (via a deadface switch) from the AND gate, routing a logic 0 to its input; the AND gate is disabled and the light is inhibited. If the light is lit due to low fuel or oxidizer pressure, it goes off only when adequate pressure is restored.

2.9.3.4.4 DES QTY Warning Light.

The DES QTY warning light goes on to indicate a low supply in descent fuel tank No. 1 or 2, or in descent oxidizer tank No. 1 or 2, equal to 120 seconds of burning time before staging. The CWEA receives low-level fuel and oxidizer signals from the MPS. These signals are fed through an OR gate to an AND gate. A descent engine-on command from the control electronics section (CES) of the GN&CS, coincident with the low-level fuel or oxidizer signal, enables the AND gate. The low-level signal is then gated to a relay driver; relay contacts route this signal to the DES QTY light. Stage separation provides an inhibit signal and the light goes off.

Table 2-61. Caution and Warning Electronics Assembly - Malfunction Detection

Input No.	Input Description (Telemetry Code No.)	Malfunction	Illuminated By	CWEA Voltage Trip Level (volts dc)	Light (Telemetry Code No.)	Reset	Inhibit/Enable (Telemetry Code No.)	Light No.
1	Helium regulator pressure, system A (GR1201)	High or low helium regulator outlet pressure in RCS system A	High- or low-pressure signal (> 204.3 or < 164.4 psia) from sensor in helium line	2.918 2.349	RCS A REG (GL4032) warning (W)	Restored pressure	Inhibited if main shut-off solenoid valves in system A are closed (GR9609)	1
2	Helium regulator pressure, system B (GR1202)	High or low helium regulator outlet pressure in RCS system B	High- or low-pressure signal (> 204.3 or < 164.4 psia) from sensor in helium line	2.918 2.349	RCS B REG (GL4033) W	Restored pressure	Inhibited if main shut-off solenoid valves in system B are closed (GR9610)	2
5	RCS helium pressure, tank A (GR1101)	Low helium tank pressure in RCS system A	Low-pressure signal (< 1,696 psia) from sensors at helium tank	2.423	RCS (GL4052) caution (C)	TEMP/PRESS MON selector switch (panel 2) set to He		3
6	RCS helium pressure, tank B (GR1102)	Low helium tank pressure in RCS system B	Low-pressure signal (< 1,696 psia) from sensors at helium tank	2.423		TEMP/PRESS MON selector switch set to He		
7	Commander's bus voltage (GC0301V)	Low-voltage condition	Low-voltage signal (< 26.50V) from bus top	3.312	DC BUS (GL4034) W	Restored voltage		4
8	LM Pilot's bus voltage (GC0302V)	Low-voltage condition		3.312				
9	Inverter bus voltage (GC0071V)	Inverter output voltage	Out-of-tolerance voltage signal (< 112v) from top on a-c bus	4.480	INVERTER (GL4046) C	Restored voltage	Inhibited when INVERTER switch (panel 14) is set to OFF	5
10	Inverter bus frequency (GC0155F)	Inverter output frequency	Out-of-tolerance frequency (< 398 cps or > 402 cps)	2.250 2.750				

Table 2-61. Caution and Warning Electronics Assembly - Malfunction Detection (cont)

Input No.	Input Description (Telemetry Code No.)	Malfunction	Illuminated By	CWEA Voltage Trip Level (volts dc)	Light (Telemetry Code No.)	Reset	Inhibit/Enable (Telemetry Code No.)	Light No.
15 16 17 112 113 114	Battery No. 1 (GC9961U) Battery No. 5 (GC9965U) Battery No. 6 (GC9966U) Battery No. 2 (GC9962U) Battery No. 3 (GC9963U) Battery No. 4 (GC9964U)	Failure in any one of the four descent or two ascent batteries	Overcurrent, reverse-current, or over-temperature condition in any one or more of the six batteries		BATTERY (GL4047) C	Restored condition in affected batteries	Inhibited when affected battery is turned off	6
20 21	Emergency O ₂ valve electrically open (GF3572X) Emergency O ₂ valve position indicator (VPI) open (GF3081X)	Low cabin pressure	Low-pressure signal (< 4.15 ± 0.15 psia) from cabin pressure switch		CABIN (GL4036) C	Restored cabin pressure (4.8 psia)	Inhibited during cabin depressurization and when CABIN REPRESS valve on ECS package is manually set to open.	7
22 23	Suit outlet pressure (GF1301P) Suit fan No. 2 failure (GF1084X)	Low suit pressure (spare suit compressor failure) Low ΔP (< 6 in. H ₂ O) in suit fan No. 2	Low-pressure signal (< 3.12 psia) from sensor in suit circuit Low ΔP signal across suit fan section when suit fan No. 2 is in use (SUIT FAN component caution light, panel 2, goes on.)	1.556	SUIT/FAN (GL4037) W	Restored suit pressure	Inhibit - ECS: SUIT FAN 2 circuit breaker (panel 16)	8
25	Coolant pump No. 2 failure (GF2935X)	Glycol pump failure (selected coolant pump failure)	Low ΔP signal (< 3 psia) from sensor in coolant line downstream of glycol pumps No. 1 and 2 (GLYCOL component caution light, panel 2, goes on.)		ECS (GL4056) C	GLYCOL switch (panel 2)		9

Table 2-61. Caution and Warning Electronics Assembly - Malfunction Detection (cont)

Input No.	Input Description (Telemetry Code No.)	Malfunction	Illuminated By	CWEA Voltage Trip Level (volts dc)	Light (Telemetry Code No.)	Reset	Inhibit/Enable (Telemetry Code No.)	Light No.
26	CO ₂ partial pressure (GF1521P)	High CO ₂ partial pressure	High CO ₂ partial pressure signal (>7.6 mm Hg) from sensor (CO ₂ component caution light goes on.)	2.274		Restored CO ₂ partial pressure (CO ₂ component caution light remains on until CO ₂ CANISTER SEL valve on ECS package is set to PRIM.)	Inhibit - ECS: CO ₂ SENSOR circuit breaker (panel 16)	
27	Water separator No. 1 and 2 speed (GF9999U)	Water separator failure	Low rpm signal (< 800 rpm) from sensor in centrifuge of selected water separator (H ₂ O SEP component caution light goes on.)	1.651		Newly selected water separator		
28	Suit fan No. 1 (GF1083)	Suit fan No. 1 failure	Low ΔP signal (< 6 in. H ₂ O) across suit fan assembly (SUIT FAN component caution light goes on.)			SUIT FAN switch (panel 2) set to position 2	Inhibit - ECS: SUIT FAN 1 circuit breaker (panel 11)	
29	Descent tank water quantity (GF4581Q)	Low quantity in descent water tank	Low-level signal from sensor in descent water tank (16% remaining)	0.798	WATER QTY (GL4059) C	O ₂ /H ₂ O QTY MON selector switch (panel 2) set to C/W RESET	Enabled by staging deadface switch	10
30	Ascent tank No. 1 water quantity (GF4582Q)	Ascent tanks < full	Less-than-full signal from sensor in either ascent water tank	4.731				10

Table 2-61. Caution and Warning Electronics Assembly - Malfunction Detection (cont)

Input No.	Input Description (Telemetry Code No.)	Malfunction	Illuminated By	CWEA Voltage Trip Level (volts dc)	Light (Telemetry Code No.)	Reset	Inhibit/Enable (Telemetry Code No.)	Light No.
31	Ascent tank No. 2 water quantity (GF4583Q)	Ascent tanks \neq	Unequal-level signal from comparator in water tank	4.739				10
32	Descent oxygen tank pressure (GF3584P)	Low descent-oxygen-tank pressure	Low-pressure signal from sensor in descent oxygen tank (< 135 psia)	0.5	O ₂ QTY (GL4057) C	O ₂ /H ₂ O QTY MON selector switch set to C/W RESET	Enabled by staging deadface switch	11
33	Ascent oxygen tank No. 1 pressure (GF3582P)	Ascent tank No. 1, less-than-full pressure or low pressure	Less-than-full pressure signal (< 684 psia) or low-pressure signal (< 100 psia) from sensor in tank	3.408 0.498				11
34	Ascent oxygen tank No. 2 pressure (GF3583P)	Ascent tank No. 2 less-than-full pressure	Less-than-full pressure signal (< 684 psia) from sensor in tank	3.412				11
35	Coolant fluid level (GF2041X)	Low glycol quantity	Low-level signal (< 10% remaining in accumulator) from sensor in glycol tank		GLYCOL (GL4058) C		Inhibited when GLYCOL switch is set to INST (SEC)	12
36	Water-sublimator coolant outlet temperature (GF9998U)	Coolant evaporator outlet high temperature	High-temperature signal (> +50° F) from sensor at outlet of coolant evaporator	1.499		Restored temperature	Inhibited when GLYCOL switch is set to INST (SEC)	12
37	Helium tank No. 1 pressure (GP0001P)	Low helium-tank pressure	Low-pressure signal (< 2,773 psia) from sensors (two) in tank	3.742	ASC PRESS (GL4022) W	Restored pressure (possible only if temperature rises)	Enabled by staging deadface switch	13
38	Helium tank No. 2 pressure (GP0002P)	Low helium-tank pressure						13

Table 2-61. Caution and Warning Electronics Assembly - Malfunction Detection (cont)

Input No.	Input Description (Telemetry Code No.)	Malfunction	Illuminated By	CWEA Voltage Trip Level (volts dc)	Light (Telemetry Code No.)	Reset	Inhibit/Enable (Telemetry Code No.)	Light No.
39	Fuel bipropellant valve inlet pressure (GP1501P)	Low propellant pressure at bipropellant valve inlet of ascent stage	Low-pressure signal (< 120 psia) from sensors in fuel line at bipropellant valve	2.395		Restored pressure		13
40	Oxidizer bipropellant valve inlet pressure (GP1503F)							13
41	Fuel tank low level (GP0908X)	Low ascent fuel quantity	Low-quantity-level signal from sensor in ascent fuel tank		ASC QTY (GL4042) C		Enabled when ascent engine is on (GH1260)	14
42	Oxidizer tank low level (GP1408X)	Low ascent oxidizer quantity	Low-quantity-level signal from sensor in ascent oxidizer tank					14
43	Regulator outlet manifold pressure (GP0025P)	High ascent-helium-regulator outlet pressure	High-pressure signal (> 220 psia) from sensor in ascent helium lines downstream of regulators	3.658	ASC HI REG (GL4041) C	Reduced pressure (Close affected regulator.)		15
47	Descent propellant tanks (GQ4455X)	Low descent propellant quantity	Low-quantity-level signal from sensors in descent fuel or oxidizer tanks (approximately 2 minutes burn time remaining)		DES QTY (GL4024) W		Enabled when descent engine is on (GH1301)	16
48	Helium regulator outlet manifold pressure (GQ3018P)	High or low descent-helium-regulator outlet pressure	High- or low-pressure signal (> 260 or < 220 psia) from sensor in descent helium line downstream of regulators	4.318 3.654	DES REG (GL4024) W	Restored pressure	Enabled by staging deadface switch and delayed (6±0.5-second delay) descent engine-on command (GH1348)	17

Table 2-61. Caution and Warning Electronics Assembly - Malfunction Detection (cont)

Input No.	Input Description (Telemetry Code No.)	Malfunction	Illuminated By	CWEA Voltage Trip Level (volts dc)	Light (Telemetry Code No.)	Reset	Inhibit/Enable (Telemetry Code No.)	Light No.
49	+15 vdc (GH1406V)	Failure of any of d-c power supplies in CES	Out-of-tolerance voltage signal: ±15 vdc (< 14v or > 16v)	4.118 4.706	CES DC (GL4027) W	GYRO TEST switch (panel 3) set to POS RT or NEG RT		18
50	-15 vdc (GH1407V)							
51	+4.3 vdc (GH1408V)							
52	+6.0 vdc (GH1493V)							
53	-6.0 vdc (GH1494V)							
54	-4.7-volt supply (GH1488V)	Failure of regulated power supply that provides power to RCS jet preamplifiers	Out-of-tolerance voltage signal (< -4.2v or > -5.2v) from either of two parallel redundant -4.7-volt regulated power supplies in CES	3.500 4.333	PRE AMPS (GL4050)	Restored voltage	Enabled by DES BATS switch (panel 14); inhibited by ABORT pushbutton (panel 1) (GY0050)	19
55	-4.7-volt supply (GH1489V)							
56	28 vac, 1φ (GH1405V)	Failure in either of two a-c power supplies in CES	Out-of-tolerance voltage signal: 28 vac (< 26v or > 30v) 26 vac (< 23v or > 29v)	4.194 4.839 3.833 4.833	CES AC (GL4026) W	GYRO TEST switch set to POS RT or NEG RT		20
57	26 vac, φA (GH1401V)							
58	26 vac, φB (GH1402V)							
59	26 vac, φC (GH1403V)							

Table 2-61. Caution and Warning Electronics Assembly - Malfunction Detection (cont)

Input No.	Input Description (Telemetry Code No.)	Malfunction	Illuminated By	CWEA Voltage Trip Level (volts dc)	Light (Telemetry Code No.)	Reset	Inhibit/Enable (Telemetry Code No.)	Light No.
60 61	Pitch trim (GH1323X) Roll trim (GH1330X)	Failure of automatic function in Y- or Z-axis descent engine gimbal drive assembly Unstable ascent engine combustion	Discrepancy between gimbal drive signal and gimbal response from Y- or Z-axis trim function Vibration sensed by rough combustion cutoff assembly (RCCA)		GDA/RCCA (GL4043) C	RCCA switch (panel 2) set to OFF/RESET	Enabled by descent engine arm signal; inhibited when staging occurs RCCA switch set to ENABLE	21
62	LM guidance computer (GG9001X)	Failure in any LGC regulated power supply Counter failure Scaler failure	Out-of-tolerance voltage signal from 28-, 3-, or 13-volt supply Failure in counter, sensed by program checks Failure in scaler, sensed by program checks		LGC (GL4029) W	Restored voltage	Inhibited when GUID CONT switch (panel 1) is set to AGS (GH1621)	22
63	Inertial subsystem (GG9002X)	Inertial measurement unit (IMU) failure Pulsed integrating pendulous accelerometer (PIPA) failure	Excessive servo error; 3.2-kc power supply; 800-cps 5% supply PIPA failure during main engine thrusting		ISS (GL4030) W		Inhibited when GUID CONT switch is set to AGS (GH1621)	23
64	Primary guidance and navigation section (GG9003X)	IMU coupling data unit failure IMU excessive gimbal angle	Coupling display unit failure Roll gimbal angle greater than +6° or -6° (GIMBAL LOCK light on panel 4 goes on.)		PGNS (GL4045) C	RESET push-button (panel 4)	Inhibited when GUID CONT switch is set to AGS (GH1621)	24

Table 2-61. Caution and Warning Electronics Assembly - Malfunction Detection (cont)

Input No.	Input Description (Telemetry Code No.)	Malfunction	Illuminated By	CWEA Voltage Trip Level (volts dc)	Light (Telemetry Code No.)	Reset	Inhibit/Enable (Telemetry Code No.)	Light No.
	Primary guidance and navigation section (cont)	LGC program alarm	Failure(s) detected by alarm code numbers displayed on DSKY (panel 4) register (PROG light of DSKY goes on.)					
		Out-of-tolerance IMU temperature	IMU temperature deviation ($\pm 0.5^\circ \text{F}$) from normal (TEMP light of DSKY goes on.)					
		LGC restart signal	Word incorrectly transferred from LGC memory (parity circuit failure); computer is in program abort situation; computer interrupted for 30 milliseconds; computer does not accomplish new job routine within 1.28 seconds (night watchman); test alarm generated by program control (RESTART light of DSKY goes on.)					
		Rendezvous radar CDU failure	Rendezvous radar operate signal in LGC mode (switch on RADAR portion of panel 3) coincident with radar CDU failure signal at AND gate (TRACKER light of DSKY goes on.)					
		Rendezvous radar data not good	Auto track signal (from rendezvous radar) coincident with data-not-good signal (NO TRACK light, panel 3, goes on.)					

Table 2-61. Caution and Warning Electronics Assembly - Malfunction Detection (cont)

Input No.	Input Description (Telemetry Code No.)	Malfunction	Illuminated By	CWEA Voltage Trip Level (volts dc)	Light (Telemetry Code No.)	Reset	Inhibit/Enable (Telemetry Code No.)	Light No.
	Primary guidance and navigation section (cont)	Landing radar data not good	Landing radar data-not-good signal coincident with landing radar power-on signal (derived from antenna position signals) at AND gate, or a data-good signal with ambiguous antenna position signal. NOTE LDG RDR caution light does not go on if RENDEZVOUS RADAR selector switch (panel 3) is not set to AUTO TRACK.					
		PIPA failure during nonthrusting periods						
65	Landing altitude (GN7521X)	Range data not good	Altitude data-not-good signal from sensor in landing radar assembly		LDG RDR (GL4049) C	Restored data-good condition	Inhibited when landing radar power is off. LDG RDR caution light is not enabled until range and velocity data-good signals are achieved.	25
66	Landing rate (GN7557X)	Velocity data not good	Velocity data-not-good signal from sensor in landing radar assembly			Restored data-good condition		
67	Rendezvous radar data (GN7621X)	Rendezvous radar data not good (No track indication)	Data-not-good signals from sensors in rendezvous radar assembly		RNDZ RDR (GL4048) C	Restored data-good condition	Enabled when RENDEZVOUS RADAR selector switch is set to AUTO TRACK	26

INSTRUMENTATION SUBSYSTEM

Table 2-61. Caution and Warning Electronics Assembly - Malfunction Detection (cont)

Input No.	Input Description (Telemetry Code No.)	Malfunction	Illuminated By	CWEA Voltage Trip Level (volts dc)	Light (Telemetry Code No.)	Reset	Inhibit/Enable (Telemetry Code No.)	Light No.
68	28-volt supply (GI3214V)	Failure of regulated power supply in AGS	Out-of-tolerance voltage signal, or failure signal, from AEA test assembly	3.857 4.714 3.937 4.812 0.625 4.375	AGS (GL4028) W	Restored voltage	Inhibited when AGS STATUS switch (panel 6) is set to OFF (GI3305)	27
69	12-volt supply (GI3215V)							
70	28-volt, 400-cps supply (GI3233F)							
71	AEA test mode failure (GI3232V)							
72	Temperature - quad 1 cluster (GR6001T)	RCS thruster quad heater failure	High- or low-temperature signal from heater assemblies (< +119°F or > +190°F)	2.750 4.725	HEATER (GL4053) C	TEMP MONITOR switch (panel 3) set to affected heater position (Switch must be set to all positions, including return to starting position.)		28
73	Temperature - quad 2 cluster (GR6002T)							
74	Temperature - quad 3 cluster (GR6003T)							
75	Temperature - quad 4 cluster (GR6004T)							
76	Landing radar temperature (GN7563T)	Landing radar assembly heater failure	High- or low-temperature signal (< -15°F or > +150°F)	2.305 4.361				
77	Rendezvous radar temperature (GN77237)	Rendezvous radar assembly heater failure	High- or low-temperature signal (< -50°F or > +150°F)	1.869 4.361				
78	S-band antenna temperature (GT0454T)	S-band antenna assembly heater failure	High- or low-temperature signal (< -60°F or > +155°F)	1.743 4.421				

Table 2-61. Caution and Warning Electronics Assembly - Malfunction Detection (cont)

Input No.	Input Description (Telemetry Code No.)	Malfunction	Illuminated By	CWEA Voltage Trip Level (volts dc)	Light (Telemetry Code No.)	Reset	Inhibit/Enable (Telemetry Code No.)	Light No.
79	Jet driver A4D output command (GH1419V)	Failure of TCA in RCS system A or B	Discrepancy between primary coil command to fire specific TCA and chamber pressure response at that TCA, or failure such that opposing collinear jets are on simultaneously (If TCA fails, a QUAD talk-back (panel 2) is displayed.)		RCS TCA (GL4031) W		Inhibited when isolation valve associated with failed TCA is closed (QUAD switch, panel 2, set to CLOSE)	29
80	Thrust chamber A4D response (GR5032P)							
81	Jet driver A4R output command (GH1421V)							
82	Thrust chamber A4R response (GR5034P)							
83	Jet driver B4U output command (GH1418V)							
84	Thrust chamber B4U response (GR5031P)							
85	Jet driver B4F output command (GH1420V)							
86	Thrust chamber B4F response (GR5033P)							
87	Jet driver A3U output command (GH1422V)							
88	Thrust chamber A3U response (GR5035P)							
89	Jet driver A3R output command (GH1425V)							
90	Thrust chamber A3R response (GR5038P)							
91	Jet driver B3D output command (GH1422V)							
92	Thrust chamber B3D response (GR5036P)							
93	Jet driver A3R output command (GN1424V)							

Table 2-61. Caution and Warning Electronics Assembly - Malfunction Detection (cont)

Input No.	Input Description (Telemetry Code No.)	Malfunction	Illuminated By	CWEA Voltage Trip Level (volts dc)	Light (Telemetry Code No.)	Reset	Inhibit/Enable (Telemetry Code No.)	Light No.
94	Thrust chamber B3A response (GR5037P)							
95	Jet driver A2D output command (GH1427V)							
96	Thrust chamber A2D response (GR5040P)							
97	Jet driver A2A output command (GH1428V)							
98	Thrust chamber A2A response (GR5041P)							
99	Jet driver B2U output command (GH1426V)							
100	Thrust chamber B2U response (GR5039P)							
101	Jet driver B2L output command (GH1429V)							
102	Thrust chamber B2L response (GR5042P)							
103	Jet driver A1U output command (GH1430V)							
104	Thrust chamber A1U response (GR5043P)							
105	Jet driver A1F output command (GH1432V)							
106	Thrust chamber A1F response (GR5045P)							
107	Jet driver B1D output command (GH1431V)							
108	Thrust chamber B1D response (GR5044P)							

Table 2-61. Caution and Warning Electronics Assembly - Malfunction Detection (cont)

Input No.	Input Description (Telemetry Code No.)	Malfunction	Illuminated By	CWEA Voltage Trip Level (volts dc)	Light (Telemetry Code No.)	Reset	Inhibit/Enable (Telemetry Code No.)	Light No.
109	Jet driver B1L output command (GH1433V)							
110	Thrust chamber B1L response (GR5046P)							
CWEA circuit breaker (28 vdc)	CWEA power supply	Failure of CWEA regulated power supply	Out-of-tolerance voltage signal from CWEA +9-, +23-, +4-, and -3-volt power supplies		C/W PWR (GL4054)C	Restored voltage		
	Master arm relay K1 or any one or combination of stage sequence relays K2 through K6 (GY0201X - ED system A, and GY0202X - ED system B)	Any one or combination of ED relays K1 through K6 fails on.	Relay contact closure (SYS A and/or SYS B component caution lights, panel 8, also go on.)		ED RELAYS (GL4051)C	If relay K2 fails, STAGE RELAY switch (panel 8) set to RESET	Inhibited when MASTER ARM switch (panel 8) or ABORT STAGE pushbutton (panel 1) is used	
	S-Band receiver (GT0994V)	Failure in S-Band receiver automatic gain control (loss of uplink voice)	SIGNAL STRENGTH indicator (panel 12) indicates less than 1.		S-BD RCVR C	FUNCTIONS RANGE switch (panel 12) set to OFF/RESET	Enabled when FUNCTIONS RANGE switch is set to TV/CWEA ENABLE	

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

2.9.3.4.5 DES REG Warning Light.

The DES REG warning light goes on if pressure in the descent helium lines downstream of the regulators exceeds 260 psia or is below 220 psia. CWEA low- and high-pressure helium comparators receive helium regulator outlet pressure signals from the MPS. If the compared input is less than 220 psia or exceeds 260 psia, a low- or high-pressure signal, respectively, is fed through an OR gate to an AND gate, which is enabled by descent engine-on commands. The logic 1 output at the AND gate is fed to a relay driver; relay contacts route the high- or low-pressure signal to the DES REG light. The light is extinguished when nominal pressure is restored or when stage separation occurs and an inhibit signal removes the staged input signal (via a deadface switch) from the AND gate.

2.9.3.4.6 RCS A REG and RCS B REG Warning Lights. (See figure 2-169.)

The RCS A REG and RCS B REG warning lights go on if the pressure in the helium line of Reaction Control Subsystem (RCS) systems A and B exceeds 205 psia or is below 165 psia. CWEA low- and high-pressure helium regulator comparators receive the helium regulator A and B outlet pressure signals from the RCS. If the compared input is less than 165 psia or exceeds 205 psia, a low- or high-pressure signal, respectively, is fed through an OR gate to an AND gate. An inverted input from the RCS main shutoff valves, coincident with the low- or high-pressure signal at the AND gate, inhibits the light when the valves are closed. The lights are extinguished when nominal pressure is restored (both valves of system A or B, depending on which is being used, are closed) or when secondary system A or B, depending on which is malfunctioning, is used.

2.9.3.4.7 RCS TCA Warning Light. (See figure 2-169.)

The CWEA thrust chamber assembly failure-detection logic can detect TCA failures (on or off), in the primary guidance control mode or in the abort guidance control mode. Figure 2-169 illustrates on or off failures for TCA's A1U or A1F. The logic shown is typical for detecting failures of the other TCA's.

An on failure is a thrusting condition without the presence of an on command from the LGC. This condition is caused by a malfunction of the command signal sources upstream of the TCA's or by a short circuit within the TCA valves. Uncorrected, this condition results in excessive propellant consumption. The opposing command signals from the jet drivers are routed to a CWEA AND gate. Opposing collinear TCA's are not fired simultaneously unless it is necessary to compensate for the effect of a failed-on TCA. The AND gate senses this failure and provides an output to the set side of a flip-flop. The flip-flop output is routed to a QUAD talkback (SYSTEM A QUAD 1 talkback for jet driver A1U and A1F failures) and to the RCS TCA light.

An off failure is detected when a thruster response signal (TCA A1U) is not coincident with the thruster driver command signal (TCA A1U) at the CWEA AND gate. This failure can be caused by an open circuit or TCA malfunction; it degrades attitude and translation control. If the response signal is not present, the inverted input signal is routed as an off failure to the set side of the flip-flop. The flip-flop output is routed to the RCS TCA light and to a QUAD talkback (SYSTEM A QUAD 1 talkback for jet driver A1U and A1F failures).

The detection logic has a counter and delay circuitry because TCA's may not respond to all individual command signals if they are of short duration (less than 80 ± 8 milliseconds). Pulse skipping is not critical until six consecutive short pulses do not produce a thrust response signal; then the failure signal is detected. However, if one long pulse (in excess of 80 ± 8 milliseconds) is skipped, and a thrust response signal is not produced, a failure is detected. The failure-detection networks are provided with reset capabilities by setting the appropriate QUAD switch (panel 2) to CLOSE.

300LM3-324-1

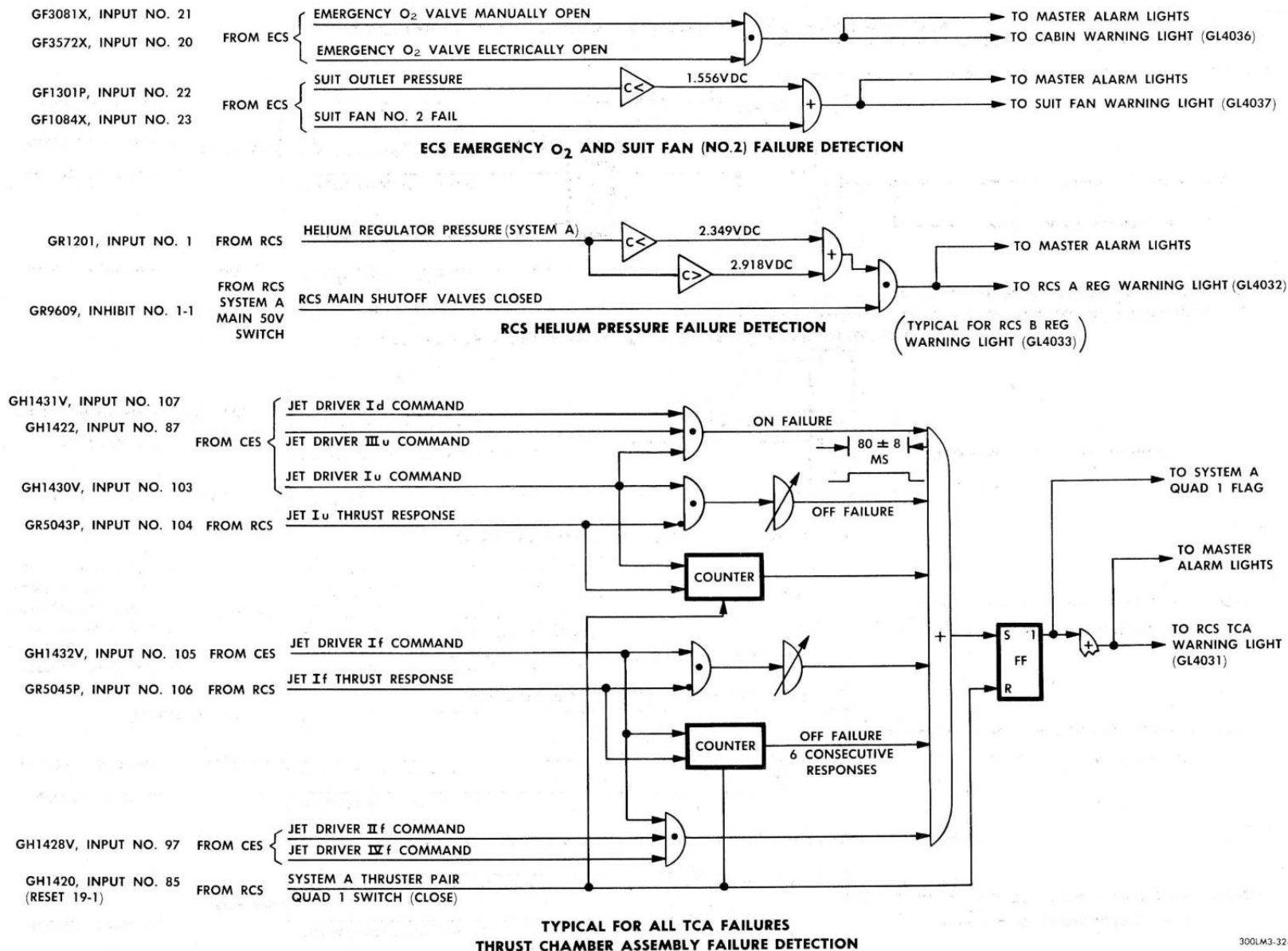
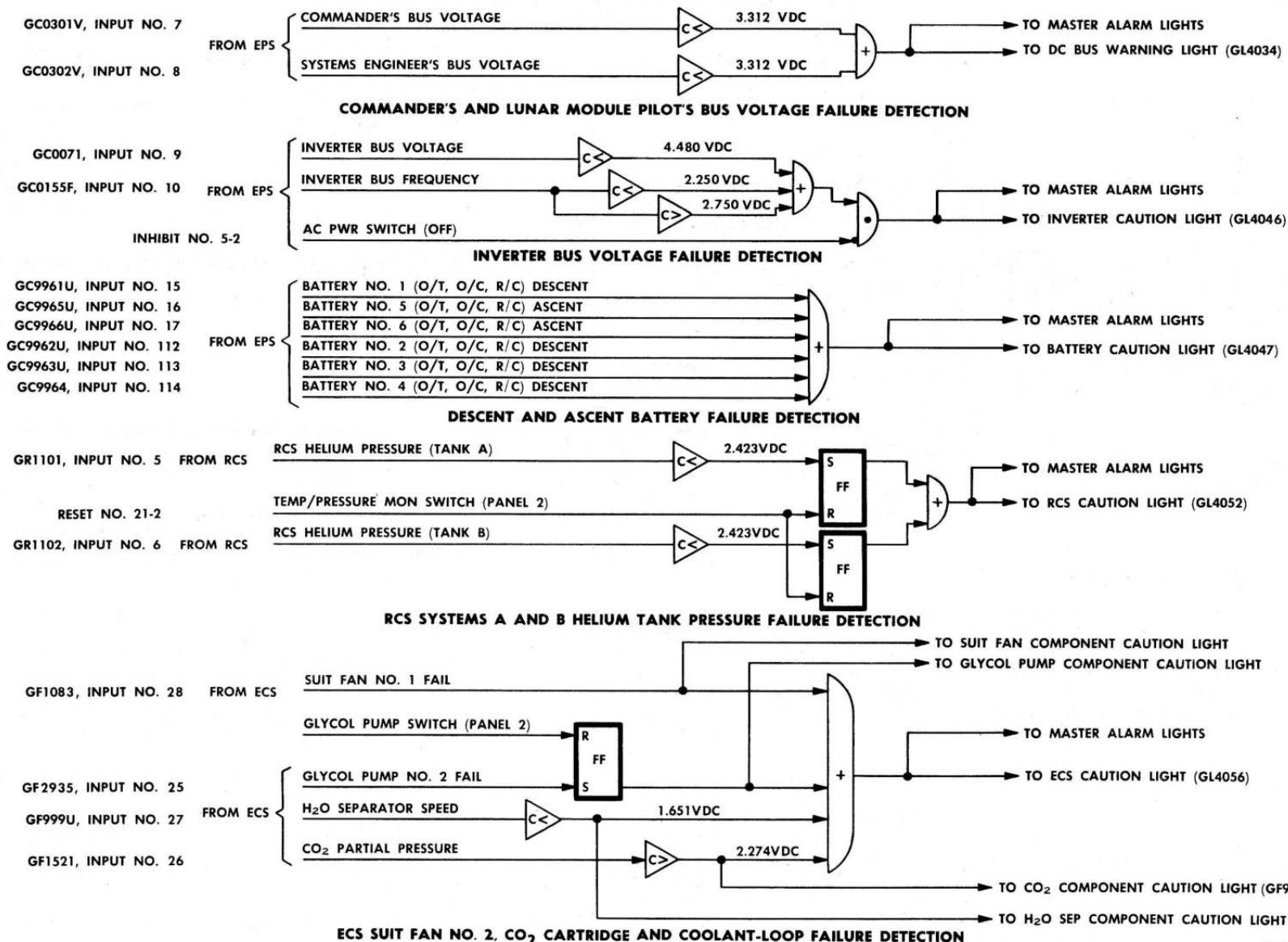


Figure 2-169. Caution and Warning Electronics Assembly Logic Detection Circuits (Sheet 1 of 2)

INSTRUMENTATION SUBSYSTEM



300LM3-324-2

Figure 2-169. Caution and Warning Electronics Assembly Logic Detection Circuits (Sheet 2 of 2)

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

2.9.3.4.8 DC BUS Warning Light. (See figure 2-169.)

The DC BUS warning light goes on to indicate low voltage (less than 26.5 volts dc) at the Commander's or LM Pilot's d-c bus. CWEA low-voltage comparators receive the Commander's and LM Pilot's bus voltage from the EPS. If the compared inputs are less than 26.5 volts dc, low-voltage output signals are fed to an OR gate. Either signal enables a relay driver; relay contacts route the signal to the DC BUS light. When the EPS is switched to a redundant power source the light goes off.

2.9.3.4.9 AGS Warning Light.

The AGS warning light goes on when the AGS power supplies do not supply +28 and +12 volts dc and 28 volts ac. CWEA high- and low-voltage comparators receive inputs from the abort sensor assembly of the AGS. If the compared inputs are out of tolerance, the signals are fed to an OR gate. The OR gate also receives a test mode fail input from the abort electronics assembly of the AGS. Any one, or all, of these inputs provide an output to the set side of a flip-flop whose output energizes a relay driver; relay contacts route the malfunction signal or signals to the AGS light. The reset side of the flip-flop has an AGS STATUS switch (panel 6) input. In the OFF position, this switch resets the flip-flop, extinguishing the light. If the light goes on after the AGS STATUS switch is again set to ON, manual control is necessary.

2.9.3.4.10 CES DC Warning Light.

The CES DC warning light goes on to indicate a decrease or increase in voltage from the GN&CS d-c power supplies, which supply +4.3, +6, -6, +15, and -15 volts dc to the CWEA. CWEA high- and low-voltage comparators receive inputs from the CES. If the compared inputs are out of tolerance, the high- or low-voltage signals are fed to an OR gate. Any of these signals provides an output to the set side of a flip-flop whose output is fed to a relay driver; relay contacts route the signal to the CES DC light. The reset side of the flip-flop has a GYRO TEST switch (panel 3) input. When set to POS RT or NEG RT, the switch resets the flip-flop, extinguishing the light. If the light remains on, the attitude and translation control assembly of the CES is disabled and manual control is necessary.

2.9.3.4.11 CES AC Warning Light.

The CES AC warning light goes on to indicate a decrease or increase in voltage from the GN&CS a-c power supplies, which supply 28-volt, 800-cps, single-phase ac and 26-volt, 800-cps, three-phase ac to the CWEA. CWEA high- and low-voltage comparators receive inputs from the CES. If the compared inputs are out of tolerance, the high- or low-voltage signals are fed through an OR gate to an AND gate. The malfunction signal at the AND gate is coincident with an inverted input from the GYRO TEST switch. The AND gate output is fed to a relay driver; relay contacts route the signal to the CES AC light. The light goes off when the GYRO TEST switch is set to POS RT or NEG RT. If the light remains on, the attitude and translation control assembly of the CES is disabled and manual control is necessary.

2.9.3.4.12 LGC Warning Light.

The LGC warning light goes on to indicate a power failure in the LGC (which supplies +28, +13, and +3 volts dc), a failure in its counter, or a failure in its scaler. A CWEA inverter detects the malfunction signals and routes them to relay drivers; relay contacts route the signals to the LGC light. The malfunction input at the inverter is coincident with an input from the GUID CONT switch (panel 1). Setting the switch to AGS disables the inverter and inhibits the light. If the light remains on, manual control is necessary.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

2.9.3.4.13 ISS Warning Light.

The ISS warning light goes on to indicate a failure in the inertial subsection (ISS) 3.2-kc power supply, 800-cps supply, pulse integrating pendulous accelerometer (PIPA) during main engine thrusting, or the coupling data units (CDU's) of the primary guidance and navigation section (PGNS) of the GN&CS. The malfunction signals and the inhibit signal (GUID CONT switch) are routed through CWEA logic circuitry typical to that for the LGC warning light.

2.9.3.4.14 ASC HI REG Caution Light.

The ASC HI REG caution light goes on if the helium pressure downstream of the regulators in the ascent helium lines exceeds 220 psia. A CWEA high-pressure comparator senses this malfunction signal and routes it to the ASC HI REG light. The light goes off when the pressure is restored to a nominal limit. The remedial action is to close ascent regulator solenoid valves No. 1 and 2, causing the light to go off. If, upon opening valve No. 1, the light goes on, this valve malfunctioned; valve No. 1 must be closed and valve No. 2 must be opened.

2.9.3.4.15 ASC QTY Caution Light.

The ASC QTY caution light goes on when the quantity of fuel or oxidizer remaining in the ascent tanks is sufficient only for approximately 10 seconds of burning time. The low-level signals are detected by a CWEA OR gate and routed to an AND gate. The malfunction signal at the AND gate is coincident with an ascent engine-on signal. This input enables the AND gate and routes the signal to the ASC QTY light. Manually shutting down the ascent engine prevents possible explosion due to depletion of either propellant before the other. Additionally, this malfunction indication advises that ascent engine thrusting is not available for midcourse correction or rendezvous braking. If feasible, the astronaut will prepare to use the RCS for thrusting.

2.9.3.4.16 GDA/RCCA Caution Light.

The GDA/RCCA caution light goes on if a difference between the gimbal drive signal and gimbal response signal from the Y- or Z-axis trim function is sensed. The pitch (Y) and roll (Z) trim malfunction signals are detected by a CWEA OR gate whose output is routed to the GDA/RCCA light. This signal is enabled only if the descent engine is armed. The signal is disabled following staging (via a deadface switch). The astronaut can monitor the RCS duty cycle (propellant quantity depletion rate) on the A and B QUANTITY indicators (panel 2) to determine the extent that the center of gravity and trim are off.

If the GDA/RCCA caution light goes on during ascent engine burns, the ascent engine rough combustion cutoff assembly (RCCA) sensed a 1,200 g force, peak-to-peak, at a center frequency of 7.5 ± 2.5 kc, for a pulse duration of 20 to 40 milliseconds. When this malfunction occurs, the ascent engine automatically shuts down. The RCCA switch (panel 2) is used to reset the RCCA.

2.9.3.4.17 PGNS Caution Light.

The PGNS caution light goes on if any of the following conditions are sensed: (1) middle roll gimbal angle exceeds $+60^\circ$ or -60° , (2) deviations from normal IMU temperature exceed $\pm 5^\circ$, (3) rendezvous radar operate and radar CDU fail signals to the CWEA AND gate are coincident, (4) rendezvous radar track enable and rendezvous radar data-not-good signals to the CWEA AND gate are coincident, (5) landing radar data-not-good and landing radar power-on signals (derived from the presence of antennas position signals) to the CWEA AND gate are coincident or a data-good signal and an ambiguous antenna position signal to the CWEA AND gate are coincident. These malfunction signals are detected by a CWEA inverter and routed to the PGNS light. When the GUID CONT switch is set to AGS (backup mode), an inhibit signal disables the inverter and the light goes off.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

2.9.3.4.18 INVERTER Caution Light. (See figure 2-169.)

The INVERTER caution light goes on if the a-c bus voltage is less than 112 volts or if the a-c bus frequency is less than 398 cps or exceeds 402 cps. CWEA high- and low-voltage comparators detect the malfunction signals and route them through an OR gate to an AND gate. The malfunction signal at the AND gate is coincident with an input from the INVERTER switch. When this switch is set to OFF, an inhibit signal disables the AND gate and the light goes off. A reset condition for this malfunction exists when nominal voltage is restored. If nominal voltage is not restored, the backup mode is selected by setting the INVERTER switch to 2.

2.9.3.4.19 BATTERY Caution Light. (See figure 2-169.)

The BATTERY caution light goes on if an overcurrent (O/C) reverse-current (R/C), or overtemperature (O/T) condition occurs in any of the four descent or two ascent batteries. A CWEA OR gate detects and routes these malfunction signals to the BATTERY light. The light is inhibited when the affected battery is turned off.

2.9.3.4.20 RNDZ RDR Caution Light.

The RNDZ RDR caution light goes on if a rendezvous radar data-not-good signal occurs. This signal is routed from sensors in the rendezvous radar assembly to a CWEA AND gate that is enabled only if the RENDEZVOUS RADAR selector switch (panel 3) is set to AUTO TRACK. The light goes off if a data-good condition is restored or if the radar is turned off, at which time the astronauts revert to rendezvous, with ranging done by the Command module.

2.9.3.4.21 LDG RDR Caution Light.

The LDG RDR caution light goes on if the landing radar altitude range data are not good or if the velocity data are not good. The attitude range data-not-good and the velocity data-not-good signals are routed from sensors in the landing radar assembly to a CWEA AND gate that is enabled when the landing radar power is on. The light goes off if a data-good condition is restored or if the landing radar is turned off.

2.9.3.4.22 PRE AMPS Caution Light.

The PRE AMPS caution light goes on to indicate an out-of-tolerance condition (less than -4.2 volts or more than -5.2 volts) in either of the parallel redundant -4.7-volt regulated power supplies in the CES. These supplies provide power to the RCS TCA preamplifiers. CWEA high- and low-voltage comparators detect the malfunction signals and route them through an AND gate to the PRE AMPS light. The AND gate is enabled by normally closed contacts of the staging deadface switch. This malfunction indicates an abort mission, because subsequent failure of the remaining -4.7-volt supply necessitates attitude control when the ROLL, PITCH, and YAW switches (panel 3) are set to DIR. The light is inhibited when the ABORT pushbutton (panel 1) is pressed. The ABORT pushbutton is used when aborting a mission, using the descent engine.

2.9.3.4.23 RCS Caution Light. (See figure 2-169.)

The RCS caution light goes on when RCS helium tank pressure (system A or B) is less than 1,700 psia. Low-pressure signals are routed from sensors at the helium tank of either system. The A and B PRESS indicator (panel 2) indicates which RCS helium tank pressure (system A or B) malfunctioned. CWEA low comparators detect the malfunction signals and route them to the set side of flip-flops. The flip-flop output is routed through an OR gate to the RCS light. The flip-flops reset and the light goes off when the TEMP/PRESS MON selector switch (panel 2) is set to He. Depending on the mission phase, the remedial action is either to use the ascent interconnect (during ascent burn) or the crossfeed (before ascent pressurization).

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

2.9.3.4.24 HEATER Caution Light.

The HEATER caution light goes on if the RCS TCA quad heaters, rendezvous radar antenna assembly heaters, landing radar antenna assembly heaters, or S-band antenna assembly heaters malfunction. CWEA low and high comparators detect the malfunction signals and route them to set flip-flops. The flip-flop output is routed through an OR gate to the HEATER light. The flip-flops reset and the light goes off when the TEMP MONITOR selector switch (panel 3) is set to the affected heater position. The out-of-tolerance temperatures that cause the HEATER light to go on are as follows:

RCS TCA quads - less than +119° F or greater than +190° F

Rendezvous radar - less -50° F or greater than +150° F

Landing radar - less than -15° F or greater than +150° F

S-band antenna - less than -60° F or greater than +155° F.

All positions of the TEMP MONITOR switch must be selected to determine whether one or more heater assemblies are affected. High-temperature conditions are eliminated when the affected heater assembly circuit breaker (HEATERS: S-BD ANT on panel 16, HEATERS: RNDZ RDR and LDG RDR on panel 11, and HEATERS RCS A/B-1: QUAD 1, 2, 3, and 4 on panel 11) is opened.

2.9.3.4.25 C/W PWR Caution Light.

The C/W PWR caution light goes on if out-of-tolerance regulated voltage signals (+9, +23, +4, 3, -2.3, or +2.3) are generated from the CWEA power supply. The CWEA power supply receives 28 volts dc from the EPS and routes regulated voltage outputs to CWEA components. It also supplies a reference voltage to CWEA comparators, where inputs from various subsystems are compared for the correct operating voltage. If the power supply outputs are not within design tolerance, a failure-detection network feeds these outputs to an OR gate. Any one, or all, of these malfunctions are gated to a relay driver; relay contacts route the signal or signals to the C/W PWR light. The light goes off when nominal power is restored.

2.9.3.4.26 ECS Caution Light. (See figure 2-169.)

The ECS caution light goes on if the operating primary glycol pump malfunctions, CO₂ partial pressure is high, the water separator fails, or suit fan No. 1 fails.

If the operating primary glycol pump fails, a low ΔP (less than 4 psia) signal from a sensor in the coolant line downstream of glycol pumps No. 1 and 2 causes the ECS light to go on. The malfunction signal is routed to the set side of a CWEA flip-flop. The flip-flop output is routed through an OR gate to the ECS light. The GLYCOL component caution light (panel 2) also goes on. The ECS light and the component caution light go off if the ΔP is restored to normal, or if a reset signal is routed to the flip-flop by setting the GLYCOL switch (panel 2) to PUMP 2 if pump No. 1 has failed or to INST (SEC) if pump No. 2 has failed.

If CO₂ partial pressure exceeds 7.6 mm Hg, a sensor signal causes the ECS light to go on. A CWEA high-pressure comparator detects the malfunction signal and provides two outputs; one is OR'd and gated to the ECS light; the other, is routed to the CO₂ component caution light (panel 2). The increase in CO₂ partial pressure is monitored on the PART PRESS CO₂ indicator (panel 2). The ECS light goes off when the partial pressure is reduced, or if the backup mode is selected by setting the CO₂ CANISTER SEL valve (on the ECS module) to SEC. In the latter case, the ECS light goes off, but the CO₂ component caution light remains on. After the primary CO₂ cartridge is replaced and the CO₂ CANISTER SEL valve is set to PRIM, the CO₂ component caution light goes off. Monitoring the PART PRESS CO₂ indicator ensures that CO₂ partial pressure is restored.

INSTRUMENTATION SUBSYSTEM

If the operating water separator is malfunctioning, a low-rpm signal (indicating less than 800 rpm) from a sensor in the centrifuge causes the ECS light to go on. A CWEA low-pressure comparator detects the malfunction signal and provides two outputs: one is OR'd and gated to the ECS LIGHT; the other is routed to the H₂O SEP component caution light (panel 2). The lights go off when nominal water separator speed is restored or if the WATER SEP SEL valve handle (on the ECS module) is pulled to select separator No. 2 (backup water separator).

If suit fan No. 1 is malfunctioning, a low ΔP (less than 6 inches of water) signal across the suit fan assembly is routed to the ECS light. The SUIT FAN component caution light (panel 2) also goes on, followed by the H₂O SEP component caution light. Setting the SUIT FAN selector switch (panel 2) to 2 selects suit fan No. 2 (backup mode); the ECS and component caution lights go off.

2.9.3.4.27 O₂ QTY Caution Light.

The O₂ QTY caution light goes on if a low-quantity condition (indicated by pressure signal less than 135 psia) occurs in the descent oxygen tank, or if a less-than-full quantity condition (indicated by pressure signal less than 684 psia) occurs in either ascent oxygen tank, or if a low-quantity condition (indicated by pressure signal less than 100 psia) occurs in ascent oxygen tank No. 1. To determine which tank pressure is low, the O₂/H₂O QTY MON selector switch (panel 2) is cycled through all positions and the corresponding pressure is monitored on the O₂ QUANTITY indicator on panel 2.

Low-pressure comparators detect the malfunction signals and route them to the set side of flip-flops. The flip-flop that is set due to a descent oxygen tank low-pressure signal is routed to an AND gate, which is enabled by normally closed contacts of the staging deadface switch. The AND-gate output is OR'd with the remaining malfunction signals, which are processed through flip-flop circuits in the same manner as the descent oxygen tank low-pressure signal. Any one, or all, of these signals are gated to the O₂ QTY light. When the ascent and descent stages separate, contacts of the staging deadface switch disable the AND gate that receives the descent oxygen tank low-pressure signal and the O₂ QTY light goes off. The O₂/H₂O QTY MON switch, when set to C/W RESET, resets the flip-flop. If the descent tank malfunctioned, the #1 ASC O₂ (ascent oxygen tank No. 1) valve (on the ECS module) must be opened. The O₂ QUANTITY indicator is monitored for this tank by setting the O₂/H₂O QTY MON switch to ASC 1. If ascent oxygen tank No. 1 indicates a low quantity, the #2 ASC O₂ (ascent oxygen tank No. 2) valve (on the ECS module) must be opened.

2.9.3.4.28 GLYCOL Caution Light.

The GLYCOL caution light goes on if the quantity of glycol in the primary coolant loop is low or if the glycol temperature in the primary loop, sensed at the heat transport section water sublimator outlet, exceeds +50° F. A CWEA comparator detects the high-temperature malfunction signal. Its output is OR'd with the low-glycol-quantity malfunction signal and routed to an AND gate. The AND gate, enabled by an inverted input from the GLYCOL switch, routes the malfunction signal to the GLYCOL caution light. The light goes off when the GLYCOL switch is set to INST (SEC).

2.9.3.4.29 WATER QTY Caution Light.

The WATER QTY caution light goes on when a low-level (16% of water remaining) signal from the descent water tank is sensed, when a less-than-full signal is sensed in either ascent water tank (before actual use), or while, using the ascent water tanks, unequal level signals are sensed. Refer to paragraph 2.9.3.4.27 for operation of the O₂/H₂O QTY MON selector switch to determine which tank pressure is low. The water quantities are monitored on the H₂O QUANTITY indicator (panel 2). If the quantity in the descent water tank is low, the backup mode is selected by setting the WATER TANK SELECT valve (on the ECS module) to ASC.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

The logic circuitry used to detect these malfunctions is typical to that described in paragraph 2.9.3.4.27. The staging deadface switch inhibits the descent water tank malfunction signal in the same manner as described for the descent oxygen tank low-pressure signal. The difference between the two logic circuits is that, in addition to each water tank (descent, ascent No. 1, and ascent No. 2) malfunction being detected by low-pressure comparators, the two ascent tank inputs are routed to a comparator that detects unequal tank pressures.

2.9.3.4.30 **ED RELAYS Caution Light.**

The ED RELAYS caution light goes on when a failure occurs in the master arm relay (K1) or, in any one or combination of the stage sequence relays (K2 through K6) located in both EDS relay boxes (system A and system B). The SYS A and/or SYS B component caution lights on the EXPLOSIVE DEVICES portion of panel 8 also go on. If any one or combination of relays K3 through K6 caused the ED RELAYS light and the SYS A and/or SYS B component caution lights to go on, there is no way of isolating the faulty relay or relays. However, K2 can be reset by momentarily holding the STAGE RELAY switch (panel 8) to RESET; if the lights go off K2 was at fault. If the lights do not go off, the ED: LOGIC PWRA and/or LOGIC B circuit breakers (depending on which component caution light is on) on panels 11 and 16, respectively, must be opened.

The MASTER ARM switch (panel 8) must not be touched. If this switch is set to ON while a failure exists in the stage sequence relays, a complete staging operation, or part of the staging operation (depending on which relay or relays failed) would result. Deactivating one EDS system (A or B) will not prevent EDS tasks. Either system can perform EDS functions.

2.9.3.4.31 **S-BD RCVR Caution Light.**

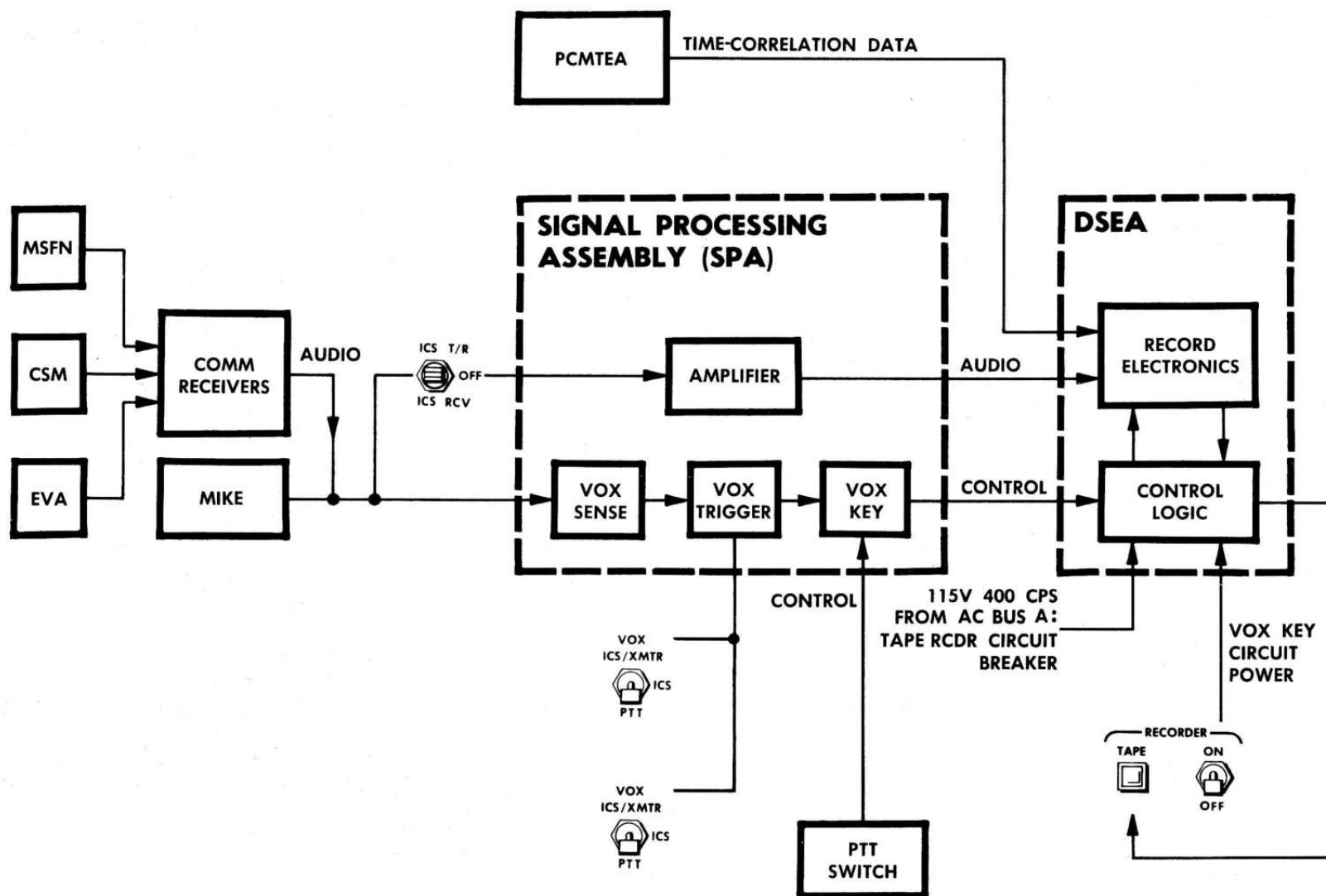
The S-BD RCVR caution light goes on if the S-band receiver automatic gain control fails (loss of S-band uplink voice). The loss of MSFN reception can be monitored on the SIGNAL STRENGTH indicator on panel 12. It will indicate less than 1. Communications can be obtained by setting the XMTR/RCVR switch (panel 12) to SEC. The CWEA S-BD RCVR light circuitry is enabled only if the RANGE FUNCTIONS switch (panel 12) is set to TV/CWEA ENABLE. The light goes off when this switch is set to OFF/RESET.

2.9.3.5 **Data Storage Electronics Assembly. (See figure 2-170.)**

The DSEA is a single-speed, four-track, magnetic-tape recorder that stores voice and time-correlation data (TCD) (mission elapsed time). A maximum of 10 hours of recording time is provided (2.5 hours on each track) by driving the tape in one direction over the record head and, on completion of a pass, switching to the next track and reversing tape direction. The tape is supplied in a magazine, consisting of a supply reel and takeup reel. Once the magazine is properly placed in the DSEA and the control logic is placed in track No. 1 forward condition (reset), the DSEA is operated with the RECORDER switch on the COMMUNICATIONS portion of panel 12, in conjunction with the VOX trigger signal supplied by the signal-processing assembly (SPA) of the CS.

The DSEA operates in either a manual or semiautomatic mode. In the manual mode, ICS T/R switch on the AUDIO portion of panel 8 or 12 is set to ICS/TR and the VOX switch on either panel is set to PTT. The PTT position bypasses the automatic voice sense circuits. The Commander or LM Pilot can close a push-to-talk switch (on the attitude controller assemblies or the umbilicals) and speak into a microphone. The push-to-talk switch energizes the VOX key relay, providing a ground for activation of the power control logic in the DSEA. In the energized state, this relay routes operating power to be applied to the recorder electronics. The audio signal generated by the astronaut is conditioned by the SPA and fed to the recorder for transfer to tape. For operation in the semiautomatic mode, the VOX switch is set to ICS/XMTR. With the switch set to this position, the VOX trigger circuit is enabled. The VOX sense circuit senses voice input from within the cabin or from the communications receivers and feeds this signal to the VOX trigger circuit. When the two inputs are coincident, the

INSTRUMENTATION SUBSYSTEM



300LM3-190

Figure 2-170. Data Storage Electronics Assembly - Functional Block Diagram

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

trigger is activated. Setting the VOX switch to ICS results in a continuous key for the recorder. When operating in this mode, recorder motion is manually controlled with the RECORDER switch (panel 12). The RECORDER TAPE talkback (panel 12) indicates tape motion during recording.

The DSEA consists of signal-conditioning electronics, a power supply, control logic, and a tape-motion amplifier. The signal-conditioning electronics accepts audio and TCD signals and conditions them before they are fed to the record head. Audio signals routed through the astronauts' intercommunications bus are applied to a voice amplifier that provides the band-pass filtering, impedance matching, and signal amplification required to drive the record head. Simultaneously with the voice input, TCD is supplied (as binary inputs) from the serial time code generator in the PCMTEA. A DSEA time-correlation data modulator accepts and converts serial binary-coded decimal data to frequency-coded data for recording. The binary input signals modulate a voltage-controlled oscillator to produce an output frequency of 4,175 cps, with a binary 1 input; 4,625 cps, with a binary 0 input. These voice and timing signals are mixed with the outputs of a reference oscillator that supplies a constant 5.2-kc signal for subsequent use in the DSEA test station, servoamplifiers, and a bias oscillator, which provides a 33-kc signal that eliminates nonlinear response in playback of voice and data. This permits recording multiplexed data on each of the four tracks. The control logic provides transport control, automatic track switching for the four tape passes, and starting and stopping of the DSEA. The tape transport uses a closed-loop capstan drive system with controlled tension in the record/reproduce head area. Dual capstans with a high angle of tape wrap provide sufficient driving friction without the use of pinch rollers. The drive motor in the tape transport is of the single-phase, 400-cycle, hysteresis, synchronous type with constant speed (+0.1% of input power). During recording, the reproduce head reads the recorded track and, through the tape-motion amplifier, supplies the signal that operates the TAPE talkback.

2.9.3.5.1 Power Supply.

The DSEA power supply consists of a power converter and voltage regulator, which provide regulated d-c power for all DSEA electronics.

The power converter conditions 115-volt, 400-cps ac, supplied from control logic circuits, to voltage levels of +17 and -8 volts dc. The +17 volts operates relays in control logic and tape-motion monitor circuits. It is also applied to the voltage regulator, along with the -8 volts. A-C power for the capstan drive motor is supplied from a tap on the primary winding of a transformer (T1).

The voltage regulator regulates the +17 and -8 volts dc, from the power converter, to +11.5 and -3.5 volts, respectively. These voltage levels are required for DSEA electronic circuitry.

2.9.3.6 Developmental Flight Instrumentation. (See figure 2-171.)

The DFI is used to validate the LM design. The instrumentation section of the DFI consists of subsystem sensors, power control and distribution equipment, strain/temperature signal conditioners, four 90-segment time-division multiplexers, three double-pole three-segment vibration commutators, three proportional-bandwidth modulation assemblies, a constant-bandwidth modulation assembly, and a signal-conditioning box. The signal-conditioning box is used primarily as a junction box; it performs some conditioning. The strain/temperature signal conditioners perform most of the conditioning. The communications section of the DFI consists of five VHF/FM transmitters, a five-channel multiplexer, diplexer, SLA VHF antenna, LM antenna, two C-band transponders, and a C-band transponder antenna system.

2.9.3.6.1 Sensors.

The DFI sensors are in individual subsystems; they sense high-level preconditioned signals and low-level strain and temperature signals.

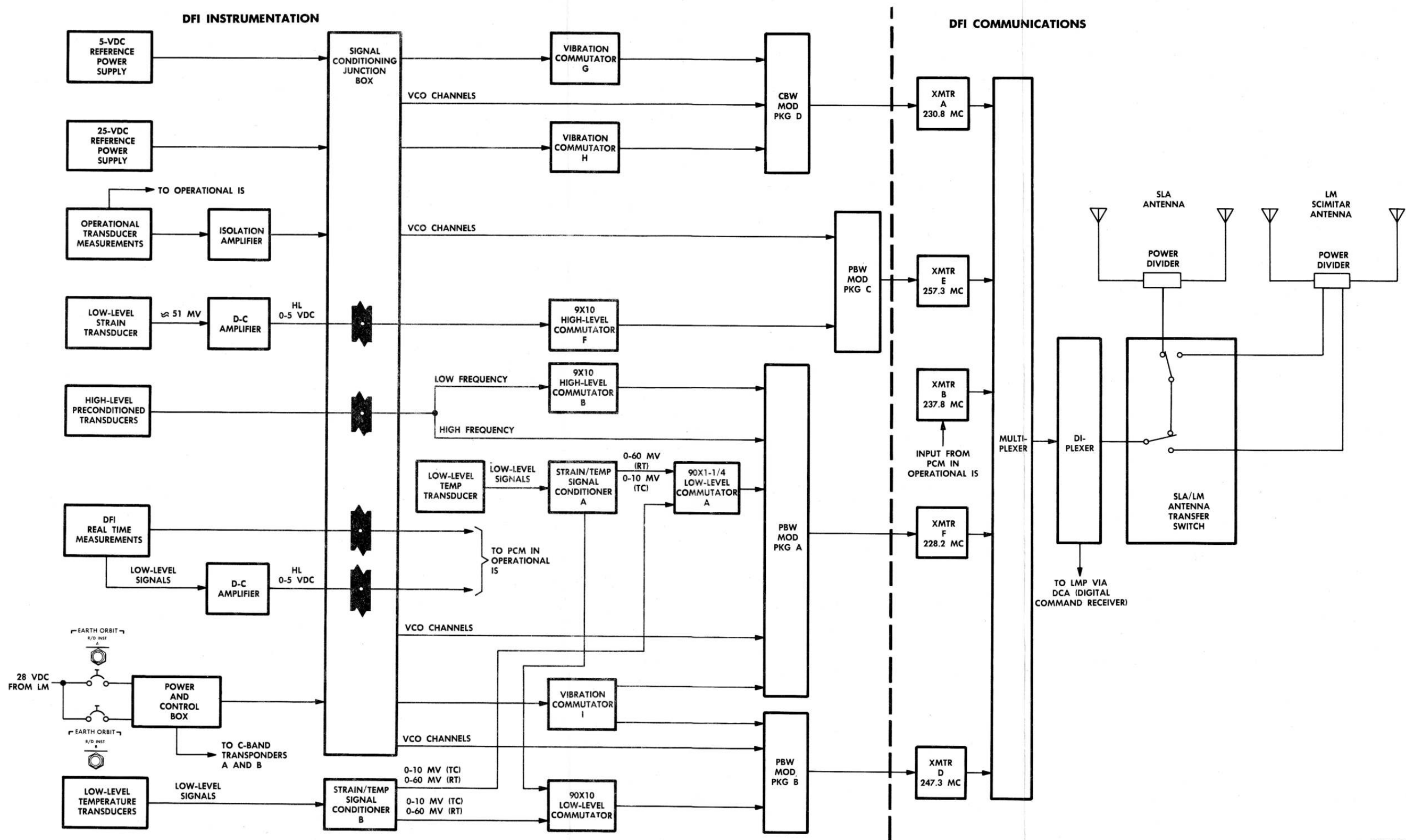


Figure 2-171. Developmental Flight Instrumentation - Overall Functional Block Diagram

The high-level preconditioned signals are sensed by pressure transducers that accept unregulated voltages (20 to 50 volts dc) and provide a 0- to 5-volt d-c output that is directly proportional to the pressure being sensed. The transducers operate in the range of 0 to 2 psia, 0 to 35 psia, or 0 to 2,000 psia. The low-frequency outputs of the transducers are fed through the signal conditioner to a 90 x 10 high-level commutator. The high-frequency outputs are fed directly to the voltage-controlled oscillator (VCO) channels (No. 2 through 16) in proportional-bandwidth (PBW) modulation package A, B or C for constant sampling.

The low-level strain transducers, comprising resistors in a Wheatstone bridge configuration, are excited by 10 volts dc. These transducers supply outputs of approximately 51 millivolts. These low-level outputs are fed to d-c amplifiers for proper voltage-level conditioning, required by PBW modulation packages. Like the output of the preconditioned pressure transducers, the high-level, 0- to 5-volt d-c conditioned signals from the d-c amplifiers are fed either directly to PBW modulation packages or indirectly by way of a 90 x 10 high-level commutator. The low-frequency outputs of the d-c amplifiers are fed to the 90 x 10 commutator for sampling. The high-frequency outputs are fed directly to the VCO channels (No. 2 through 16) in the PBW modulation packages for constant sampling.

The low-level temperature transducers are resistance thermometers (RT's), thermocouples (TC's) and various low-voltage sensors. The low-level transducer outputs (0 to 60 millivolts from RT's; 0 to 10 millivolts from TC's) are fed to strain/temperature signal conditioner A or B (ST-A and ST-B) for proper voltage-level conditioning, required by the 90 x 10 and 90 x 1-1/4 low-level commutators. The transducers outputs that provide the ST-A and ST-B with low-level signals are fed to channel No. 14 of PBW modulation package A or channel E of modulation package B.

The DFI real-time measurement transducers provide 0- to 5-volt d-c signals to the PCMTEA in the IS, by way of the DFI signal conditioner. The low-level DFI real-time measurements are fed to a d-c amplifier, which provides the 0- to 5-volt d-c output required by the PCMTEA in the IS. The IS transducer measurements that are fed to the IS are also routed to isolation amplifiers in the DFI. These isolation amplifiers provide ground isolation between the IS and DFI.

2.9.3.6.2 Power Control and Distribution Equipment.

The power control and distribution equipment includes the EARTH ORBIT: R/D INST A and R/D INST B circuit breakers (panel 11), which operate in conjunction with a power control box. To activate the DFI (instrumentation and communications sections), the EARTH ORBIT: SLA/LEM ANT TRNFR A and SLA/LEM ANT TRNFR B circuit breakers (panel 11) and the R/D INST A and B circuit breakers are closed and the EARTH ORBIT: C-BAND PWR switch (panel 11) is set to ON. The R/D INST A and B circuit breakers apply LM 28±4-volt d-c power to the power control box for distribution. Opening these circuit breakers shuts down the entire DFI.

The power control box provides 28±4-volt d-c power distribution to the signal-conditioning box for bus voltage and relay control, which is provided with a direct umbilical ground. The power control box also supplies power to C-band transponders (A and B) via C-band line filters, one for each transponder. The transponders provide radar tracking of the LM during near-earth orbits.

2.9.3.6.3 Strain/Temperature Signal Conditioners.

The strain/temperature signal conditioners condition signals from the strain, temperature, thermocouple and resistance transducers. The low-level outputs from these components are conditioned to 0 to 60 millivolts (resistance-type sensors) and 0 to 10 millivolts (thermocouple-type sensors). There are two signal-conditioning units in the DFI; they are ST in system A and ST in system B. System A contains eight modules; system B, four modules. Each module has 11 channels. This provides a total of 132 channels for conditioning. The 11 channels consist of regulators,

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

signal-conditioning circuits, power supply connections, and connections to external strain- and temperature-sensing systems. The 11-channel module for the strain system is the same as that for the temperature systems, except for different power requirements. The ST system A and B output is fed to a 90 x 1-1/4 or a 90 x 10 commutator that samples and provides 0- to 5-volt d-c outputs required by channel No. 14 of PBW modulation package A and channel No. E of modulation package B.

2.9.3.6.4 Ninety-Segment Time-Division Multiplexers.

The DFI 90-segment time-division multiplexers are two 90 x 10 high-level commutators, one 90 x 10 low-level commutator, and one 90 x 1-1/4 low-level commutator. The commutators accept 90 data inputs. Channels 1 and 2 are used for calibration; channels No. 89 and 90, for synchronization. The remaining 86 channels accept continuous DFI data inputs. These commutators accept and condition almost all DFI data required by the DFI modulation packages. The commutators multiply and produce pulse-amplitude-modulated (PAM) outputs in an RZ serial data train. These commutators can be crossed strapped if samples for a given measurement are critical and more accurate decoding is necessary.

Preconditioned high-level pressure signals (0- to 5-volts d-c) are fed directly to the 90 x 10 high-level commutators. Low-level strain transducer signals (approximately 51 millivolts) are also fed to the 90 x 10 high-level commutators, but through d-c amplifiers, where they are converted to 0- to 5-volt d-c signals. The eighty-eight 0- to 5-volt inputs to these commutators are the low-frequency outputs of the pressure transducers or d-c amplifiers. The commutators sample the 88 input signals 10 times per second and time-multiplex these signals into a PAM wavetrain. The PAM wavetrain is fed to the FM/FM telemetry system for data transmission through the RF transmitter and recovery by MSFN. The high-frequency outputs of the pressure transducers or d-c amplifiers are fed directly to the VCO channels in PBW modulation packages A and C.

The 90 x 10 and 90 x 1-1/4 low-level commutators receive low-level temperature transducer signals via the ST-A and ST-B. The 88 inputs to these commutators are in the range of 0 to 60 millivolts when received from resistance thermometers; 0 to 10 millivolts when received from thermocouples. The commutators sample the 88 input signals 10 or 1-1/4 times per second and time-multiplex these signals into a PAM wavetrain. The PAM wavetrain is fed to the FM/FM telemetry system for data transmission through the RF transmitter and recovery by MSFN. The 90 x 1-1/4 commutator PAM outputs are fed to PBW modulation package A; the 90 x 10 commutator PAM outputs, to PBW modulation package B.

2.9.3.6.5 Vibration Commutators.

The vibration commutators are two 3-position switches that accept continuous vibration data. The commutators accept six inputs and divide these inputs into two outputs, each containing three measurements on a 1.25-second time-shared basis. In position 1, the commutator routes the first measurement in 1.25 seconds from each output, at which time an internal frame synchronization of 50 milliseconds is generated. Following this frame synchronization, the commutator switches to position 2. In this position, the commutator routes its second measurement in 1.25 seconds from each output, at which time the 50-millisecond frame synchronization is again generated. This procedure is repeated for the third measurement. These vibration data are fed to modulation packages A, B, and D.

2.9.3.6.6 Constant-Bandwidth Modulation Package D.

The constant-bandwidth (CBW) modulation package consists of 10 VCO's amplifiers, a calibrator, and a plug-in chassis. Channels No. 1 and 6 of this modulation package receive the outputs from vibration commutator G; channels No. 5 and 2, the outputs from vibration commutator H. The remaining VCO channels receive data from subsystem transducers.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

The VCO's are frequency modulated by 0- to 5-volt d-c input signals and the VCO multivibrator set center frequencies are specified by the Inter-Range Instrumentation Group at a 2.5-volt d-c input. At zero or 5 volts dc, the output frequency varies 2 kc below or above the set center frequency. The output of each VCO is accepted by the amplifiers, which frequency-modulate all inputs as required by the VHF transmitters. Because this subcarrier and the transmitter carrier are frequency modulated, the system is referred to as FM/FM.

The amplifiers have two outputs: one, a composite of each oscillator output used for modulating out of the transmitters; the other, an oscillator composite hardline output used for ground equipment monitoring.

The calibrator module permits in-flight calibrations to be performed. Calibration should be performed before and after each major event. To calibrate the DFI, the EARTH ORBIT: R/D TLM CALIBRATE switch (panel 11) is held to ON for at least 12 seconds to assure a complete calibration cycle. After one calibration cycle, the system automatically returns to data transmission, regardless of the switch setting.

The plug-in chassis houses the modulation package components and all interconnecting wiring. The chassis serves as the electrical and mechanical connection between the CBW modulation package and the vehicle.

2.9.3.6.7 Proportional-Bandwidth Modulation Packages A, B, and C.

These modulation packages contain the same components as the CBW modulation package, except that these contain 16 VCO's. Like the CBW package, these supply FM outputs required by the VHF transmitters.

In modulation package A, channel E accepts a 90 x 10 high-level commutator output; channel No. 14, the 90 x 1-1/4 low-level commutator outputs; and channel No. 11, one of the outputs of vibration commutator I. The remaining VCO channels accept data from subsystem transducers.

In modulation package C, channel E receives the outputs from a 90 x 10 high-level commutator; channels No. 2 through 16, data from subsystem transducers.

2.9.3.6.8 DFI Communications Equipment.

The DFI communications equipment consists of five VHF/FM telemetry transmitters, a five-channel VHF multiplexer, a VHF/UHF diplexer, a SLA VHF antenna system, a LM VHF telemetry/command antenna system, two C-band transponders, and a C-band transponder antenna system.

Four of the transmitters are used for telemetry links that transmit LM data that is not required in real time. The PCM/VHF transmitter is used to telemeter real-time data from the PCMTEA. The PCM/VHF transmitter is set for 237.8 megacycles; the other four transmitters, for 230.9, 228.2, 247.3, and 257.3 megacycles. The transmitters receive FM inputs from the CBW and PBW modulation packages. The FM inputs are again frequency modulated; they provide a nominal output of 10 watts each to the five-channel multiplexer. The five-channel multiplexer combines all five transmitter inputs without interaction and provides a single output. The multiplexer output is fed to a VHF/UHF diplexer, which connects the output of the multiplexer and the digital command assembly (DCA) of the LM mission programmer to a common antenna system. During transmission, the diplexer permits VHF data to channel through contacts No. 2 of the SLA/LM ANT TRANSFER switch (located external to the LM, at the SLA attachment point) and blocks VHF data from reaching the DCA. When receiving, the diplexer permits UHF data to channel through to the DCA and blocks the data from entering the five-channel multiplexer.

The SLA antenna system and the LM antenna system are each composed of two broadband antennas, operating at 228 to 450 megacycles and fed by a power divider.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

The SLA antennas are mounted 180° apart on the S-IVB/CM attachment point. The antenna coverage exceeds 85% with SLA panels closed; 80% with the panels deployed to 45°. This system provides LM data and receives commands, from time of launch until separation of the LM from the SLA, through contacts No. 2 of the SLA/LM ANT TRANSFER switch. When the SLA and LM separate, the SLA/LM ANT TRANSFER switch automatically switches to contacts No. 1, connecting the LM antenna system. Transmission and reception are accomplished through the LM antennas for the remainder of the mission. The C-band transponder system provides tracking of the LM during earth-orbital missions. The system comprises C-band line filters A and B, C-band transponders A and B, two power dividers, and four antennas (two for each transponder).

The transponders receive pulses via their antennas, and transmit pulses back to earth at a different frequency over the same antennas. The received pulses are at 5690 ± 2 megacycles; the transmitted pulses are at 5765 ± 4 megacycles. The line filters, between the DFI power control box and their transponder, attenuate the transponder inputs. The power divider, between each pair of antennas and their transponder, provides transmission to, and reception from, MSFN.

2.9.4

FAILURE MODES.

The IS failure modes and the effect on mission capability are given in table 2-62.

Table 2-62. Instrumentation Subsystem - Failure Modes

Failure	Indication	Vehicle Capability
TELEMETRY PCM switch failed open (HI position).	MSFN continues to receive high-bit-rate information of 51.2 kilobits per second (normal mode) after switching to low-bit-rate information of 1.6 kilobits per second (reduced mode).	Only high-bit-rate information is monitored.
TELEMETRY PCM switch failed closed (LO position).	MSFN continues to receive low-bit-rate information after switching to high-bit-rate information.	Only low-bit-rate information is monitored.
INST: PCM/TE circuit breaker	MSFN does not receive telemetry signals.	Telemetry transmission is impossible.
PCMTEA programmer	All PCM data are not received by MSFN.	None
PCMTEA analog-to-digital converter (coder)	All analog PCM data are not received by MSFN.	None
PCMTEA output register and data transfer buffer	All PCM data are not received by MSFN.	None
PCMTEA power supply	All PCM data are not received by MSFN.	None
PCMTEA digital multiplexer	Most PCM data are not received by MSFN.	None
CWEA power supply	C/W PWR caution light goes on to indicate that subsystem failures (possibly all, depending on extent of power supply failure) may not be detected by CWEA circuits.	Most malfunctions are monitored by MSFN telemetry signals. Some are monitored on displays.

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-62. Instrumentation Subsystem - Failure Modes (cont)

Failure	Indication	Vehicle Capability
INST: CWEA circuit breaker	C/W PWR caution light goes on to indicate that CWEA is completely inoperative and that all subsystem failures cannot be detected.	Most malfunctions are monitored by MSFN telemetry signals. Some are monitored on displays.
SCEA Channel failure (in ERA-1 and/or ERA-2)	MSFN does not receive telemetry signals from affected conditioning units in affected ERA. Also, there is no display indication if affected unit is routed to display.	Conditioning unit outputs to CWEA circuits are also disabled. Other associated measurements may be used to determine vehicle status.
INST: SIG CONDR 1 circuit breaker.	MSFN does not receive telemetry signals from any conditioning unit in ERA-1. Also, there is no display indication for units in ERA-1 that are routed to displays.	None. ERA-1 outputs to CWEA circuits are also disabled.
INST: SIG CONDR 2 circuit breaker	MSFN does not receive telemetry signals from any conditioning unit in ERA-2. Also, there is no display indication for units in ERA-2 that are routed to displays.	None. ERA-2 outputs to CWEA circuits are also disabled.
DSEA manual mode	RECORDER TAPE talkback barber-pole display (when DSEA is in use)	Semiautomatic mode
AC BUS A: TAPE RCDR circuit breaker	RECORDER TAPE talkback barber-pole display (when DSEA is in use)	None. Recorder will not operate.

2.9.5 PERFORMANCE AND DESIGN DATA.

The performance and design data for the IS are given in table 2-63.

Table 2-63. Instrumentation Subsystem - Performance and Design Data

Pulse-code-modulation and timing electronics assembly	
Height	6.72 inches
Width	5.12 inches
Length	19.75 inches
Weight	23.0 pounds (approximate)
Power Requirements	
Excitation	28 volts dc
Consumption	11 watts
Operating temperature (ambient)	+30° to +130° F

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-63. Instrumentation Subsystem - Performance and Design Data (cont)

Pulse-code-modulation and timing electronics assembly (cont)

Reliability

Component calibration	Amplifiers, analog-to-digital converter, and all analog circuitry with functions common to 10 or more measurements
Calibration levels	4.250 volts, 0.750 volts
Accuracy	±9 millivolts on high level

High-level analog signals

Number of channels	277
Normal bit rate (51.2 kilobits per second)	200 channels externally programmed, 77 channels internally redundant
Reduced bit rate (1.6 kilobits per second)	113 channels externally programmed, 41 channels internally redundant
Signal levels	0 to 5 volts
Analog error	0.5% (maximum)
Sampling rate	1, 10, 50, 100, or 200 samples per second
Bits formed per channel input	8

Parallel digital signals

Number of channels	75
Normal bit rate	1, 10, 50, 100 or 200 samples per second
Reduced bit rate	1 sample per second
Signal levels	
Binary 1	+3.5 to +10 volts
Binary 0	-0.5 to +1.5 volts
Bits per output word	8, 16, or 32
Sampling sequence for 8-, 16-, and 32-bit input words	Sequential, with eight most significant bits first

Serial digital signals

Number of channels	2 channels, serial by bit
Signal levels	
Binary 1	+3.5 to +10 volts
Binary 0	-0.5 to +1.5 volts
Word length	One 24-bit channel One 40-bit channel
Normal bit rate	50 samples per second
Reduced bit rate	None

1,024-kpps input signals

Type	Square wave
Amplitude	7±3 volts, peak to peak

Input power

20 to 32 volts dc

NRZ output

Bit rate	51.2 or 1.6 kilobits per second
Signal levels	

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-63. Instrumentation Subsystem - Performance and Design Data (cont)

Pulse-code-modulation and timing electronics assembly (cont)

NRZ output (cont)

Binary 1	+6±0.5 volts
Binary 0	0.0 to +0.5 volt

RZ output

Bit rate	51.2 or 1.6 kilobits per second
Signal levels	
Binary 1	+3.0±0.5 volts
Binary 0	0.0 to 0.5 volts

Data rate timing output

Frequency	51.2 or 1.6 kpps (selected by remote switching)
Signal levels	0.0 to 0.5 volt and +3.0±0.5 volts

Subcarrier reference output

Frequency	51.2 pps
Signal levels	
10-kilohm output load	0.0 to +0.5 volt and +6±0.5 volts
100-ohm output load	0.0 to +0.5 volt and +3.0±0.5 volts

Subframe sync pulse output

Frequency	1 pps
Signal levels	0.0 to +0.5 volt and +3.0±0.5 volts

512-kc timing output signals

Frequency	512 kpps
Signal levels	0.0 to 0.5 volt and +3.0±0.5 volts

6.4-kc timing output signals

Frequency	6,400 pps
Signal levels	0.0 to 0.5 volt and +3.0±0.5 volts

1.6-kc timing output signals

Frequency	1,600 pps
Signal levels	0.0 to 0.5 volt and +3.0±0.5 volts

10-cps timing output signal

Frequency	10 pps
Signal levels	0.0 to 0.5 volt and +3.0±0.5 volts

1024-kc timing output signal

Frequency	1024 kpps
Signal levels	0.0 to 0.5 volt and +3.0±0.5 volts

Low-bit-rate split-phase data outputs

Bit rate	1.6 kilobits per second
Signal levels	+6.0±0.5 volts (up level)
	+0.0 to 0.5 volt (down level)

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-63. Instrumentation Subsystem - Performance and Design Data (cont)

Pulse-code-modulation and timing electronics assembly (cont)

Analog-to-digital conversion

Each analog sample	8-bit binary word output
Full-scale input to ADC	11111110
Zero input	00000001
Greater than full scale	11111111
Less than zero	00000000

Signal-conditioning electronics assembly

Height	8.0 inches
Width	5.25 inches
Length	23.90 inches
Weight	100.215 pounds (total)
ERA-1	35.428 pounds
ERA-2	34.787 pounds

Power requirements

Excitation	28 volts dc
Consumption	
ERA-1	16.04 watts
ERA-2	14.23 watts

Thermal characteristics

An efficient thermal path exists between heat-producing sources within subassemblies and an external heat sink.

Environmental limits

Vibration	8.1g rms from 5 to 2,000 cps
Acceleration	8g
Shock	15g sawtooth
Temperature	
Operating	+30° to +130° F
Nonoperating	-65° to +160° F

D-C amplifiers

Inputs	
Unipolar mode	0 to 200 millivolts dc and 0 to 5 volts dc
Bipolar mode	-100 millivolts to -2.5 volts dc and +100 millivolts to +2.5 volts dc
Output	0 to 5 volts dc (4 single channels)

Alternators

Inputs	
Unipolar mode	0 to 5 volts dc (minimum attenuation)
	0 to 40 volts dc (attenuation of 8)
Bipolar mode	-2.5 to +2.5 volts dc and -20 to +20 volts dc
Output	0 to 5 volts dc (4 single channels)

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-63. Instrumentation Subsystem - Performance and Design Data (cont)

Signal-conditioning electronics assembly (cont)

AC-to-dc converters

Input frequency	380 to 840 cps
Output	0 to 5 volts dc (3 single channels)

Analog signal isolating buffer

Input	0 to 5 volts dc
Output	0 to 5 volts dc (4 single channels)

Discrete signal isolating buffers

504-2

Turn-on voltage	0.5 to 2.5 volts dc
Output voltage	0 to 5 volts dc (10 dual channels)

504-3-4

Output voltage	0 to 5 volts dc (12 dual channels)
----------------	------------------------------------

504-5

Output voltage	0 to 5 volts dc (12 single channels)
----------------	--------------------------------------

Frequency-to-dc converter

Input frequency	380 to 420 cps
Output	0 to 5 volts dc

Resistance-to-dc converters

Resistance changes	665 to 2,795 ohms (-200° to +500° F)
Output	0 to 5 volts dc (4 dual channels)

Phase-sensitive demodulators

Output	0 to 5 volts dc
--------	-----------------

Caution and warning electronics assembly

Height	7.0 inches
Width	6.750 inches
Length	11.750 inches
Weight	19.75 pounds (approximate)

Power requirements

Excitation	28 volts dc
Consumption	13 watts
Internally generated	+4, +23, +12, +9, -3, +7, and 16.3 volts dc, rectified Three 34-volt, zero-to-peak, 10-kc, center-tapped square waves One 15.5-volt, zero-to-peak, 10-kc, center-tapped square wave Two 10-kc reference signals

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-63. Instrumentation Subsystem - Performance and Design Data (cont)

Caution and warning electronics assembly (cont)

Environmental limits

Temperature	
Operating	+35° to +135° F
Nonoperating	-65° to +160° F
Vibration	8g peak from 380 to 2,000 cps
Shock	15g sawtooth
Acceleration	8g

Input signals

Caution

Discrete	26
Analog	23
Inhibit	3
Enable	4

Warning

Discrete	10
Analog	22
Inhibit	7
Enable	2

Indicator reset

Caution	10
Warning	1

Thrust chamber assembly (TCA) logic

Command (discrete or analog)	16
Response (discrete)	16

Output signals

Caution light	18
Warning light	14
Component caution light	2
Talkback	8
MASTER ALARM pushbutton/light	2

Inputs

Analog signals	0.5 to 5.0 volts dc
Discrete	
Malfunction level	3.4 to 6.0 volts dc
No malfunction	0 to 0.5 volt dc
Out-of-limit inputs	Delay time (input to output): 0.5 second

Telemetry output

Malfunction	4.0 to 10 volts dc
No malfunction	-0.5 to +0.5 volt dc

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-63. Instrumentation Subsystem - Performance and Design Data (cont)

Caution and warning electronics assembly (cont)

Voltage limits

Upper

Output signal generated when preset voltage is exceeded

Lower

Output signal generated when preset voltage is exceeded

Data storage electronics assembly

Height

2.05 inches

Width

4.0 inches

Length

6.22 inches

Weight

38 ounces

Power requirements

Power supply input

115±2.5 volts rms, 400 cps, single phase

Reset command

28±4 volts dc

VOX command input

28±4, -8 volts dc

Output

+17 volts dc unregulated; +11.5 volts dc regulated; 26.0 volts rms

Magnetic heads

2 record/reproduce heads to provide 4 tracks

Voice record amplifier

Input level

-3 to +7 dbm

Frequency response

±0.5 db from 300 to 2,000 cps
+5 db preemphasis at 3 kc

Time-correlation data

Serial input level

Binary 1

6±1 volts peak

Binary 0

-0.5 to +1.5 volts peak

Serial input bit rate

100 bits per second

Bias oscillator

Output frequency

33 kc±10%

Output level

5±1 milliamperes

Tape

Speed

0.6 inch per second

Total recording time

10 hours (maximum)

Length of tape between
sensor strips

450 feet (minimum)

Power Source

AC

115±2.5 volts rms

DC

28 volts dc

DSEA transport

Speed error

0.05 of input power deviation

Start time

100 milliseconds after receipt of VOX trigger

Stop time

300 milliseconds after cessation of VOX trigger

Record time

Total of 10 hours

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-63. Instrumentation Subsystem - Performance and Design Data (cont)

Data storage electronics assembly (cont)	
DSEA transport (cont)	
End of tape	Automatically sensed
VOX input	300 to 3,000 cps
Time-correlation data	
Input	Serial NRZ-C (bits per second)
Input levels	
Binary 1	6±1 volts
Binary 0	-0.5 to 1.5 volts

2.9.6

OPERATIONAL LIMITATIONS AND RESTRICTIONS.

The operational limitations and restrictions for the IS are as follows:

- PCMTEA, SCEA, and signal sensors (for preconditioned transducers) must be warmed up for 5 minutes after coolant-loop stabilization, before use. If the 5-minute warmup period is not allowed, the accuracy of data will be uncertain.
- Total DSEA recording time (voice keyed) for the DSEA voice tape recorder is 10 hours. The DSEA will not record voice after 10-hour use.
- The DFI should be calibrated before and after each major event. The EARTH ORBIT: R/D TLM CALIBRATE switch must be held to ON for at least 12 seconds to assure a complete calibration cycle. After one calibration cycle, the system returns to data transmission. If the DFI is not calibrated before and after each major event, the accuracy of DFI data will become more uncertain as time elapses.

2.9.7

TELEMETRY MEASUREMENTS.

The DFI telemetry data are given in table 2-64. "Structures", "thermodynamics", and "mechanical design" are listed in the third column to indicate signal origin. Telemetry data for signals that are routed through the IS and require conditioning are given in tables 2-57 and 2-58. The DFI is recorded by MSFN only, therefore, the "Display Range" column and "Crew Display" column in table 2-64 is blank. The code number in parentheses are time shared with the code number listed.

Table 2-64. Developmental Flight Instrumentation - Telemetry Measurements

Code	Description	From (Subsystem)	Telemetry Range	Display Range	Crew Display
GA0083T	+Z landing leg outrigger No. 1 temperature	Structures	0° to +500° F		
GA0084T	+Z landing leg outrigger No. 2 temperature		0° to +500° F		
GA0085T	+Z landing leg apex fitting temperature		0° to +500° F		

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-64. Developmental Flight Instrumentation - Telemetry Measurements (cont)

Code	Description	From (Subsystem)	Telemetry Range	Display Range	Crew Display
GA0201T	Descent engine cavity temperature No. 1	Structures (cont)	0° to +500° F		
GA0202T	Descent engine cavity temperature No. 2		0° to +500° F		
GA0203T	Descent engine cavity temperature No. 3		0° to +500° F		
GA0204T	Descent engine cavity temperature No. 4		0° to +500° F		
GA0601S (GB0807P)	+Z beam booster strut No. 1 load		0 to 17,000 pounds		
GA0602S (GB0808P)	+Z beam booster strut No. 2 load		0 to 24,000 pounds		
GA0603S (GA3002A)	+Z beam booster strut No. 3 load		0 to 24,000 pounds		
GA0604S (GB0809P)	+Z beam booster strut No. 4 load		0 to 17,000 pounds		
GA0605S (GB0812P)	-Z beam booster strut No. 1 load		0 to 17,000 pounds		
GA0606S (GB0810P)	-Z beam booster strut No. 2 load		0 to 24,000 pounds		
GA0607S (GB0802P)	-Z beam booster strut No. 3 load		0 to 24,000 pounds		
GA0608S (GA3005A)	-Z beam booster strut No. 4 load		0 to 17,000 pounds		
GA0609S (GA3004A)	+Y beam booster strut No. 1 load		0 to 17,000 pounds		
GA0610S (GA3003A)	+Y beam booster strut No. 2 load		0 to 24,000 pounds		
GA0611S	+Y beam booster strut No. 3 load		0 to 24,000 pounds		
GA0612S (GR5046-34)	+Y beam booster strut No. 4 load		0 to 17,000 pounds		
GA0613S (GR5042-38)	-Y beam booster strut No. 1 load		0 to 17,000 pounds		
GA0614S (GB0801)	-Y beam booster strut No. 2 load		0 to 24,000 pounds		
GA0615S (GA3006)	-Y beam booster strut No. 3 load		0 to 24,000 pounds		
GA0616S (GB0621)	-Y beam booster strut No. 4 load		0 to 17,000 pounds		

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-64. Developmental Flight Instrumentation - Telemetry Measurements (cont)

Code	Description	From (Subsystem)	Telemetry Range	Display Range	Crew Display
GA1113T	Top surface ascent stage heat shield temperature	Structures (cont)	-30° to +250° F		
GA1133P	Top surface ascent stage heat shield pressure		0 to 2 psia		
GA1501D	Ascent engine support vibration structure side No. 1		-30g to +30g		
GA1502D (GA2525)	Ascent engine support vibration structure side No. 2		-30g to +30g		
GA1503D	Ascent engine support vibration structure side No. 3		-30g to +30g		
GA1571D	Ascent structure oxidiz- er tank vibration, X-axis		-10g to +10g		
GA1572D	Ascent structure oxidiz- er tank vibration, Y-axis		-10g to +10g		
GA1573D	Ascent structure oxidiz- er tank vibration, Z-axis		-10g to +10g		
GA2001T	Descent stage heat shield temperature No. 1		0° to +2,500° F		
GA2002T	Descent stage heat shield temperature No. 2		0° to +2,500° F		
GA2003T	Descent stage heat shield temperature No. 3		-100° to +2,000° F		
GA2004T	Descent stage heat shield temperature No. 4		0° to +2,500° F		
GA2005T	Descent stage heat shield temperature No. 5		0° to +2,500° F		
GA2006T	Descent stage heat shield temperature No. 6		-100° to +2,000° F		
GA2007T	Descent stage heat shield temperature No. 7		-100° to +2,000° F		
GA2008T	Descent stage heat shield temperature No. 8		-100° to +2,000° F		
GA2009T	Descent stage heat shield temperature No. 9		-100° to +2,000° F		
GA2010T	Descent stage heat shield temperature No. 10		-250° to +500° F		
GA2201T	Window temperature No. 1		-30° to +250° F		

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-64. Developmental Flight Instrumentation - Telemetry Measurements (cont)

Code	Description	From (Subsystem)	Telemetry Range	Display Range	Crew Display
GA2202T	Window temperature No. 2	Structures (cont)	-30° to +250° F		
GA2203T	Window temperature No. 3		-30° to +250° F		
GA2321S (GR5015)	+Y descent engine support strut No. 1 load		-5,800 to +1,800 pounds		
GA2524S (GR5023)	+Y descent engine support strut No. 4 load		-5,800 to +1,800 pounds		
GA2525S (GA1502)	-Y descent engine support strut No. 1 load		-5,800 to +1,800 pounds		
GA2528S (GR5018)	-Y descent engine support strut No. 4 load		-5,800 to +1,800 pounds		
GA2681D	Descent structure oxidiz- er tank No. 1 vibration, X-axis		-10g to +10g		
GA2682D	Descent structure oxidiz- er tank No. 1 vibration, Y-axis		-10g to +10g		
GA2683D	Descent structure oxidiz- er tank No. 1 vibration, Z-axis		-10g to +10g		
GA3001A	X-axis No. 1 accelera- tion		-10g to +10g		
GA3002A (GA0603)	X-axis No. 2 accelera- tion		-20 to +20 rad/sec ²		
GA3003A (GA0610)	Y-axis No. 1 accelera- tion		-2g to +2g		
GA3004A (GA0609)	Y-axis No. 2 accelera- tion		-20 to +20 rad/sec ²		
GA3005A (GA0608)	Z-axis No. 1 accelera- tion		-2g to +2g		
GA3006A (GA0615)	Z-axis No. 2 accelera- tion		-20 to +20 rad/sec ²		
GA3601D	Ascent stage equipment rack vibration, X-axis		-20g to +20g		
GA3602D	Ascent stage equipment rack vibration, Y-axis		-20g to +20g		
GA3603	Ascent stage equipment rack vibration, Z-axis		-20g to +20g		
GA3661D	Tunnel equipment area vibration No. 1		-30g to +30g		
GA3662D	Tunnel equipment area vibration No. 2		-30g to +30g		

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-64. Developmental Flight Instrumentation - Telemetry Measurements (cont)

Code	Description	From (Subsystem)	Telemetry Range	Display Range	Crew Display
GA3663D	Tunnel equipment area vibration No. 3	Structures (cont)	-30g to +30g		
GB0101T	No. 1 black box temperature	Thermodynamics	-30° to +250° F		
GB0102T	No. 2 black box temperature		-30° to +250° F		
GB0103T	No. 2 black box temperature		0° to +500° F		
GB0201T	No. 1 ascent engine cover - cabin temperature		-30° to +250° F		
GB0203T	Cabin tunnel tem- perature		-30° to +250° F		
GB0204T	Cabin skin temperature No. 1		-30° to +250° F		
GB0205T	Cabin skin temperature No. 2		-30° to +250° F		
GB0301T	Ascent stage bottom surface temperature No. 1		-250° to +500° F		
GB0302T	Ascent stage bottom surface temperature No. 2		-250° to +500° F		
GB0303T	Ascent stage bottom surface temperature No. 3		-250° to +500° F		
GB0304T	Ascent stage bottom surface temperature No. 4		-250° to +500° F		
GB0305T	Ascent stage bottom surface temperature No. 5		-250° to +500° F		
GB0306T	Ascent stage surface surface temperature No. 6		-250° to +500° F		
GB0307T	Ascent stage bottom surface temperature No. 7		-250° to +500° F		
GB0401T	Descent stage top surface temperature No. 1		-250° to +500° F		
GB0402T	Descent stage top surface temperature No. 2		-250° to +500° F		

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-64. Developmental Flight Instrumentation - Telemetry Measurement (cont)

Code	Description	From (Subsystem)	Telemetry Range	Display Range	Crew Display
GB0403T	Descent stage top surface temperature No. 3	Thermodynamics (cont)	-250° to +500° F		
GB0521T	Descent engine blast deflect temperature No 1		-250° to +500° F		
GB0522T	Descent engine blast deflect temperature No. 2		-250° to +500° F		
GB0601T	Ascent engine compart- ment temperature No. 1		-250° to +500° F		
GB0602T	Ascent engine compart- ment temperature No. 2		-250° to +500° F		
GB0603T	Ascent engine compart- ment temperature No. 3		-250° to +500° F		
GB0621P (GA0616)	Ascent engine compart- ment pressure No. 1		0 to 2 psia		
GB0622P	Ascent engine compart- ment pressure No. 2		0 to 2 psia		
GB0623P	Ascent engine compart- ment pressure No. 3		0 to 2 psia		
GB0801P (GA0614)	Ascent stage bottom surface pressure No. 1		0 to 2 psia		
GB0802P (GA0607)	Ascent stage bottom surface pressure No. 2		0 to 2 psia		
GB0803P	Ascent stage bottom surface pressure No. 3		0 to 2 psia		
GB0804P	Ascent stage bottom surface pressure No. 4		0 to 2 psia		
GB0805P	Ascent stage bottom surface pressure No. 5		0 to 2 psia		
GB0806P	Ascent stage bottom surface pressure No. 6		0 to 2 psia		
GB0807P (GA0601)	Ascent stage bottom surface pressure No. 7		0 to 2 psia		
GB0808P (GA0602)	Ascent stage bottom surface pressure No. 8		0 to 2 psia		
GB0809P (GA0604)	Ascent stage bottom surface pressure No. 9		0 to 2 psia		
GB0810P (GA0606)	Ascent stage bottom surface pressure No. 10		0 to 2 psia		

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-64. Developmental Flight Instrumentation - Telemetry Measurements (cont)

Code	Description	From (Subsystem)	Telemetry Range	Display Range	Crew Display
GB0811P	Ascent stage bottom surface pressure No. 11	Thermodynamics (cont)	0 to 2 psia		
GB0812P (GA0605)	Ascent stage bottom surface pressure No. 12		0 to 2 psia		
GB0813P	Ascent stage bottom surface pressure No. 13		0 to 2 psia		
GB0814	Ascent stage bottom surface pressure No. 14		0 to 2 psia		
GB0815P	Ascent stage bottom surface pressure No. 15		0 to 2 psia		
GB0816P	Ascent stage bottom surface pressure No. 16		0 to 2 psia		
GB0817P	Ascent stage bottom surface pressure No. 17		0 to 2 psia		
GB0818P	Ascent stage bottom surface pressure No. 18		0 to 2 psia		
GB0901P	Descent stage top surface pressure No. 1		0 to 2 psia		
GB0902P	Descent stage top surface pressure No. 2		0 to 2 psia		
GB0903P	Descent stage top surface pressure No. 3		0 to 2 psia		
GB0904P	Descent stage top surface pressure No. 4		0 to 2 psia		
GB0905P	Descent stage top surface pressure No. 5		0 to 2 psia		
GB0906P	Descent stage top surface pressure No. 6		0 to 2 psia		
GB0907P	Descent stage top surface pressure No. 7		0 to 2 psia		
GB3020T	Interior ascent blanket temperature No. 1		0° to +500° F		
GB3021T	Interior descent blanket temperature No. 1		0° to +500° F		
GB3022T	Ascent stage top surface temperature No. 2		-100° to +2,000° F		
GB3023T	Descent blanket surface temperature No. 1		-100° to +2,000° F		
GB3024T	Ascent stage top surface temperature No. 3		-250° to +500° F		

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-64. Developmental Flight Instrumentation - Telemetry Measurements (cont)

Code	Description	From (Subsystem)	Telemetry Range	Display Range	Crew Display
GB3025T	Interior descent blanket temperature No. 2	Thermodynamics (cont)	-250° to +500° F		
GB3026T	Ascent stage top surface temperature No. 4		-250° to +500° F		
GB3027T	Descent blanket surface temperature No. 2		-250° to +500° F		
GB3028T	Ascent stage top surface temperature No. 5		0° to +6,500° F		
GB3029T	Interior descent blanket temperature No. 3		0° to +500° F		
GB3030T	Ascent stage top surface temperature No. 6		-100° to +1,250° F		
GB3031T	Descent surface blanket temperature No. 3		-100° to +1,250° F		
GB3032T	Ascent stage top surface temperature No. 7		-100° to +1,250° F		
GB3033T	Descent surface blanket temperature No. 4		-100° to +1,250° F		
GB3102H	Separation distance No. 1		0 to 4 feet		
GB3103H	Separation distance No. 2		0 to 4 feet		
GB3104H	Separation distance No. 3		0 to 4 feet		
GB3105H	Separation distance No. 4		0 to 4 feet		
GB3727T	Steerable S-band antenna temperature No. 1		-100° to +1,250° F		
GB3728T	Steerable S-band antenna temperature No. 2		-100° to +250° F		
GB3729T	Steerable S-band antenna temperature No. 3		-100° to +250° F		
GB3730T	Omni antenna temperature No. 1		-100° to +1,250° F		
GB3733T	UHF in-flight antenna temperature		-100° to +1,250° F		
GB6001T	Electric package cold plate No. 1 temperature		0° to +150° F		

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-64. Developmental Flight Instrumentation - Telemetry Measurements (cont)

Code	Description	From (Subsystem)	Telemetry Range	Display Range	Crew Display
GB6002T	Electric package cold plate No. 2 temperature	Thermodynamics (cont)	0° to +150° F		
GB6003T	Electric package cold plate No. 3 temperature		0° to +500° F		
GC3501T	Battery No. 1 temperature	EPS	0° to +200° F		
GC3502T	Battery No. 2 temperature		0° to +200° F		
GC3503T	Battery No. 3 temperature		0° to +200° F		
GC3504T	Battery No. 4 temperature		0° to +200° F		
GC3505T	Battery No. 5 temperature		0° to +200° F		
GC3506T	Battery No. 6 temperature		0° to +200° F		
GF1071R (GF9995)	Prime suit compressor rate	ECS	14,000 to 30,000 rpm		
GF1072R (GF9995)	Spare suit compressor rate		14,000 to 30,000 rpm		
GF1191R	Cabin fan No. 1 rate		4,300 to 14,300 rpm		
GF1192R	Cabin fan No. 2 rate		4,300 to 14,300 rpm		
GF1261P	Water separator No. 1 ΔP		0 to 1.5 psid		
GF1262P	Water separator No. 2 ΔP		0 to 1.5 psid		
GF1681T	Suit compressor discharge temperature		0° to +200° F		
GF1701T	Suit oxygen outlet temperature		+0° to +200° F		
GF1701T	Suit oxygen outlet temperature		+0° to +200° F		
GF2011R (GF9996)	Coolant pump No. 1 rate		2,000 to 6,000 rpm		
GF2012R (GF9996)	Coolant pump No. 2 rate		2,000 to 6,000 rpm		
GF2013R (GF9996)	Coolant pump No. 3 rate		2,000 to 6,000 rpm		

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-64. Developmental Flight Instrumentation - Telemetry Measurements (cont)

Code	Description	From (Subsystem)	Telemetry Range	Display Range	Crew Display
GF2521T	Main water-sublimator coolant inlet temperature	ECS (cont)	0° to +200° F		
GF2621T	Cabin heat-exchanger coolant inlet temperature		0° to +200° F		
GF2781T	Regenerative heat- exchanger coolant outlet temperature		0° to +200° F		
GF2841T	Regenerative heat- exchanger coolant inlet temperature		0° to +200° F		
GF2871T	Cabin heat-exchanger coolant outlet temperature		0° to +200° F		
GF3585T (PCM)	Ascent oxygen tank No. 1 surface temperature		0° to +200° F		
GF3586T (PCM)	Ascent oxygen tank No. 2 surface temperature		0° to +200° F		
GF3587T (PCM)	Descent oxygen tank surface temperature		0° to +200° F		
GF4102P	Redundant water REG/ARS ΔP		0° to +200° F		
GF4561T	Descent tank outlet water temperature		0° to +200° F		
GF4562T	Ascent tank No. 1 outlet water temperature		0° to +200° F		
GF4563T	Ascent tank No. 2 outlet water temperature		0° to +200° F		
GF9995U	Selected suit compressor rate		14,000 to 30,000 rpm		
GF9996U	Selected coolant pump rate		2,000 to 6,000 rpm		
GG1111V	2.5-vdc TM bias DFI voltage	GN&CS	0 to 5 volts dc		
GG2220V	IG CDU fine error voltage		-1.2 to +1.2 volts rms		
GG2250V	MG CDU fine error voltage		-1.2 to +1.2 volts rms		
GG2280V	DG CDU fine error voltage		-1.2 to +1.2 volts rms		
GG2302X	IMU heater on		Off - on		

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-64. Developmental Flight Instrumentation - Telemetry Measurements (cont)

Code	Description	From (Subsystem)	Telemetry Range	Display Range	Crew Display
GG2303X	IMU blower on	GN&CS (cont)	Off - on		
GG3311V	Radar shaft CDU fine voltage		-1.2 to +1.2 volts rms		
GG3321V	Radar trunnion CDU fine voltage		-1.2 to +1.2 volts rms		
GG6001D	Navigation bas (roll) vibration		-2g to +2g		
GG6002D	Navigation base (pitch) vibration		-2g to +2g		
GG6003D	Navigation base (yaw) vibration		-2g to +2g		
GH1450V	Pitch trim error voltage	GN&CS (CES)	-14 to +14 volts dc		
GH1452V	Toll trim error voltage		-14 to +14 volts dc		
GL0220F (GL0251)	TE sync frequency (R09) to displays	IS	512,000 cps		
GL0222F (GL0251)	TE sync frequency (R02) to AGS		1,024,000 cps		
GL0223F (GL0251)	TE sync frequency (R03) to communications		512,000 cps		
GL0224F	TE sync frequency (R04) to EPS		6,400 cps		
GL0225F (GL0251)	TE sync frequency (R05) to EPS		6,400 cps		
GL0226F (GL0251)	TE sync frequency (R06) to EPS		6,400 cps		
GL0227F (GL0251)	TE sync frequency (R07) to CES		1,600 cps		
GL0228F (G0251)	TE sync frequency (R08) to displays		10,000 cps		
GL0236X	50-pps start signal (D08) to LGC		0 to 5 volts dc		
GL0237X	2-kpps bit sync signal (D010) to LGC		0 to 5 volts dc		
GL0238X	50-pps stop signal (D09) to GLC		0 to 5 volts dc		
GL0241V	1,200-pps bit sync to AGS (on)		0 to 5 volts dc		
GL0242V	50-pps stop signal to AGS (on)		0 to 5 volts dc		

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-64. Developmental Flight Instrumentation - Telemetry Measurements (cont)

Code	Description	From (Subsystem)	Telemetry Range	Display Range	Crew Display
GL0243V	AGS serial data to PCMTEA (on)	IS (cont)	0 to 5 volts dc		
GL0251U	TE no-go/go sync signals		0 to 5 volts dc		
GL0801X	1024-kc timing signals to PCMTEA		0 to 5 volts dc		
GL0802X	LGC serial data to PCMTEA (on)		0 to 5 volts dc		
GL4221X (PCM)	R/D telemetry calibration (PCA)		0 to 5 volts dc		
GL4222X (PCM)	DFI measure switchover LM/SLA separation		0 to 5 volts dc		
GM0046X	+Z landing gear RS deploy lock		0 to 5 volts dc		
GM0048X	+Y landing gear RS deploy lock		0 to 4 volts dc		
GM0062T	+Z landing gear primary strut temperature No. 3		0° to +500° F		
GM0063T	+Z landing gear primary strut temperature No. 2		0° to +500° F		
GM0066T	-Y landing gear primary strut temperature No. 1		0° to +500° F		
GM0068T	-Z landing gear primary strut temperature No. 1		0° to +500° F		
GM0070T	+Y landing gear primary strut temperature No. 1		0° to +500° F		
GM0072T	+Z landing gear pad-X-surface		0° to +500° F		
GM0073T	+Z landing gear pad +X-surface		0° to +500° F		
GM0077T	-Z landing gear pad +X-surface		0° to +500° F		
GM0081T	+Z landing gear secondary strut temperature No. 1	Mechanical design	0° to +500° F		
GM0082T	+Z landing gear cross-brace temperature No. 1		0° to +500° F		
GM0091T	+Y lunar surface sensor probe temperature U		0° to +500° F		
GM0092T	-Y lunar surface sensor probe temperature No. 1		0° to +500° F		
GN2505V	Azimuth error voltage	GN&CS (radars)	-10 to +10.6 volts dc		

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-64. Developmental Flight Instrumentation - Telemetry Measurements (cont)

Code	Description	From (Subsystem)	Telemetry Range	Display Range	Crew Display
GN2506V	Elevation error voltage	GN&CS (radars) (cont)	-10.6 to +10.6 volts dc		
GN7559D	Landing radar antenna vibration		-20g to +20g		
GN7560X	Landing radar antenna position No. 1 (descent)		0 to 5 volts dc		
GN7561X	Landing radar antenna position No. 2 (hover)		0 to 5 volts dc		
GN7564T	Landing radar antenna temperature No. 2		-250° to +500° F		
GN7565T	Landing radar antenna temperature No. 3		-250° to +500° F		
GN7589V	D1 at angle 0°				
GN7590V	D2 at angle 0°				
GN7592V	FR at angle 0°				
GN7593V	D1 at angle of 90°				
GN7594V	D2 at angle of 90°				
GN7596V	FR at angle of 90°				
GN7689V	RR servoamplifier shaft input voltage		-15 to +15 volts dc		
GN7690V	RR servoamplifier trunnion input voltage		-15 to +15 volts dc		
GN7691D	RR antenna dish vibration		-10g to +10g		
GN7721T	RR antenna temperature No. 3		-100° to +2,000° F		
GN7722T	RR antenna temperature No. 2		-100° to +2,000° F		
GP0019P (GQ3009)	Primary upstream regulator inlet helium pressure	MPS (ascent stage)	0 to 4,000 psia		
GP0020P (GQ3010)	Secondary upstream regulator inlet helium pressure		0 to 4,000 psia		
GP0025P (GQ3018)	Regulator outlet manifold pressure		0 to 300 psia		
GP0501P	Fuel tank ullage pressure		0 to 300 psia		
GP0504P	Fuel tank vent relief valve inlet pressure		0 to 350 psia		

INSTRUMENTATION SUBSYSTEM

Page 2.9-106 Mission LM 3 Basic Date 1 January 1968 Change Date _____

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-64. Developmental Flight Instrumentation - Telemetry Measurements (cont)

Code	Description	From (Subsystem)	Telemetry Range	Display Range	Crew Display
GP0616P	Fuel tank bottom to interface ΔP	MPS (ascent stage) (cont)	0 to 35 psia		
GP1001P	Oxidizer ullage tank pressure		0 to 300 psia		
GP1004P	Oxidizer tank vent relief valve inlet pressure		0 to 350 psia		
GP116P	Oxidizer tank bottom to interface ΔP		0 to 35 psid		
GP1501P (GQ3611)	Fuel isolation valve inlet pressure		0 to 250 psia		
GP1503P (GQ4111)	Oxidizer isolation valve inlet pressure		0 to 250 psia		
GP2001P (GQ6501)	Fuel injector inlet pressure		0 to 250 psia		
GP2006P (GQ6506)	Oxidizer injector inlet pressure		0 to 250 psia		
GP2010P (GQ6510)	Thrust chamber pressure		0 to 150 psia		
GP2701T	Thrust chamber external wall No. 1 temperature		0° to +500° F		
GP2702T	Thrust chamber external wall No. 2 temperature		0° to +500° F		
GP2703T	Thrust chamber external wall No. 3 temperature		0° to +500° F		
GP2704T	Thrust chamber external wall No. 4 temperature		0° to +500° F		
GP2706T	Injector surface temperature		0° to +500° F		
GP2801D (GQ7301)	Thrust chamber X-axis vibration		0g to 25g rms		
GP2802D (GQ7302)	Thrust chamber Y-axis vibration		0g to 25g rms		
GP2803D (GQ7303)	Thrust chamber Z-axis vibration		0g to 25g rms		
GP7606T	Engine interface fuel temperature		0° to +200° F		
GP7608T	Engine interface oxidizer temperature		0° to +200° F		
GQ3009R (GP0019)	Primary upstream regulator inlet helium pressure	MPS (descent stage)	0 to 2,000 psia		

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-64. Developmental Flight Instrumentation - Telemetry Measurements (cont)

Code	Description	From (Subsystem)	Telemetry Range	Display Range	Crew Display
GQ3010P (GP0020)	Secondary regulator inlet helium pressure	MPS (descent stage) (cont)	0 to 2,000 psia		
GQ3018P (GP0025)	Helium regulator outlet manifold pressure		0 to 300 psia		
GQ3309X (PCM)	Helium primary solenoid valve closed		0 to 5 volts dc		
GQ3310X (PCM)	Helium secondary solenoid valve open		0 to 5 volts dc		
GQ3451T	S/C helium supply tank outlet temperature		-425° to -300° F		
GQ3455T	S/C helium/helium heat-exchanger inlet temperature		-210° to +75° F		
GQ3459T	S/C helium/helium heat-exchanger outlet temperature		-360° to -50° F		
GQ3463T	S/C fuel/helium heat- exchanger outlet temperature		-210° to +75° F		
GQ3476T	S/C helium tank No. 1 temperature		+20° to +120° F		
GQ3501P	Fuel tank No. 1 ullage pressure		0 to 300 psia		
GQ3505P	Fuel tank vent relief valve inlet pressure		0 to 250 psia		
GQ3611P (GP1501)	Engine interface fuel pressure		0 to 300 psia		
GQ3666P	Fuel tank No. 2 bottom engine inter- face ΔP		0 to 35 psid		
GQ3811T	Engine interface fuel temperature		0° to +200° F		
GQ4001P	Oxidizer tank No. 1 ullage pressure		0 to 300 psia		
GQ4005P	Oxidizer tank vent relief valve inlet pressure		0 to 350 psia		
GQ4111P (GP1503)	Engine interface oxidizer pressure		0 to 300 psia		
GQ4116P	Oxidizer tank No. 1 bottom engine interface ΔP		0 to 35 psid		
GQ4311T	Engine interface oxidizer temperature		0° to +200° F		

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-64. Developmental Flight Instrumentation - Telemetry Measurements (cont)

Code	Description	From (Subsystem)	Telemetry Range	Display Range	Crew Display
GQ6501P (GP2001)	Fuel injector inlet pressure	MPS (descent stage) (cont)	0 to 300 psia		
GQ6506P (GP2006)	Oxidizer injector inlet pressure		0 to 300 psia		
GQ6510P (GP2010)	Thrust chamber pressure		0 to 200 psia		
GQ7206T	Injector surface temperature		0° to +500° F		
GQ7211T	Engine heat shield outer surface temperature No. 1		0° to +500° F		
GQ7212T	Engine heat shield outer surface temperature No. 2		0° to +500° F		
GQ7213T	Engine heat shield outer surface temperature No. 3		0° to +500° F		
GQ7214T	Engine heat shield outer surface temperature No. 4		0° to +500° F		
GQ7301D (GP2801)	Thrust chamber X-axis vibration		0g to 30g rms		
GQ7302D (GP2802)	Thrust chamber Y-axis vibration		0g to 30g rms		
GQ7303D (GP2803)	Thrust chamber Z-axis vibration		0g to 30g rms		
GR4322T	TCA fuel inlet temperature PR 4B surface	RCS	+20° to +120° F		
GR4323T	TCA fuel inlet temperature PR 3A surface		+20° to +120° F		
GR4326T	TCA fuel inlet temperature PR 2B surface		+20° to +120° F		
GR4327T	TCA fuel inlet temperature PR 1A surface		+20° to +120° F		
GR4424T	TCA oxidizer inlet temperature PR 3B surface		+20° to +120° F		
GR4431T	TCA oxidizer inlet temperature PR 4A surface		+20° to +200° F		

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-64. Developmental Flight Instrumentation - Telemetry Measurements (cont)

Code	Description	From (Subsystem)	Telemetry Range	Display Range	Crew Display
GR4435T	TCA oxidizer inlet temperature PR 2A surface	RCS (cont)	+20° to +200° F		
GR4438T	TCA oxidizer inlet temperature PR 1B		+200° to +200° F		
GR4570T	TCA injector head temperature No. IVd		0° to +500° F		
GR4571T	TCA injector head temperature No. IVf		0° to +500° F		
GR4573T	TCA injector head temperature No. IIIu		0° to +500° F		
GR4574T	TCA injector head temperature No. III d		0° to +500° F		
GR4577T	TCA injector head temperature No. IIu		0° to +500° F		
GR4578T	TCA injector head temperature No. II d		0° to +500° F		
GR4582T	TCA injector head temperature No. Id		0° to +500° F		
GR4583T	TCA injector head temperature No. If		0° to +500° F		
GT0224C	S-band power amplifier anode No. 1 current	CS	---		
GT0225C	S-band power amplifier anode No. 2 current		---		
GT0226E	VHF XMTR A and B RF power output		---		
GT0604V	VHF receiver A AGC	GN&CS (LMP)	0.12 to 0.42 volt dc		
GT0605V	VHF receiver B AGC		0.12 to 0.42 volt dc		
GW5151V (PCM)	PRA compare pulse voltage		---		
GW5153V (PCM)	Clock pulse voltage		---		
GW5154X (PCM)	Landing gear deploy A and B (PCA)		---		
GW5158X (PCM)	Coolant pump selected		---		

INSTRUMENTATION SUBSYSTEM

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

2.10 MISCELLANEOUS.

2.10.1 INTRODUCTION.

This subsection deals with LM heating and lighting circuits which have been briefly discussed in other subsections. The following discussions provide ready access to material not given prime consideration elsewhere in this manual.

Heaters maintain proper operating temperatures in the Reaction Control Subsystem (RCS) thrust chamber assemblies (TCA's), the landing radar, rendezvous radar, and S-band antenna assemblies, the cabin windows, and the alignment optical telescope (AOT) mirrors. Exterior lighting is used for LM and CSM tracking and docking maneuvers. Interior lighting facilities provide illumination of the cabin proper, controls, and displays.

2.10.2 FUNCTIONAL DESCRIPTION.

2.10.2.1 Heating.

Because of the extreme temperature variations (-260° to +260° F) encountered in space environment, heaters are provided to maintain the external antennas and the TCA's at their required operating temperature. Redundant heater assemblies maintain the antenna and TCA temperatures at proper values if a single heater assembly fails. Temperature transducers sense the temperatures and route signals to the signal conditioning electronics assembly (SCEA) of the Instrumentation Subsystem (IS). The SCEA conditions these signals to the proper voltage level (0 to 5 volts dc) required by the pulse-code-modulation and timing electronics assembly (PCMTEA) and the caution and warning electronics assembly (CWEA) of the IS.

When an out-of-tolerance temperature (malfunction limit) is sensed, the PCMTEA output provides MSFN with a malfunction telemetry signal. The malfunction signal is routed to low and high comparator circuits within the CWEA. The comparators route corresponding malfunction signals to the HEATER caution light (panel 2) to alert the astronauts to the malfunction condition. The out-of-tolerance temperature limits that cause the HEATER light to go on are as follows:

- RCS TCA's - less than +119° F or greater than +190° F
- Rendezvous radar antenna - less than -50° F or greater than +150° F
- Landing radar antenna - less than -50° F or greater than +150° F
- S-band antenna - less than -60° F or greater than +155° F

The high temperature limits are eliminated by deactivating the circuit breaker of the affected heater assembly (HEATERS: S-BD ANT on panel 16, HEATERS: RNDZ RDR and LDG RDR on panel 11, HEATERS RCS SYS A/B-1: QUAD on panel 11, and HEATERS: RCA A/B-2 on panel 16).

The TEMP MONITOR selector switch and the TEMP indicator on the HEATER CONT portion of panel 3 are used to detect a malfunction. The TEMP MONITOR selector switch must be sequentially set to all positions to determine which heater assembly or assemblies are affected. The TEMP indicator displays the temperature of each heating area selected with the TEMP MONITOR selector switch.

2.10.2.2 Lighting. (See figure 2-172.)

Exterior and interior lighting facilities are provided to aid in the performance of crew (visual) tasks, to lessen astronaut fatigue, and to lessen interior-exterior glare effects. Power for exterior and interior lighting is routed through the LTG circuit breakers and AC BUS A and AC BUS B lighting circuit breakers on panels 11 and 16.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

The EXTERIOR LTG selector switch on the LIGHTING portion of panel 3 controls the five docking lights and the high-intensity tracking light on the LM exterior.

The SIDE PANELS switches (panels 3 and 5) control interior lighting for the LM and Commander's side panels. The INTEGRAL control (panel 5) adjusts the light intensity for the side panels, respectively. Interior side panel floodlighting is provided by setting the OVHD/FWD FLOOD switch (panel 3) to ALL. This switch position also turns the Commander's and LM Pilot's forward and overhead floodlights on. The light intensity of the forward and overhead floodlights is controlled with the OVHD/FWD FLOOD controls (panels 3 and 5). The light intensity of the side panel floodlights cannot be adjusted.

2.10.3 MAJOR COMPONENT/FUNCTIONAL DESCRIPTION.

2.10.3.1 Heating.

The operating temperature of the heaters within the RCS TCA's and the S-band, landing radar, and rendezvous radar antenna assemblies are monitored with the TEMP indicator and TEMP MONITOR selector switch (panel 3). The operating temperature of the forward and docking window heaters is not monitored; proper heater operation directly affects crew visibility, and is visually determined.

2.10.3.1.1 Landing Radar Antenna Heaters.

When the LR is operating, the temperature of the antenna must be maintained at -15° to $+150^{\circ}$ F. Out-of-limit temperatures cause malfunction signals to be generated. The temperature of the LM surface upon which the LR antenna is mounted may vary between -260° and $+260^{\circ}$ F depending on mission phase. The LR antenna is partially protected against these extremes by thermal blankets and nonabsorptive finishes. Because this protection is inadequate for low-temperature extremes when the LR is not operating, heaters (cal-rods) are imbedded in the transmitting array support structure to provide additional protection. These heaters maintain the LR antenna temperature between 0° and $+20^{\circ}$ F while the LR is not operating.

Power (28 volts dc) for the LR antenna heaters is routed through the HEATERS LDG RDR circuit breaker and contacts of a relay, located in the cabling subassembly, to the control circuits and heater elements. Maximum power drain of the heater elements and the control circuits is 65 watts. When the PGNS: LDG RDR circuit breaker (panel 11) is opened, power is applied to the LR low-voltage power supply, energizing the relay and disabling the heaters. When the LR is not operating, the heater control circuits enable a power amplifier, which acts as a 28-volt d-c switch that turns on the heaters when the antenna internal temperature reaches 0° F, and disables this power amplifier to turn off the heaters when the temperature reaches $+20^{\circ}$ F.

If a heater malfunctions, a temperature sensor routes a signal to electronics replaceable assembly No. 1 (ERA-1) in the SCEA. The ERA-1 output is routed to the PCMTEA, HEATER caution light (panel 3), and the TEMP indicator (panel 3). To monitor the malfunction, the TEMP MONITOR selector switch is set to LDG.

2.10.3.1.2 Rendezvous Radar Antenna Heaters.

The rendezvous radar (RR) antenna heaters include four gyro heaters, a multiplier chain heater, and four microwave heaters. These heaters maintain the RR antenna temperature between the limits of -50° F and $+150^{\circ}$ F. Out-of-limit temperatures cause malfunction signals to be generated.

MISCELLANEOUS

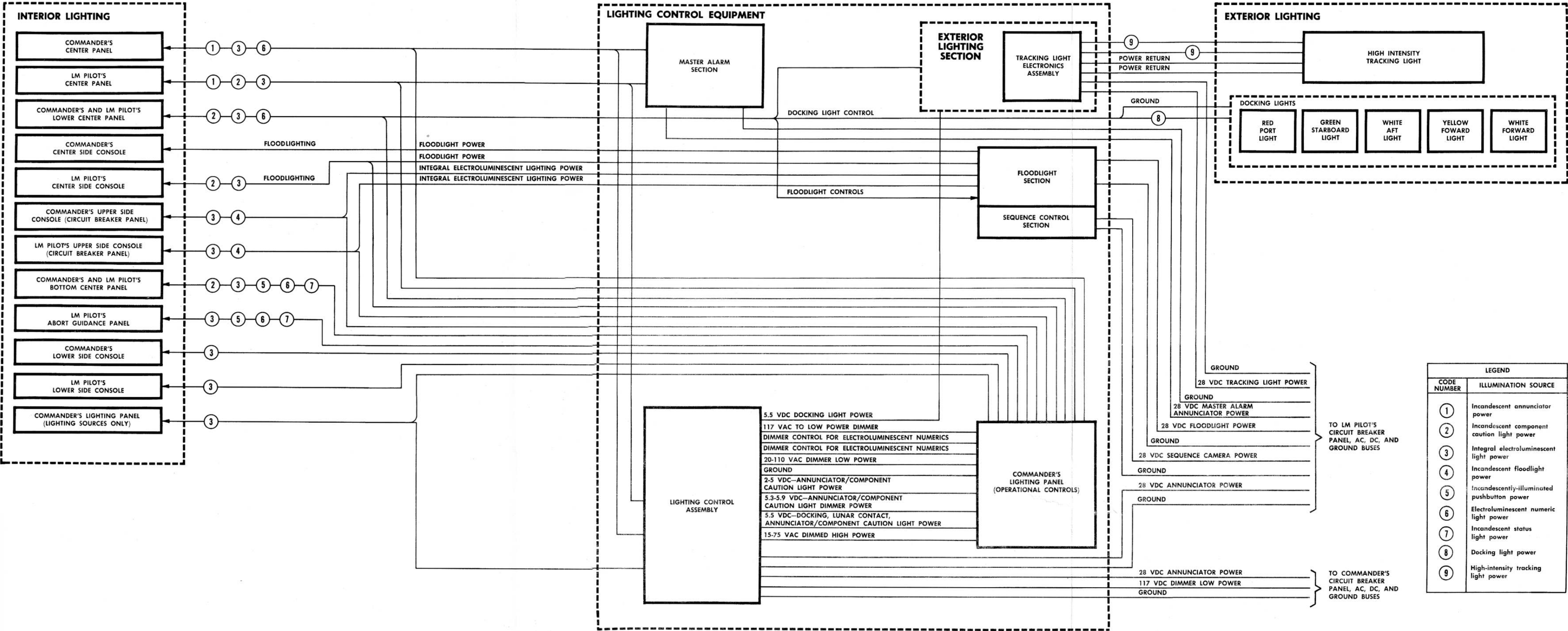


Figure 2-172. Lighting Control Equipment

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

The RR antenna heaters receive power through the HEATERS: RNDZ STDBY and OPR circuit breakers (panel 11). Due to a required warmup time of the RR heaters the STDBY circuit breaker is opened at least 1 hour before RR use.

If a heater malfunctions, a temperature sensor routes a signal to ERA-1 in the SCEA. The ERA-1 output is routed to the PCMTEA, HEATER caution light (panel 3), and the TEMP indicator (panel 3). To monitor the malfunction, the TEMP MONITOR select switch (panel 3) is set to RNDZ.

2.10.3.1.3 RCS TCA Quad Heaters.

The RCS TCA quad heaters maintain TCA temperature at +119° to +190° F to keep injector temperatures within a safe range. Out-of-limit temperatures cause malfunction signals to be generated. Each of the four quad cluster assemblies consists of four TCA's; two for RCS system A, and two for RCS system B. Each TCA has two heaters (No. 1 and No. 2), one mounted on each side (total of 32 heaters).

Each HEATERS RCS SYS A/B-1: QUAD circuit breaker (panel 11) routes power directly to heaters No. 1 of systems A and B. The specific quad heaters activated depends on the QUAD circuit breaker closed (QUAD 1 through QUAD 4). Each HEATERS: RCS SYS A/B-2 QUAD circuit breaker (panel 16) routes power to heaters No. 2 through the RCS SYS A/B-2 QUAD switches (panel 3).

All TCA heaters are capable of intermittent or continuous duty cycles. Each heater comprises a heating element and a central control mechanism that turns the heating element on and off (to maintain TCA operating temperature limits). Heaters No. 1 cycle on and off automatically. Heaters No. 2 can be manually controlled with the RCS SYS A/B-2 QUAD switches. Setting the QUAD 1 switch to AUTO causes TCA heaters No. 2 in quad 1 to cycle on and off automatically to maintain TCA operating temperature limits. In the OFF switch position, heaters No. 2 are off. In the MAN switch position, the central control mechanism is bypassed and the heaters remain on regardless of the TCA temperature.

As in the case of the radar antenna assembly heaters, TCA heater malfunction signals are sensed and routed to the PCMTEA, the HEATER caution lamp (panel 2) through the SCEA (ERA-1), and to the TEMP indicator (panel 3). The malfunction of a particular quad cluster is isolated by selecting each QUAD position with the TEMP MONITOR selector switch (panel 3) and monitoring the TEMP indicator.

2.10.3.1.4 S-Band Antenna Heaters.

The S-band antenna heaters receive their power through the HEATERS: S-BD ANT circuit breakers (panel 16). A heater and redundant thermostat assembly are installed in the S-band microwave network, the electronics package, and on the X- and Y-axis spindles. These heaters maintain the S-band antenna temperature between -60° to +155° F. Out-of-limit temperatures cause malfunction signals to be generated by the related sensor.

A temperature sensor routes the malfunction signals to ERA-2 in the SCEA. Like the malfunction signals routed by ERA-1 for the LR and RR, ERA-2 routes its output to the PCMTEA, HEATER caution light (panel 2), and the TEMP indicator (panel 3). The S-band antenna temperature is monitored by setting the TEMP MONITOR selector switch (panel 3) to S-BAND and observing the TEMP indicator.

MISCELLANEOUS

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

2.10.3.1.5 Forward and Docking Window Heaters.

The forward window heaters receive operating power through the AC BUS B: SE WIND HTR and the AC BUS A: CDR WIND HTR circuit breakers (panel 11). The docking window heaters receive operating power through the HEATERS: DOCK WINDOW circuit breaker (panel 11). Window heater malfunctions are detected by visual window observation.

2.10.3.1.6 Alignment Optical Telescope Mirror Heaters.

The AOT mirror heaters receive operating power through the HEATERS: AOT circuit breaker (panel 11). This power is applied 30 minutes before initially using the AOT and is then left on for the remainder of the mission. AOT mirror heater malfunctions are indicated by visual observation.

2.10.3.2 Lighting Section.

The lighting section consists of exterior and interior lights and lighting control equipment. (See figure 2-172.) The exterior lighting enables the astronauts to visually guide and orient the LM and CSM to achieve successful tracking or docking. Interior lighting is divided into seven categories: incandescent annunciators, component caution lights, floodlights and status lights, integral electroluminescent (EL) lighting, numeric EL lighting, and incandescently illuminated pushbuttons.

2.10.3.2.1 Exterior Lighting. (See figure 2-173.)

Exterior lighting includes a radioluminescent docking target, five docking lights, and a high-intensity tracking light. The exterior lights and their respective color and brightness are listed in table 2-65. Exterior lighting controls are located on the LIGHTING portion of panel 3.

Docking Target. The docking target is a three-dimensional, self-illuminated standoff cross that is separated by a shaft from a circular base. Illumination is provided by radioluminescent disks, which outline the cross and circular base markings. The docking target provides a visual alignment of the LM to the CSM during final docking maneuvers.

Docking Lights. (See figure 2-174.) Five running lights mounted on the exterior of the LM provide visual orientation and permit gross attitude determination relative to a line of sight through the CSM windows during rendezvous and docking. The lights are controlled with the EXTERIOR LTG selector switch. Before earth launch, this switch is set to DOCK to provide for future automatic turn-on of the docking lights. For transposition and docking, the docking lights are turned on by the normally open SLA/LM antenna transfer switch (located at SLA attachment points). This switch is automatically released to the closed position upon deployment of the spacecraft launch-vehicle adapter (SLA) panels. Upon completing the docking maneuver, LM power is turned off and the docking lights go off. Setting the EXTERIOR LTG selector switch to OFF interrupts the input power to the docking and tracking lights. The lights are visible, and their color recognizable, at a maximum distance of 1,000 feet.

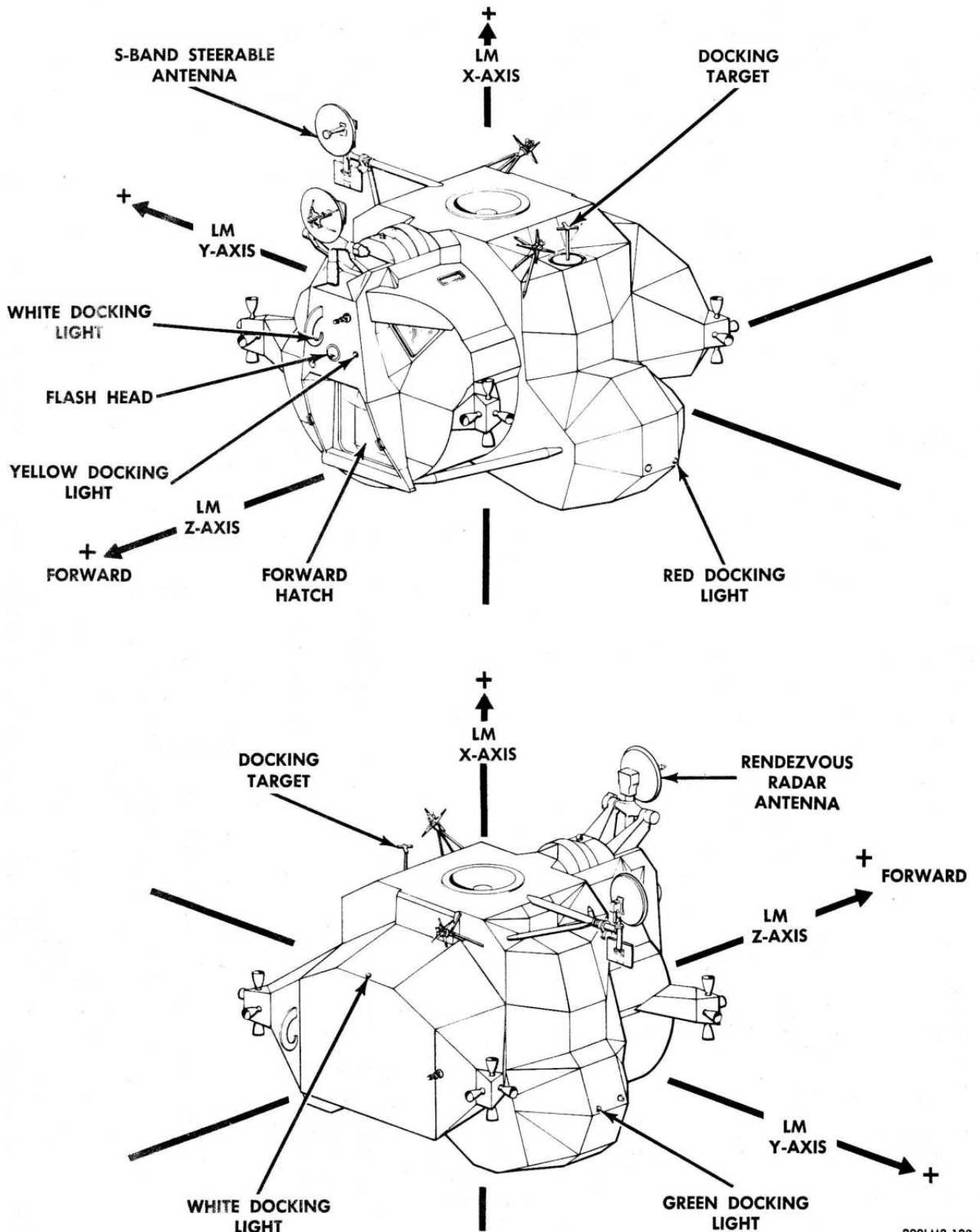
Tracking Light. The tracking light permits visual tracking of the LM by the CSM. The light has a 60° beam spread. It is turned on by setting the EXTERIOR LTG selector switch to TRACK. A flash tube in the tracking light electronics assembly causes the light to flash at a rate of 60 flashes per minute.

2.10.3.2.2 Interior Lighting.

Interior lighting consists of integral panel and instrument lighting (control and display areas), backup floodlighting, electroluminescent lighting, and general ambient lighting. Interior lights and their respective color and brightness are listed in table 2-66. Interior lighting controls are located on the LIGHTING portion of panels 3 and 5.

MISCELLANEOUS

LMA790-3-LM 3
 APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA



300LM3-128

Figure 2-173. Exterior Lighting

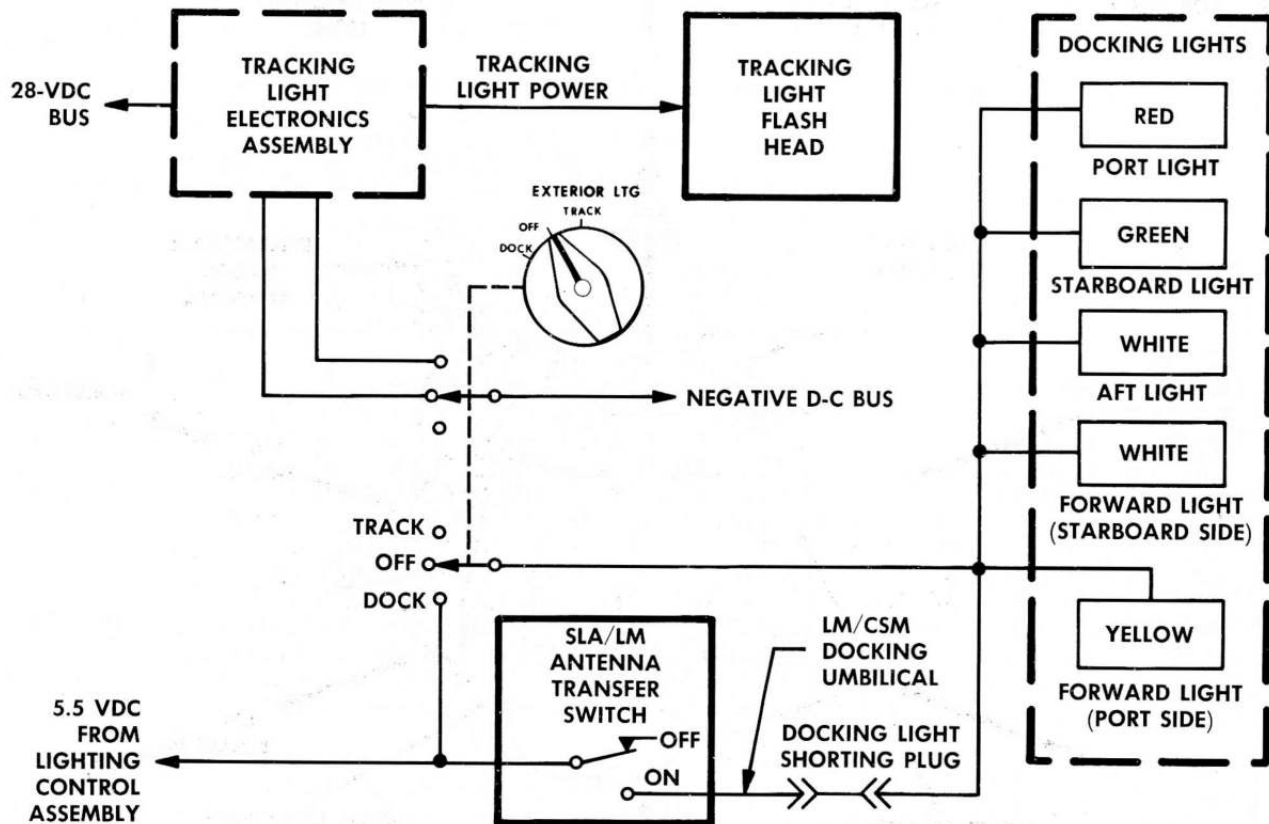
MISCELLANEOUS

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-65. Exterior Lights - Color, Brightness, and Lighting Method

Component	Lighting Method	Color	Brightness at Rated Capacity	Brightness Adjustment
Docking target	Radioluminescent materials	Green	0.3 foot-lambert minimum*	Fixed
Docking lights				
Port	Incandescent	Aviation red	0.15 candlepower minimum	Fixed
Starboard	Incandescent	Aviation green	0.15 candlepower minimum	Fixed
Forward (2 lights)	Incandescent	Aviation white and yellow	0.23 candlepower minimum	Fixed
Aft	Incandescent	Aviation white	0.23 candlepower minimum	Fixed
Tracking light	Gaseous discharge	White	9,000 effective beam candlepower	One step to 1/150 of initial value

*Value represents level at time of launch.



300LM3-321

Figure 2-174. Exterior Lighting - Simplified Block Diagram

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-66. Interior Lights - Color, Brightness, and Lighting Method

Component	Primary Lighting Method	Color	Brightness Adjustment	Color Under Incident Illumination
Control panels and pushbuttons (illuminated-character type)	Integral (EL) (primary)	White	Continuous from zero foot-lamberts	Control panels: gray Pushbuttons Background: black Characters: white
Floodlights	Flood (incandescent)	White (unfiltered)	Continuous from less than 0.1 foot-candle	
Circuit breakers	Flood (EL)	White	Continuous from zero foot-lamberts	Background: black Characters: white
EL numeric readouts	Integral (EL)	Green	Continuous from zero foot-lamberts	Background: gray
LUNAR CONTACT lights	Integral (incandescent)	Blue	Fixed	Background: non-specular gray
MASTER ALARM pushbutton/lights	Integral (incandescent)	Aviation red	Fixed (press to turn off)	Background: translucent gray/white Legends: black
Caution lights	Integral (incandescent)	Aviation yellow	Continuous from 1.5±0.5 foot-lamberts	Background: translucent gray/white Legends: black
Warning lights		Aviation red		
Component caution lights	Integral (incandescent)	Aviation yellow	Continuous from 0.5±0.2 foot-lamberts	Background: translucent gray/white Legends: black
Engine START pushbutton/light	Integral (incandescent)	Aviation red	Continuous from 0.5±0.2 foot-lamberts	Background: translucent gray/white
Engine STOP pushbutton/light	Integral (EL)	White	Continuous from zero foot-lamberts	Legends: black
Status lights (DSKY and DEDA)	Integral (incandescent)	Aviation white	Continuous from zero foot-lamberts	Background: translucent gray/white
Component caution lights (DSKY)		Aviation yellow		Legends: black
Self-luminous devices (toggle switch tips, landing-point designator)	Radio-luminescent	Green	Fixed	Pale green Pale yellow for LPD inner reticle
Talkbacks Two-position	Integral (EL)	White background and black striping (energized)	Continuous from zero foot-lamberts	Alternate black and white striping (energized) Gray (deenergized)
Three-position	Integral (EL)	White background and black	Continuous from zero foot-lamberts	Red Letters: black on gray Gray (deenergized) Alternate black and white striping (energized)

MISCELLANEOUS

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-66. Interior Lights - Color, Brightness, and Lighting Method (cont)

Component	Primary Lighting Method	Color	Brightness Adjustment	Color Under Incident Illumination
Indicator pointers	Silhouette of EL flood			Black-yellow "Switzer" - rocket red or fire orange
Indicia (arrows, symbols, etc.)	Integral (EL)	White	Continuous from zero foot-lamberts	Black - white
Characters (numbers and letters on displays)	Integral (EL)	White	Continuous from zero foot-lamberts	Black - white
Time-shared labels and multipliers (X10 indicators)	Integral (EL)	Green	Continuous from zero foot-lamberts	None
Range marking (color bands, normal mode)	Integral (EL)	Green	Continuous from zero foot-lamberts	Green
Immediate or emergency action controls	Integral (EL)	Yellow	Continuous from zero foot-lamberts	Alternate yellow and black striping, at 45° (yellow is 3 times thickness of black)
Indicator power failure lights	Integral	Aviation red	Continuous from 0.005±0.02 foot-lambert	Translucent gray/white

Integrally Lighted Components. There are three types of integrally lighted components: displays, panel areas, and caution and warning annunciators. These components use EL or incandescent devices. The brightness of an integrally lighted component is controlled by a potentiometer-type dimming control. All nomenclature on the control and display panels is integrally lighted by white electroluminescent lamps with overlays. The displays have EL light sources within the display enclosure; the data are displayed as white illuminated markings on a background that is not illuminated. The pointer, which is not illuminated, travels over an illuminated background.

Numeric EL displays have illuminated green or white digital markings on a background that is not illuminated. The brightness of EL displays can be controlled manually. A manual override switch can bypass the EL integral lighting and EL numerics dimming controls, if required. The caution and warning annunciators and component caution lights have a fail-safe circuit, which automatically bypasses a failed dimming control and supplies fully regulated current to the lamps.

Two MASTER ALARM pushbutton/lights (panels 1 and 2) go on to visually alert the astronauts whenever a failure or out-of-tolerance condition is sensed by the caution and warning electronics assembly (CWEA). The signal that causes the MASTER ALARM pushbutton/lights to go on also activates an audio tone (3,000 cps) generator to provide an aural alert. Pressing either MASTER ALARM pushbutton/light extinguishes the MASTER ALARM lights and deactivates the tone generator.

The SIDE PANELS switches (figure 2-175) on the LIGHTING portion of panels 3 and 5 turn the EL lighting on and off for the Commander's and LM Pilot's side panels. With these switches set to ON, the integral lights of the side panels are connected to the INTEGRAL control and the INTEGRAL OVERRIDE switch (panel 5). The INTEGRAL control adjusts the light intensity of the side panels when the INTEGRAL OVERRIDE

MISCELLANEOUS

LMA790-3-LM 3
 APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

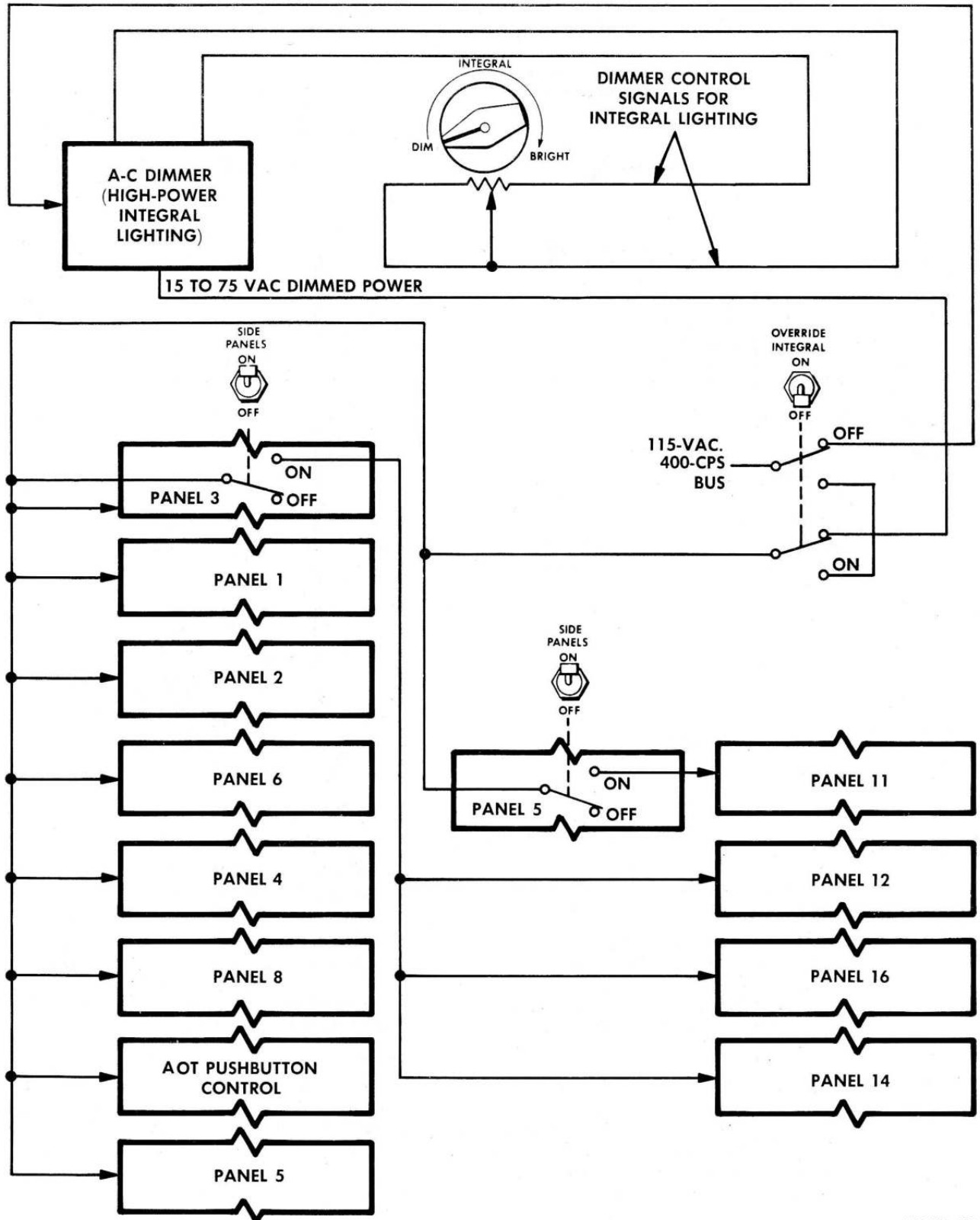
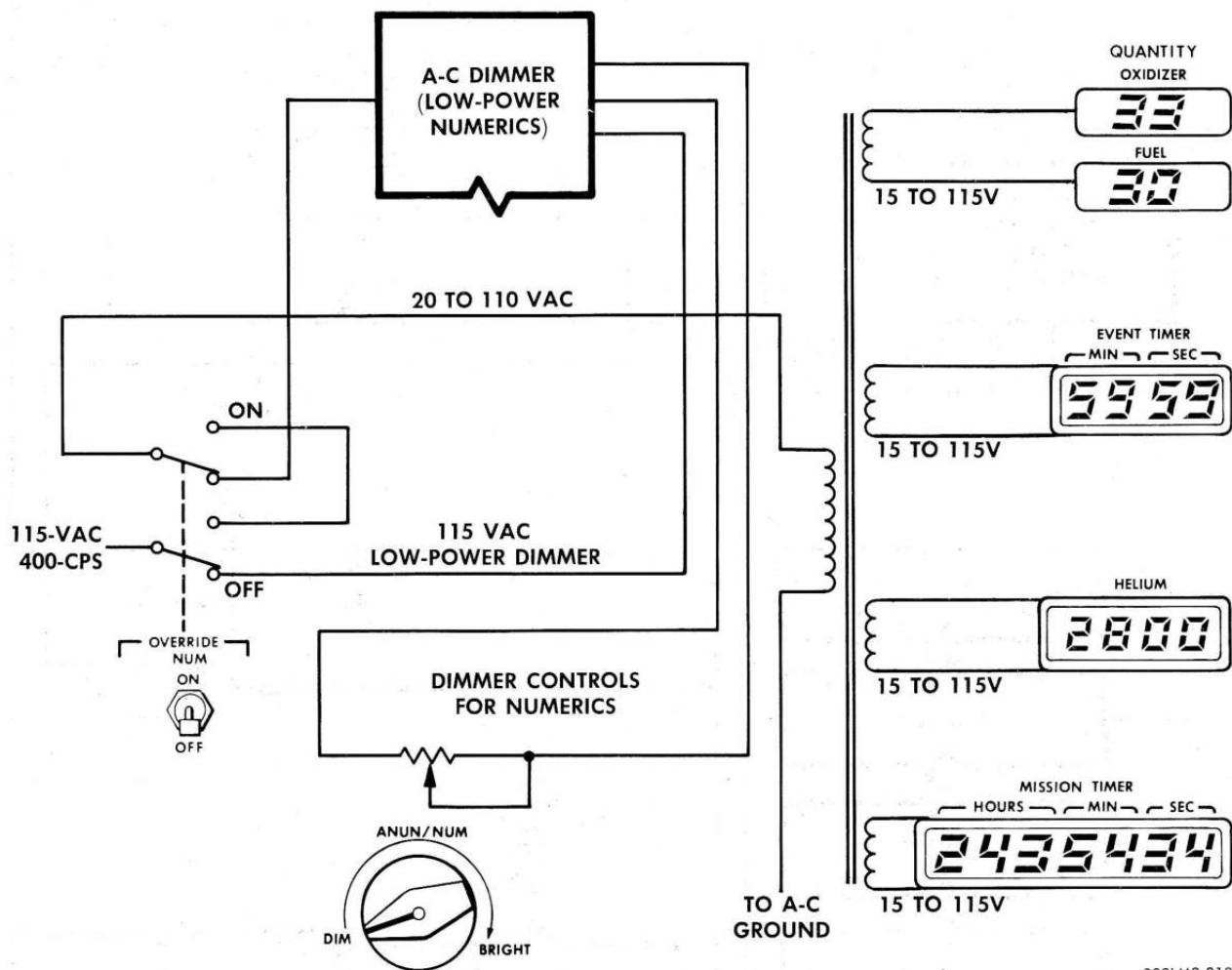


Figure 2-175. Integral Lighting - Simplified Diagram

300LM3-317

MISCELLANEOUS



300LM3-318

Figure 2-176. Numeric Lighting - Simplified Diagram

switch is set to OFF. If the INTEGRAL control fails, the INTEGRAL OVERRIDE switch bypasses the INTEGRAL control and routes 115-volt a-c bus voltage directly to the integral lights.

When the NUM OVERRIDE switch (figure 2-176) on panel 5 is set to OFF, it provides EL power to the NUM portion of the ANUN/NUM control. This portion of the control adjusts the light intensity of the EL numerics and the time-shared displays. If the NUM portion of the control fails, the NUM OVERRIDE switch bypasses the NUM portion of the control and routes 115-volt a-c bus voltage directly to the numerics and the time-shared displays.

With the ANUN OVERRIDE switch (figure 2-177) set to OFF, the ANUN portion of the ANUN/NUM control adjusts the light intensity of the caution and warning annunciators (except the C/W PWR caution light), the component caution lights (except the DC BUS FAULT light), the incandescent pushbuttons, and the indicator power failure lights at the top of indicators on panels 1 and 2. The C/W PWR caution light goes on if a CWEA

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

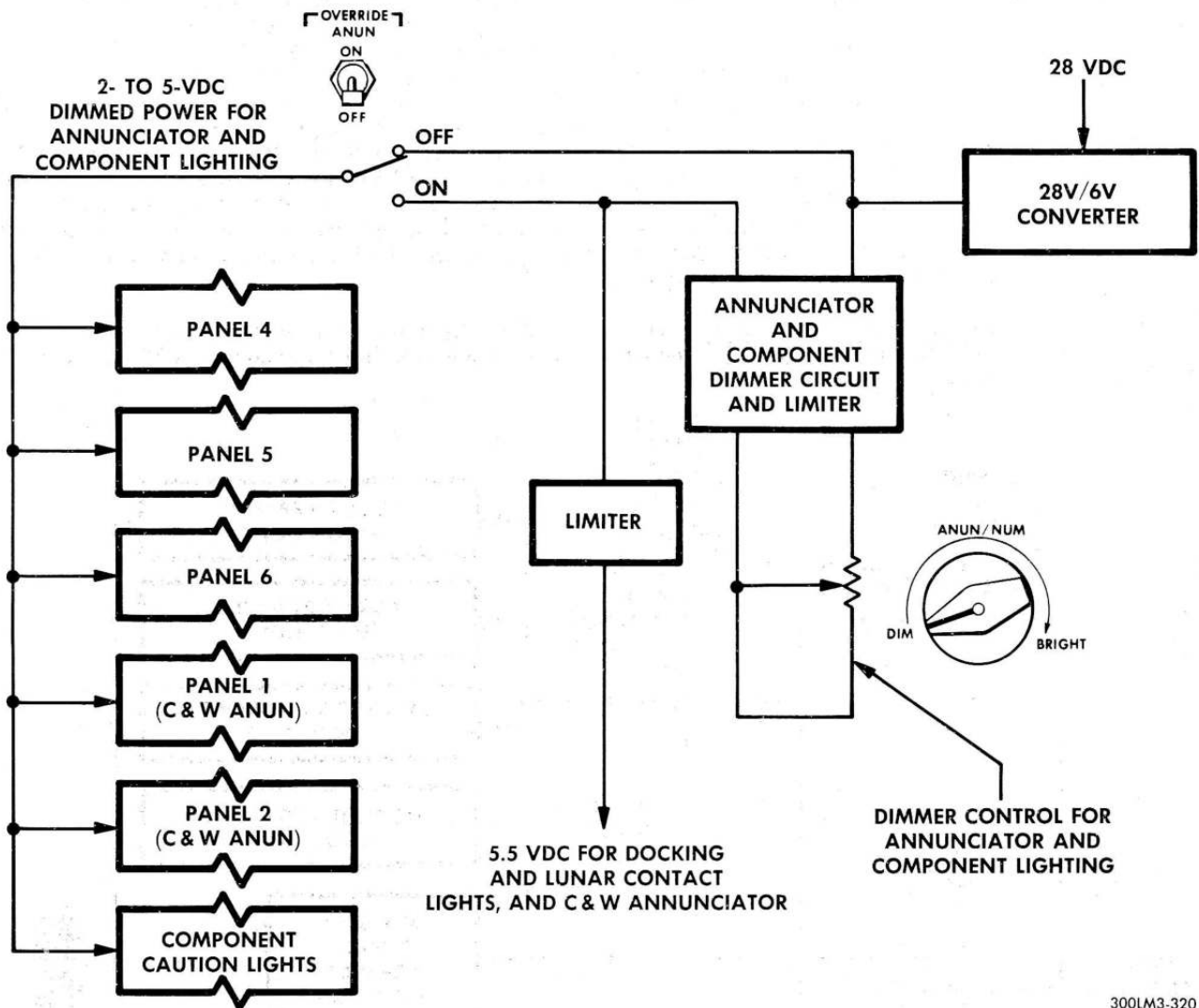


Figure 2-177. Annunciator/Component Lighting - Simplified Diagram

power supply failure is detected. For this reason, it is not controlled by the ANUN/NUM control. The DC BUS FAULT component caution light goes on if an Electrical Power Subsystem (EPS) bus voltage failure is detected. For this reason, it, too, is not controlled by the ANUN/NUM control. If the ANUN portion of the control fails, the ANUN OVERRIDE switch bypasses the ANUN portion of the control and routes 5-volt dc power directly to the lights.

Lunar Contact Lights. Two LUNAR CONTACT lights (panels 1 and 3) go on during a lunar mission when the probes on the landing gear contact the lunar surface. These lights are not used in the LM 3 mission.

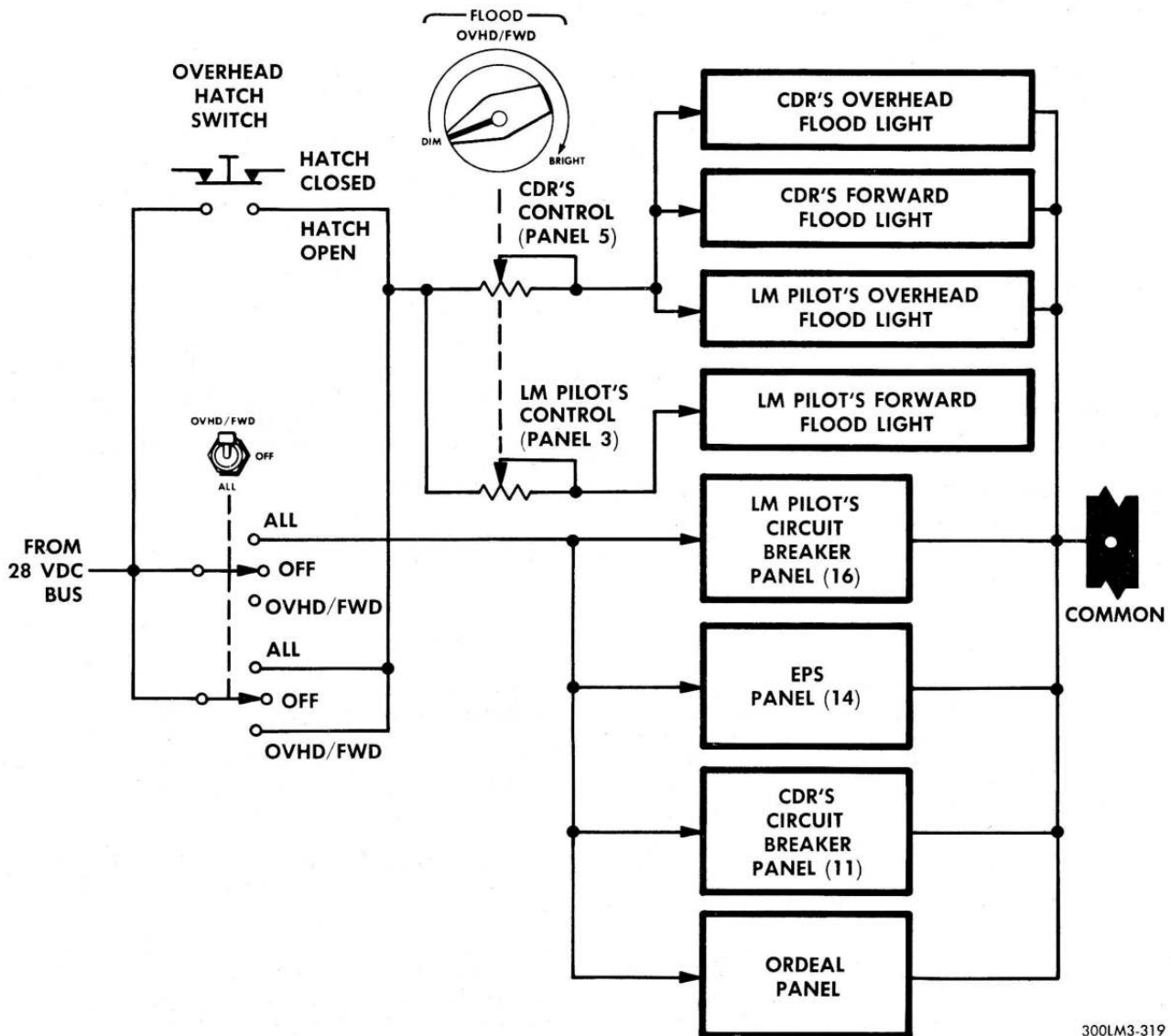
Floodlighting. (See figure 2-178.) Floodlighting is used for general cabin illumination and as a secondary source of illumination for the control and display panels. Floodlighting is provided by the Commander's overhead and forward floodlights, the LM Pilot's overhead and forward floodlights, and recessed floodlights in the bottom of extending side panels. These fixtures provide an even distribution of light with minimum reflections. Every panel area has more than one lamp for its illumination requirements.

MISCELLANEOUS

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

When the SIDE PANELS switches are set to OFF, the Commander's and LM Pilot's side panel integral lighting is interrupted. Setting the OVHD/FWD FLOOD switch (panel 3) to ALL routes 28 volts dc to the Commander's and LM Pilot's overhead and forward floodlights, and to their side panel floodlights. The OVHD/FWD FLOOD controls (panels 3 and 5) adjust the intensity of floodlight illumination on the LM Pilot's and Commander's side of the cabin, respectively. In this mode of lighting there is no intensity control for the side panels. Setting the OVHD/FWD FLOOD switch to OVHD/FWD routes 28 volts dc to the Commander's and LM Pilot's overhead and forward floodlights only. With the OVHD/FWD FLOOD switch set to OFF, all floodlights are off, unless the overhead hatch is open. The overhead hatch contains a microswitch that overrides the OVHD/FWD FLOOD switch and routes the 28-volt d-c bus voltage to light the overhead and forward floodlights.

Optical Sight Reticle Light. The crewman's optical alignment sight (COAS), used to sight the docking target on the CSM, has a reticle that is illuminated by a 28-volt d-c lamp.



300LM3-319

Figure 2-178. Floodlighting - Simplified Diagram

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Alignment Optical Telescope Lights. A computer control and reticle dimmer assembly mounted on the AOT has a thumbwheel to control the brightness of the AOT reticle. The lamp voltage may be adjusted from 0.2 ± 0.1 to 4.0 ± 0.5 volts rms. The lamps edge-light the reticle with incandescent red light.

Lamp and Tone Test. (See figure 2-179.) The LAMP/TONE TEST switch (panel 3) is used to perform a functional test of lights and the master alarm tone. The ALARM TONE position tests the MASTER ALARM pushbutton/lights (panels 1 and 2) and related tone. The C/W 1, C/W 3, and C/W 4 positions test the lamps of some of the caution and warning annunciators (panels 1 and 2). The ENG PB-C/W 2 position tests the lamps in the engine STOP and START pushbutton/lights (panel 5) and the remainder of the caution and warning annunciators. The COMPNT position tests the component caution lights and the LUNAR CONTACT lights (panel 3).

2.10.4 FAILURE MODES.

The heater section and lighting section failure modes are given in tables 2-67 and 2-68, respectively.

2.10.5 PERFORMANCE AND DESIGN DATA.

The performance and design data for the heater section and lighting section are given in tables 2-69 through 2-71.

2.10.6 OPERATIONAL LIMITATIONS AND RESTRICTIONS.

The operational limitations and restrictions for the heater section and lighting section are given in paragraphs 2.10.6.1 and 2.10.6.2, respectively.

2.10.6.1 Heater Section.

The operational limitations and restrictions for the heater section are as follows:

- LR antenna operating temperature must be maintained at -15° to $+150^{\circ}$ F. If these temperature limits are exceeded, altitude and velocity data are unreliable.
- RR antenna operating temperature must be maintained at -50° to $+150^{\circ}$ F. To operate within this range, the RR heaters must be turned on 1 hour before the RR is used; otherwise, the RR will not operate or its data are unreliable.
- TCA operating temperature must be maintained at $+119^{\circ}$ to $+190^{\circ}$ F. To operate within this range, the TCA heaters must be turned on 1 hour before TCA firing; otherwise, TCA firing is unreliable. Extreme low temperatures ($+85^{\circ}$ F) of a TCA (one TCA temperature is not detectable) can result in possible explosion. Heaters that have been turned off after once being fired must be warmed again.
- S-band antenna operating temperature must be maintained at -60° to $+155^{\circ}$ F. If these temperature limits are exceeded, S-band data are unreliable.
- The LM window heaters must be turned on when the astronauts enter the LM. The heaters must be left on until the astronauts leave, to prevent window fogging.
- The alignment optical telescope mirror heaters must be turned on 30 minutes before AOT use and must be left on for entire mission. If this restriction is not observed, the telescope mirrors will fog, causing inaccurate data or inability to view stars.

MISCELLANEOUS

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

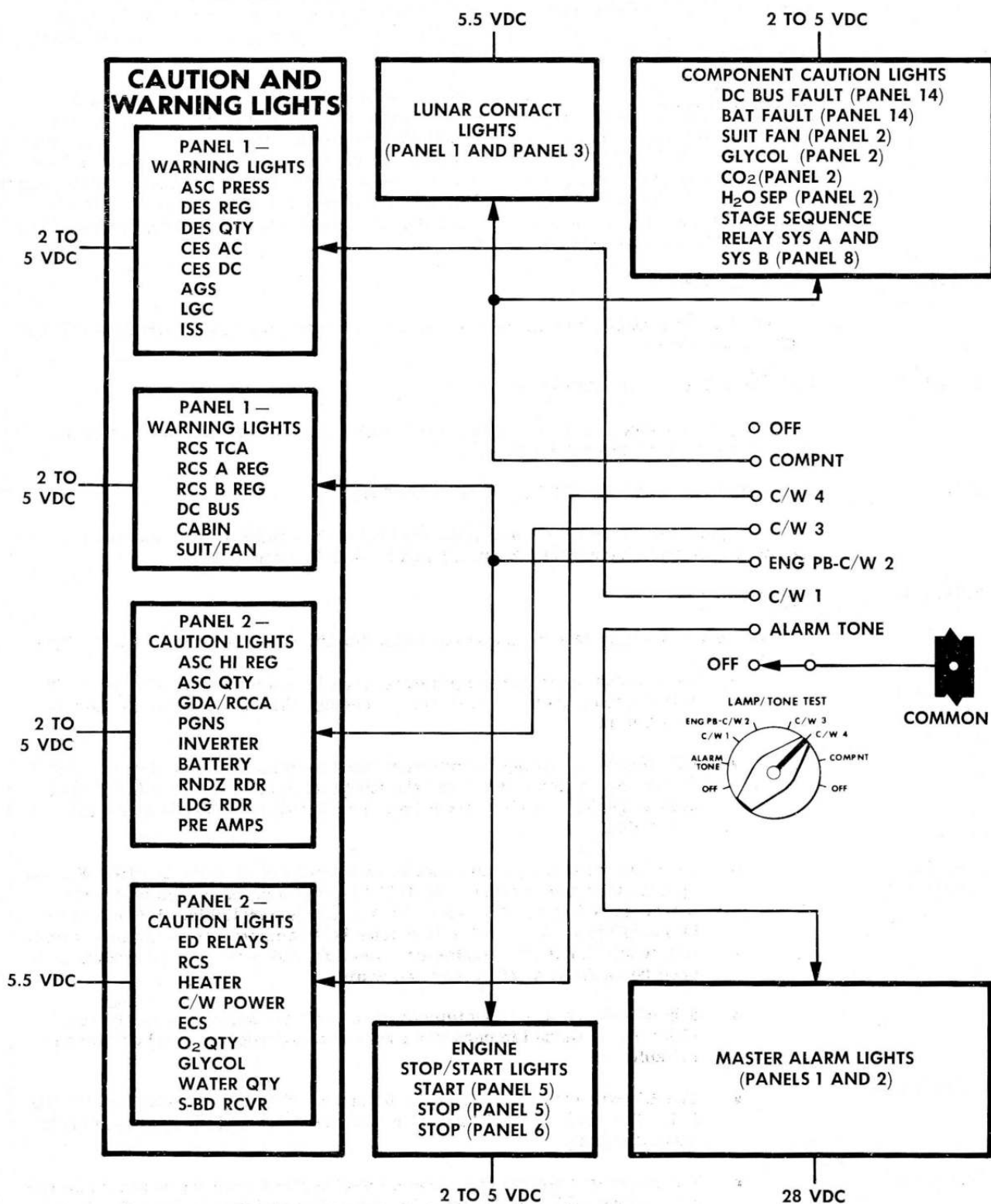


Figure 2-179. Lamp Tone Test - Simplified Diagram

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-67. Heater Section - Failure Modes

Failure	Indication	Vehicle Capability
LR antenna heaters	HEATER caution light (panel 2) goes on. Temperature is displayed on TEMP indicator (panel 3) when TEMP MONITOR selector switch (panel 3) is set to LDG.	Redundant heaters are provided.
RR antenna heaters	HEATER caution light goes on. Temperature is displayed on TEMP indicator when TEMP MONITOR selector switch is set to RNDZ.	Redundant heaters are provided.
S-band antenna heaters	HEATER caution light goes on. Temperature is displayed on TEMP indicator when TEMP MONITOR selector switch is set to S-BAND.	Redundant heaters are provided.
Forward and docking window heaters	Visual observation	Redundant heaters are provided.
Alignment optical telescope mirror heaters	Visual observation	Redundant heaters are provided.
RCS TCA heaters	HEATER caution light goes on. Temperature is displayed on TEMP indicator when TEMP MONITOR selector switch is set to related QUAD position.	Redundant heaters are provided. RCS SYS A/B-2 QUAD switches (panel 3) can be used to automatically operate, manually operate, or turn off heaters No. 2 in RCS systems A and B.

Table 2-68. Lighting Section - Failure Modes

Failure	Indication	Vehicle Capability
Commander's and LM Pilot's side panel lighting	Visual	INTEGRAL OVERRIDE switch (panel 5) provides direct input to panels if INTEGRAL control failed. Side panel floodlighting is also provided.
Caution and warning annunciator lighting	Visual	ANUN OVERRIDE switch (panel 5) provides direct input to annunciators if ANUN portion of ANUN/NUM control failed.
EL numeric lighting	Visual	NUM OVERRIDE switch (panel 5) provides direct input to numerics if NUM portion of ANUN/NUM control failed.
Docking lights	Visual	Docking procedures are degraded. Docking target and RR is primary means for docking.
Tracking lights	Visual	Visual tracking of LM by CSM is degraded. RR is used.

MISCELLANEOUS

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

Table 2-69. Heater Section - Performance and Design Data

Landing radar antenna heaters	
Type	Cal-rod elements
Operating power	28 volts dc
Maximum power drain	65 watts at 31.5 volts dc; 44 watts at 28 volts dc
Rendezvous radar antenna heaters	
Operating power	28 volts dc
Preoperating temperature	-10° to +20° F (except multiplier chain, which is +18° to +44° F)
RCS quad heaters	
Type	Resistance-wire element
Operating Power	28 volts dc
S-band antenna heaters	
Operating power	28 volts dc

Table 2-70. Exterior Lights - Performance and Design Data

Tracking light	
Type	High intensity, flashing
Dimming	1/150 of initial value (one step)
Intensity	9,000 beam candlepower (minimum)
Visibility	Cone centered on LM +Z-axis, with semivertex angle of 30°
Dim	Visual: less than 10 nautical miles CSM sextant: less than 30 nautical miles
Bright	Visual: 10 to 130 nautical miles CSM sextant: 30 to 400 nautical miles
Docking lights	
Type	Incandescent
Intensity	Fixed
Visibility	1,000 feet (When docking lights are visible, tracking lights should be turned off.)
Docking target	
Type	Self-luminous
Intensity	Fixed

MISCELLANEOUS

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-71. Interior Lights - Performance and Design Data

	Intensity	Power
Control panels and pushbuttons		
Primary	0.5±0.2 foot-lambert	75 volts, 400 cps
Backup	0.2 foot-candle (minimum)	24 volts dc
Circuit breakers	0.5±0.2 foot-lambert	75 volts, 400 cps
EL numeric readout	8 foot-lamberts	115 volts, 400 cps (DSKY: 250 volts, 800 cps)
LUNAR CONTACT lights, and caution and warning annunciators	50±10 foot-lamberts	5 volts dc
MASTER ALARM pushbutton/lights	150±30 foot-lamberts	28 volts dc
Component caution lights	15±3 foot-lamberts	5 volts dc
Engine START and STOP pushbutton/lights		
Incandescent	15±3 foot-lamberts	5 volts dc
EL	0.5±0.2 foot-lambert	75 volts, 400 cps
Status indicators (DSKY and DEDA)	10+8-2 foot-lamberts	5 volts dc
Self-luminous devices	0.05±0.02 foot-lambert	
Talkbacks (two- and three-position)	0.5±0.2 foot-lambert	75 volts, 400 cps
Displays		
Characters and indicia	0.5±0.2 foot-lambert	75 volts, 400 cps
Labels and multipliers	8 foot-lamberts (minimum)	115 volts, 400 cps
Range markings	0.4±0.1 foot-lambert	75 volts, 400 cps
Immediate or emergency action controls	0.1 foot-lambert (minimum)	75 volts, 400 cps
Indicator power failure lights	20±5 foot-lamberts	5 volts dc

2.10.6.2 Lighting Section.

The operational limitations and restrictions for the lighting section are as follows:

- The tracking light should be turned off when the docking lights are visible. When docking, the tracking light is not visible and unnecessary power is used.
- The docking lights shall not be used at distances in excess of 1,000 feet. Beyond 1,000 feet, these lights cannot be distinguished from stars.

2.10.7 TELEMETRY MEASUREMENTS.

The heating section and lighting section telemetry data are given in table 2-72. "(R)" in the "Telemetry Range" column signifies a real-time telemetry measurement.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

Table 2-72. Heating and Lighting Sections - Telemetry Measurements

Code	Description	Telemetry Range	Display Range	Crew Display
GM2435U	Lunar contact	Contact closure		LUNAR CONTACT lights (panels 1 and 3)
GN7563T	LR antenna temperature	-200° to +200° F (R)	-100° to +200° F	TEMP indicator (panel 3)
GN7723T	RR antenna temperature	-200° to +200° F (R)	-100° to +200° F	TEMP indicator
GR6001T	Quad cluster No. 4	0° to +200° F (R)	-100° to +200° F	TEMP indicator
GR6002T	Quad cluster No. 3	0° to +200° F (R)	-100° to +200° F	TEMP indicator
GR6003T	Quad cluster No. 2	0° to +200° F (R)	-100° to +200° F	TEMP indicator
GR6004T	Quad cluster No. 1	0° to +200° F (R)	-100° to +200° F	TEMP indicator
GT0454T	S-band steerable antenna temperature	-200° to +200° F	-200° to +200° F	TEMP indicator

MISCELLANEOUS

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

2.11 CREW PERSONAL EQUIPMENT.

2.11.1 INTRODUCTION.

This subsection covers crew personal equipment, which includes equipment required for life support and astronaut safety, and accessories related to successful completion of the mission. The portable life support system (PLSS) oxygen and water recharge connectors interface with the Environmental Control Subsystem (ECS) for refills of oxygen and water. The pressure garment assembly (PGA) interfaces with the ECS for conditioned oxygen through oxygen umbilicals, and with the Communications and Instrumentation Subsystems for communications and bioinstrumentation, through the electrical umbilical. Power to the crewman optical alignment sight is supplied by the Electrical Power Subsystem. For stowage locations of crew personal equipment, refer to paragraph 2.11.9.

2.11.2 EXTRAVEHICULAR MOBILITY UNIT. (See figures 2-180 and 2-181.)

The extravehicular mobility unit (EMU) provides life support in a pressurized or unpressurized cabin, and up to four hours of extravehicular life support.

In its extravehicular configuration the EMU provides an anthropomorphic, closed-circuit pressure vessel that envelops the astronaut entirely. The environment inside the pressure vessel consists of 100% oxygen at a nominal pressure of 3.85 psia. The oxygen is provided at a flow rate of 6 cfm. The extravehicular configuration includes the following:

- Liquid-cooled garment
- Pressure garment assembly
- Integrated thermal micrometeoroid garment
- Portable life support equipment
- Interim oxygen purge system
- Fecal containment subsystem
- Communications carrier
- EMU waste management system
- EMU maintenance kit
- Biomedical belt
- Urine collection and transfer assembly.

During intravehicular phases of the mission, several configurations are possible. The basic configuration provides intravehicular life support independent of the ECS. It includes the following:

- Pressure garment assembly (with PLSS)
- Integrated thermal micrometeoroid garment
- Communications carrier, with or without helmet (The suit, helmet and gloves are part of the pressure garment assembly.)
- Constant wear garment (not used in LM)

CPE

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

- Liquid-cooled garment
- Urine collection and transfer assembly
- Auxiliary equipment.

2.11.2.1 Liquid-Cooled Garment. (See figure 2-180.)

The liquid-cooled garment (LCG) is worn by the astronauts while in the LM and during all extravehicular activity. It cools the astronaut's body during extravehicular activity by absorbing body heat and transferring excessive heat to the sublimator in the portable life support system. The LCG is a one-piece, long-sleeved, integrated-stocking undergarment of netting material. It consists of an inner liner of nylon chiffon, to facilitate donning, and an outer layer of nylon Spandex into which a network of Tygon tubing is woven. The tubing does not pass through the stocking area. A double connector for incoming and outgoing water is located on the front of the garment. Cooled water, supplied from the portable life support system, is pumped through the tubing. Pockets for bioinstrumentation signal conditioners are located around the waist. A zipper that runs up the front is used for donning and doffing the LCG; an opening at the crotch is used for urinating. Dosimeter pockets and snaps for attaching a biomedical belt are part of the LCG.

2.11.2.2 Pressure Garment Assembly. (See figures 2-180 and 2-182.)

The PGA is the basic pressure vessel of the EMU. It provides a mobile life-support chamber in the event of loss of cabin pressure due to leaks or puncture of the vehicle. The PGA consists of a torso and limb suit, helmet, and intravehicular gloves; it requires an oxygen hose for oxygen and an electrical cable for telecommunications.

2.11.2.2.1 Torso and Limb Suit. (See figure 2-180.)

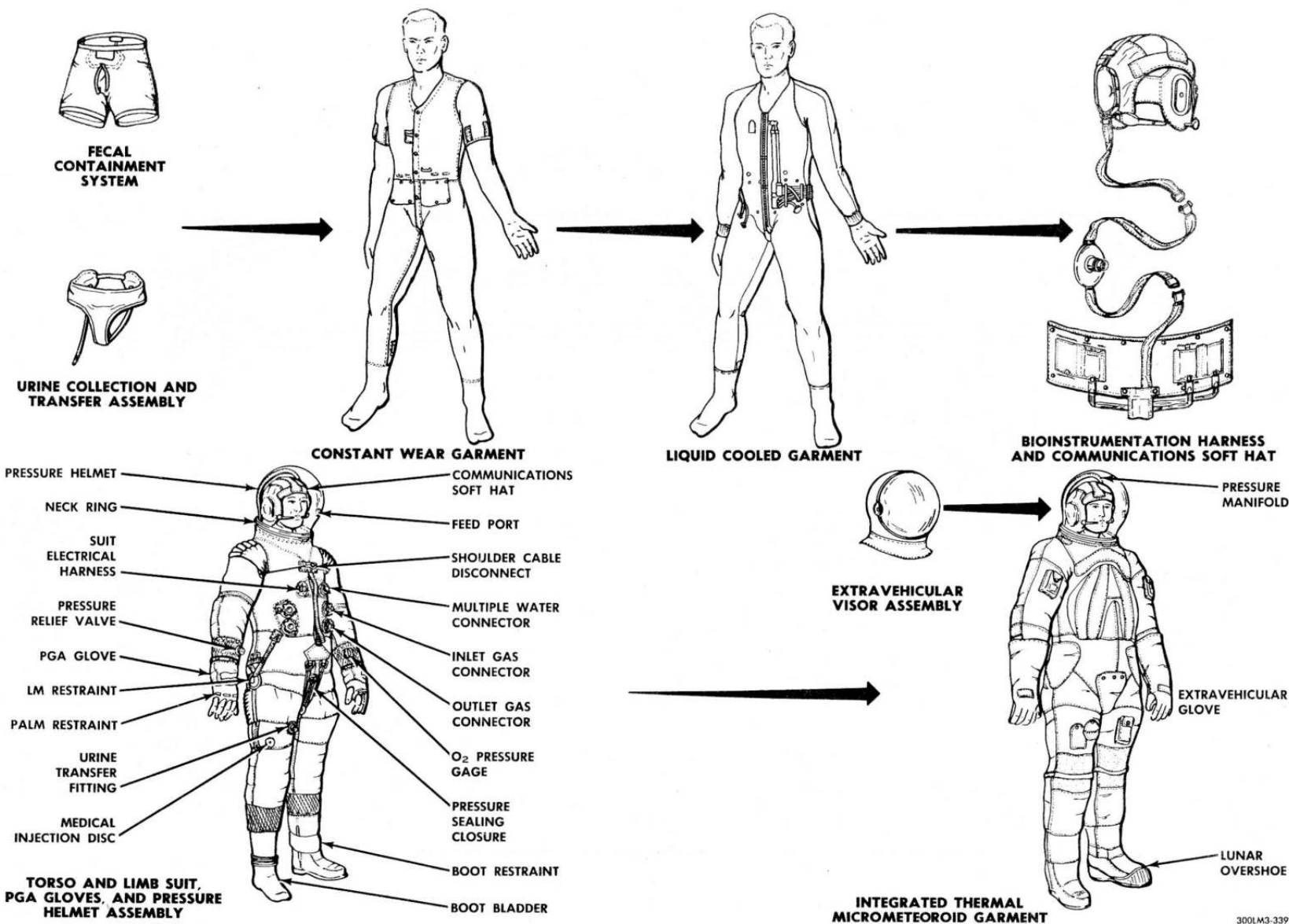
The torso and limb suit is composed of an inner layer of nylon twill (to make the suit comfortable and to diffuse ventilating gas), a gas-retention layer of neoprene-coated nylon, a restraint layer of nylon oxford cloth (to shape the gas-retention layer to the astronaut's body), and an outer integrated TMG layer. The gas-retention layer has convoluted joints at the shoulders, elbows, wrists, knees, and ankles to aid mobility. Boots with chafing patches, on the upper instep area, and neoprene soles are an integral part of the suit.

The suit has a neck ring for securing the helmet, and wrist rings for securing gloves. A double zipper that runs along the back, from the crotch to the neck ring, is used for donning and doffing the suit.

The left wrist area has a pressure gage that is graduated from 2.5 to 5.0 psig, in increments of 0.5 psig. A cable, which runs laterally from the chest, around the biceps, and across the spine, prevents ballooning. The cable is attached or detached at the chest.

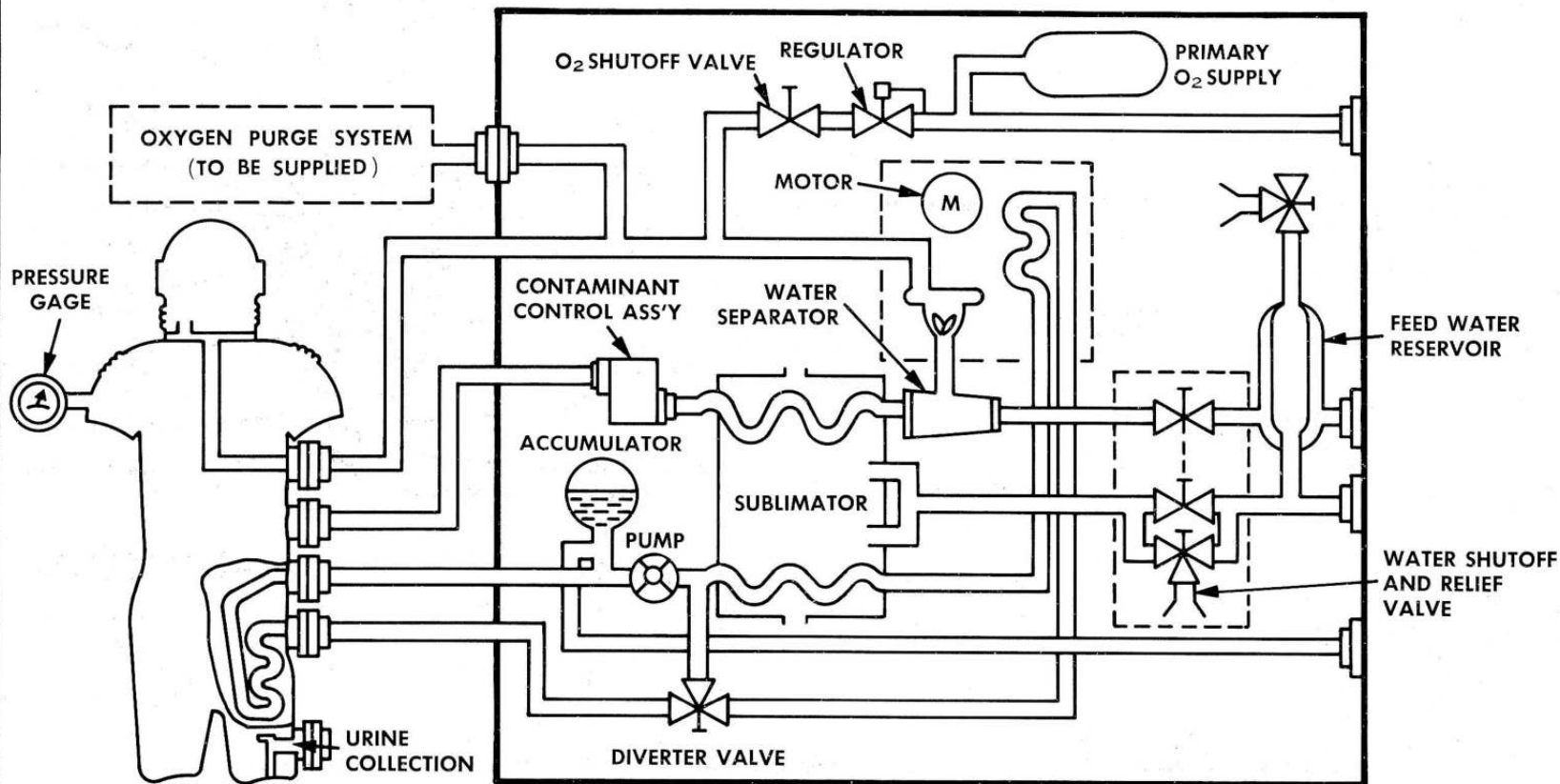
A 61-pin telecommunications connector is on the right chest area. On the interior of the suit, a 9-pin bioinstrumentation connector and a 21-pin communications electrical connector are formed directly from the telecommunications harness.

The PGA multiple water receptacle is on the left chest area. Supply and return hoses with separate connectors to the PLSS are inside the suit. Two sets of oxygen hose connectors are on the lower rib-cage area: one set is to the right; the other set, to the left. The two inlets and outlets are connected by a plenum, which enables the astronaut to change from one ventilating system to another without depressurizing the suit. Divorter valves on the inlets equalize gas distribution through a vent duct assembly, between the suit and helmet, and can route all gas to the helmet during extravehicular activity. The oxygen hose connectors are identical. Normally, the left connector is for portable life support system hoses; the right, for ECS hoses.



300LM3-339

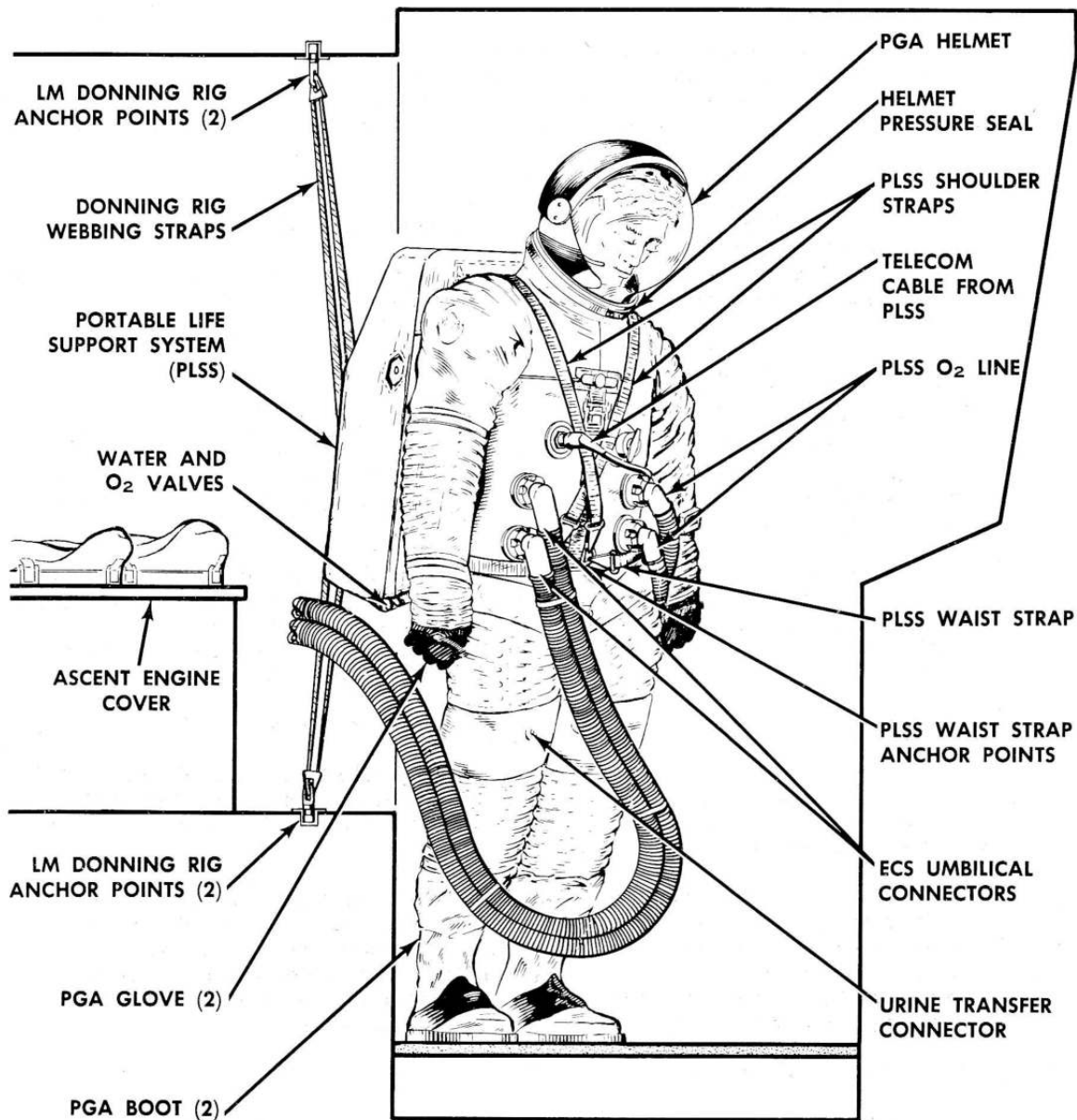
Figure 2-180. Extravehicular Mobility Unit



300LM3-248

Figure 2-181. Extravehicular Mobility Unit with OPS

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA



300LM3-249

Figure 2-182. Pressure Garment Assembly and PLSS Donning Rig

The PGA urine transfer connector on the suit right leg permits dumping the urine collection bag without depressurizing the PGA. The PGA pressure relief valve on the suit right sleeve enables venting in the event of overpressurization. The valve opens at approximately 4.6 psig and reseats at 4.3 psig. If the valve does not open, it can be manually overridden.

A low-pressure warning-tone switch and pressure transducer are part of the PLSS equipment. Refer to paragraph 2.11.2.4.5.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

2.11.2.2.2 Helmet. (See figure 2-180.)

The helmet is a Lexan shell with a bubble-type visor, a vent-pad assembly, and a helmet attaching ring. The vent-pad assembly permits a constant flow of oxygen over the inner front surface of the helmet. The astronaut can turn his head within the helmet neck-ring area. The helmet does not turn independently of the torso and limb suit.

2.11.2.2.3 Intravehicular Gloves. (See figure 2-180.)

The intravehicular gloves are worn during operations in the LM cabin. The gloves are secured to the wrist rings of the torso and limb suit with a slide lock; they rotate by means of a ball-bearing race. Freedom of rotation, along with convoluted bladders at the wrists and adjustable antiballooning restraints on the knuckle areas, permits manual operations while wearing the gloves.

2.11.2.3 Communications Carrier.

A communications carrier (cap) is a polyurethane-foam headpiece with two independent earphones and microphones, which are connected to the suit 21-pin communications electrical connector. The communications carrier is worn with or without the helmet during intravehicular operations. It is worn with the helmet during extravehicular operations.

The helmets are stowed in protective bags secured on top of the ascent engine cover. Each bag has a hollow-shell plastic base with a circular channel for the helmet and the extravehicular visor assembly (EVVA), two recessed holes for glove connector rings, and a slot for the EMU maintenance kit. The bag is made of cloth, with a circumferential zipper; it folds toward the plastic base when empty.

2.11.2.4 Integrated Thermal Micrometeoroid Garment. (See figure 2-180.)

The integrated thermal micrometeoroid garment (ITMG) consists of a thermal micrometeoroid suit, extravehicular gloves and boots, and the EVVA. The ITMG is worn over the PGA and protects the astronaut from harmful radiation, heat transfer, and micrometeoroid activity.

The integrated thermal micrometeoroid garment is a one-piece, form-fitting multilayered garment that is laced over the PGA and remains with it. The EVVA, gloves, and boots are donned separately. From the outer layer in, the garment is made of a protective cover, a micrometeoroid-shielding layer, a thermal-barrier blanket (multiple layers of aluminized mylar), and a protective liner. A zipper on the garment permits connecting or disconnecting umbilical hoses.

2.11.2.4.1 Extravehicular Gloves. (See figure 2-180.)

For extravehicular activity, the PGA gloves are replaced with the extravehicular gloves. The extravehicular gloves are made of the same material as the ITMG to permit handling intensely hot or cold objects outside the cabin and for protection against lunar temperatures.

2.11.2.4.2 Extravehicular Boots. (See figure 2-180.)

The extravehicular boots are worn over the PGA boots for extravehicular activity. They are made of the same material as the ITMG. The soles have additional insulation for protection against intense temperatures.

2.11.2.4.3 Extravehicular Visor Assembly. (See figure 2-180 and 2-183.)

The EVVA provides protection against solar heat, space particles, and radiation, and helps to maintain thermal balance. The two pivotal visors of the assembly may be attached to a pivot mounting on the PGA helmet. The lightly tinted (inner) visor

CREW PERSONAL EQUIPMENT

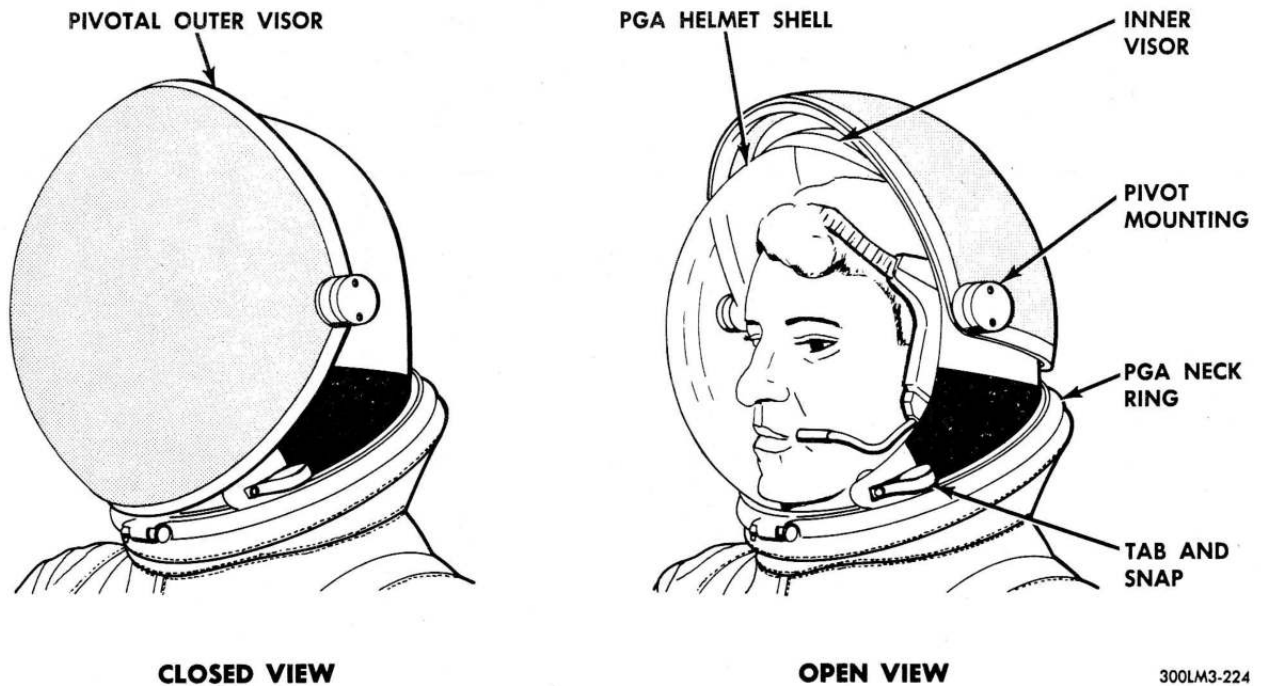


Figure 2-183. Extravehicular Visor Assembly

reduces fogging in the helmet. The outer visor has a vacuum-deposited, gold-film reflective surface, which provides protection against solar radiation and space particles. The assembly is held snug to the PGA helmet by a tab-and-strap arrangement that allows the visors to be rotated approximately 90° up or down, as desired. Two EVVA's are stowed in the PGA helmet bags secured on the ascent engine cover.

2.11.2.5

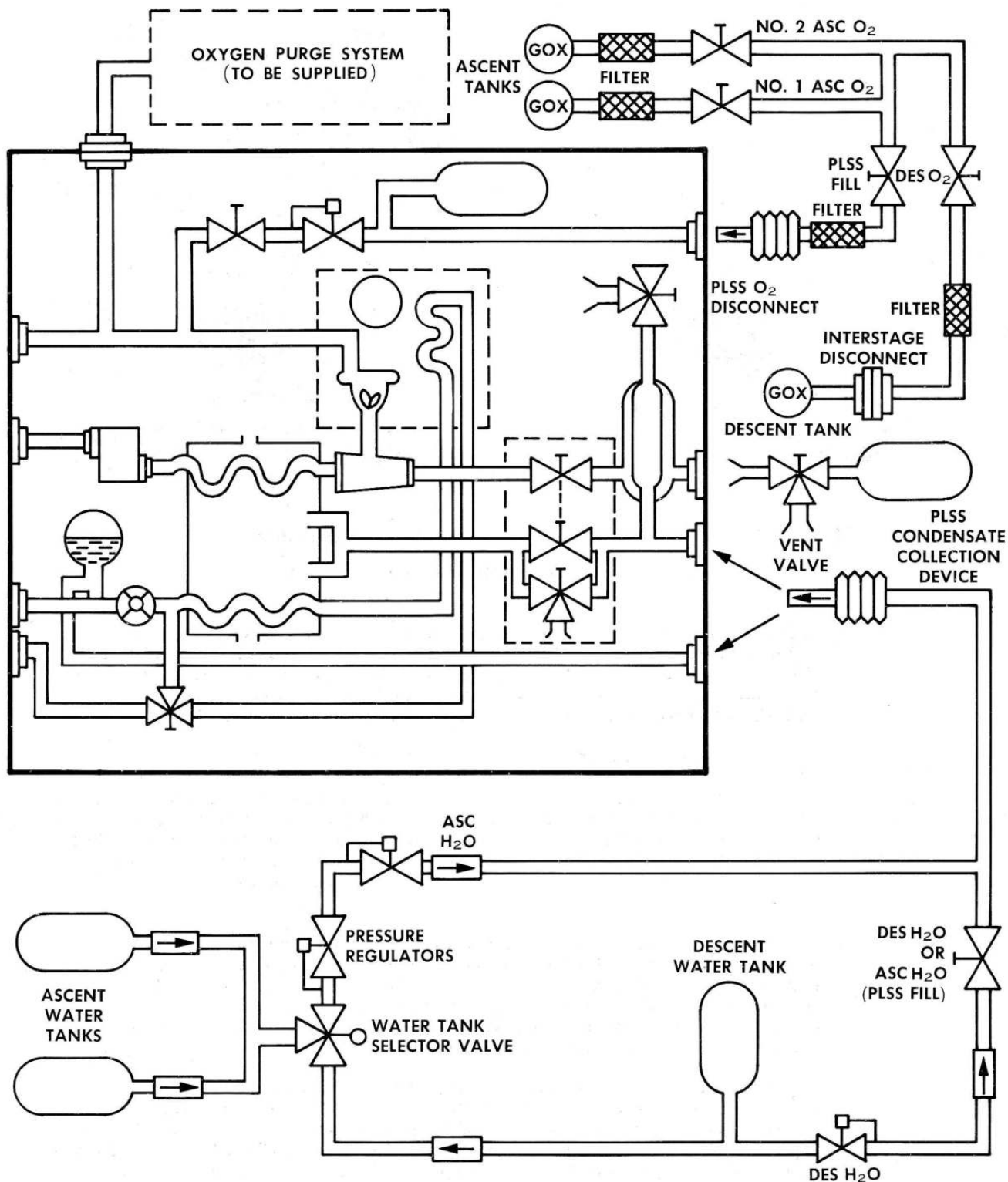
Portable Life Support System. (See figure 2-184.)

The PLSS is a self-contained, self-powered, rechargeable environmental control system. In the extravehicular configuration of the EMU, the PLSS is worn on the astronaut's back. The PLSS supplies pressurized oxygen to the PGA, cleans and cools the expired oxygen, circulates cool liquid in the LCG through the liquid transport loop, transmits astronaut biomedical data, and functions as a dual VHF transceiver for communication.

The PLSS (figure 2-185) has a contoured fiberglass shell to fit the back, and a thermal micrometeoroid protective cover. The PLSS weighs approximately 68 pounds; it is rectangular (26 inches high, 18 inches wide, and 11 inches deep). It has three control valves, and two control switches, a volume control, and a five-position switch for the dual VHF transceiver on a separate control box. The control box is set on the front of the astronaut, below the neck ring.

Fully charged, the equipment can assimilate an average astronaut output of 1,600 Btu per hour with peak rates of 2,000 Btu per hour. The PLSS can operate for 4 hours in space environment before oxygen and feedwater must be replenished and the battery replaced. The basic systems and loops of the PLSS are: primary oxygen system, oxygen ventilating circuit, feedwater loop, liquid transport loop, and electrical system.

LMA790-3-LM 3
 APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

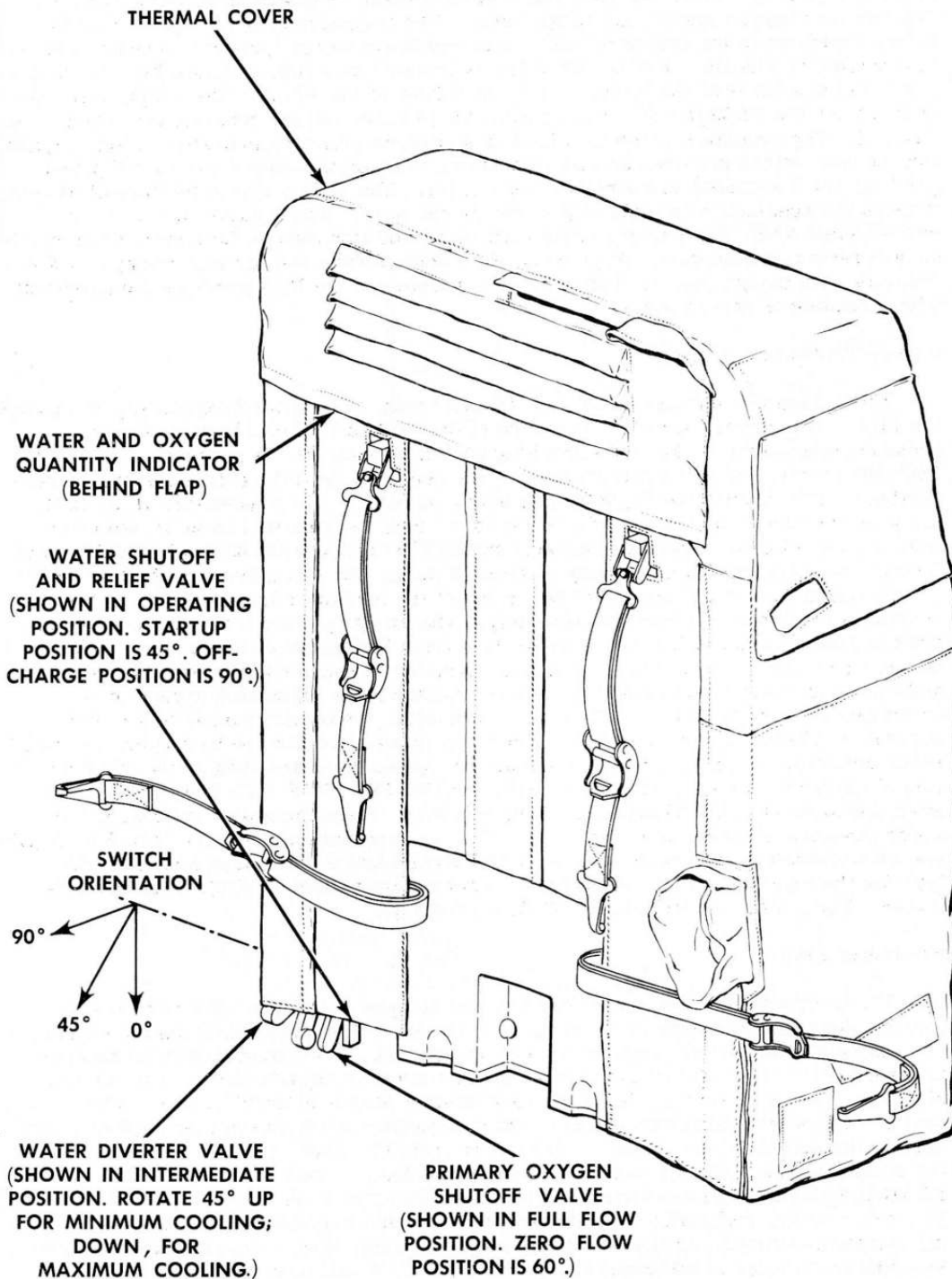


300LM3-246

Figure 2-184. Portable Life Support System - Environmental Control Subsystem Interface

CREW PERSONAL EQUIPMENT

Note:
 New control box
 to be supplied.



300LM3-196

Figure 2-185. PLSS Controls

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

2.11.2.5.1 Primary Oxygen System.

The primary oxygen system stores oxygen and regulates its pressure in the PLSS at 3.85 ± 0.15 psig. Fully charged, the system contains 0.92 pound of usable oxygen. The primary oxygen system is rechargeable. The regulator assembly has a shutoff valve, upstream of the regulator valve, and a primary oxygen pressure sensor to provide telemetry signals. The shutoff valve is actuated by a linkage assembly, which is connected to a lever at the lower right front corner of the PLSS. The shutoff valve is closed when the PLSS is not in use or when the primary oxygen subsystem is being charged. The regulator assembly also has an oxygen pressure indicator; a high oxygen flow sensor, which provides an audible warning when oxygen flow reaches 0.6 pound per hour for 5 seconds; and a restricting orifice. The orifice limits the flow of oxygen through the regulator assembly to 3.6 pounds per hour. To recharge the primary oxygen subsystem, the primary oxygen fill connector is mated to the female vehicle oxygen recharge connector. Approximately 1 hour is required for recharging to 100% capacity. An oxygen quantity indicator on the sleeve of the PGA provides the astronaut with a reading of oxygen quantity.

2.11.2.5.2 Oxygen Ventilating Circuit.

The oxygen ventilating circuit circulates a fresh, regenerated oxygen supply through the PGA. The normal operating pressure of the PGA is 3.85 ± 0.15 psig. A suit pressure transducer in the PLSS provides a telemetry signal. A pressure gage, on the PGA left sleeve, indicates suit pressure. Oxygen from the PGA enters the oxygen ventilating circuit through the PLSS oxygen inlet connector. The oxygen then flows to the contaminant control assembly, where the body odors are removed by activated charcoal, carbon dioxide is removed through chemical reaction with lithium hydroxide, and foreign particles are filtered out by an Orlon filter. The contaminant control assembly is an integral part of the feedwater reservoir of the feedwater loop; together, they constitute the canister-reservoir assembly. The oxygen passes from the contaminant control assembly to a sublimator, where heat from the oxygen is transferred to feedwater. The feedwater passes through porous plates to space environment; it freezes, and dissipates heat by sublimation. The sublimator cools circulated oxygen to an outlet temperature of $+50^{\circ}$ F. From the sublimator, the oxygen passes to a water separator, where excess water entrained in the oxygen is collected by a nylon felt wick in the collection section. The water separator routes the drainwater to the outer section of the feedwater reservoir through the WATER SHUTOFF AND RELIEF VALVE when the valve is in the START-UP position (-45°). From the water separator, the water passes to the fan motor assembly. The fan supplies the pressure (4 to 5 in. H_2O) needed to circulate oxygen between the PLSS and PGA at 6 cfm. It is a centrifugal-type fan that operates at $18,000 \pm 600$ rpm, powered by a water-cooled, brushless, d-c motor. The motor is energized by 16.8 ± 0.8 volts dc.

2.11.2.5.3 Feedwater Loop.

The feedwater loop feeds expendable water to the sublimator. The sublimator freezes the water by exposure to space environment. Heat absorbed from the oxygen ventilating circuit and the liquid transport loop causes the ice to sublime at ambient pressure below 0.4 mm Hg. The feedwater reservoir is separated into sections by a bladder. The inner section stores approximately 7 pounds of usable water. The outer section stores the drainwater from the water separator. The drainwater applies pressure to the outside of the bladder. Feedwater from the bladder is then forced out to the sublimator as required, depending on the heat load. The WATER SHUTOFF AND RELIEF VALVE permits selection of two water-flow rates. In the START-UP position, water flow to the sublimator is restricted by an orifice to prevent flooding when the sublimator is started. In the OPERATE position, water flow is not restricted and the sublimator operates at full capacity. In the OFF-CHARGE position, the valve opens at 16.5 psig to relieve excess pressure in the reservoir and permits simultaneous filling and draining of the reservoir. The valve reseats at 15.0 psig. In the START-UP

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

and OPERATE positions, the drain from the water separator to the drainwater section of the reservoir is open. A feedwater pressure transducer provides a telemetry signal.

2.11.2.5.4 Liquid Transport Loop.

The liquid transport loop of the sublimator chills the water that circulates through the LCG to an outlet temperature of +45° F. The water passes from the sublimator and circulates around the fan motor to cool the electronic package. From the fan motor, the water passes to a diverter valve, which permits selection of three liquid transport water temperatures at the inlet to the LCG. The WATER DIVERTER VALVE has three positions: INTERMEDIATE, UP (minimum cooling), and DOWN (maximum cooling). For intermediate and minimum cooling, the diverter valve admits some water from a bypass around the sublimator into its outgoing stream. The flow at the outlet in all valve positions is 4.0 ± 0.10 pounds per minute. The water passes from the diverter valve into the LCG. A temperature transducer in the loop provides an LCG water inlet temperature signal for telemetry. The water circulates over the astronaut's body and passes to an accumulator. A differential temperature transducer provides a telemetry signal that represents the difference in temperature between the water leaving and entering the PLSS. The accumulator stores water, supplies it to the liquid transport loop, and maintains it at a pressure of 11.9 to 20.0 psig by means of a spring-powered piston, which forces water into the loop when loop pressure decreases. The piston shaft is marked in three places to indicate the condition of the accumulator: full (groove at top of green mark, 6.9 to 7.1 cubic inches), danger (groove at intersection of red and green marks, 3.8 to 4.2 cubic inches), and empty (groove at bottom of red mark, 0.0 cubic inches). From the accumulator, the water passes to a pump-motor assembly, which circulates the water through the liquid transport loop and the LCG at a flow rate of approximately 4 pounds per minute. The pump motor is energized with 16.8 volts dc; a vibrating diaphragm forces the water through the loop. Inlet and outlet check valves allow flow in only one direction. The pressure rise across the pump is approximately 5.65 psi. A water fill connector, between the pump-motor assembly and the sublimator, permits initial charging of the loop and topping of the accumulator charge between extravehicular stints.

2.11.2.5.5 Electrical System.

The PLSS electrical system is composed primarily of the power supply (battery) and the space suit communications system. The power supply interfaces with the EMU components that use power. The space suit communications system interfaces with the EMU transducers, sensors, and warning devices.

The battery provides nominal 16.8 ± 0.8 volts dc for operation of the PLSS and electrical controls within the EMU. It is stored dry and is activated before start of the mission. After a 4-hour soak, the battery is fully charged. During operation, the battery delivers 60 watts continuously over a 4-hour cycle. Peak discharge voltage is 20.5 volts dc with a 45- to 65-watt variation. It can withstand four 2-second pulses of 80 watts during the discharge cycle without degrading its performance.

Anticipated power consumption for EMU electrical components is as follows:

Communications system module (all transducers, indicators, microphones, and electrocardiograph)	11.55 watts
Pump	10.0 watts
Fan	30.0 watts

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

The space suit communications system provides duplex voice communications between two astronauts on the lunar surface. Its four basic capabilities include two-way voice communications between the LM and extravehicular astronaut; processing biomedical, environmental, and expendables-status transducer outputs for telemetry transmission to the LM; generation of an audible warning to alert of dangerous suit environmental conditions; and backup for the duplex voice transceiver for emergency voice communication (between astronauts) if the primary transceiver fails.

The space suit communications system module contains the primary and secondary transceivers, voltage regulators, signal-conditioning oscillators for conversion of transducer outputs to transmitter-modulating voltages, a mixer for coupling the seven telemetry-signal-conditioning oscillators to the primary transmitter, low-suit-pressure and high-oxygen-flow signal generators, a diplexer, and an antenna switch for coupling the single antenna to the primary or secondary transceiver. The module has receptacles for connections to space suit transducers, microphone and binaural headset-receiver isolation networks, an ac-to-dc converter, a pneumograph, an antenna, a mode selection switch, volume control, and power input. Power to the transducers and to a water-and-oxygen quantity indicator is voltage regulated.

The communications system MODE SELECTION SWITCH (figure 2-185) permits four manually selected operations. The PRIMARY ON/TEL ON position is the normal operating position for voice-actuated transmission or seven-channel telemetry signals. The seven channels of telemetry data are transmitted when the voice-operated switch is bypassed; the transmitter is held on, and the signal-conditioner oscillator outputs are connected to the transmitter modulator. Five telemetry signal channels carry suit environmental data: oxygen quantity, feedwater pressure, suit pressure, LCG inlet temperature, and LCG water-temperature rise. The other two channels are used for biomedical data and for PLSS battery-current monitoring. External transducers of the PGA and PLSS control the signal-conditioning oscillator frequencies; voltage changes in transducer output vary the oscillator frequencies proportionally. The PRIMARY ON/TEL OFF position energizes the primary transceiver and permits continuous receiver operation, with the transmitter inoperative until voice actuated. The antenna couples to the primary transceiver through the antenna switch and diplexer. Using the LM Communications Subsystem as a relay station to relay to MSFN, the space suit communications system receives on 296.8 mc and transmits on 259.7 mc. The SECONDARY/ON position energizes the secondary transceiver, but does not connect it to signal-conditioning oscillator outputs. Telemetry transmission is not possible and the transmitting and receiving frequencies are the reverse of those used when the MODE SELECTION SWITCH is set to PRIMARY ON/TEL OFF. The PRIMARY ON/TEL ON BV CHECK position provides the same transmit-receive capability as does the PRIMARY ON/TEL ON position, except that the last of the seven telemetry channels carries information for checking the battery under load instead of battery-current drain.

The warning tone generators and microphones, common to primary and secondary operation, are continuously energized. Power is switched to the warning tone generators without limiting, for either primary or secondary transceiver operation. The microphones have separate current limiters in series with the power source. The outputs of the warning tone generators are coupled directly to the headset receiver isolation network. They are turned on automatically by high oxygen flow (0.6 pound per hour for 5 seconds) or by low suit pressure (3.15 ± 0.15 psig). High oxygen flow activates generator No. 2, producing an amplitude-modulated, 3,000-cps warble in the headsets. Low suit pressure activates generator No. 1, producing a continuous 1,500-cps tone in the headsets. Each tone is identifiable if the generators are activated simultaneously, and is distinguishable while receiving other data.

2.11.2.5.6

PLSS Donning.

The PLSS is attached to the astronauts back, over the ITMG; it is connected by a shoulder harness assembly. (See figure 2-182.) The donning station is in the LM midsection. It consists of webbed straps (stowed in the TMG stowage bag) and clip

CREW PERSONAL EQUIPMENT

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

inserts attached forward of the overhead hatch and on the work-shelf area near the ascent engine cover. When the clips are inserted, the PLSS is attached and is held to the webbed straps. The astronaut backs against the pack, makes PGA and harness connections, and draws free of the donning station restraints.

2.11.2.6 Interim Oxygen Purge Systems.

Two interim oxygen purge systems (IOPS's) are stowed in the LM at earth launch. The IOPS's are steel boxes and are housed in an adapter frame compatible, and interchangeable, with the PLSS recharge station support structure. The IOPS's with adapter frame are on the mounting structure on the cabin floor, near the forward hatch. Each IOPS is approximately 7.5 inches high, 8.5 inches wide, and 17 inches in depth. It weighs approximately 37 pounds. The IOPS holds 4 pounds of usable oxygen, stored at a pressure of 7,500±750 psig. Each IOPS has a pressure regulator, a shutoff valve, and an umbilical hose with a check valve at the PGA end. In use, the IOPS is set on top of the PLSS and the IOPS hose is unstowed and connected to the PGA left oxygen outlet receptacle. The PGA diverter valve diverts oxygen into the PGA. In an emergency, each IOPS can supply oxygen for a half hour.

2.11.2.7 EMU Maintenance Kit.

The EMU maintenance kit consists of an accumulator key for the PLSS, lubricant, spare O-rings, and patching tape for repair of the EMU. The kit is stowed in the helmet stowage bag until needed for extravehicular activity.

2.11.3 UMBILICAL ASSEMBLY.

The umbilical assembly consists of hoses and connectors for securing the PGA to the ECS, CS, and IS. Separate oxygen and electrical umbilicals connect to each astronaut.

2.11.3.1 Oxygen Umbilical.

The oxygen umbilical consists of silicon rubber hoses (1.25-inch inside diameter) with wire reinforcement. The connectors are of the quick-disconnect type, with a 1.25-inch, 70° elbow at the PGA end. Each assembly is made up of two hoses and a dual-passage connector at the ECS end and two separate hoses (supply and exhaust) at the PGA end. When not connected to the PGA, the ECS connector end remains attached and the hoses stowed. The hoses are fastened together with keepers.

2.11.3.2 Electrical Umbilical.

The electrical umbilical carries voice communications and biomedical data, and electrical power for warning tone impulses.

2.11.4 CREW LIFE SUPPORT.

The crew life support equipment includes food and water, a waste management system, personal hygiene items, and medical equipment for in-flight emergencies.

2.11.4.1 Food and Water.

A potable-water unit and food packages contain sufficient life-sustaining supply for completion of the LM mission.

2.11.4.1.1 Crew Water System.

The water dispenser assembly consists of an aluminum mounting bracket, a coiled hose, and a button-actuated, metering water dispenser. The hose and dispenser extend approximately 72 inches to dispense water from the ECS water feed control assembly.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

After the hose is removed from the ECS package and mated to the metering water dispenser, the ECS water feed control valve is opened to permit water flow. The dispenser assembly supplies water at +50° to +90° F for drinking or food preparation. The water dispenser is inserted directly into the mouth for drinking. Pressing a trigger-type control supplies half-ounce quantities of water. The quantity dispensed is recorded by a meter (counter).

2.11.4.1.2 Food Preparation and Consumption.

The astronaut's food supply (3,200 calories per man per day) includes liquids and solids with adequate nutritional value and low waste content. Food packages are stowed in the LM midsection, on the shelf above PLSS No. 1.

The food is vacuum packed in plastic bags that have one-way poppet valves into which the water dispenser can be inserted. Another valve allows food passage for eating. The food bags are packaged in aluminum-foil-backed plastic bags for stowage and are color coded: red (breakfast), white (lunch) and blue (snacks).

Food preparation involves reconstituting the food with water. The food bag poppet-valve cover is cut with scissors and pushed over the water dispenser nozzle after its protective cover is removed. Pressing the water dispenser trigger releases half ounces of water. The desired consistency of the food determines the quantity of water added. After withdrawing the water dispenser nozzle, the protective cover is replaced and the dispenser returned to its stowage position. The food bag is kneaded for approximately 3 minutes, after which the food is considered reconstituted. After cutting off the neck of the food bag, food can be squeezed into the mouth through the food-passage valve. A germicide tablet, attached to the outside of the food bag, is inserted into the bag after food consumption, to prevent fermentation and gas formation. The bag is rolled to its smallest size, banded, and placed in the waste disposal compartment.

2.11.4.2 EMU Waste Management System. (See figure 2-186.)

The EMU waste management system provides for the disposal of body waste through use of a fecal containment system, a urine collection and transfer assembly, and for neutralizing odors. The fecal containment system is composed of a pair of elastic underwear shorts with an absorbent liner in the rear half and an opening for scrotum and penis. The shorts are worn under the LCG. The urine collection and transfer assembly is a rubberized bag for receiving and containing urine. It is worn over the LCG and is connected with tubing to the PGA urine transfer connector. Personal hygiene items are stowed in the food supply container on the midsection left shelf.

2.11.4.2.1 Waste Fluid Transfer.

Waste fluids are transferred to a waste fluid collector assembly by a controlled difference in pressures between the PGA and cabin (ambient). The primary waste fluid collector consists of a long transfer hose, control valve, short transfer hose, and a 8,900-cc multilaminate bag. The long transfer hose is stowed on a connector plate when not in use. To void his in-suit urine container, the astronaut attaches the hose to the PGA quick-disconnect, which has a visual flow indicator. Rotating the handle of the spring-loaded waste control valve controls passage of urine to the assembly. The 8,900-cc bag is in the PLSS LiOH storage unit, with the short transfer hose connected between the waste control valve and the bag.

With cabin pressure normal (4.8 psia), the long transfer hose is removed from the connector stowage plate and attached to the PGA male disconnect. The PGA is over-pressurized by 1.0 psia and the waste control valve is opened. Urine flows from the PGA to the collector assembly at a rate of approximately 200 cc per minute.

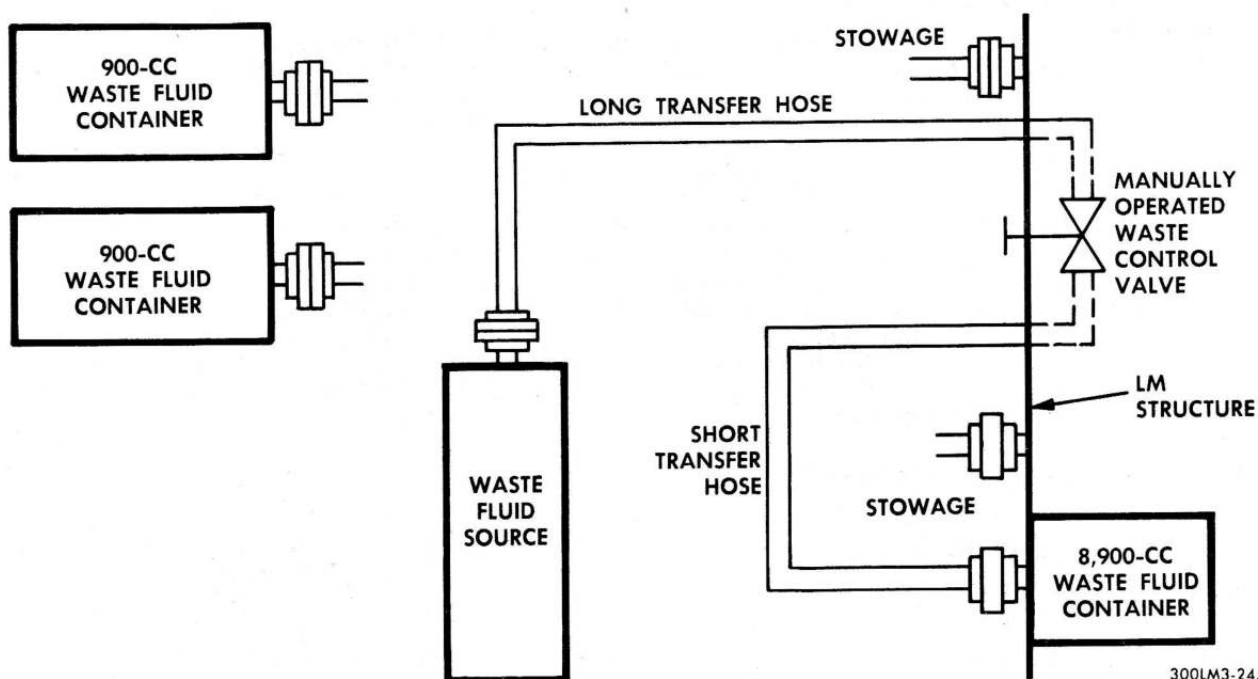


Figure 2-186. Waste Management System

A secondary waste fluid collector system provides 900-cc bags, which attach directly to the PGA. Urine is transferred directly from the PGA, through the connectors, to the bags. These bags can then be emptied into the 8,900-cc collector assembly.

2.11.4.2.2 Fecal Containment System.

The fecal containment system consists of an outer bag (with an enclosing three-layer, laminated-mylar-film fabric) that has a sealing zipper and a smaller inner bag. The inner bag has waxed tissue on its adhesive inner surface. Polyethylene-backed toilet tissue and a disinfectant package are stored on the inner bag.

To defecate, the astronaut removes the inner fecal bag from the outer bag. After unfastening the PGA and removing undergarments, the waxed tissue is peeled off the bag's adhesive inner surface and the bag is placed securely over the anal area. After defecating, the used toilet tissue is deposited in the used fecal bag and the disinfectant package is pinched and broken inside the bag. The used bag is then closed, kneaded, and inserted in the outer bag. The zipper is closed to seal the outer bag, which is then placed in the waste disposal compartment.

2.11.4.3 Personal Hygiene Items.

Personal hygiene items consist of wet and dry cleansing cloths, chemically treated and sealed in plastic covers, and packs of ingestible chewing gum. The cloths measure 4 by 4 inches and are folded into 2-inch squares. They are stored in the food package container along with the teeth-cleansing ingestible gum.

2.11.5 MEDICAL EQUIPMENT.

The medical equipment consists of biomedical sensors, personal radiation dosimeters, and emergency medical equipment.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

2.11.5.1 Bio Instrumentation.

The biomedical sensors gather physiological data for telemetry. Government-furnished impedance pneumographs continuously record heart beat (EKG) and respiration rate. Each assembly (one for each astronaut) has four electrodes which contain electrolyte paste; they are attached with tape to the astronaut's body.

2.11.5.2 Personal Radiation Dosimeters.

The dosimeters are small ionization chambers used to detect radiation. They contain thermoluminescent powder, nuclear emulsions, and film that is sensitive to beta, gamma, and neutron radiation. Six dosimeters are provided for each astronaut. They are placed on the forehead or right temple, chest, wrist, thigh, and ankle to detect radiation to eyes, bone marrow, and skin. Serious, perhaps critical, damage results if radiation dosage exceeds a predetermined level. For quick, easy reference each astronaut has a dosimeter mounted on his EMU. Dosimeters are government-furnished equipment.

2.11.5.3 Emergency Medical Equipment.

The emergency medical equipment consists of a kit of six capsules: four pain killers (Darvon) and two pep pills (Dexedrine). The kit is attached to the interior of the food compartment, readily accessible to both astronauts. The emergency medical equipment is government furnished.

2.11.6 CREW SUPPORT AND RESTRAINT EQUIPMENT. (See figure 2-187.)

The crew support and restraint equipment includes armrests, handholds (grips), Velcro on the floor to interface with the PGA boots, and a restraint assembly operated by a rope-and-pulley arrangement that secures the astronauts in an upright position under zero-g conditions.

2.11.6.1 Armrests.

The armrests, at each astronaut station, provide stability for operation of the thrust/translation controller assembly and the attitude controller assembly, and restrain the astronaut laterally. The armrests are adjustable (four positions) to accommodate the astronaut; they also have stowed (fully up) and docking (fully down) positions. The armrests, held in position by spring-loaded detents, can be moved from the stowed position by grasping them and applying downward force (30 pounds). Other positions are selected by pressing latch buttons on the armrest forward area. Shock attenuators are built into the armrests for protection against positive-g forces (lunar landing). The maximum energy absorption of the armrest assembly is a 200-pound force, which will cause a 4-inch armrest deflection.

2.11.6.2 Handholds.

The handholds, at each astronaut station and at various locations around the cabin, provide support for the upper torso when activity involves turning, reaching, or bending; they attenuate movement in any direction. The forward panel handholds are single upright, peg-type, metal grips. They are fitted into the forward bulkhead, directly ahead of the astronauts, and can be grasped with the left or right hand.

2.11.6.3 Restraint Assembly.

The restraint assembly consists of ropes, restraint rings, and a constant-force reel system. The ropes attach to D-rings on the PGA sides, waist high. Two pins (docking adjustments) attach to the rope assembly on the PGA outboard and inboard sides. For side-to-side movement, the pin associated with left or right movement is inserted in the forward reel assembly receptacle in panel 3 (lighting panel) and the constant-force reel is locked. The constant-force reel control provides a downward

CREW PERSONAL EQUIPMENT

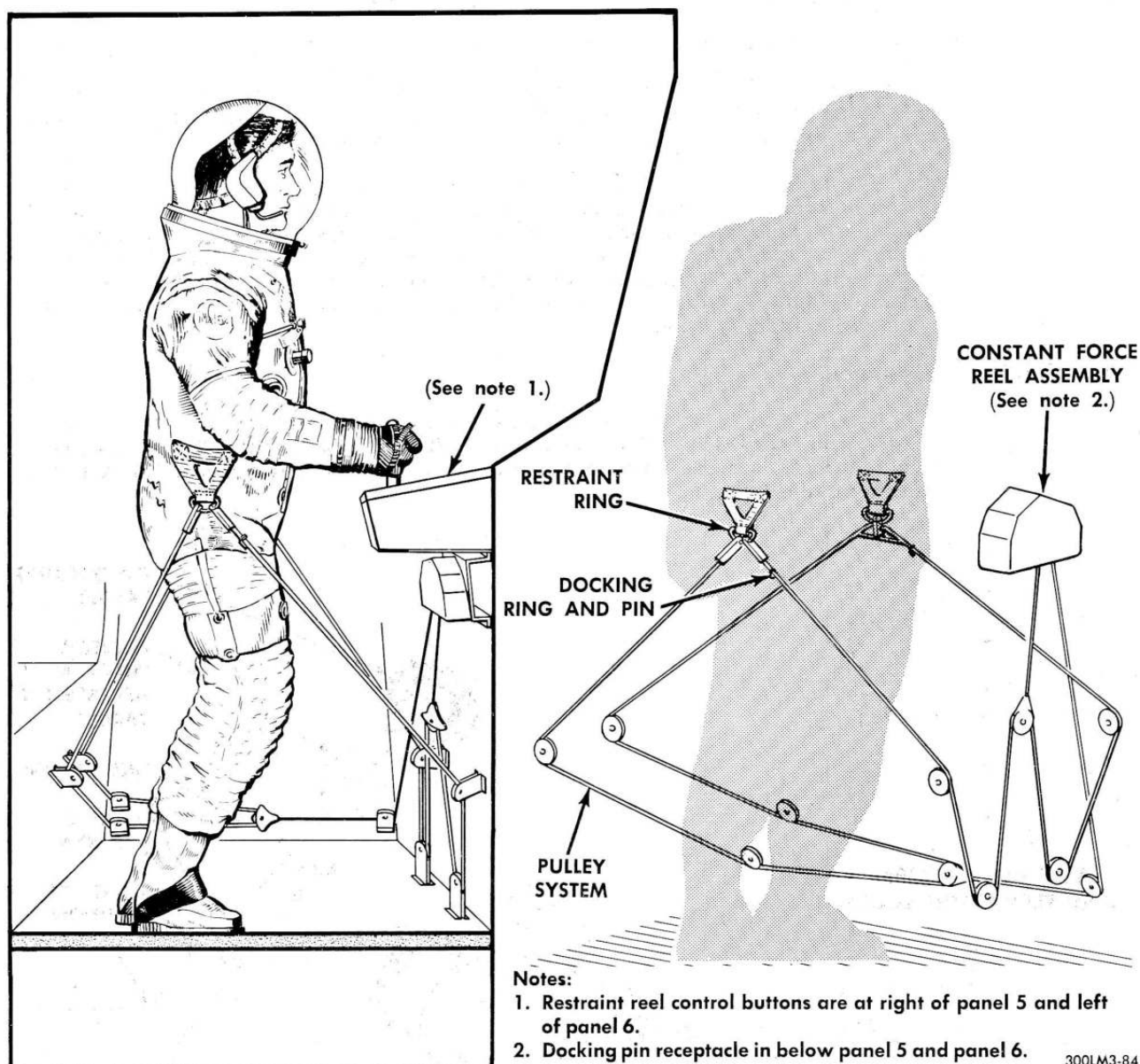


Figure 2-187. Restraint Equipment

force of approximately 30 pounds; it is locked during landing or docking operations. When the constant-force reel is locked, the ropes are free to reel in. A ratchet stop prevents paying out of the ropes and thus provides zero-g restraint. During docking maneuvers, the commander uses pin adjustments to enable him to use the crewman optical alignment sight (COAS) at the overhead (docking) window.

2.11.7

DOCKING AIDS AND TUNNEL HARDWARE.

Docking operations require special equipment and tunnel hardware to effect linkup of the LM with the CSM. Docking equipment includes the COAS and a docking target. A drogue assembly, probe assembly, CM forward hatch, and hardware inside the LM tunnel enable completion of the docking maneuver.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

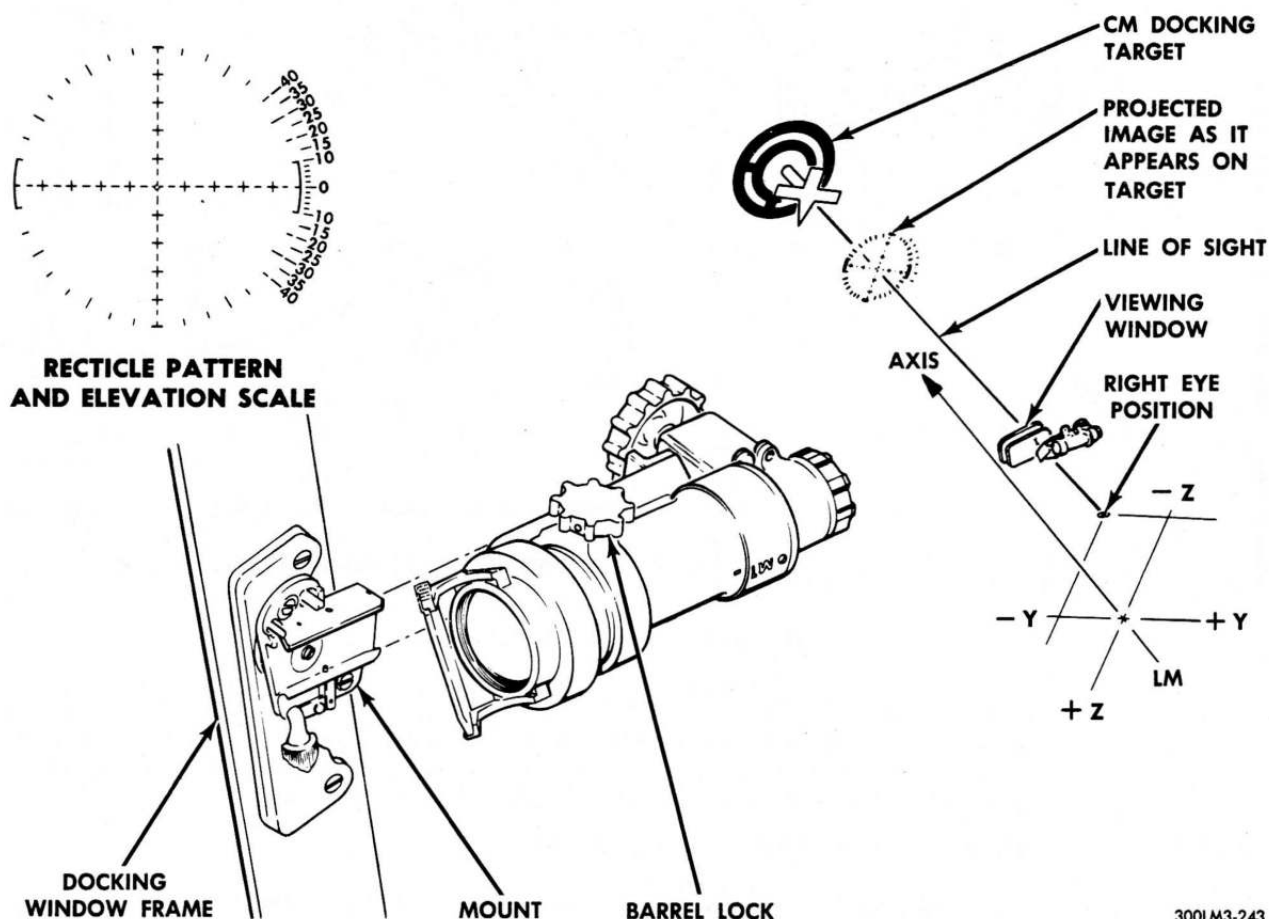
2.11.7.1 Crewman Optical Alignment Sight. (See figure 2-188.)

The COAS provides the Commander with gross range cues and closing rate cues during the docking maneuver. The closing operation, from 150 feet to contact, is an ocular, kinesthetic coordination that requires control with minimal use of fuel and time. The COAS provides the Commander with a fixed line-of-sight attitude reference image, which appears to be the same distance away as the target.

The COAS is a collimating instrument. It weighs approximately 1.5 pounds, is 8 inches long, and operates from a 28-volt, d-c power source. The COAS consists of a lamp with an intensity control, a reticle, a barrel-shaped housing and mounting track, and a combiner and power receptacle. The reticle has vertical and horizontal 10° gradations in a 10° segment of the circular combiner glass, on an elevation scale (right side) of -10° to +31.5°. The COAS is capped and secured to its mount above the overhead (docking) window.

2.11.7.1.1 Operation.

The COAS is installed in its docking-window position, which is also its stowed position, and the COAS switch (panel 8) is set from OFF to OVHD. The intensity control is turned clockwise until the reticle appears on the combiner glass; it is adjusted for required brightness.



300LM3-243

Figure 2-188. Crewman Optical Alignment Sight

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

2.11.7.2 Docking Target. (See figure 2-189.)

The docking target permits docking to be accomplished on a three-dimensional alignment basis. The target is located at the intersection of +Y46.3 and +Z203; it does not protrude beyond the LM launch configuration envelope or the maximum contact envelope. The target consists of an inner circle and a standoff cross of radioluminescent green within an outer circumference of Dayglo orange. The target-base diameter is 17.68 inches. The standoff cross is centered 15 inches higher than the base and, as seen at the intercept, is parallel to the X-axis and perpendicular to the Y-axis and the Z-axis.

2.11.7.3 Drogue Assembly.

The drogue assembly consists of a conical structure mounted within the LM docking tunnel. It is secured at three points on the periphery of the tunnel, below the LM docking ring. The LM docking ring is part of the LM midsection outer structure, concentric with the X-axis. The drogue assembly can be removed from the CSM end or LM end of the tunnel.

Basically, the assembly is a three-section aluminum cone that is secured with mounting lugs to the LM tunnel ring structure. A lock and release mechanism on the probe, controls capture of the CSM probe at CSM-LM contact. Handles are provided to release the drogue from its tunnel mounts.

2.11.7.4 Tunnel Hardware.

The tunnel contains hardware essential to final docking operations. This includes connectors for the electrical umbilicals, docking latches, probe mounting lugs, tunnel lights, and deadfacing switches. Refer to paragraph 2.11.8.2, for the tool required in docking.

2.11.7.5 Probe Assembly.

The probe assembly provides initial CSM-LM coupling and attenuates impact energy imposed by vehicle contact. The probe assembly may be folded for removal and for stowage within either end of the CSM transfer tunnel.

2.11.7.6 CM Forward Hatch.

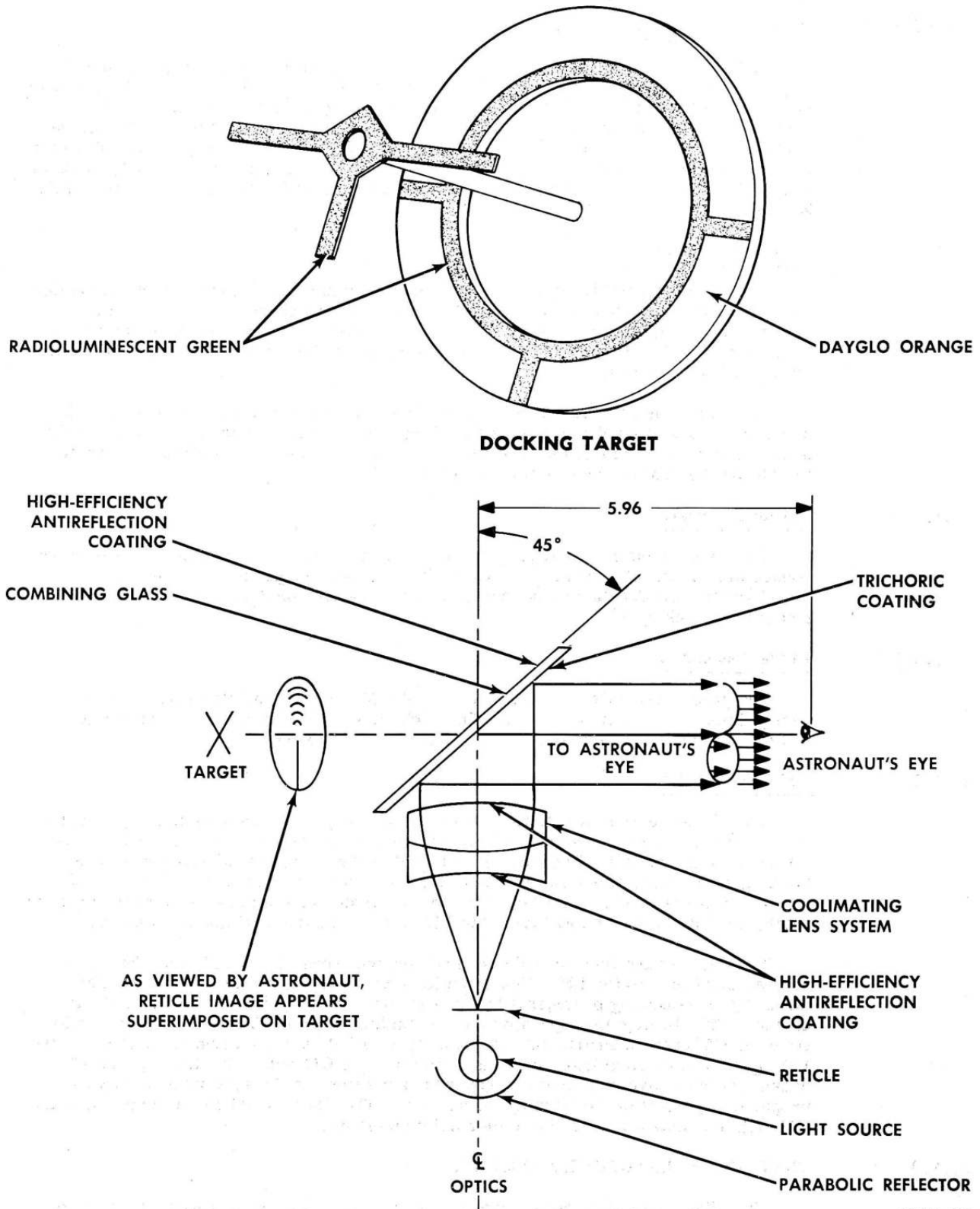
The CM tunnel has two forward hatches: an inner (forward pressure) hatch and an outer (forward thermal) hatch. The forward pressure hatch can be removed into the CM crew compartment. The hatch is retained at the aft end of the CM tunnel by a latching mechanism whose linkage is driven from the crew compartment by a handle off-center of the hatch. A socket opposite the handle, on the tunnel side of the pressure hatch, permits hatch removal from the LM side, using the in-flight tool (tool B).

The CM forward thermal hatch can be removed from the tunnel, into the CM crew compartment or into the LM. The hatch is retained at the forward end of the CM tunnel by an expanding peripheral latching mechanism, which also serves as a water barrier. The linkage that operates the mechanism is driven by an off-center handle, from the CM crew compartment side, and by a socket, using emergency tool B, on the LM side. The thermal hatch is reinstalled from the CM side only; three of the 12 docking latches have expendable stops, which position the thermal hatch axially for proper engagement of the latching mechanism. The CM thermal hatch is stowed in the CM right equipment bay, within a thermal stowage bag.

2.11.8 CREW MISCELLANEOUS EQUIPMENT.

Miscellaneous equipment required for completion of crew operations consists of in-flight data with checklists, tool, ingress and egress accessories, window shades, and an alignment optical telescope (AOT) platform.

LMA790-3-LM 3
 APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA



300LM3-244

Figure 2-189. COAS Schematic and Docking Target

CREW PERSONAL EQUIPMENT

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

2.11.8.1 In-flight Data.

The in-flight data are provided in three polyethylene-coated kits. The Commander's checklist and the LM Pilot's checklist are stowed at their respective stations. The in-flight data kit is stowed in a stowage compartment. The kit includes the flight plan, experiments data and checklist, mission log and data book, systems data book, and star charts.

2.11.8.2 Tool B (See figure 2-190.)

The in-flight tool consists of tool B (emergency wrench), which, basically, is a modified Allen-head L-wrench. It is 6.25 inches long and has a 4.250-inch drive shaft with a 7/16-inch drive. The wrench can apply a torque of 1,475 inch-pounds; it has a ball-lock device to lock the head of the drive shaft. The wrench is stowed on the right side of the TMG stowage area inside the cabin. It is a contingency tool for use with the probe and drogue, battery removal from descent stage, CM hatch from outside, and with the water dispenser. Tool B is used for CM forward hatch operations from the LM side only.

2.11.8.3 Window Shades.

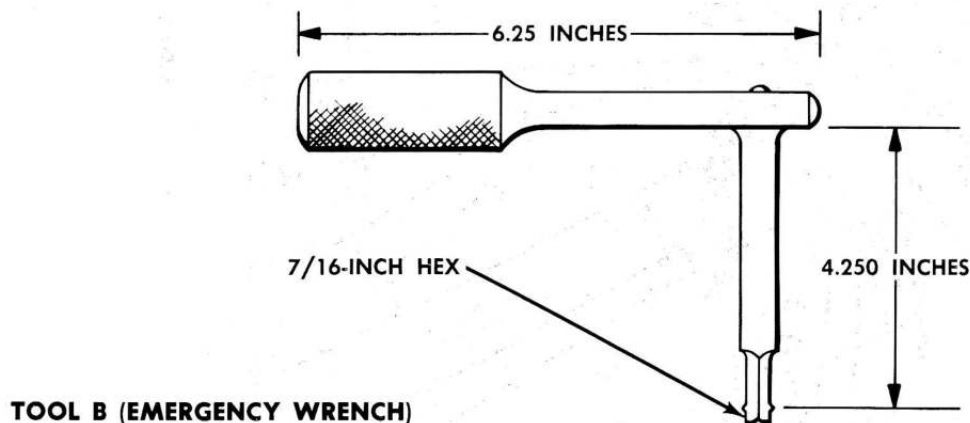
Window shades are used for the docking window and forward windows. The window shade material is Aclar. The surface facing outside the cabin has a highly reflective metallic coating. The shade is secured at the top (rolled position) with Velcro. To cover the window, the shade is unrolled and flattened against the frame area.

2.11.8.4 Alignment Optical Telescope Platform.

The AOT platform is a metal-trevarno, movable step. The platform is stowed against the bulkhead, aft of the Commander's station. To use the AOT, the platform is placed forward on the floor to provide a single step upward. Refer to paragraph 2.11.6.3 for restraint assembly adjustments.

2.11.9 STOWAGE LOCATIONS.

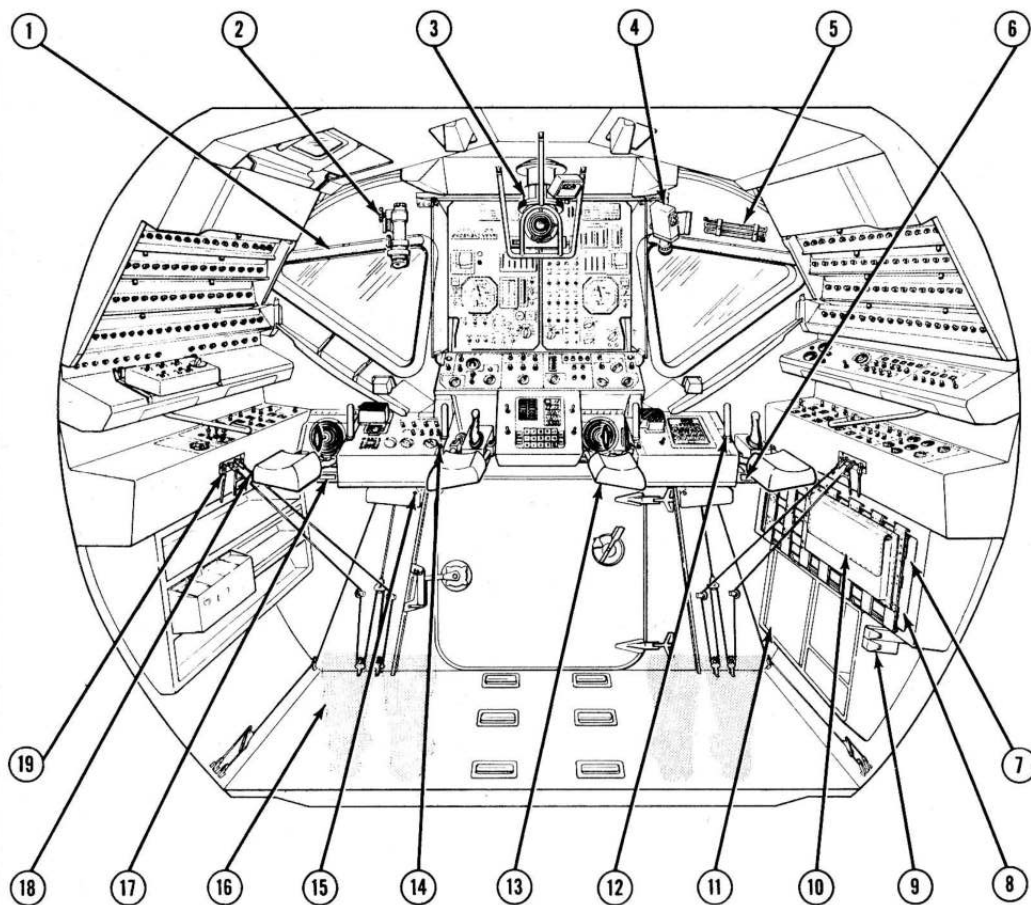
The stowage locations (figure 2-191) for crew personal equipment show actual stowage positions as accurately as possible. Some items can be shown only in areas closest to actual stowage locations. The equipment is identified as contractor-furnished equipment (CFE), government-furnished equipment (GFE), or government-furnished property (GFP).



TOOL B (EMERGENCY WRENCH)

300LM3-247

Figure 2-190. Tool B

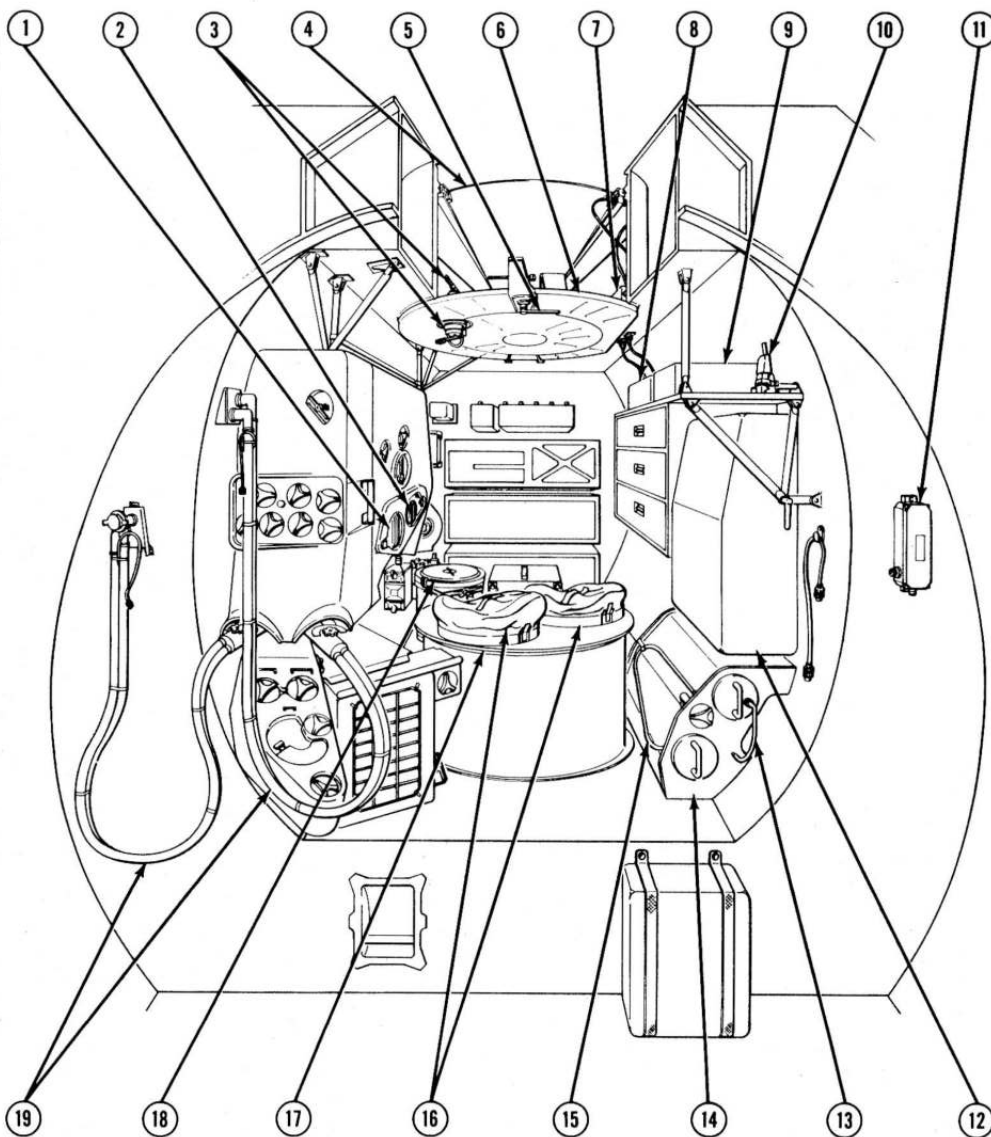


VIEW LOOKING FORWARD

Item	Nomenclature	Location	Remarks
1	Window shades (3)	Rolled above windows	CFE
2	Crewman optical alignment sight	Left forward window	Move to docking window for use. CFE
3	Alignment optical telescope	Center forward over panel 1 and 2	GFE
4	16-mm camera (film and lens)	Above right window	GFP
5	Power cable	Above right forward window	CFE
6	LMP's checklist	Below attitude controller assembly	CFE
7	TMG stowage compartment: TMG, Tool kit pouch, urine bags, Defecation device, Emesis bag, and waste container	Lower right of LMP	CFE
8	TV cable	Lower right of TMG stowage	GFP
9	Tool B Emergency wrench	Lower right TMG stowage	GFE
10	Flight data file and charts	On face of TMG stowage	CFE
11	Radiation survey meter	Lower left of TMG stowage	GFF
12	Handgrips (4)	Forward of CDR's and LMP's stations	CFE
13	Armrests	CDR's and LMP's stations	CFE
14	Restraint reel controls	Lower right panel 5 and lower left panel 6	CFE
15	Docking pin receptacle	Below panels 5 and 6	CFE
16	Personal equipment on PGA: marking pen, mechanical pencil, scissors, penlight, sunglasses and pouch, watch band and chronograph, bioinstruments, and helmets	Various places on PGA	On crewman GFP
17	CDR's checklist	Below thrust/translation controller assembly	CFE
18	Docking rings	On restraint harness cable	CFE
19	Restraint ropes and hooks	CDR's and LMP's stations	Attach to crewman for use. CFE
20	Oxygen purge system	TBD	

300LM3-259-1

Figure 2-191. Stowage Locations (Sheet 1 of 2)



VIEW LOOKING AFT

Item	Nomenclature	Location	Remarks
1	LiOH cartridge (ECS)	— Z27 bulkhead	CFE
2	LiOH cartridge (PLSS)		CFE
3	Cabin relief and dump valve and handle	Upper side of upper hatch	CFE
4	Dump valve control, drogue, hardware, and hatch steps,	Inside upper hatch	Reference
5	Tool B (emergency wrench)	Cabin side of upper hatch	On hatch cover in use CFE
6	Upper hatch and tunnel	Center aft overhead	Reference
7	Power umbilical	Inside upper hatch	CFE
8	Emergency medical kit	Front flap of food stowage	GFP
9	Food package and personal hygiene kit	Shelf above PLSS No. 1	GFP
10	Water dispenser (probe)	In cradle (above PLSS NO. 1)	GFP
11	Data storage electronics assembly	+ Z27 bulkhead	CFE
12	PLSS	Left side — Z27 bulkhead	GFE
13	Long waste fluid hose	Attached, waste management	CFE
14	Waste management section	Below PLSS	CFE
15	Short waste fluid hose	Attached, waste management	CFE
16	Helmet stowage bags, EVA gloves, and EMU maintenance kit	Ascent engine cover	CFE/GFP
17	Ascent engine cover	Midsection aft	Reference
18	LiOH cartridge container	Midsection aft (ascent engine cover)	CFE
19	ECS umbilicals	+ Z27 bulkhead	CFE
20	Oxygen purge system	TBD	

300LM3-259-2

Figure 2-191. Stowage Locations (Sheet 2 of 2)

SECTION 3
CONTROLS AND DISPLAYS

INTRODUCTION

This section contains detailed descriptions of the LM 3 controls and displays. A cross-reference system, which permits quick and easy reference to any control or display, is provided in table 3-1. This table lists each item alphabetically, the item reference designation, the panel that contains the item, and the page number.

Figures 3-1, 3-2, and 3-3, at the end of this section, show the controls and displays, panel areas, and panel numbers.

Column headings for the tabular presentation, together with a description of the entries made under each, are as follows:

- Location/Ref Des. Gives the location of a particular control or display in LM 3, by panel number and reference designation, as required.
- Name and Position. Gives the placarded nomenclature of the control or display and the control positions exactly as placarded on the panel. In the absence of placards, a functional name is used for the nomenclature, and the control position is described.
- Function. Gives a brief description of the function of the control or display.
- Circuit Breaker. Gives the nomenclature and location of circuit breaker(s) that controls the electrical power to the control or display.
- Power Source. Gives the rating and nomenclature of the immediate bus or source that supplies power to the control or display.
- Remarks. Contains additional data and explanatory remarks.

Display behavior varies for different malfunction conditions. A list of malfunction conditions and resulting display behavior follows the controls and displays tabulation.

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
CONTROLS AND DISPLAYS

Table 3-1. Controls and Displays - Alphabetical Index

NAME AND REFERENCE DESIGNATION	PANEL NO.	PAGE NO.
#1 ASC O ₂ valve control (7H21)	ECS	3-134
#2 ASC O ₂ valve control (7H5)	ECS	3-134
+X TRANSL pushbutton (1S12)	5	3-73
-A-		
ABORT STAGE pushbutton (1S14)	1	3-28
ABORT pushbutton (1S13)	1	3-28
AC BUS A: AC BUS VOLT circuit breaker (4CB27)	11	3-90
AC BUS A: AOT LAMP circuit breaker (4CB212)	11	3-90
AC BUS A: BUS TIE INV 1 circuit breaker (4CB23)	11	3-90
AC BUS A: BUS TIE INV 2 circuit breaker (4CB24)	11	3-90
AC BUS A: CDR FDAI circuit breaker (4CB209)	11	3-91
AC BUS A: CDR WIND HTR circuit breaker (4CB144)	11	3-90
AC BUS A: DECA GMBL circuit breaker (4CB207)	11	3-90
AC BUS A: GASTA circuit breaker (4CB201)	11	3-91
AC BUS A: INTGL LTG circuit breaker (4CB211)	11	3-90
AC BUS A: RNDZ RDR circuit breaker (4CB206)	11	3-90
AC BUS A: RNG/RNG RT; ALT/ALT RT circuit breaker (4CB204)	11	3-91
AC BUS A: TAPE RCDR circuit breaker (4CB202)	11	3-90
AC BUS B: AGS circuit breaker (4CB203)	11	3-89
AC BUS B: AOT LAMP circuit breaker (4CB214)	11	3-89
AC BUS B: BUS TIE INV 1 circuit breaker (4CB185)	11	3-89
AC BUS B: BUS TIE INV 2 circuit breaker (4CB186)	11	3-89
AC BUS B: He/PQGS PROPUL DISP circuit breaker (4CB169)	11	3-89
AC BUS B: NUM LTG circuit breaker (4CB200)	11	3-89
AC BUS B: ORDEAL circuit breaker (4CB226)	11	3-89
AC BUS B: S-BD ANT circuit breaker (4CB34)	11	3-89
AC BUS B: SE FDAI circuit breaker (4CB210)	11	3-89
AC BUS B: SE WIND HTR circuit breaker (4CB152)	11	3-89
ACA/4 JET switches (CDR & LMP) (1S21) (1S23)	4	3-67
Address indicator (12M1)	6	3-79
AGS STATUS switch (12S17)	6	3-79
AGS warning light (6DS8)	1	3-14
ALT SET control (9R1)	ORDEAL	3-144
Altitude/range indicator (9M9)	1	3-20
AMPS indicator (4M3)	14	3-113
ANUN OVERRIDE switch (16S4)	5	3-75
ANUN/NUM control (16R2)	5	3-77
ASC He SEL switch (2S3)	8	3-83
ASC HI REG caution light (6DS21)	2	3-31
ASC H ₂ O valve (7H13)	ECS	3-136
ASC PRESS warning light (6DS2)	1	3-13
ASC QTY caution light (6DS22)	2	3-31
ASCENT He REG 1 talkback (10FL1)	1	3-26
ASCENT He REG 1 switch (10S3)	1	3-25
ASCENT He REG 2 talkback (10FL2)	1	3-26
ASCENT He REG 2 switch (10S4)	1	3-26
ATTITUDE CONTROL: PITCH switch (11S3)	3	3-60
ATTITUDE CONTROL: ROLL switch (11S4)	3	3-60
ATTITUDE CONTROL: YAW switch (11S5)	3	3-60
Attitude controller (CDR) (1A1)	ACA	3-142
Attitude controller (LMP) (1A2)	ACA	3-142
ATTITUDE MON switch (CDR) (9S3)	1	3-20
ATTITUDE MON switch (LMP) (9S10)	2	3-52
AUDIO CONT switch (15BS5)	8	3-87
AUDIO CONT switch (15AS5)	12	3-104
-B-		
BAL CPL switch (1S9)	1	3-25
BAT FAULT component caution light (4DS1)	14	3-113

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
CONTROLS AND DISPLAYS

Table 3-1. Controls and Displays - Alphabetical Index (cont)

NAME AND REFERENCE DESIGNATION	PANEL NO.	PAGE NO.
-B-		
BAT 5 BACK UP CDR FEED switch (4S12)	14	3-121
BAT 5 BACK UP CDR FEED talkback (4FL7)	14	3-121
BAT 5 NORMAL SE FEED switch (4S10)	14	3-120
BAT 5 NORMAL SE FEED talkback (4FL5)	14	3-120
BAT 6 BACK UP SE FEED switch (4S13)	14	3-122
BAT 6 BACK UP SE FEED talkback (4FL8)	14	3-122
BAT 6 NORMAL CDR FEED switch (4S11)	14	3-120
BAT 6 NORMAL CDR FEED talkback (4FL6)	14	3-121
BATTERY caution light (6DS27)	2	3-32
-C-		
C-BAND PWR switch (19S1)	11	3-101
C/W PWR caution light (6DS34)	2	3-33
CABIN GAS RETURN valve (7H17)	ECS	3-137
CABIN PRESS indicator (7M2A)	2	3-49
Cabin relief and dump valve lever (forward and upper hatches) (7H11) (7H20) . .	ECS	3-139
CABIN REPRESS valve (7H3)	ECS	3-133
CABIN TEMP indicator (7M3A)	2	3-49
Cabin TEMP valve (7H12)	ECS	3-139
CABIN warning light (6DS16)	1	3-15
CAMR: SEQ circuit breaker (4CB33)	16	3-131
CDR BAT 3 HI VOLTAGE switch (4S3)	14	3-117
CDR BAT 3 LOW VOLTAGE switch (4S7)	14	3-117
CDR BAT 3 talkback (4FL3)	14	3-118
CDR BAT 4 HI VOLTAGE switch (4S4)	14	3-118
CDR BAT 4 LOW VOLTAGE switch (4S8)	14	3-118
CDR BAT 4 talkback (4FL4)	14	3-119
CES AC warning light (6DS6)	1	3-13
CES DC warning light (6DS7)	1	3-13
CLR pushbutton (CDR) (3S5)	4	3-70
CLR pushbutton (LMP) (12S13)	6	3-80
CO ₂ CANISTER SEL valve (7H19)	ECS	3-137
CO ₂ component caution light (7DS6)	2	3-53
COAS switch (16S14)	8	3-88
COMM: CDR AUDIO circuit breaker (4CB86)	11	3-97
COMM: DISP circuit breaker (4CB153)	16	3-127
COMM: PMP circuit breaker (4CB102)	16	3-128
COMM: PRIM S-BD PWR AMPL circuit breaker (4CB30)	16	3-128
COMM: PRIM S-BD XMTR/RCVR circuit breaker (4CB111)	16	3-128
COMM: S-BD ANT circuit breaker (4CB110)	16	3-128
COMM: SE AUDIO circuit breaker (4CB85)	16	3-128
COMM: SEC S-BD PWR AMPL circuit breaker (4CB136)	11	3-97
COMM: SEC S-BD XMTR/RCVR circuit breaker (4CB137)	11	3-97
COMM: TV circuit breaker (4CB104)	16	3-129
COMM: UP DATA LINK circuit breaker (4CB228)	11	3-97
COMM: VHF A RCVR circuit breaker (4CB87)	11	3-97
COMM: VHF A XMTR circuit breaker (4CB115)	16	3-128
COMM: VHF B RCVR circuit breaker (4CB114)	16	3-128
COMM: VHF B XMTR circuit breaker (4CB162)	11	3-97
COMPTR ACTY indicator (3DS15)	4	3-69
CRSFD switch (8S20)	2	3-46
CRSFD talkback (8FL17)	2	3-47
-D-		
DC BUS FAULT component caution light (4DS2)	14	3-113
Data display registers (CDR) (3M4) (3M5) (3M6)	4	3-70
Data indicator (LMP) (12M2)	6	3-79
DC BUS warning light (6DS14)	1	3-15

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
CONTROLS AND DISPLAYS

Table 3-1. Controls and Displays - Alphabetical Index (cont)

NAME AND REFERENCE DESIGNATION	PANEL NO.	PAGE NO.
-D-		
DEAD BAND switch (11S2)	3	3-59
DES BATS switch (4S9)	14	3-119
DES BATS talkback (4FL9)	14	3-119
DES ENG CMD OVRD switch (1S15)	3	3-55
DES ENG OVRD circuit breaker (4CB233)	16	3-126
DES H ₂ O valve (7H26)	ECS	3-136
DES O ₂ valve (7H15)	ECS	3-134
DES PROPULSION FUEL VENT switch (10S9)	8	3-81
DES PROPULSION FUEL VENT talkback (10FL5)	8	3-81
DES PROPULSION OXID VENT switch (10S10)	8	3-81
DES PROPULSION OXID VENT talkback (10FL6)	8	3-82
DES PRPLNT ISOL VLV switch (2S9)	8	3-82
DES QTY warning light (6DS4)	1	3-13
DES RATE switch (1S5)	5	3-73
DES REG warning light (6DS3)	1	3-13
DES VENT switch (2S6)	8	3-82
DESCENT He REG 1 switch (10S5)	1	3-27
DESCENT He REG 1 talkback (10FL3)	1	3-27
DESCENT He REG 2 switch (10S7)	1	3-27
DESCENT He REG 2 talkback (10FL4)	1	3-28
-E-		
EARTH-LUNAR switch (9S25)	ORDEAL	3-144
ECS caution light (6DS36)	2	3-34
ECS: CABIN FAN 1 circuit breaker (4CB107)	11	3-96
ECS: CABIN FAN 2 circuit breaker (4CB108)	16	3-129
ECS: CABIN FAN CONT circuit breaker (4CB109)	16	3-129
ECS: CABIN REPRESS circuit breaker (4CB113)	16	3-129
ECS: CO ₂ SENSOR circuit breaker (4CB84)	16	3-130
ECS: DISP circuit breaker (4CB140)	16	3-129
ECS: DIVERT VLV circuit breaker (4CB112)	16	3-130
ECS: GLYCOL PUMP 1 circuit breaker (4CB117)	11	3-97
ECS: GLYCOL PUMP 2 circuit breaker (4CB141)	11	3-97
ECS: GLYCOL PUMP AUTO TRNFR circuit breaker (4CB217)	11	3-97
ECS: GLYCOL PUMP SEC circuit breaker (4CB96)	16	3-129
ECS: PRIM GLYCOL EVAP FLOW circuit breaker (4CB98)	16	3-129
ECS: SUIT FAN Δ P circuit breaker (4CB120)	16	3-130
ECS: SUIT FAN 1 circuit breaker (4CB138)	11	3-96
ECS: SUIT FAN 2 circuit breaker (4CB119)	16	3-129
ECS: SUIT FLOW CONT circuit breaker (4CB234)	16	3-127
ECS: SUIT/CABIN REPRESS circuit breaker (4CB235)	16	3-127
ED: LDG GEAR FLAG circuit breaker (4CB149)	11	3-95
ED: LOGIC PWR A circuit breaker (4CB76)	11	3-96
ED: LOGIC PWR B circuit breaker (4CB75)	16	3-125
ED VOLTS switch (4S17)	14	3-113
ENG ARM switch (1S1)	1	3-24
ENG GMBL switch (1S8)	3	3-55
Engine START pushbutton (1S2)	5	3-73
Engine STOP pushbutton (CDR) (1S3)	5	3-73
Engine STOP switch (LMP) (1S4)	6	3-79
ENTR pushbutton (DEDA) (12S14)	6	3-80
ENTR pushbutton (DSKY) (3S8)	4	3-71
EPS: ASC ECA circuit breaker (4CB15)	11	3-100
EPS: ASC ECA circuit breaker (4CB14)	16	3-131
EPS: ASC ECA CONT circuit breaker (4CB6)	11	3-100
EPS: ASC ECA CONT circuit breaker (4CB7)	16	3-131
EPS: INV 1 circuit breaker (4CB12)	11	3-100
EPS: INV 2 circuit breaker (4CB13)	16	3-131
EPS: BAT FEED TIE (2) circuit breakers (4CB18) (4CB26)	11	3-99

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
CONTROLS AND DISPLAYS

Table 3-1. Controls and Displays - Alphabetical Index (cont)

NAME AND REFERENCE DESIGNATION	PANEL NO.	PAGE NO.
-E-		
EPS: BAT FEED TIE (2) circuit breakers (4CB17) (4CB25)	16	3-132
EPS: -CROSS TIE - BAL LOADS circuit breaker (4CB184)	11	3-99
EPS: -CROSS TIE - BAL LOADS circuit breaker (4CB183)	16	3-132
EPS: -CROSS TIE - BUS circuit breaker (4CB20)	11	3-99
EPS: -CROSS TIE - BUS circuit breaker (4CB19)	16	3-132
EPS: DC BUS VOLT circuit breaker (4CB22)	11	3-100
EPS: DC BUS VOLT circuit breaker (4CB21)	16	3-131
EPS: DES ECA circuit breaker (4CB10)	11	3-100
EPS: DES ECA circuit breaker (4CB11)	16	3-131
EPS: DES ECA CONT circuit breaker (4CB8)	11	3-99
EPS: DES ECA CONT circuit breaker (4CB9)	16	3-132
EPS: DISP circuit breaker (4CB16)	16	3-131
EPS: XLUNAR BUS TIE circuit breaker (4CB4)	11	3-99
EPS: XLUNAR BUS TIE circuit breaker (4CB5)	16	3-132
EVENT TIMER indicator (9M11)	1	3-16
EVENT TIMER RESET/COUNT switch (9S11)	3	3-63
EVENT TIMER SLEW CONT MIN switch (9S13)	3	3-64
EVENT TIMER SLEW CONT SEC switch (9S14)	3	3-64
EVENT TIMER TIMER CONT switch (9S12)	3	3-64
EXTERIOR LTG switch (16S2)	3	3-66
-F-		
FDAI 1 switch (9S23)	ORDEAL	3-143
FDAI 2 switch (9S24)	ORDEAL	3-143
Flight director attitude indicator (FDAI) (9M1)	1	3-20
Flight director attitude indicator (FDAI) (9M6)	2	3-51
FLIGHT DISPLAYS: CDR FDAI circuit breaker (4CB97)	11	3-93
FLIGHT DISPLAYS: COAS circuit breaker (4CB188)	11	3-93
FLIGHT DISPLAYS: GASTA circuit breaker (4CB88)	11	3-93
FLIGHT DISPLAYS: MISSION TIMER circuit breaker (4CB159)	11	3-92
FLIGHT DISPLAYS: ORDEAL circuit breaker (4CB227)	11	3-93
FLIGHT DISPLAYS: RNG/RNG RT; ALT/ALT RT circuit breaker (4CB123)	11	3-92
FLIGHT DISPLAYS: THRUST DISP circuit breaker (4CB168)	11	3-92
FLIGHT DISPLAYS: X-PNTR circuit breaker (4CB133)	11	3-92
FLOOD OVHD/FWD control (16R4)	3	3-66
FLOOD OVHD/FWD control (16R1)	5	3-76
FLOOD OVHD/FWD switch (16S6)	3	3-65
FLT DISP: EVENT TIMER/SE FDAI circuit breaker (4CB126)	16	3-123
FLT DISP: X-PNTR circuit breaker (4CB134)	16	3-123
FUEL QUANTITY indicator (10M5B)	1	3-18
FUNCTIONS PCM switch (13S4)	12	3-107
FUNCTIONS RANGE switch (13S1)	12	3-108
FUNCTIONS VOICE switch (13S6)	12	3-107
-G-		
GDA/RCCA caution light (6DS23)	2	3-31
GIMBAL LOCK condition indicator (3DS9)	4	3-68
GLYCOL caution light (6DS38)	2	3-34
GLYCOL component caution light (7DS3)	2	3-53
GLYCOL PRESS indicator (7M5A)	2	3-50
GLYCOL selector switch (7S3)	2	3-52
GLYCOL TEMP indicator (7M5B)	2	3-49
GUID CONT switch (9S6)	1	3-21
GYRO TEST POS RT switch (11S1)	3	3-59
GYRO TEST ROLL switch (11S7)	3	3-59

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
CONTROLS AND DISPLAYS

Table 3-1. Controls and Displays - Alphabetical Index (cont)

NAME AND REFERENCE DESIGNATION	PANEL NO.	PAGE NO.
-H-		
H ₂ O QUANTITY indicator (7M4A)	2	3-50
H ₂ O SEP component caution light (7DS7)	2	3-53
He PRESS ASCENT switch (2S4)	8	3-84
He PRESS DES START switch (2S1)	8	3-84
He PRESS RCS switch (2S2)	8	3-83
HEATER caution light (6DS33)	2	3-33
HEATERS RCS SYS A/B-1: QUAD 1 circuit breaker (4CB218)	11	3-96
HEATERS RCS SYS A/B-1: QUAD 2 circuit breaker (4CB219)	11	3-96
HEATERS RCS SYS A/B-1: QUAD 3 circuit breaker (4CB220)	11	3-96
HEATERS RCS SYS A/B-1: QUAD 4 circuit breaker (4CB221)	11	3-96
HEATERS: AOT circuit breaker (4CB213)	11	3-94
HEATERS: DISP circuit breaker (4CB68)	16	3-130
HEATERS: DOCK WINDOW circuit breaker (4CB129)	11	3-94
HEATERS: LDG RDR circuit breaker (4CB157)	11	3-94
HEATERS: RNDZ RDR OPR circuit breaker (4CB155)	11	3-93
HEATERS: RNDZ RDR STBY circuit breaker (4CB156)	11	3-93
HEATERS: S-BD ANT circuit breaker (4CB31)	16	3-131
HEATERS: RCS SYS A/B-2: QUAD 1 circuit breaker (4CB222)	16	3-130
HEATERS: RCS SYS A/B-2: QUAD 2 circuit breaker (4CB223)	16	3-130
HEATERS: RCS SYS A/B-2: QUAD 3 circuit breaker (4CB224)	16	3-130
HEATERS: RCS SYS A/B-2: QUAD 4 circuit breaker (4CB225)	16	3-130
HELIUM indicator (10M1)	1	3-18
HELIUM MON switch (10S6)	1	3-30
HOLD pushbutton (12S16)	6	3-80
-I-		
ICS T/R switch (CDR) (15AS3)	8	3-86
ICS T/R switch (SE) (15BS3)	12	3-103
ICS VOLUME thumbwheel (CDR) (15AR7)	8	3-86
ICS VOLUME thumbwheel (LMP) (15BR7)	12	3-103
IMU CAGE switch (3S1)	1	3-23
INST: CWEA circuit breaker (4CB99)	16	3-127
INST: PCM/TE circuit breaker (4CB125)	16	3-127
INST: SIG CONDR 1 circuit breaker (4CB131)	11	3-94
INST: SIG CONDR 2 circuit breaker (4CB1)	16	3-127
INST: SIG SENSOR circuit breaker (4CB132)	16	3-127
INTEGRAL control (16R3)	5	3-77
INTEGRAL OVERRIDE switch (16S3)	5	3-76
INVERTER caution light (6DS26)	2	3-32
INVERTER switch (4S14)	14	3-114
ISS warning light (6DS10)	1	3-14
-K-		
KEY REL condition indicator (3DS7)	4	3-68
KEY REL pushbutton (3S7)	4	3-71
Keyboard pushbutton (DEDA) (12S1 thru 12S12)	6	3-80
Keyboard pushbuttons (DSKY) (3S10 thru 3S21)	4	3-71
-L-		
LAMP/TONE TEST selector switch (16S10)	3	3-66
LDG ANT switch (17S5)	3	3-55
LDG GEAR DEPLOY talkback (2FL1)	8	3-83
LDG GEAR DEPLOY switch (2S10)	8	3-83
LDG RDR caution light (6DS29)	2	3-33
LGC warning light (6DS9)	1	3-14
LIGHTING switch (9S26)	ORDEAL	3-144
LTG: ANUN DOCK/COMPNT circuit breaker (4CB146)	11	3-96

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
CONTROLS AND DISPLAYS

Table 3-1. Controls and Displays - Alphabetical Index (cont)

NAME AND REFERENCE DESIGNATION	PANEL NO.	PAGE NO.
-L-		
LTG: ANUN/DOCK COMPNT circuit breaker (4CB148)	16	3-125
LTG: FLOOD circuit breaker (4CB128)	16	3-125
LTG: MASTER ALARM circuit breaker (4CB147)	16	3-125
LTG: TRACK circuit breaker (4CB160)	16	3-125
LUNAR CONTACT light (CDR) (1DS1)	1	3-16
LUNAR CONTACT light (LMP) (1DS2)	3	3-16
-M-		
MAN THROT switch (1S10)	1	3-24
MASTER ALARM pushbutton/light (CDR) (6S2)	1	3-19
MASTER ALARM pushbutton/light (LMP) (6S3)	2	3-51
MASTER ARM switch (2S7)	8	3-82
MASTER VOL thumbwheel (CDR) (15AR15)	8	3-88
MASTER VOL thumbwheel (LMP) (15BR15)	12	3-106
MISSION TIMER indicator (9M12)	1	3-16
MISSION TIMER: SLEW CONT HOURS switch (9S22)	5	3-74
MISSION TIMER: SLEW CONT MIN switch (9S21)	5	3-74
MISSION TIMER: SLEW CONT SEC switch (9S20)	5	3-75
MISSION TIMER: TIMER CONT switch (9S19)	5	3-73
MODE CONTROL selector switch (11S6)	3	3-61
MODE SEL switch (9S9)	1	3-21
MODE switch (9S27)	ORDEAL	3-145
MODULATE switch (13S5)	12	3-106
-N-		
NO ATT condition indicator (3DS5)	4	3-68
NO TRACK light (17DS1)	3	3-56
NOUN display indicator (3M3)	4	3-70
NOUN pushbutton (3S4)	4	3-70
NUM OVERRIDE switch (16S5)	5	3-75
-O-		
O ₂ QTY caution light (6DS37)	2	3-34
O ₂ QUANTITY indicator (7M4B)	2	3-50
O ₂ /H ₂ O QTY MON selector switch (7S2)	2	3-54
OPR ERR condition indicator (DSKY) (4DS14)	4	3-69
OPR ERR condition indicator (DEDA) (12DS1)	6	3-79
OXIDIZER QUANTITY indicator (10M5A)	1	3-18
-P-		
PART PRESS CO ₂ indicator (7M1)	2	3-49
PITCH control (14B2)	12	3-111
PITCH indicator (14M3)	12	3-111
PGNS caution light (6DS25)	2	3-31
PGNS: IMU OPR circuit breaker (4CB124)	11	3-99
PGNS: IMU STBY circuit breaker (4CB161)	11	3-98
PGNS: LDG RDR circuit breaker (4CB105)	11	3-98
PGNS: LGC/DSKY circuit breaker (4CB122)	11	3-98
PGNS: RNDZ RDR circuit breaker (4CB29)	11	3-98
PGNS: SIG STR DISP circuit breaker (4CB154)	11	3-98
PLSS FILL valve (7H4)	ECS	3-133
POWER/TEMP MON selector switch (4S15)	14	3-113
PRE AMPS caution light (6DS30)	2	3-33
PRESS indicator (10M3)	1	3-19
PRESS indicator (System A) (8M1A)	2	3-35
PRESS indicator (System B) (8M1B)	2	3-35

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
CONTROLS AND DISPLAYS

Table 3-1. Controls and Displays - Alphabetical Index (cont)

NAME AND REFERENCE DESIGNATION	PANEL NO.	PAGE NO.
-P-		
PRESS REG A valve (7H1)	ECS	3-134
PRESS REG B valve (7H2)	ECS	3-134
PRIM EVAP FLOW switch (7S4)	ECS	3-140
PRIM EVAP FLOW VALVE NO. 2 (7H16)	ECS	3-135
PRIMARY CO ₂ CANISTER (7H23)	ECS	3-138
PRO pushbutton (3S6)	4	3-70
PROG condition indicator (3DS10)	4	3-68
PROG display indicator (3M1)	4	3-69
PROPUL: ASC He REG circuit breaker (4CB53)	16	3-125
PROPUL: DES He REG circuit breaker (4CB74)	11	3-93
PROPUL: PQGS circuit breaker (4CB32)	16	3-124
PRPLNT QTY MON switch (10S8)	1	3-29
PROPUL: TEMP/PRESS DISP-FLAGS circuit breaker (4CB103)	16	3-124
PRPLNT TEMP/PRESS MON switch (10S1)	1	3-29
PWR AMPL switch (13S2)	12	3-106
-Q-		
QUANTITY indicator (8M4)	2	3-34
-R-		
R/D INST A circuit breaker (4CB229)	11	3-100
R/D INST B circuit breaker (4CB181)	11	3-101
R/D TLM CALIBRATE switch (19S2)	11	3-101
RADAR TEST switch (17S6)	3	3-56
RATE/ERR MON switch (CDR) (9S2)	1	3-19
RATE/ERR MON switch (LMP) (9S7)	2	3-51
RATE SCALE switch (9S29)	1	3-23
RCCA switch (1S24)	2	3-48
RCS A REG warning light (6DS12)	1	3-15
RCS B REG warning light (6DS13)	1	3-15
RCS caution light (6DS32)	2	3-33
RCS QUAD 1 heater switch (11S4)	3	3-65
RCS QUAD 2 heater switch (11S5)	3	3-65
RCS QUAD 3 heater switch (11S6)	3	3-65
RCS QUAD 4 heater switch (11S7)	3	3-65
RCS SYS A: ASC FEED 1 circuit breaker (4CB51)	11	3-92
RCS SYS A: ASC FEED 2 circuit breaker (4CB231)	11	3-92
RCS SYS A: ISOL VLV circuit breaker (4CB67)	11	3-92
RCS SYS A: MAIN SOV circuit breaker (4CB72)	11	3-91
RCS SYS A: QUAD 1 TCA circuit breaker (4CB63)	11	3-91
RCS SYS A: QUAD 2 TCA circuit breaker (4CB62)	11	3-91
RCS SYS A: QUAD 3 TCA circuit breaker (4CB61)	11	3-91
RCS SYS A: QUAD 4 TCA circuit breaker (4CB60)	11	3-91
RCS SYS B: ASC FEED 1 circuit breaker (4CB52)	16	3-123
RCS SYS B: ASC FEED 2 circuit breaker (4CB232)	16	3-123
RCS SYS B: CRSFD circuit breaker (4CB54)	16	3-124
RCS SYS B: ISOL VLV circuit breaker (4CB49)	16	3-123
RCS SYS B: MAIN SOV circuit breaker (4CB73)	16	3-124
RCS SYS B: PQGS DISP circuit breaker (4CB121)	16	3-124
RCS SYS B: QUAD 1 TCA circuit breaker (4CB45)	16	3-123
RCS SYS B: QUAD 2 TCA circuit breaker (4CB44)	16	3-123
RCS SYS B: QUAD 3 TCA circuit breaker (4CB43)	16	3-124
RCS SYS B: QUAD 4 TCA circuit breaker (4CB42)	16	3-124
RCS SYS B: TEMP/PRESS DISP-FLAGS circuit breaker (4CB50)	16	3-124
RCS TCA warning light (6DS11)	1	3-14
READOUT pushbutton (12S15)	6	3-80
RECORDER switch (13S11)	12	3-110
RECORDER TAPE talkback (13FL1)	12	3-110

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
CONTROLS AND DISPLAYS

Table 3-1. Controls and Displays - Alphabetical Index (cont)

NAME AND REFERENCE DESIGNATION	PANEL NO.	PAGE NO.
-R-		
Relay switch (CDR) (15AS4)	8	3-86
Relay switch (LMP) (15BS4)	12	3-104
RENDEZVOUS RADAR mode switch (17S3)	3	3-58
RESTART condition indicator (3DS11)	4	3-68
RNDZ RDR caution light (6DS28)	2	3-32
RNG/ALT MON switch (9S4)	1	3-22
RSET pushbutton (3S9)	4	3-71
-S-		
S-BAND selector switch (14S5)	12	3-112
S-BAND TR switch (CDR) (15AS1)	8	3-85
S-BAND TR switch (LMP) (15BS1)	12	3-103
S-BAND VOLUME thumbwheel (CDR) (15AR14)	8	3-85
S-BAND VOLUME thumbwheel (LMP) (15BR14)	12	3-103
S-BAND XMTR/RCVR switch (13S8)	12	3-106
SE BAT 1 HI VOLTAGE switch (4S1)	14	3-115
SE BAT 1 LOW VOLTAGE switch (4S5)	14	3-115
SE BAT 1 talkback (4FL1)	14	3-116
SE BAT 2 HI VOLTAGE switch (4S2)	14	3-116
SE BAT 2 LOW VOLTAGE switch (4S6)	14	3-116
SE BAT 2 talkback (4FL2)	14	3-117
SEC EVAP FLOW valve (7H18)	ECS	3-135
SECONDARY CO ₂ CANISTER (7H24)	ECS	3-138
SHFT/TRUN ∇ switch (9S8)	1	3-22
SIDE PANELS switch (CDR) (16S1)	5	3-76
SIDE PANELS switch (LMP) (16S9)	3	3-65
SIGNAL STRENGTH indicator (14M1)	12	3-111
SIGNAL STRENGTH indicator (17M1)	3	3-56
SLA/LEM ANT TRNFR A circuit breaker (4CB35)	11	3-100
SLA/LEM ANT TRNFR B circuit breaker (4CB36)	11	3-100
SLEW RATE switch (17S2)	3	3-57
SLEW switch (17S1)	3	3-58
SLEW switch (9S28)	ORDEAL	3-145
SQUELCH VHF A thumbwheel (13R10)	12	3-108
SQUELCH VHF B thumbwheel (13R15)	12	3-109
STAB/CONT: ABORT STAGE circuit breaker (4CB3)	11	3-94
STAB/CONT: ABORT STAGE circuit breaker (4CB2)	16	3-126
STAB/CONT: AEA circuit breaker (4CB28)	16	3-125
STAB/CONT: AELD circuit breaker (4CB40)	11	3-94
STAB/CONT: AELD circuit breaker (4CB41)	16	3-126
STAB/CONT: ASA circuit breaker (4CB79)	16	3-126
STAB/CONT: ATCA (AGS) circuit breaker (4CB230)	16	3-126
STAB/CONT: ATCA (PGNS) circuit breaker (4CB81)	11	3-94
STAB/CONT: ATCA circuit breaker (4CB82)	16	3-126
STAB/CONT: ATT DIR CONT circuit breaker (4CB59)	11	3-95
STAB/CONT: DECA PWR circuit breaker (4CB69)	11	3-95
STAB/CONT: ENG ARM circuit breaker (4CB37)	16	3-126
STAB/CONT: ENG CONT circuit breaker (4CB80)	11	3-95
STAB/CONT: ENG START OVRD circuit breaker (4CB106)	11	3-95
STAGE switch (2S5)	8	3-84
STAGE RELAY switch (2DS8)	8	3-85
STAGE SEQUENCE RELAYS SYS A component caution light (2DS1)	8	3-84
STAGE SEQUENCE RELAYS SYS B component caution light (2DS2)	8	3-85
STBY condition indicator (3DS6)	4	3-68
SUIT CIRCUIT RELIEF valve (7H9)	ECS	3-138
SUIT FAN component caution light (7DS1)	2	3-53
SUIT FAN selector switch (7S1)	2	3-53
SUIT GAS DIVERTER valve (7H8)	ECS	3-133

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
CONTROLS AND DISPLAYS

Table 3-1. Controls and Displays - Alphabetical Index (cont)

NAME AND REFERENCE DESIGNATION	PANEL NO.	PAGE NO.
-S-		
SUIT ISOL valves (7H6) (7H7)	ECS	3-135
SUIT PRESS indicator (7M2B)	2	3-49
SUIT TEMP valve (7H22)	ECS	3-137
SUIT TEMP indicator (7M3B)	2	3-49
SUIT/FAN warning light (6DS17)	1	3-15
SYSTEM A ASC FEED 1 switch (8S8)	2	3-35
SYSTEM A ASC FEED 2 switch (8S22)	2	3-36
SYSTEM A ASC FUEL talkback (8FL6)	2	3-36
SYSTEM A ASC OXID talkback (8FL18)	2	3-37
SYSTEM A MAIN SOV switch (8S7)	2	3-47
SYSTEM A MAIN SOV talkback (8FL5)	2	3-47
SYSTEM A THRUSTER PAIR QUAD 1 switch (8S11)	2	3-37
SYSTEM A THRUSTER PAIR QUAD 1 talkback (8FL9)	2	3-37
SYSTEM A THRUSTER PAIR QUAD 2 switch (8S12)	2	3-38
SYSTEM A THRUSTER PAIR QUAD 2 talkback (8FL10)	2	3-38
SYSTEM A THRUSTER PAIR QUAD 3 switch (8S15)	2	3-39
SYSTEM A THRUSTER PAIR QUAD 3 talkback (8FL13)	2	3-39
SYSTEM A THRUSTER PAIR QUAD 4 switch (8S16)	2	3-39
SYSTEM A THRUSTER PAIR QUAD 4 talkback (8FL14)	2	3-40
SYSTEM B ASC FEED 1 switch (8S10)	2	3-40
SYSTEM B ASC FEED 2 switch (8S23)	2	3-41
SYSTEM B ASC FUEL talkback (8FL8)	2	3-42
SYSTEM B ASC OXID talkback (8FL19)	2	3-42
SYSTEM B MAIN SOV switch (8S9)	2	3-48
SYSTEM B MAIN SOV talkback (8FL7)	2	3-48
SYSTEM B THRUSTER PAIR QUAD 1 switch (8S13)	2	3-42
SYSTEM B THRUSTER PAIR QUAD 1 talkback (8FL11)	2	3-43
SYSTEM B THRUSTER PAIR QUAD 2 switch (8S14)	2	3-43
SYSTEM B THRUSTER PAIR QUAD 2 talkback (8FL12)	2	3-43
SYSTEM B THRUSTER PAIR QUAD 3 switch (8S17)	2	3-44
SYSTEM B THRUSTER PAIR QUAD 3 talkback (8FL15)	2	3-44
SYSTEM B THRUSTER PAIR QUAD 4 switch (8S18)	2	3-45
SYSTEM B THRUSTER PAIR QUAD 4 talkback (8FL16)	2	3-45
-T-		
T/W indicator (9M4)	1	3-21
TELEMETRY BIOMED switch (13S3)	12	3-109
TELEMETRY PCM switch (13S13)	12	3-110
TEMP condition indicator (3DS8)	4	3-67
TEMP indicator (10M4)	1	3-19
TEMP indicator (18M1)	3	3-62
TEMP indicator (System A) (8M2A)	2	3-35
TEMP indicator (System B) (8M2B)	2	3-35
TEMP MONITOR selector switch (18S2)	3	3-62
TEMP/PRESS MON selector switch (8S19)	2	3-46
TEST/MONITOR selector switch (17S8)	3	3-56
THR CONT switch (1S11)	1	3-23
Throttle/jets select lever (CDR) (1H1)	TTCA	3-143
Throttle/jets select lever (LMP) (1H2)	TTCA	3-143
THRUST indicator (9M7)	1	3-17
Thrust/translation controller (CDR) (1X1)	TTCA	3-142
Thrust/translation controller (LMP) (1X2)	TTCA	3-142
TRACK MODE switch (14S3)	12	3-110
TRACKER condition indicator (3DS12)	4	3-69
TTCA/TRANSL switches (CDR & LMP) (1S20) (1S22)	4	3-67
-U-		
UPLINK ACTY condition indicator (3DS1)	4	3-67

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
CONTROLS AND DISPLAYS

Table 3-1. Controls and Displays - Alphabetical Index (cont)

NAME AND REFERENCE DESIGNATION	PANEL NO.	PAGE NO.
-V-		
VERB pushbutton (3S3)	4	3-70
VERB display indicator (3M2)	4	3-70
VHF A switch (CDR) (15AS2)	8	3-87
VHF A switch (LMP) (15BS2)	12	3-105
VHF A RCVR switch (13S10)	12	3-108
VHF A VOLUME thumbwheel (CDR) (15AR12)	8	3-87
VHF A VOLUME thumbwheel (LMP) (15BR12)	12	3-105
VHF A XMTR switch (13S7)	12	3-108
VHF selector switch (14S6)	12	3-111
VHF B RCVR switch (13S15)	12	3-109
VHF B switch (CDR) (15AS9)	8	3-87
VHF B switch (LMP) (15BS9)	12	3-105
VHF B VOLUME thumbwheel (CDR) (15AR13)	8	3-88
VHF B VOLUME thumbwheel (LMP) (15BR13)	12	3-105
VHF B XMTR switch (13S12)	12	3-108
VOLTS indicator (4M2)	14	3-113
VOX SENS thumbwheel (CDR) (15AR8)	8	3-87
VOX SENS thumbwheel (LMP) (15BR8)	12	3-104
VOX switch (CDR) (15AS6)	8	3-86
VOX switch (LMP) (15BS6)	12	3-104
-W-		
WATER QTY caution light (6DS39)	2	3-34
WATER SEP SEL valve (7H10)	ECS	3-139
WATER TANK SELECT valve (7H14)	ECS	3-135
-X-		
X-Pointer indicator (CDR) (9M2)	1	3-16
X-Pointer indicator (LMP) (9M3)	2	3-50
X-Pointer Scale switch (CDR) (9S17)	1	3-17
X-Pointer Scale switch (LMP) (9S18)	3	3-16
XMTR/RCVR switch (13S8)	12	3-106
X-TRANSL Switch (1S6)	1	3-25
-Y-		
YAW control (14B1)	12	3-111
YAW indicator (14M4)	12	3-111

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 1	WARNING LIGHTS				
6DS2	ASC PRESS (MPS)	Goes on if pressure in either ascent helium tank drops below 3,000 psia prior to staging or if blanket pressure in fuel or oxidizer lines at bipropellant valves drops below 120 psia.	LTG: ANUN DOCK/ COMPNT (panel 11 and/or panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	Light goes off when deadface switch is actuated by separation of descent and ascent stages, or by restoration of fuel or oxidizer blanket pressure.
6DS3	DES REG (MPS)	Goes on if, after pressurization, pressure in descent helium lines downstream of regulators exceeds 260 psia or drops below 220 psia.	LTG: ANUN DOCK/ COMPNT (panel 11 and/or panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	Light goes off when nominal pressure is restored or when ascent and descent stages are separated.
6DS4	DES QTY (MPS)	Goes on if, before staging, descent tanks contain fuel for only approximately 2 minutes of burning time.	LTG: ANUN DOCK/ COMPNT (panel 11 and/or panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	This low-level signal is enabled only if descent engine-on command is present.
6DS6	CES AC (GN&CS)	Goes on if a-c voltage in control electronics section of GN&CS is out of tolerance.	LTG: ANUN DOCK/ COMPNT (panel 11 and/or panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	A-C voltage (28 volts, single-phase; or 26 volts, 800 cps, three-phase) is required. Light goes off when GYRO TEST switch is placed in POS RT or NEG RT position.
6DS7	CES DC (GN&CS)	Goes on if voltage of any d-c power supply in CES is out of tolerance.	LTG: ANUN DOCK/ COMPNT (panel 11 and/or panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	D-C power supply voltages are +15, -15, +4.3, +6, and -6 volts. Light goes on when GYRO TEST switch is placed in POS RT or NEG RT position.

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 1 (cont)	AGS (GN&CS)	Goes on if any ASA power supply fails or if fail signal is generated by AEA test assembly.	LTG: ANUN DOCK/ COMPNT (panel 11 and/or panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	Power supply voltages are +28 and +12 volts dc, and 28 volts 400 cps. Signal is inhibited when AGS STATUS switch is set to OFF. Thermal switch is in series with +12 vdc. Switch opens at 150±5° F, closes at 130±5° F. When AGS STATUS switch is moved from OFF to STBY, AGS light flashes and MASTER ALARM goes on. When switch is moved from STBY to OPR, AGS light goes on, then off and MASTER ALARM goes off.
		Goes on if LGC power supplies, counter, or scaler fail.	LTG: ANUN DOCK/ COMPNT (panel 11 and/or panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	Power supply voltages are +28, +14, or +4 volts dc. Light goes off when nominal voltage is restored or GUID CONT switch is set to AGS.
		Lights if failure of IMU, PIPA during main engine thrusting, or CDU occurs.	LTG: ANUN DOCK/ COMPNT (panel 11 and/or panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	Light goes off when GUID CONT switch is set to AGS.
		Goes on if there is primary coil command to fire specific thruster, but there is no chamber pressure at that thruster. Goes on if opposing collinear jets are on simultaneously.	LTG: ANUN DOCK/ COMPNT (panel 11 and/or panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	Light is extinguished when thruster pair or quad isolation valve associated with failed TCA is closed.
	RCS TCA (RCS)				

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
CONTROLS AND DISPLAYS

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks	
Panel 1 (cont)	6DS12	RCS A REG (RCS)	Goes on when pressure sensed by pressure transducer downstream of system A pressure regulators exceeds 205 psia or drops below 165 psia.	LTG: ANUN DOCK/ COMPNT (panel 11 and/or panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	Light is inhibited when SYSTEM A MAIN SOV switch is set to CLOSE.
	6DS13	RCS B REG (RCS)	Goes on when pressure sensed by pressure transducer downstream of system B pressure regulators exceeds 205 psia or drops below 165 psia.	LTG: ANUN DOCK/ COMPNT (panel 11 and/or panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	Light is inhibited when SYSTEM A MAIN SOV switch is set to CLOSE.
	6DS14	DC BUS (EPS)	Goes on if d-c voltage drops below 26.5 volts on either Commander's or LM Pilot's d-c bus.	LTG: ANUN DOCK/ COMPNT (panel 11 and/or panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	Light goes off when nominal voltage is restored.
	6DS16	CABIN (ECS)	Goes on if cabin pressure drops below 4.15±0.15 psia.	LTG: ANUN DOCK/ COMPNT (panel 11 and/or panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	Light goes on when cabin pressure is restored to 4.8 psia. It does not light during intentional cabin de-pressurization.
	6DS17	SUIT/FAN (ECS)	Goes on if pressure within suit drops below 3.12 psia or if suit circulating fan No. 2 fails.	LTG: ANUN DOCK/ COMPNT (panel 11 and/or panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	Light goes on when nominal suit pressure is restored.

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks	
Panel 1 (cont)	9M12	MISSION TIMER indicator	Displays digital readout of elapsed time in hours, minutes, and seconds. Indicator is controlled with TIMER CONT and SLEW CONT switches. Maximum time displayed is 999 hours 59 minutes 59 seconds.	FLIGHT DISPLAYS: MISSION TIMER (panel 11)	CDR's 28-vdc bus	MISSION TIMER indicator can only count up.
	9M11	EVENT TIMER indicator	Displays digital readout of time. (0 minutes 0 seconds to 59 minutes 59 seconds, or 59 minutes 59 seconds to 0 minutes 0 seconds). EVENT TIMER is controlled with RESET/COUNT switch, TIMER CONT switch, SLEW CONT MIN switch, and SLEW CONT SEC switch.	FLIGHT DISPLAYS: EVENT TIMER/ SE FDAI (panel 16)	LMP's 28-vdc bus	EVENT TIMER indicator can count up or down. If it fails, MISSION TIMER indicator can be used.
	9M2	X-Pointer indicator	Displays forward and lateral velocities, lateral velocities only, or rendezvous radar LOS elevation and azimuth angular rates, depending upon setting of RATE/ERR MON switch and MODE SEL switch.	FLIGHT DISPLAYS: X-PNTR (panel 11)	CDR's 28-vdc bus	Forward and lateral velocities are coincident with LM Z and Y body axis velocities when PGNS drives display. When LR drives display, forward and lateral velocities are coincident with LM Z and Y axes (from hi-gate point to touchdown). When AGS drives display, lateral Y-axis velocity only is displayed. When RR is selected, LOS rates are displayed.
	1DS1	LUNAR CONTACT light	Both lights (red) go on when probe(s) on landing gear touches lunar surface, to indicate that descent engine should be turned off.	N/A	N/A	Light goes off when either engine STOP switch is pressed.

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 1 (cont) 9S17	X-POINTER SCALE switch HI MULT LO MULT	Controls scale range of X-pointer indicator. When LOS azimuth and elevation rates are displayed, this position provides a scale of ± 20 mrad/sec. When horizontal velocities are displayed, this position illuminates the X10 multiplier to provide range of ± 200 fps. When LOS azimuth and elevation rates are displayed, this position illuminates the X.1 multiplier to provide a range of ± 2 mrad/sec. When horizontal velocities are displayed, this position provides range of ± 20 fps.	N/A	N/A	
9M7	THRUST indicator	Displays descent engine chamber pressure, which corresponds to thrust (left pointer) and manual or LGC thrust commands to the engine (right pointer). Both scales read from 0% to 100%. Automatic or manual throttle commands can be displayed, depending on setting of THR CONT switch. The CMD (right) scale indicates 10% thrust command at all times, even when engine is not firing because indicator input is not thrust command input to engine unless the engine is on and TTCA is at minimum position. Thrust command to engine, when GUID CONT switch is set to PGNS, is sum of thrust commands from LGC and TTCA. TTCA provides a minimum thrust command 10% at all times; it cannot be set to zero. When THR CONT switch is set to	FLIGHT DISPLAYS: THRUST DISP (panel 11)	CDR's 28-vdc bus	Normally, during LGC command authority, both pointers will be aligned. If not, a malfunction exists or manual throttle authority is being introduced to enable smooth transition to full manual control. If manual control is desired, THR CONT

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 1 (cont)		AUTO position, and TTCA is at minimum position, LGC commands 10% less than required and is summed with 10% command from TTCA to provide required thrust level. When THR CONT switch is set to MAN, LGC commands are removed and all thrust commands originate from TTCA.			switch is set to MAN when CMD pointer reaches 10%; pointers will then realign. If TTCA control is moved beyond minimum thrust position, LGC commands correspondingly less thrust. It is, therefore, possible to command more thrust than LGC requires, but not possible to command less.
	MAIN PROPULSION QUANTITY indicators	Indicate quantity of usable propellant remaining in descent tanks.	AC BUS B: He PQGS PROPUL DISP (panel 11)	CDR's 115-vac bus B	Quantity gage is accurate from 0% to 95%.
	10M5A OXIDIZER	Displays digital readout of percentage (0% to 95%) of usable oxidizer remaining in descent tanks, as selected with PRPLNT QTY MON switch.			
	10M5B FUEL	Displays digital readout of percentage (0% to 95%) of usable fuel remaining in descent tanks, as selected with PRPLNT QTY MON switch.			
	10M1 HELIUM indicator	Indicates supercritical helium pressure (0 to 1,750 psia) of descent cryogenic storage vessel, ambient pressure of descent helium bottle (0 to 1,250 psia), and ambient temperature (-120° to +140° F) or pressure (0 to 3,500 psia) of ascent helium tanks, as selected with HELIUM MON switch.	AC BUS B: He PQGS PROPUL DISP (panel 11)	CDR's 115-vac bus B	

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 1 (cont)					
10M4	TEMP indicator	Indicates fuel and oxidizer temperature (+40° to +100° F) for ascent or descent propellant sections, as selected with PRPLNT TEMP/PRESS MON switch.	N/A	N/A	
10M3	PRESS indicator	Indicates fuel and oxidizer pressures (0 to 300 psia) for ascent or descent propellant sections, as selected with PRPLNT TEMP/PRESS MON switch.	PROPUL: TEMP/ PRESS DISP-FLAGS (panel 16)	LMP's 28-vdc bus	
6S2	MASTER ALARM pushbutton/light Audible tone	Lights flash when any caution or warning light goes on. Initiated in conjunction with MASTER ALARM switch-light and caution/warning array light(s).	LTG: MASTER ALARM (panel 16)	LMP's 28-vdc bus	Pressing Commander's or LM Pilots switch-light extinguishes both MASTER ALARM lights and terminates audible tone, but has no effect on caution or warning light(s).
9S2	RATE/ERR MON switch RNDZ RADAR LDG RDR/CMPTR	Selects inputs for FDAI and X-pointer indicator. Shaft and trunnion angles from the RR are displayed by pitch and yaw error needles of FDAI; LOS azimuth and elevation rates are displayed on X-Pointer indicator (illuminating LOS AZ and LOS ELEV). Vehicle attitude errors (PGNS or AGS as selected with ATTITUDE MON switch) are displayed by FDAI error needles. Forward and lateral velocities from the LR (PGNS or AGS as selected with MODE SEL switch) are displayed on the X-pointer indicator (illuminating LAT VEL and FWD VEL).	N/A	N/A	When switch is set to LDG RDR/CMPTR, data input is dependent upon settings of MODE SEL and ATTITUDE MON switches. AGS provides only lateral velocity data.

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 1 (cont)					
9S3	ATTITUDE MON switch	Selects input for FDAI total attitude display and input for attitude error needles during landing.	N/A	N/A	The input is dependent on whether PGNS or AGS is controlling system.
	PGNS	LM total attitude signals, after conditioning by GASTA are fed to FDAI ball; LGC attitude error signals are fed to FDAI pitch, roll, and yaw error needles.			
	AGS	AGS LM total attitude signals are fed to FDAI ball; AGS attitude error signals are fed to FDAI pitch, roll, and yaw error needles.			
9M1	Flight director attitude indicator (FDAI)	Displays total vehicle attitudes, attitude rates and attitude errors, or vehicle attitude, attitude rates, and RR shaft and trunnion angles, depending on setting of RATE/ERR MON switch. Setting ATTITUDE MON switch selects PGNS or AGS as source of vehicle total attitude and attitude errors displayed on FDAI. Shaft and trunnion angles are displayed by pitch and yaw error needles, respectively, when RATE/ERR MON switch is set to RNDZ RADAR.	AC BUS A: CDR FDAI and FLIGHT DISPLAYS: CDR FDAI (panel 11)	CDR's 28-vdc bus CDR's 115-vac bus A	Attitude rates displayed are always obtained from CES rate gyro assembly.
9M9	Altitude/range indicator	Displays range/range rate data or altitude/altitude rate data as selected with RNG/ALT MON switch. Range/range rate data are from RR. Altitude/altitude rate data are from LR, PGNS, or AGS, as selected with MOD SEL switch. When LR data is selected, true altitude and altitude rate data are available from	FLIGHT DISPLAYS: RNG/RNG RT ALT/ ALT RT and AC BUS A: RNG/RNG RT ALT/ ALT RT (panel 11)	CDR's 28-vdc bus CDR's 115-vac bus A	

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 1 (cont)		low-gate point to touchdown if LM X-axis is vertical. Before reaching low-gate point, only true altitude data are available from LR. When PGNS or AGS is selected, inertially derived altitude and altitude rate data are available for display.			
9M4	T/W indicator	Displays instantaneous X-axis acceleration in lunar g units (1 lunar g unit 5.23 ft/sec ²).	N/A	N/A	Indicator, a self-contained accelerometer, may be used to provide a gross check of engine performance, because any given throttle setting provides specific acceleration when the vehicle has given mass.
9S6	GUID CONT switch PGNS AGS	Selects PGNS or AGS for guidance control mode of LM. Provides 800-cps power to activate ACA and TTCA, proportional rate command inputs to LGC from ACA, LGC engine on-off signals, descent engine gimbal trim command outputs from LGC, translation on-off commands from TTCA, enabling signals for primary preamplifiers of ATCA, and applies follow-up signal to AEA. Provides 800-cps power to activate ACA and TTCA, proportional rate commands to ATCA from ACA, AGS mode trim command, and enabling signals to the abort preamplifiers of ATCA.	N/A	N/A	When AGS mode is selected, PGNS remains operational. PGNS data may be displayed if desired.
9S9	MODE SEL switch	Selects radar or computer data for display on X-Pointer and altitude/range indicators.	N/A	N/A	Data from selected source are displayed on appropriate horizontal velocity indicator only when RATE/ERR MON switches are set to LDG RDR/COMPTR. Data from selected

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 1 (cont)	LDG RADAR	Radar altitude, altitude rate, and forward and lateral velocity are displayed.			source are displayed on altitude/ range indicators only when RNG/ ALT MON switch is set to ALT/ ALT RT.
	PGNS	LGC-computed altitude, altitude rate, and forward and lateral velocity are displayed.			
	AGS	AGS-computed altitude, altitude rate and lateral velocity are displayed.			
	9S4	RNG/ALT MON switch	N/A	N/A	
	RNG/RNG RT	Selects display legend on altitude/ range indicator and displays RR range/range rate data or LR or computer altitude/altitude rate data.			
	ALT/ALT RT	RR range and range rate data are displayed on altitude/range indi- cator. Data from source selected with MODE SEL switch are displayed on altitude/range indicator.			
9S8	SHFT/TRUN ∇ switch	Selects range of RR shaft and trun- nion angles to be displayed by FDAI pitch and yaw error needles when either RATE/ERR MON switch is set to RNDZ RADAR.	FLIGHT DISPLAYS: CDR FDAI (panel 11)	CDR's 28-vdc bus	
	$\pm 50^\circ$	Full deflection of FDAI pitch and yaw error needles indicates shaft and trunnion angles of $+50^\circ$ or -50° or greater.			
					Less-than-full-deflection positions of needles are linearly proportional to shaft and trunnion angles less than $+50^\circ$ or -50° .

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 1 (cont)	$\pm 5^\circ$	Full deflection of FDAI pitch and yaw error needles indicates shaft and trunnion angles of $+5^\circ$ or -5° or greater.			Less-than-full-deflection positions of needles are linearly proportional to shaft and trunnion angles less than $+5^\circ$ or -5° .
9S29	RATE SCALE Switch $25^\circ/\text{sec}$ $5^\circ/\text{sec}$	Selects scale factors of roll, pitch, and yaw rate scales of FDAI. Selects 25° per second full scale for rate scales. Selects 5° per second full scale for rate scales.	N/A	N/A	
3S1	IMU CAGE switch ON OFF	Aligns inner, outer, and middle gimbals to Y, X, and Z body axes, respectively. Used to avoid gimbal lock condition. Enables IMU cage mode of operation. Disables IMU cage mode of operation.	N/A	N/A	Switch must be set to ON, to properly use ORDEAL.
1S11	ENGINE THRUST CONT switches THR CONT switch AUTO	Permits switching from automatic (LGC) throttle control to manual throttle control. LGC command signals are summed with manual command signals of throttles selected with MAN THROT switch for descent engine throttle control. TTCA always provides minimum 10% command; it cannot be set below this level.	STAB/CONT: ENG ARM (panel 11)	CDR's 28-vdc bus	When switch is set to AUTO, THRUST indicator displays LGC command plus 10% fixed bias which is summed with LGC signal to compensate for this 10%. Manual throttle commands may be introduced by displacing active TTCA. This causes displayed % THRUST CMD to decrease because only LGC commands plus fixed bias are displayed.

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 1 (cont)	MAN	Interrupts LGC throttle commands insuring that descent engine throttle is fed only by manual throttle command signals.			THRUST indicator displays manual throttle commands.
1S10	MAN THROT switch	Selects thrust/translation controller for manual adjustment of descent engine thrust level, if corresponding THROTTLE-JETS control select lever is set to THROTTLE. This switch also routes manual throttle commands from controller to DECA.	N/A	N/A	
	CDR	Enables Commander's thrust/translation controller to adjust descent engine thrust level.			
	SE	Enables LM Pilot's thrust/translation controller to adjust descent engine thrust level.			
1S1	ENG ARM switch	Provides arming signals to engines.	STAB/CONT: ENG ARM (panel 16)	LMP's 28-vdc bus	Regardless of switch setting, appropriate engine is armed if ABORT or ABORT STAGE switches are actuated.
	ASC	Provides arming signal to enable firing of ascent engine and simultaneously signals LGC that engine is armed.			
	OFF	Removes arming signal from engine valves and LGC.			
	DES	Provides arming signal to enable firing descent engine and simultaneously signals LGC that engine is armed.			

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 1 (cont) 1S6	X-TRANSL switch	Selects number of jets for X-axis translation maneuvers.	STAB/CONT: ATT DIR (panel 11)	CDR's 28-vdc bus	This control can only be used with AGS.
	4 JETS	Provides four jets for X-axis translation maneuvers.			
	2 JETS	Provides two jets for X-axis translation maneuvers.			
1S9	BAL CPL switch	Selects either balanced pairs of RCS jets in a couple or unbalanced X-axis RCS jets to maintain pitch and roll attitude during ascent engine thrust phase when AGS is in guidance control loop.			Used only in conjunction with AGS. Normally in this position (balanced couples) during initial phases of ascent, for maximum stabilization and control of any center-of-gravity thrust vector misalignment. After some minimum burn time when balanced-couple operation is not required, switch can be set to OFF to conserve fuel.
	ON	Applies 28-vdc enable voltage to abort preamplifiers 1, 5, 9, 13.			
	OFF	Removes enable voltage from abort preamplifiers 1, 5, 9, 13.			
10S3	ASCENT He REG 1 switch	Selects inputs to normally open, latching solenoid-operated helium valve upstream of primary pressure regulator.	PROPUL: ASC He REG (panel 16)	LMP's 28-vdc bus	Switch is spring loaded to center position. Gray talkback is displayed when valve is open. Barber-pole talkback is displayed when valve is closed.
	OPEN	Energizes solenoid that drives helium valve to open position.			
	Center	Removes solenoid excitation; valve remains in last commanded position.			
	CLOSE	Energizes solenoid that drives helium valve to closed position.			

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 1 (cont)	10FL1	ASCENT He REG 1 talkback Gray display Barber-pole display	PROPUL: TEMP/ PRESS DISP-FLAGS (panel 16)	LMP's 28-vdc bus	
		Indicates helium primary line solenoid valve controlled by ASCENT He REG 1 switch is open. Indicates helium primary line solenoid valve controlled by ASCENT He REG 1 switch is closed.			
	10S4	ASCENT He REG 2 switch OPEN Center CLOSE	PROPUL: ASC He REG (panel 16)	LMP's 28-vdc bus	Switch is spring loaded to center position Gray talkback is displayed when valve is open. Barber-pole talkback is displayed when valve is closed.
		Selects inputs to normally open latching solenoid-operated helium valve upstream of secondary pressure regulator. Energizes solenoid that drives helium valve to open position. Removes solenoid excitation; valve remains in last commanded position. Energizes solenoid that drives helium valve to closed position.			
10FL2	ASCENT He REG 2 talkback Gray display Barber-pole display	Indicates helium secondary line solenoid valve controlled by ASCENT He REG 2 switch is open. Indicates helium secondary line solenoid valve controlled by ASCENT He REG 2 switch is closed.	PROPUL: TEMP/ PRESS DISP-FLAGS (panel 16)	LMP's 28-vdc bus	

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 1 (cont) 10S5 10FL3 10S7	DESCENT He REG 1 switch	Selects inputs to normally open, latching solenoid-operated helium valve upstream of primary pressure regulator.	PROPUL: DES He REG (panel 11)	CDR's 28-vdc bus	Switch is spring loaded to center position.
	OPEN	Energizes solenoid that drives helium valve to open position.			Gray talkback is displayed when valve is open.
	Center	Removes solenoid excitation; valve remains in last commanded position.			
	CLOSE	Energizes solenoid that drives helium valve to closed position.			Barber-pole talkback is displayed when valve is closed.
	DESCENT He REG 1 talkback		PROPUL: TEMP/ PRESS DISP-FLAGS (panel 16)	LMP's 28-vdc bus	
	Gray display	Indicates helium primary line solenoid valve controlled by DESCENT He REG 1 switch is open.			
	Barber-pole display	Indicates helium primary line solenoid valve controlled by DESCENT He REG 1 switch is closed.			
	DESCENT He REG 2 switch	Selects inputs to normally closed, latching solenoid-operated helium valve upstream of secondary pressure regulator.	PROPUL: DES He REG (panel 11)	CDR's 28-vdc bus	Switch is spring loaded to center position.
	OPEN	Energizes solenoid that drives helium valve to open position.			Gray talkback is displayed when valve is open.
	Center	Removes solenoid excitation; valve remains in last commanded position.			
	CLOSE	Energizes solenoid that drives helium valve to closed position.			Barber-pole talkback is displayed when valve is closed.

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 1 (cont)	10FL4	DESCENT He REG 2 talkback Gray display Barber-pole display	PROPUL: TEMP/ PRESS DISP-FLAGS (panel 16)	LMP's 28-vdc bus	
	1S13	ABORT pushbutton	Actuated to initiate abort, using descent engine. Reset by pressing a second time.	STAB/CONT: ENG CONT (panel 11)	CDR's 28-vdc bus Actuation of switch causes following events to occur at appropriate times: command signal is sent to arm descent engine; signal is sent, via instrumentation to telemetry, to indicate that LM is preparing for abort; and signal is sent to LGC and AGS to compute and execute abort trajectory, using abort program. ABORT pushbutton does not enable descent engine pressurization.
	1S14	ABORT STAGE pushbutton	Actuated to initiate abort, using only ascent engine. Reset by pressing a second time.	STAB/CONT: ABORT STAGE (panel 11 and panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus Actuation of switch arms the ascent engine. The AGS enters semiautomatic submode. Vehicle is reoriented to proper attitude. AGS continues to command engine off. When ullage ΔV is attained, AGS issues engine-on command, which initiates staging sequence and ignites ascent engine. When engine-on verification is received, AGS enters attitude hold submode for prescribed time (1 to 10 seconds), then enters guidance steering submode. When ΔV_{gx} falls below threshold, AGS issues engine-off command and enters attitude hold submode (So at address 400 set to zero). Ascent engine is subsequently cutoff (after CES delays and

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 1 (cont)					thrust tail-off). AGS continues to command engine off. (PGNS is capable of this operation if LGC is provided with ABORT STAGE software.)
10S8	PRPLNT QTY MON switch DES 1 DES 2 OFF	Selects inputs to oxidizer and fuel quantity indicating devices in descent propellant tanks. Enables discrete outputs from quantity gaging sensor probes of oxidizer tank No. 1 and fuel tank No. 1 to QUANTITY indicators. Enables discrete outputs from quantity gaging sensor probes of oxidizer tank No. 2 and fuel tank No. 2 to QUANTITY indicators. Removes d-c power from gaging system; quantities are not displayed on QUANTITY indicators.	AC BUS B: He PQGS PROPUL DISP (panel 11)	CDR's 115-vac bus B	Switch permits monitoring quantity of oxidizer and fuel remaining in descent tanks.
10S1	PRPLNT TEMP/PRESS MON switch ASC DES 1 DES 2	Selects inputs to propellant temperature- and pressure-indicating devices in ascent or descent propellant tanks. Connects output of temperature and pressure sensors in ascent propellant tanks to TEMP and PRESS indicators. Connects output of temperature and pressure sensors in descent propellant tank No. 1 to TEMP and PRESS indicators. Connects output of temperature and pressure sensors in descent propellant tank No. 2 to TEMP and PRESS indicators.	PROPUL: TEMP/ PRESS DISP-FLAGS (panel 16)	LMP's 28-vdc bus	Switch permits monitoring propellant tank temperatures and pressures.

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 1 (cont)					
10S6	HELIUM MON selector switch	Selects inputs to helium pressure-indicating device in descent cryogenic storage vessel, from temperature- and pressure-indicating devices in ascent helium tanks, and from pressure-indicating device in helium bottle.	N/A	115-vac bus	Switch permits monitoring super-critical helium pressure of descent cryogenic storage vessel, ambient temperature or pressure of ascent helium tanks, and ambient pressure of descent helium bottle.
	OFF	Removes power from HELIUM indicator; values are not displayed.			
	DES AMB PRESS	Connects output of pressure sensor in descent ambient helium bottle to HELIUM indicator.			
	DES SUPCRIT PRESS	Connects output of pressure sensor in descent cryogenic storage vessel to HELIUM indicator.			
	ASC TEMP 1	Connects output of temperature sensor in ascent helium tank No. 1 to HELIUM indicator.			
	ASC TEMP 2	Connects output of temperature sensor in ascent helium tank No. 2 to HELIUM indicator.			
	ASC PRESS 1	Connects output of pressure sensor in manifold downstream of ascent helium tank No. 1 and upstream of explosive valve to HELIUM indicator.			
	ASC PRESS 2	Connects output of pressure sensor in manifold downstream of ascent helium tank No. 2 and upstream of explosive valve to HELIUM indicator.			

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 2	CAUTION LIGHTS				
6DS21	ASC HI REG (MPS)	Goes on if helium pressure downstream of regulators in ascent helium lines exceeds 220 psia.	LTG: ANUN DOCK/ COMPNT (panel 11 and/or panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	Goes off when pressure is reduced to nominal values.
6DS22	ASC QTY (MPS)	Goes on if fuel or oxidizer in ascent tank is sufficient for only 10-second burn.	LTG: ANUN DOCK/ COMPNT (panel 11 and/or panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	Signal permits manual shutdown of ascent engine to avoid explosive potential, resulting from depletion of fuel before oxidizer or vice versa. If light goes on, ascent engine thrusting is not available for mid-course correction or rendezvous braking.
6DS23	GDA/RCCA (MPS)	Lights if difference between gimbal drive signal and gimbal response from Y- or Z-axis trim function is sensed and if ascent engine rough combustion cutoff has occurred.	LTG: ANUN DOCK/ COMPNT (panel 11 and/or panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	GDA signal is enabled only when descent engine is armed and is disabled after separation of ascent and descent stages. RCCA light is extinguished when RCCA switch is set to OFF/RESET.
6DS25	PGNS (GN&CS)	Goes on if any of following conditions are sensed: (a) middle roll gimbal angle exceeds $\pm 60^\circ$ (gimbal lock). (b) IMU temperature deviates $\pm 5^\circ$ from normal. (c) AND of RR operate and CDU fail. (d) AND of RR track enable and data-not-good.	LTG: ANUN DOCK/ COMPNT (panel 11 and/or panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	Goes off when GUID CONT switch is set to AGS or DSKY RSET push-button is pressed.

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 2 (cont)		(e) AND of LR data not good and LR antenna in descent or hover position or data-good signal with ambiguous antenna position signal. (f) program alarm failure. (g) LGC restart. (h) PIPA failure during non-thrusting periods.			
6DS26	INVERTER (EPS)	Goes on if a-c bus voltage is less than 112 volts, or if a-c bus frequency is less than 398 cps or exceeds 402 cps.	LTG:ANUN DOCK/ COMPNT (panel 11 and/or panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	Light goes off when within-tolerance conditions are restored or when AC PWR switch is set to OFF.
6DS27	BATTERY (EPS)	Goes on if overcurrent, reverse current, or overtemperature occurs in any descent or ascent battery.	LTG: ANUN DOCK/ COMPNT (panel 11 and/or panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	Light goes off when nominal conditions are restored, or if affected battery is turned off.
6DS28	RNDZ RDR (GN&CS)	Goes on if RR data-not-good condition occurs.	LTG: ANUN DOCK/ COMPNT (panel 11 and/or panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	Signal is enabled only when rendezvous radar selector switch is set to AUTO TRACK. Light goes off when data-good condition is restored or RR is turned off.

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 2 (cont)					
6DS29	LDG RDR (GN&CS)	Goes on if LR range data are not good or if velocity data are not good.	LTG: ANUN DOCK/ COMPNT (panel 11 and/or panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	Light goes off when range and velocity data-good condition is restored.
6DS30	PRE AMPS (RCS)	Goes on if either of two parallel redundant -4.7-volt d-c regulated power supplies that provide power to RCS jet preamplifiers are out of tolerance.	LTG: ANUN DOCK/ COMPNT (panel 11 and/or panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	Light goes off when DES BATS switch is set to DEADFACE or ABORT pushbutton is pressed.
6DS32	RCS	Goes on if pressure of helium tank in system A or B drops below 1,700 psia.	LTG: ANUN DOCK/ COMPNT (panel 11 and/or panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	Light goes off when both helium regulator shutoff valves of affected system are closed.
6DS33	HEATER	Goes on if out-of-tolerance temperature exists in RCS thruster quad, RR assembly, LR antenna assembly, or S-band steerable antenna.	LTG: ANUN DOCK/ COMPNT (panel 11 and/or panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	
6DS34	C/W PWR (CWEA)	Goes on if any regulated power supply fails.	LTG: ANUN DOCK/ COMPNT (panel 11 and/or panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	Light goes off when normal power is restored to CWEA. Regulated power: +23, +9, +4, and -3 volts.

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 2 (cont)					
6DS36	ECS	Goes on if glycol pump 1 or 2 fails, CO ₂ partial pressure exceeds 7.6 mm Hg, water separator fails, or suit fan No. 1 fails.	LTG: ANUN DOCK/ COMPNT (panel 11 and/or panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	Light goes off when glycol pump pressure is restored, followed by momentarily setting GLYCOL switch to appropriate pump position; nominal water separator speed is restored; or suit fan No. 2 is selected.
6DS37	O ₂ QTY (ECS)	Goes on if pressure in descent oxygen tank drops below 135 psia, if less-than-full pressure (less than 684 psia) occurs in either ascent oxygen tank, or if pressure in ascent tank No. 1 is less than 100 psia.	LTG: ANUN DOCK/ COMPNT (panel 11 and/or panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	Light goes off when O ₂ /H ₂ O QTY MON switch is set to C/W RESET momentarily. Descent tank low-pressure signal and ascent tanks less-than-full signals are inhibited after staging.
6DS38	GLYCOL (ECS)	Goes on if quantity of glycol in primary coolant loop is low or if primary-loop glycol temperature, sensed at glycol water evaporator outlet, is high.	LTG: ANUN DOCK/ COMPNT (panel 11 and/or panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	Both signals are inhibited after GLYCOL switch is set to INST (SEC) and GLYCOL PUMP SEC circuit breaker (panel 16) is pressed. If lit due to high-temperature condition, goes off when nominal temperature level is restored.
6DS39	WATER QTY (ECS)	Goes on if quantity in descent water tank drops below 16% of capacity, if less-than-full condition occurs in either ascent water tank, or if levels in ascent tanks are unequal.	LTG: ANUN DOCK/ COMPNT (panel 11 and/or panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	Light goes off when O ₂ /H ₂ O QTY MON switch is set to C/W RESET momentarily. Descent tank low-level signal and ascent tanks less-than-full signals are inhibited after staging.
8M4	QUANTITY indicator	Continuously indicates quantity (percentage) of propellant remaining for RCS	RCS: PQGS (panel 16)	LMP's 28-vdc bus	

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 2 (cont)					
8M2	TEMP indicator	Indicates temperature (+20° to +120° F) of fuel tanks of systems A and B, as selected with TEMP/PRESS MON selector switch.	RCS: TEMP/ PRESS DISP-FLAGS (panel 16)	LMP'2 28-vdc bus	Indicator consists of two fixed dials and vertical movable pointers, Displayed information is determined by setting of TEMP/PRESS MON selector switch.
8M1	PRESS indicator	Indicates pressure (0 to 3,500 psia) of helium tank, helium regulator, and of fuel or oxidizer manifolds of systems A and B, as selected with TEMP/PRESS MON selector switch.	RCS: TEMP/ PRESS DISP-FLAGS (panel 16)	LMP's 28-vdc bus	Same as TEMP indicator.
8S8	SYSTEM A ASC FEED 1 switch	Selects inputs to two latching solenoid-operated interconnect valves in ascent propellant line, which control flow of propellant from ascent propulsion tanks.	RCS SYS A: ASC FEED 1 (panel 11)	CDR's 28-vdc bus	Switch is spring-loaded to center position. In event of RCS malfunction, ascent propulsion section can supply propellant to 8 or 16 TCA's, while traveling in +X-direction (positive g's) during ascent phases. This can be accomplished by setting ASC FEED 1 switch for system A or B, or both, to ASC FEED 1 and MAIN SOV switch for system A or B, or both, to CLOSE. (ASC FEED 2 switch must be set to ASC FEED 2.)
	ASC FEED 1	Energizes solenoids that drive ascent propellant interconnect valves to open position.			Gray talkback is displayed when interconnect valves are open.
	Center	Removes solenoid excitation.			Interconnect valves remain in last commanded position.
	CLOSE	Energizes solenoids that drive ascent propellant interconnect valves to closed position.			Barber-pole talkback is displayed when interconnect valves are closed.

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 2 (cont) 8S22	SYSTEM A ASC FEED 2 switch	Selects inputs to two latching solenoid-operated interconnect valves in ascent propellant line, which control flow of propellant from ascent propulsion tanks.	RCS SYS A: ASC FEED 2 (panel 11)	CDR's 28-vdc bus	Switch is spring-loaded to center position. In event of RCS malfunction, ascent propulsion section can supply propellant to 8 or 16 TCA's, while traveling in +X-direction (positive g's) during ascent phases. This can be accomplished by setting ASC FEED 2 switch for system A or B, or both, to ASC FEED 2 and MAIN SOV switch for system A or B, or both, to CLOSE. (ASC FEED 1 switch must be set to ASC FEED 1.)
	ASC FEED 2	Energizes solenoids that drive ascent propellant interconnect valves to open position.			Gray talkback is displayed when interconnect valves are open.
	Center	Removes solenoid excitation.			Interconnect valves remain in last commanded position.
	CLOSE	Energizes solenoids that drive ascent propellant interconnect valves to closed position.			Barber-pole talkback is displayed when interconnect valves are closed.
	SYSTEM A ASC FUEL talkback				
	Gray display	Indicates ascent fuel interconnect valves are open.			Both ascent fuel interconnect valves must be open to obtain a gray display.
8FL6	Barber-pole display	Indicates interconnect valves are closed.	RCS SYS B: TEMP/ PRESS DISP-FLAGS (panel 16)	LMP's 28-vdc bus	Barber-pole display can be obtained with only one ascent fuel interconnect valve closed.

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 2 (cont) 8FL18 8S11 8FL9	SYSTEM A ASC OXID talkback Gray display Barber-pole display	Indicates ascent oxidizer interconnect valves are open. Indicates interconnect valves are closed.	RCS SYS B: TEMP/ PRESS DISP-FLAGS (panel 16)	LMP's 28-vdc bus	Both ascent oxidizer interconnect valves must be open to obtain a gray display. Barber-pole display can be obtained with only one ascent oxidizer interconnect valve closed.
	SYSTEM A THRUSTER PAIR QUAD 1 switch OPEN Center CLOSE	Selects inputs to two normally open, latching solenoid-operated isolation valves in propellant lines upstream of TCA's, to control propellant flow to TCA No. 1u and 1f. Energizes two solenoids that drive isolation valves to open position. Removes solenoid excitation. Energizes two solenoids that drive isolation valves to closed position and feeds signal to ACEA to inhibit automatic operation of TCA's.	RCS SYS A: ISOL VLV (panel 11)	CDR's 28-vdc bus	Switch is spring loaded to center position. Isolation valves are used for emergency shutdown during flight. Gray talkback is displayed when valves are open. Isolation valves remain in last commanded position. Barber-pole talkback is displayed when isolation valves are closed.
	SYSTEM A THRUSTER PAIR QUAD 1 talkback Gray display Barber-pole display	Indicates condition of two isolation valves in propellant lines upstream of TCA's. Indicates two isolation valves controlled by QUAD 1 switch directly below talkback are open. Indicates isolation valves are closed.	RCS SYS B: TEMP/ PRESS DISP-FLAGS (panel 16)	LMP's 28-vdc bus	Gray display can be obtained with only one isolation valve open. Both isolation valves must be closed to obtain a barber-pole display.

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 2 (cont)	Red display	<p>Indicates TCA fired without an on command.</p> <p>Indicates TCA did not fire upon command to TCA primary coil.</p>			If TCA fails, SYSTEM A THRUSTER PAIR QUAD 1 switch is set to CLOSE. This shuts down failed pair of TCA's; barber-pole is displayed and RCS TCA warning light goes off.
8S12	SYSTEM A THRUSTER PAIR QUAD 2 switch OPEN Center CLOSE	<p>Selects inputs to two normally open latching, solenoid-operated, shutoff, isolation valves in propellant lines downstream of TCA's, to control propellant flow to TCA No. IId and IIf.</p> <p>Energizes two solenoids that drive isolation valves to open position.</p> <p>Removes solenoid excitation.</p> <p>Energizes two solenoids that drive isolation valves to closed position and feeds signal to ACEA to inhibit automatic operation of TCA's.</p>	RCS SYS A: ISOL VLV (panel 16)	CDR's 28-vdc bus	<p>Switch is spring loaded to center position. Isolation valves are used for emergency shutdown during flight.</p> <p>Gray talkback is displayed when valves are open.</p> <p>Isolation valves remain in last commanded position.</p> <p>Barber-pole talkback is displayed when isolation valves are closed.</p>
8FL10	SYSTEM A THRUSTER PAIR QUAD 2 talkback Gray display Barber-pole display Red display	<p>Indicates condition of two isolation valves in propellant lines downstream of TCA No. IId and IIf.</p> <p>Indicates two isolation valves controlled by QUAD 2 switch directly below talkback are closed.</p> <p>Indicates isolation valves are closed.</p> <p>Indicates TCA fired without an on command.</p>	RCS SYS B: TEMP/ PRESS DISP-FLAGS (panel 16)	LMP's 28-vdc bus	<p>Gray display can be obtained with only one isolation valve open.</p> <p>Both isolation valves must be closed to obtain a barber-pole display.</p> <p>If TCA fails, SYSTEM A THRUSTER PAIR QUAD 2 switch is set to CLOSE. This shuts down failed pair of TCA's; barber-pole is displayed and RCS TCA warning light goes out.</p>

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 2 (cont) 8S15 8FL13 8S16	SYSTEM A THRUSTER PAIR QUAD 3 switch	Selects inputs to two normally open latching, solenoid-operated, shut-off, isolation valves in propellant lines downstream of TCA's, to control propellant flow to TCA No. IIIu and IIIs.	RCS SYS A: ISOL VLV (panel 11)	CDR's 28-vdc bus	Switch is spring loaded to center position. Isolation valves are used for emergency shutdown during flight.
	OPEN	Energizes two solenoids that drive isolation valves to open position.			Gray talkback is displayed when valves are open.
	Center	Removes solenoid excitation.			Isolation valves remain in last commanded position.
	CLOSE	Energizes two solenoids that drive isolation valves to closed position and feeds signal to ACEA to inhibit automatic operation of TCA's.			Barber-pole talkback displayed when isolation valves are closed.
	SYSTEM A THRUSTER PAIR QUAD 3 talkback	Indicates condition of two isolation valves in propellant lines downstream of TCA No. IIIu and IIIs.	RCS SYS B: TEMP/ PRESS DISP-FLAGS (panel 16)	LMP's 28-vdc bus	Both isolation valves must be closed to obtain a barber-pole display. If TCA fails, SYSTEM A THRUSTER PAIR QUAD 3 switch is set to CLOSE. This shuts down failed pair of TCA's; barber-pole is displayed and RCS TCA warning light goes out.
	Gray display	Indicates two isolation valves controlled by QUAD 3 switch directly below talkback are open.			
	Barber-pole display	Indicates isolation valves are closed.			
	Red display	Indicates TCA fired without an on command. Indicates TCA did not fire upon command to TCA primary coil.			
	SYSTEM A THRUSTER PAIR QUAD 4 switch	Selects inputs to two normally open, latching, solenoid-operated, shut-off, isolation valves in propellant lines downstream of TCA's, to control propellant flow to TCA No. IVd and IVs.	RCS SYS A: ISOL VLV (panel 11)	CDR's 28-vdc bus	Switch is spring loaded to center position. Isolation valves are used for emergency shutdown during flight.

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 2 (cont)	OPEN	Energizes two solenoids that drive isolation valves to open position.			Gray talkback is displayed when valves are open.
	Center	Removes solenoid excitation.			Isolation valves remain in last commanded position.
	CLOSE	Energizes two solenoids that drive isolation valves to closed position and feeds a signal to ACEA to inhibit automatic operation of TCA's.			Barber-pole talkback is displayed when isolation valves are closed.
	8FL14 SYSTEM A THRUSTER PAIR QUAD 4 talkback	Indicates condition of two isolation valves in propellant lines downstream of TCA No. IVd and IVs.	RCS SYS B: TEMP/ PRESS DISP-FLAGS (panel 16)	LMP's 28-vdc bus	Gray display can be obtained with only one isolation valve open.
	Gray display	Indicates open condition of two isolation valves controlled by QUAD 4 switch directly below status flag.			
	Barber-pole display	Indicates isolation valves are closed.			Both isolation valves must be closed to obtain a barber-pole display.
	Red display	Indicates TCA fired without an on command. Indicates TCA did not fire upon command to TCA primary coil.			If TCA fails, SYSTEM A THRUSTER PAIR QUAD 4 switch is set to CLOSE. This shuts down failed pair of TCA's; barber-pole is displayed and RCS TCA warning light goes out.
8S10	SYSTEM B ASC FEED 1 switch	Selects inputs to two latch-type solenoid-operated interconnect valves in ascent propellant line, which control flow of propellant from ascent propulsion tanks.	RCS SYS B: ASC FEED 1 (panel 16)	LMP's 28-vdc bus	Switch is spring-loaded to center position. In event of RCS malfunction, ascent propulsion section can supply propellant to 8 or 16 TCA's, while traveling in +X-direction (positive g's) during ascent phases. This can be accomplished by setting ASC FEED 1 switch for system A or B, or both, to ASC FEED 1 and MAIN SOV switch for system A or B, or both, to CLOSE. (ASC FEED 2 switch must be set to ASC FEED 2.)

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 2 (cont)	ASC FEED 1	Energizes solenoids that drive ascent propellant interconnect valves to open position.			Gray talkback is displayed when interconnect valves are open.
	Center	Removes solenoid excitation.			Interconnect valves remain in last commanded position.
	CLOSE	Energizes solenoids that drive ascent propellant interconnect valves to closed position.			Barber-pole talkback is displayed when interconnect valves are closed.
	8S23 SYSTEM B ASC FEED 2 switch	Selects inputs to two latch-type solenoid-operated interconnect valves in ascent propellant line, which control flow of propellant from ascent propulsion tanks.	RCS SYS B: ASC FEED 2 (panel 16)	LMP's 28-vdc bus	Switch is spring-loaded to center position. In event of RCS malfunction, ascent propulsion section can supply propellant to 8 or 16 TCA's, while traveling in +X-direction (positive g's) during ascent phases. This can be accomplished by setting ASC FEED 2 switch for system A or B, or both, to ASC FEED 2 and MAIN SOV switch for system A or B, or both, to CLOSE. (ASC FEED 1 switch must be set to ASC FEED 2.)
	ASC FEED 2	Energizes solenoids that drive ascent propellant interconnect valves to open position.			Gray talkback is displayed when interconnect valves are open.
	Center	Removes solenoid excitation.			Interconnect valves remain in last commanded position.
	CLOSE	Energizes solenoids that drive ascent propellant interconnect valves to closed position.			Barber-pole talkback is displayed when interconnect valves are closed.

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 2 (cont)	8FL19	SYSTEM B ASC OXID talkback	RCS SYS B: TEMP/ PRESS DISP-FLAGS (panel 16)	LMP's 28-vdc bus	Both ascent oxidizer interconnect valves must be open to obtain a gray display.
		Gray display			
		Barber-pole display	RCS SYS B: TEMP/ PRESS DISP-FLAGS (panel 16)	LMP's 28-vdc bus	Barber-pole display can be obtained with only one ascent oxidizer interconnect valve closed.
	8FL8	SYSTEM B ASC FUEL talkback	RCS SYS B: TEMP/ PRESS DISP-FLAGS (panel 16)	LMP's 28-vdc bus	Both ascent fuel interconnect valves must be open to obtain a gray display.
		Gray display			
		Barber-pole display	RCS SYS B: ISOL VLV (panel 16)	LMP's 28-vdc bus	Barber-pole display can be obtained with only one ascent fuel interconnect valve closed.
	8S13	SYSTEM B THRUSTER PAIR QUAD 1 switch	RCS SYS B: ISOL VLV (panel 16)	LMP's 28-vdc bus	Switch is spring loaded to center position. Isolation valves are used for emergency shutdown during flight.
		OPEN			
		Center			
		CLOSE			

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 2 (cont)					
8FL11	SYSTEM B THRUSTER PAIR QUAD 1 talkback	Indicates condition of two isolation valves in propellant lines downstream of TCA No. Id and Is.	RCS SYS B: TEMP/ PRESS DISP-FLAGS (panel 16)	LMP's 28-vdc bus	<p>A gray display can be obtained with only one isolation valve open.</p> <p>Both isolation valves must be closed to obtain a barber-pole display.</p> <p>If TCA fails, SYSTEM A THRUSTER PAIR QUAD 1 switch is set to CLOSE. This shuts down failed pair of TCA's; barber-pole is displayed, and RCS TCA warning light goes out.</p>
	Gray display	Indicates two isolation valves controlled by QUAD 1 switch directly below talkback are open.			
	Barber-pole display	Indicates isolation valves are closed.			
	Red display	Indicates TCA fired without an on command. Indicates TCA did not fire upon command to TCA primary coil.			
8S14	SYSTEM B THRUSTER PAIR QUAD 2 switch	Selects inputs to two normally open, latching, solenoid-operated, shutoff, isolation valves in propellant lines downstream of TCA's, to control propellant flow to TCA No. Ilu and IIs.	RCS SYS B: ISOL VLV (panel 16)	LMP's 28-vdc bus	<p>Switch is spring loaded to center position. Isolation valves are closed during lunar-stay shutdown; they are used for emergency shutdown during flight.</p> <p>Gray talkback is displayed when valves are open.</p> <p>Isolation valves remain in last commanded position.</p> <p>Barber-pole talkback is displayed when isolation valves are closed.</p>
	OPEN	Energizes two solenoids that drive isolation valves to open position.			
	Center	Removes solenoid excitation.			
	CLOSE	Energizes two solenoids that drive isolation to closed position and feeds signal to ACEA to inhibit automatic firing of TCA's.			
8FL12	SYSTEM B THRUSTER PAIR QUAD 2 talkback	Indicates condition of two isolation valves in propellant lines downstream of TCA No. Ilu and IIs.	RCS SYS B: TEMP/ PRESS DISP-FLAGS (panel 16)	LMP's 28-vdc bus	

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 2 (cont) 8SI17 8FL15	Gray display	Indicates two isolation valves controlled by QUAD 2 switch directly below talkback are open.			A gray display can be obtained with only one isolation valve open.
	Barber-pole display	Indicates isolation valves are closed.			Both isolation valves must be closed to obtain a barber-pole display.
	Red display	Indicates TCA fired without an on command. Indicates TCA did not fire upon command to TCA primary coil.			If TCA fails, SYSTEM A THRUSTER PAIR QUAD 2 switch is set to CLOSE. This shuts down failed pair of TCA's; barber-pole is displayed, and RCS TCA warning light goes out.
	SYSTEM B THRUSTER PAIR QUAD 3 switch	Selects inputs to two normally open, latching, solenoid-operated, shutoff, isolation valves in propellant lines downstream of TCA's, to control propellant flow to TCA No. IIId and IIIf.	RCS SYS B: ISOL VLV (panel 16)	LMP's 28-vdc bus	Switch is spring loaded to center position. Isolation valves are used for emergency shutdown during flight.
	OPEN	Energizes two solenoids that drive isolation valves to open position.			Gray talkback is displayed when valves are open.
	Center	Removes solenoid excitation.			Isolation valves remain in last commanded position.
	CLOSE	Energizes two solenoids that drive isolation valves to closed position and feeds signal to ACEA to inhibit automatic firing of TCA's.			Barber-pole talkback is displayed when isolation valves are closed.
	SYSTEM B THRUSTER PAIR QUAD 3 talkback	Indicates condition of two isolation valves in propellant lines downstream of TCA No. IIId and IIIf.	RCS SYS B: TEMP/PRESS DISP-FLAGS (panel 16)	LMP's 28-vdc bus	
	Gray display	Indicates two isolation valves controlled by QUAD 3 switch directly below talkback are open.			A gray display can be obtained with only one isolation valve open.
	Barber-pole display	Indicates isolation valves are closed.			Both isolation valves must be closed to obtain a barber-pole display.

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 2 (cont)	Red display	<p>Indicates TCA fired without an on command.</p> <p>Indicates TCA did not fire upon command to TCA primary coil.</p>			If TCA fails, SYSTEM A THRUSTER PAIR QUAD 3 switch is set to CLOSE. This shuts down failed pair of TCA's; barber-pole is displayed, and RCS TCA warning light goes out.
8S18	SYSTEM B THRUSTER PAIR QUAD 4 switch OPEN Center CLOSE	<p>Selects inputs to two normally open, latching, solenoid-operated, shutoff, isolation valves in propellant lines downstream of TCA's, to control propellant flow to TCA No. IVu and IVf.</p> <p>Energizes two solenoids that drive isolation valves to open position.</p> <p>Removes solenoid excitation.</p> <p>Energizes two solenoids that drive isolation valves to closed position and feed signal to ACEA to inhibit automatic firing of TCA's.</p>	RCS SYS B: ISOL VLV (panel 16)	LMP's 28-vdc bus	<p>Switch is spring loaded to center position. Isolation valves are used for emergency shutdown during flight.</p> <p>Gray talkback is displayed when valves are open.</p> <p>Isolation valves remain in last commanded position.</p> <p>Barber-pole talkback is displayed when isolation valves are closed.</p>
8FL16	SYSTEM B THRUSTER PAIR QUAD 4 status flag Gray display Barber-pole display Red display	<p>Indicates condition of two isolation valves in propellant lines downstream of TCA No. IVu and IVf.</p> <p>Indicates two isolation valves controlled by QUAD 4 switch directly below talkback are open.</p> <p>Indicates isolation valves are closed.</p> <p>Indicates TCA fired without an on command.</p> <p>Indicates TCA did not fire upon command to TCA primary coil.</p>	RCS SYS B: TEMP/ PRESS DISP-FLAGS (panel 16)	LMP's 28-vdc bus	<p>A gray display can be obtained with only one isolation valve open.</p> <p>Both isolation valves must be closed to obtain a barber-pole display.</p> <p>If TCA fails, SYSTEM A THRUSTER PAIR QUAD 4 switch is set to CLOSE. This shuts down failed pair of TCA's; barber-pole is displayed, and RCS TCA warning light goes out.</p>

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 2 (cont) 8S19	TEMP/PRESS MON selector switch	Selects inputs to propellant temperature- and pressure-indicating devices for systems A and B.	RCS SYS B: TEMP/ PRESS DISP-FLAGS (panel 16)	LMP's 28-vdc bus	Switch permits monitoring systems A and B propellant temperature and pressure.
	He	Connects outputs of systems A and B helium tank pressure transducer to PRESS indicator.			
	PRPLNT	Connects outputs of systems A and B fuel tank temperature sensors and helium manifold pressure transducer to TEMP and PRESS indicators.			Oxidizer temperature will be approximately the same as fuel temperature.
	FUEL MANF	Connects outputs of systems A and B fuel manifold pressure transducer to PRESS indicator.			Pointers on TEMP indicator go to lowest graduation mark, because manifold temperature is not sensed.
	OXID MANF	Connects outputs of systems A and B oxidizer manifold pressure transducer to PRESS indicator.			Pointers on TEMP indicator go to lowest graduation mark, because manifold temperature is not sensed.
	8S20	CRSFD switch	RCS SYS B: CRSFD (panel 16)	LMP's 28-vdc bus	Switch is spring loaded to center position. If system A or B malfunctions, its related MAIN SOV switch is set to CLOSE, and CRSFD switch is set to OPEN. This opens crossfeed valves and permits fuel and oxidizer to flow from operative system to thrust chambers of both systems. CRSFD talkback displays status of crossfeed valves.
	OPEN	Energizes two solenoids that open crossfeed valves.			Gray talkback is displayed when crossfeed valves are open.
	Center	Removes solenoid excitation.			Crossfeed valves remain in last commanded position.
	CLOSE	Energizes two solenoids that close crossfeed valves.			Barber-pole talkback is displayed when crossfeed valves are closed.

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 2 (cont) 8S9	SYSTEM B MAIN SOV switch	Selects inputs to two latching, solenoid-operated, main shutoff valves in propellant lines downstream of propellant tanks.	RCS SYS B: MAIN SOV (panel 16)	LMP's 28-vdc bus	Switch is spring loaded to center position. These valves are normally open; if system A or B malfunctions, propellant flow to malfunctioning system is interrupted by setting corresponding switch to CLOSE.
	OPEN	Energizes solenoids that drive propellant main shutoff valves to open position.			Gray talkback is displayed when main shutoff valves are open.
	Center	Removes solenoid excitation.			Main shutoff valves remain in last commanded position.
8FL7	CLOSE	Energizes solenoids that drive propellant main shutoff valves to closed position.	RCS SYS B: TEMP/ PRESS DISP-FLAGS (panel 16)	LMP's 28-vdc bus	Barber-pole talkback is displayed when main shutoff valves are closed.
	SYSTEM B MAIN SOV talkback				
	Gray display	Indicates propellant main shutoff valves controlled by SYSTEM B MAIN SOV switch are open.			A gray display can be obtained with only one main shutoff valve open.
1824	Barber-pole display	Indicates main propellant shutoff valves are closed.	STAB/CONT: AELD (panel 11 and panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	Both main shutoff valves must be closed to obtain a barber-pole display.
	RCCA switch	Enables rough combustion cutoff assembly.			
	ENABLE	Applies power to rough combustion cutoff assembly.			
	OFF/RESET	Removes power from rough combustion cutoff assembly.			

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 2 (cont)	ENVIRONMENTAL CONTROL				
	TEMP indicator				
7M3B	SUIT °F scale	Displays suit circuit temperature (degrees Fahrenheit) sensed at suit outlet.	ECS: DISP (panel 16)	LMP's 28-vdc bus	
7M3A	CABIN °F scale	Displays cabin interior temperature (degrees Fahrenheit) sensed at cabin fan inlet.			
	PRESS indicator				
7M2B	SUIT PSIA scale	Displays suit circuit pressure (psia) sensed downstream of suit gas supply connectors.	ECS: DISP (panel 16)	LMP's 28-vdc bus	
7M2A	CABIN PSIA scale	Displays cabin interior pressure (psia) sensed by aneroid sensor on cabin pressure sensor switch.			
7M1	PART PRESS CO ₂ indicator	Displays partial pressure of carbon dioxide content of gas in ARS.	ECS: DISP (panel 16)	LMP's 28-vdc bus	
	GLYCOL indicator				
7M5B	TEMP scale	Displays glycol temperature (degrees Fahrenheit) in primary coolant loop. However, following failure of primary loop and selection of secondary coolant pump, with GLYCOL selector switch and GLYCOL PUMP SEC circuit breaker, indicator displays secondary coolant loop temperature.	ECS: DISP (panel 16)	LMP's 28-vdc bus	

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 2 (cont)	7M5A	PRESS scale			
	7M4B	QUANTITY indicator O ₂ scale	ECS: DISP (panel 16)	LMP's 28-vdc bus	
	7M4A	H ₂ O scale			
	9M3	X-Pointer indicator	FLIGHT DISPLAYS X-PNTR (panel 16)	LMP's 28-vdc bus	Forward and lateral velocities are coincident with LM Z and Y body axis velocities when PGNS drives display. When LR drives display, forward and lateral velocities are coincident with LM Z and Y axes (from hi-gate point to touch-down). When AGS drives display, lateral Y-axis velocity only is displayed. When RR is selected, LOS rates are displayed.

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 2 (cont)					
9M6	Flight director attitude indicator (FDAI)	Displays total vehicle attitudes, attitude rates and attitude errors, or vehicle attitude, attitude rates, and RR shaft and trunnion angles, depending on setting of RATE/ERR MON switch. Setting ATTITUDE MON switch selects PGNS or AGS as source of vehicle total attitude and attitude errors displayed on FDAI. Shaft and trunnion angles are displayed by pitch and yaw error needles, respectively, when RATE/ERR MON switch is set to RNDZ RADAR.	AC BUS B: SE FDAI (panel 11) FLT DISP: EVENT TIMER/ SE FDAI (panel 16)	CDR's 115-vac bus B LMP's 28-vdc bus	Attitude rates displayed are always obtained from CES rate gyro assembly.
6S3	MASTER ALARM pushbutton/light Audible tone	Lights flash when any caution or warning light goes on. Initiated in conjunction with MASTER ALARM pushbutton/light and caution/warning array light(s).	LTG: MASTER ALARM (panel 16)	LMP's 28-vdc bus	Pressing Commander's or LM Pilot's pushbutton extinguishes both MASTER ALARM lights and terminates audible tone, but has no effect on caution or warning light(s).
9S7	RATE/ERR MON switch RNDZ RADAR	Selects inputs for FDAI and X-pointer indicator. Shaft and trunnion angles from the RR are displayed by pitch and yaw error needles of FDAI; LOS azimuth and elevation rates are displayed on X-pointer indicator (illuminating LOS AZ and LOS ELEV).	N/A	N/A	When switch is set to LDG, RDR/ CMPTR, data input is dependent upon settings of MODE SEL and ATTITUDE MON switches.

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 2 (cont)	LDG RDR/COMPTR	Vehicle attitude errors (PGNS or AGS as selected with ATTITUDE MON switch), are displayed by FDAI error needles. Forward and lateral velocities from the LR (PGNS or AGS as selected with MODE SEL switch) are displayed on the X-pointer indicator (illuminating LAT VEL and FWD VEL).			AGS provides only lateral velocity data.
9S10	ATTITUDE MON switch	Selects input for FDAI total attitude display and input for attitude error needles during landing.	N/A	N/A	The input is dependent on whether PGNS or AGS is controlling system.
	PGNS	LM total attitude signals, after conditioning by GASTA, are fed to FDAI ball; LGC attitude error signals are fed to FDAI pitch, roll, and yaw error needles.			
	AGS	AGS LM total attitude signals are fed to FDAI ball; AGS attitude error signals are fed to FDAI pitch, roll, and yaw error needles.			
7S3	GLYCOL selector switch	Selects either circulating pump in primary coolant loop, or circulating pump in secondary coolant loop.	ECS: GLYCOL PUMP 1 and ECS: GLYCOL PUMP 2 (panel 11)	CDR's 28-vdc bus	Pump failure causes GLYCOL component caution light and ECS caution light to go on.
	PUMP 1	Activates glycol pump No. 1		LMP's 28-vdc bus	GLYCOL component caution light and ECS caution light go off when glycol pump No. 2 is activated.
	PUMP 2	Activates glycol pump No. 2	ECS: GLYCOL PUMP SEC (panel 16)		If glycol pump No. 2 fails, both lights will go on. Pressing ECS; GLYCOL PUMP SEC circuit breaker activates secondary glycol pump and extinguishes ECS caution light.
	INST/(SEC)	Activates glycol instrumentation.			

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 2 (cont)					
7DS3	GLYCOL component caution light	Goes on to indicate failure of active glycol pump.	ECS: GLYCOL PUMP 1 and GLYCOL PUMP 2 (panel 11)	CDR's 28-vdc bus	Light goes out when pump is re-selected and normal pressure is restored.
7DS6	CO ₂ component caution light	Goes on to indicate that CO ₂ partial pressure in suit circuit exceeds 7.6 mm Hg or if CO ₂ CANISTER SEL valve is set to SEC.	ECS: CO ₂ SENSOR (panel 16)	LMP's 28-vdc bus	Light goes off when primary canister is replaced with unsaturated canister, CO ₂ CANISTER SEL valve is set to PRIM, and CO ₂ partial pressure is restored to within-tolerance condition.
7DS7	H ₂ O SEP component caution light	Goes on to indicate low-speed condition or failure (stoppage) in selected water separator.	ECS: DISP (LMP's circuit breaker panel)	LMP's 28-vdc bus	Light goes off when other water separator is selected with H ₂ O SEP SEL valve and water separator comes up to desired speed.
7S1	SUIT FAN selector switch OFF 1 2	Selects suit fan to circulate breathing oxygen in suit circuit. Shuts off all power to suit fans. Selects fan No. 1 for operation. Selects fan No. 2 for operation.	ECS: SUIT FAN 1 (panel 11) ECS: SUIT FAN 2 (panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	Failure of suit fan No. 1 causes SUIT FAN component caution light and ECS caution light to go on. Selection of fan No. 2 and return of normal ΔP across the fans, extinguishes both lights.
7DS1	SUIT FAN component caution light	Lights to indicate low ΔP across suit fan assembly, due to malfunction of operating suit fan.	ECS: SUIT FAN ΔP (LMP's circuit breaker panel)	LMP's 28-vdc bus	Light goes off when SUIT FAN switch is set to other fan. However, light goes on if newly selected fan does not develop proper ΔP within approximately 25 seconds, or when failure occurs in selected fan.

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 2 (cont) 7S2	O ₂ /H ₂ O QTY MON selector switch	Selects, for monitoring on QUANTITY indicator, quantities remaining in descent or ascent oxygen and water storage tanks.	N/A	N/A	
	C/W RESET	Routes signal to CWEA to extinguish O ₂ QTY caution light or WATER QTY caution light if on.			
	DES	Descent oxygen tank pressure is displayed on O ₂ QUANTITY indicator and quantity remaining in descent water tank is displayed on H ₂ O QUANTITY indicator.			
	ASC 1	Ascent oxygen tank No. 1 pressure is displayed on O ₂ QUANTITY indicator and quantity remaining in ascent water tank No. 1 is displayed on H ₂ O QUANTITY indicator.			
	ASC 2	Ascent oxygen tank No. 2 pressure is displayed on O ₂ QUANTITY indicator and quantity remaining in ascent water tank No. 2 is displayed on H ₂ O QUANTITY indicator.			

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 3 1S8	ENG GMBL switch	Enables or disables engine gimbal drive capability.	AC BUS A: DECA GMBL (panel 11)	CDR's 115-vac bus	Normally set to ENABLE. If ENG GMBL caution light goes on, astronaut must set switch to OFF.
	ENABLE	Gimbal trim signals are enabled to displace descent engine along Y and Z axes.			
	OFF	Power to the GDA's is removed, disabling the gimbal drive capability.			
1S15	DES ENG CMD OVRD switch	Supplies alternate source of 28-vdc to descent engine shut-off valves.	STAB/CONT: ABORT STAGE (panel 11)	CDR's 28-vdc bus	Switch is utilized to keep valves open if DECA power fails. Circuit is completed through normally closed contacts of ABORT STAGE switch.
	ON	Applies 28-vdc to descent engine shut-off valves.			
	OFF	Removes 28-vdc from valves.	STAB/CONT: ABORT STAGE (panel 16)	LMP's 28-vdc bus	
17S5	LDG ANT switch		N/A	N/A	Because antenna cannot be driven to its first position by LGC and it is necessary to check out completely two-position capability and provide override of position drive signal if LR antenna interface fails, DES and HOVER positions are used.
	AUTO	Enables LGC to position LR antenna as function of mission phase.			
	DES	Drives antenna to first position used before hover point.			
	HOVER	Drives antenna to its second position for final landing phase.			

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 3 (cont)	17M1	SIGNAL STRENGTH indicator	Displays LR and RR data for test and flight operations, respectively, as selected with TEST/MONITOR switch.	PGNS: SIG STR DISP (panel 11)	CDR's 28-vdc bus
	17DS1	RENDEZVOUS RADAR NO TRACK light	Light goes on to indicate that RR has broken track (data not good) in any one of three tracking modes.	N/A	N/A
	17S6	RADAR TEST switch RNDZ OFF LDG	Provides testing capability of both radars. Initiates test circuitry. RR performance is checked by monitoring SIGNAL STRENGTH indicator after appropriate setting of TEST/MONITOR switch. Disables testing capability. Initiates test circuitry. LR performance is checked by monitoring SIGNAL STRENGTH indicator after appropriate setting of TEST/MONITOR switch.	N/A	N/A
	17S8	TEST/MONITOR selector switch ALT XMTR VEL XMTR	Selects LR or RR test data or flight performance data for monitoring on SIGNAL STRENGTH indicator. Provides altitude range transmitter power output for display on SIGNAL STRENGTH indicator during test and flight operations. Provides velocity transmitter power output for display on SIGNAL STRENGTH indicator during test and flight operations.	N/A	N/A

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
CONTROLS AND DISPLAYS

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 3 (cont)	AGC	Provides AGC during RR testing. Specific value of receiver signal strength should be displayed on SIGNAL STRENGTH indicator; however, during flight operations signal varies.			
	XMTR PWR	Provides specific value of transmitter power output for display on SIGNAL STRENGTH indicator during flight operations.			
	SHAFT ERR	During test, shaft angle error signals are displayed as needle fluctuations with equal amplitude on SIGNAL STRENGTH indicator. During flight operations, these error signals are displayed as needle fluctuations, usually of unequal amplitude, that represent smoothness of servo tracking.			
	TRUN ERR	Same as for SHAFT ERR position, except trunnion angle errors are displayed.			
17S2	SLEW RATE switch	Provides two rates for manually slewing radar antenna with SLEW switch.	N/A	N/A	
	HI	Selects high slew rate for quick coarse adjustments to guide antenna in direction of target.			High slew rate is 7°/sec.
	LO	Selects low slew rate for accurately peaking SIGNAL STRENGTH indicator, enabling subsequent initiation of auto track through rendezvous radar mode selector switch with assurance that main lobe lock will be achieved.			Low slew rate is 1.33°/sec.

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 3 (cont)	17S1	SLEW switch	N/A	N/A	Two antenna slew rates are available using SLEW RATE switch. Target acquisition is determined from SIGNAL STRENGTH indicator and auto track mode is enabled with rendezvous radar mode selector switch. RR antenna alignment along LM axis can be determined from FDAI pitch and yaw error needles when RATE/ERR MON switch is set to RNDZ RADAR.
		UP			
		RIGHT			
		DOWN			
		LEFT			
	17S3	RENDEZVOUS RADAR mode selector switch	N/A	N/A	Once target is acquired, radar automatically maintains track and NO TRACK light goes off.
		AUTO TRACK			
		SLEW			
		LGC			

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 3 (cont)	11S2	DEAD BAND switch			
		MAX	N/A	N/A	Switch is not functional when PGNS is in use.
		MIN			For maximum deadband, which is 5°, FDAI error needle scaling is ±14.4°.
					During main engine thrusting, minimum deadband is always operating.
					For minimum deadband, which is 3°, FDAI error needle scaling is ±1.7°.
	11S7	GYRO TEST ROLL switch			
		ROLL	N/A	N/A	Switch is associated with GYRO TEST POS RT switch.
		PITCH			
		YAW			
	11S1	GYRO TEST POS RT switch			
		POS RT	N/A	N/A	
		OFF			
		NEG RT			

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 3 (cont)					
11S4 11S3 11S5	ATTITUDE CONTROL ROLL, PITCH, and YAW switches	Used in conjunction with MODE CONTROL switch to establish at- titude control in roll, pitch, and yaw. Normally these switches are set to MODE CONT while PGNS is in control.	N/A	N/A	
	MODE CONT	Enables use of proportional mode of ACA when MODE control selector switch is set to ATT HOLD and PGNS is controlling. When MODE CON- TROL selector switch is set to AUTO, LGC supplies attitude com- mands to maneuver LM. Under AGS control, function of MODE CONT positions are the same manner as when PGNS is controlling.			
	PULSE	Under PGNS control this position is inoperative. Under AGS control, the PULSE and DIR positions differ only in how RCS thrusters fire.			
		When PULSE is selected, two jets in selected axis fire at constant pulsed rate as long as ACA is displaced more than one-fourth of full throw. PULSE and DIR positions provide open loop acceleration. Rates pro- duced must be nulled to zero by in- ducing opposite acceleration com- mand. Attitude is not maintained automatically until switch is returned to MODE CONT.			
	DIR	Under PGNS control, when MODE CONTROL selector switch is set to ATT HOLD or AUTO, DIR mode can be used in any axis. Each switch must be set to DIR independently. Displacing ACA one-fourth of full			

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 3 (cont)		throw. As in PULSE position, open loop acceleration is provided; it must be nulled in as during pulse operation.			
11S6	MODE CONTROL selector switch	Affects outputs of ACA's, TTCA's and LGC.	N/A	N/A	Switch is associated with ATTITUDE CONTROL switches and GUID CONT switch.
	OFF	Establishes the following conditions: (a) Limits operation of the ACA's to the hardover position. (b) Enables two-jet direct attitude control in axis, selected with ATTITUDE CONTROL switches. (c) Disables translation outputs of TTCA's and LGC attitude commands.			TTCA throttle commands are not affected. LGC and AGS engine-off signals are not enabled; engine must be manually turned off.
	ATT HOLD	In this mode, astronauts can command angular rates proportional to displacement of ACA's. Mode is functional with either PGNS or AGS controlling operation. When ACA is out of detent, ATTITUDE CONTROL switches set to MODE CONT, and AGS in control, attitude loops are opened and axis transducers are compared to rate gyro outputs to provide proportional commands. While maneuvering, attitude synchronizers follow as attitude changes. When ACA is returned to detent, attitude synchronizers clamp and the attitude loop is closed to hold attitude. If PGNS control is selected, astronauts can command attitude rates proportional to ACA displacement, and attitude is held when ACA is			When ATTITUDE CONTROL switches are set to PULSE or DIR, following attitude command capabilities result: With GUID CONT switch set to AGS, proportional rate commands are disabled for those axes for which PULSE or DIR was selected. With GUID CONT switch set to PGNS and one or more ATTITUDE CONTROL switches set to PULSE, attitude hold mode is not affected. With GUID CONT switch set to PGNS and one or more ATTITUDE CONTROL switches set to DIR, ACA displacement of one-fourth of full throw causes continuous two-jet firing for selected axes, without rate feedback interfering with LGC command signals.

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 3 (cont)	AUTO	<p>returned to detent. When a programmed minimum impulse mode command (entered via DSKY) is in effect, moving ACA out of detent in any axis commands a pulse to applicable RCS jets. No attitude or attitude rate stabilization is provided in this mode.</p> <p>With GUID CONT switch set to AGS, attitude error signals are sent to CES from AGS. In CES, these attitude error signals are passed through limiter, which limits angular rate and combines error signals with rate gyro damping signal. Resultant signals control firing of RCS jets through selectable deadband, logic, pulse modulators, and jet driver amplifiers. Rate commands from ACA remain active in this mode; attitude disturbances occur if ACA is displaced inadvertently. When GUID CONT switch is set to PGNS, rate-compensated steering errors are generated by LGC and on-off commands are fed to jet drivers. RCS translation outputs of TTCA's are enabled.</p>			<p>TTCA and ACA hardover outputs are not affected.</p> <p>When one or more ATTITUDE CONTROL switches are set to PULSE or DIR, the following attitude command capabilities and limitations result. With GUID CONT switch set to AGS, proportional rate commands are disabled for those axes for which PULSE or DIR was selected. With GUID CONT switch set to PGNS and one or more ATTITUDE CONTROL switches set to PULSE, attitude hold mode is not affected. With GUID CONT switch set to PGNS and one or more ATTITUDE CONTROL switches set to DIR, conflicting commands from LGC result when ACA's are displaced one-fourth of full throw.</p>
18M1	TEMP indicator	Displays temperature of radar antenna assemblies RCS quads or S-band antenna as selected with TEMP MONITOR selector switch.	HEATERS: DISP (panel 16)	LMP's 28-vdc bus	
18S10	TEMP MONITOR selector switch	Selects temperature of antennas and RCS quads for monitoring.			

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 3 (cont)	RNDZ	Selects temperature of RR antenna for monitoring.	HEATERS: RNDZ RDR STDBY and RNDZ RDR OPR (panel 11)	CDR's 28-vdc bus	
	LDG	Selects temperature of LR antenna for monitoring.	HEATERS: LDG RDR (panel 11)	CDR's 28-vdc bus	
	QUAD 1	Selects temperature of RCS quad I for monitoring.	HEATERS: RCS A/B-1: QUAD 1	CDR's 28-vdc bus	
	QUAD 2	Selects temperature of RCS quad II for monitoring.	QUAD 2		
	QUAD 3	Selects temperature of RCS quad III for monitoring.	QUAD 3		
	QUAD 4	Selects temperature of RCS quad IV for monitoring.	QUAD 4 (panel 11)		
	S-BAND	Selects temperature of S-band and antenna assembly for monitoring.	HEATERS: RCS SYS A/B-2: QUAD 1 QUAD 2 QUAD 3 QUAD 4 (panel 16)	LMP's 28-vdc bus	
9S11	EVENT TIMER RESET/COUNT switch	Controls direction in which EVENT TIMER indicator counts.	FLIGHT DISPLAYS: EVENT TIMER/ SE FDAI (panel 16)	LMP's 28-vdc bus	
	RESET	Resets EVENT TIMER indicator to zero.			
	UP	EVENT TIMER indicator counts up from 0 minutes 0 seconds to 59 minutes 59 seconds, returns to zero, and again begins counting up.			
	DOWN	EVENT TIMER indicator counts down from preset time to 0 minutes 0 seconds, returns to 59 minutes 59 seconds, and again counts down.			

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 3 (cont) 9S12	EVENT TIMER TIMER CONT switch	Starts and stops EVENT TIMER indicator.	FLIGHT DISPLAYS: EVENT TIMER/SE FDAI (panel 16)	LMP's 28-vdc bus	Switch is spring loaded to center position.
	START	Starts EVENT TIMER indicator counting in direction selected with RESET/COUNT switch.			
	STOP	Stops EVENT TIMER indicator.			
9S13	EVENT TIMER SLEW CONT MIN switch	Provides slewing function for EVENT TIMER indicator.	FLIGHT DISPLAYS: EVENT TIMER/SE FDAI (panel 16)	LMP's 28-vdc bus	Switch is spring loaded to center position.
	TENS	Slews tens-column digit of MIN columns at rate of two digits per second as long as switch is held in this position.			
	Center	Disables slewing function.			
9S14	EVENT TIMER SLEW CONT SEC switch	Provides slewing function for EVENT TIMER indicator.	FLIGHT DISPLAYS: EVENT TIMER/SE FDAI (panel 16)	LMP's 28-vdc bus	Switch is spring loaded to center position.
	TENS	Slews tens-column digit of SEC columns at rate of two digits per second as long as switch is held in this position.			
	Center	Disables slewing function.			
	UNITS	Slews units-column digit of SEC columns at rate of two digits per second as long as switch is held in this position.			

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 3 (cont)					
11S4 11S5 11S6 11S7	RCS SYS A/B-2 QUAD 1, QUAD 2, QUAD 3, and QUAD 4 heater switches AUTO OFF MAN	Control the system 2 heaters within applicable quad of RCS engines. Enables automatic temperature con- trol of each engine in a quad. Interrupts 28-vdc to the heaters. Bypasses automatic temperature control and continuously maintains 28-vdc on each engine in a quad.	HEATERS: RCS SYS A/B-2: QUAD 1 QUAD 2 QUAD 3 QUAD 4 (panel 16)	LMP's 28-vdc bus	Heater system 1 provides automatic control of RCS engine temperatures. This system has no override cap- ability. When QUAD switches are set to AUTO, engine injector tem- peratures are maintained at 120 ±8° F. If temperature of any quad exceeds 128° F, HEATER caution light goes on.
16S9	SIDE PANELS switch ON OFF	Permits control of lighting on LM Pilot's side panels, independently of lighting of forward panel. Enables on/off control of LM Pilot's side panel integral lights. Connects side panel integral lights to INTEGRAL OVERRIDE switch and INTEGRAL control on panel 5. Disconnects side panel integral lights from INTEGRAL control and INTEGRAL OVERRIDE switch on panel 5.	AC BUS A: INTGL LTG (panel 11)	CDR's 115-vac bus	
16S6	FLOOD OVHD/FWD switch ALL OFF OVHD/FWD	Energizes crew compartment flood- lights. Energizes all floodlights. Deenergizes all floodlights. Energizes two overhead and two forward floodlights.	LTG: FLOOD (panel 16)	LMP's 28-vdc bus	Floodlight power source is indepen- dent of that used for integral lighting. Overhead floodlights are fitted with rotatable reflectors.

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 3 (cont)	16R4	FLOOD OVHD/FWD control DIM to BRIGHT	LTG: FLOOD (panel 16)	LMP's 28-vdc bus	Control operates only when FLOOD OVHD/FWD switch (panel 16) is set to OVHD/FWD or ALL, and the overhead hatch is closed. If overhead hatch is open, FLOOD OVHD/FWD switch is bypassed and FLOOD OVHD/FWD control enabled.
	16S2	EXTERIOR LTG switch DOCK OFF TRACK	LTG: ANN/ DOCK/ COMPNT (panel 11 and panel 16) LTG: TRACK (panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	
	16S10	LAMP/TONE TEST selector switch OFF ALARM/TONE C/W 1 ENG PB C/W 2 C/W 3 C/W 4 COMPNT	Performs tests as indicated below. All test functions are inactive. Tests lamps in MASTER ALARM pushbuttons, and tests audible warning tone. Tests lamps in first bank of warning lights on panel 1. Tests lamps in engine START and STOP lights and in second bank of warning lights on panel 1. Tests lamps in first bank of caution lights on panel 2. Tests lamps in second bank of caution lights on panel 2. Tests lamps in component caution and lunar contact lights.	LTG: MASTER ALARM (panel 16)	LMP's 28-vdc bus OFF position is at each end of switching sequence to permit setting switch to OFF without recycling through all test positions.

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 4 1S21 1S23 1S20 1S22 3DS1 3DS8	ACA/4 JET switch (CDR and LMP) ENABLE DISABLE	Enables isolation of 28 volts dc if short occurs in ACA. Enables normal operation of ACA. Disables four-jet direct attitude control function (hardover position) of ACA.	STAB/CONT: ATT DIR CONT (panel 11)	CDR's 28-vdc bus	The nominal position of this switch is ENABLE.
	TTCA/TRANSL switch (CDR and LMP) ENABLE DISABLE	Enables isolation of 28 volts dc if short occurs in TTCA. Enables normal operation of TTCA. Disables translation control function of TTCA.	STAB/CONT: ATCA (AGS) (panel 16)	LMP's 28-vdc bus	The nominal position of this switch is ENABLE.
		NOTE White condition indicators signify computer status; yellow condition indicators describe various cautions associated with the GN&CS.			
	UPLINK ACTY condition indicator (white)	Indicates that uplink is being received by LGC.	N/A	N/A	Is energized by first character of digital uplink message received by LGC. If light is not turned off by end of uplink transmission, the astronaut should extinguish light when transmission is complete by pressing RSET pushbutton.
	TEMP condition indicator (yellow)	Indicates that stable member temperature has exceeded its limits by $\pm 4^{\circ}$ F. (Nominal operating temperature $+130.3^{\circ}$ F).	N/A	N/A	PGNS caution light also goes on.

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks	
Panel 4 (cont)	3DS5	NO ATT condition indicator (white)	Indicates that ISS is not suitable for use as attitude reference.	N/A	N/A	Indicator lamp goes on when LGC is in operate mode and there is no inertial reference, during coarse align if ISS is off or IMU is caged.
	3DS9	GIMBAL LOCK condition indicator (yellow)	Indicates that middle gimbal has driven through angle greater than +70° or -70° from its zero position.	N/A	N/A	When middle gimbal angle exceeds +85° or -85° from its zero position, LGC automatically commands coarse align mode in ISS to prevent gimbal oscillation. NO ATT condition indicator and PGNS caution light then go on.
	3DS6	STBY condition indicator (white)	Indicates that LGC is in standby condition.	N/A	N/A	Indicator lamp is deenergized if LGC is in operate mode.
	3DS10	PROG condition indicator (yellow)	Indicates that program check has failed.	N/A	N/A	Indicator is controlled by computer program. PGNS caution light goes on.
	3DS7	KEY REL condition indicator (white)	Indicates that internal program has attempted to use DSKY and found it busy due to independent operator action.	N/A	N/A	Indicator is modulated by flash signal.
	3DS11	RESTART condition indicator (yellow)	Indicates one or more of the following abnormal operations: Word has been transferred incorrectly from memory-parity fail. LGC is in endless control loop - TC trap. LGC has been interrupted for 30 msec - RUPT lock. Alarm has been generated by program control.	N/A	N/A	

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks	
Panel 4 (cont)	3DS14	OPR ERR condition indicator (white)	Indicates that astronaut has performed an improper sequence on the DSKY.	N/A	N/A	Goes out when RSET pushbutton is pressed.
	3DS12	TRACKER condition indicator (yellow)	Indicates RR CDU failure or improper data from RR or LR.	N/A	N/A	When RR or LR are on, indicator lamp is energized if: RR CDU fine error greater than 1.0 vrms occurs RR CDU coarse error greater than 2.5 vrms occurs RR read counter limit cycles at rate greater than 160 cps RR CDU analog-to-digital conversion fails RR CDU +14-vdc supply decreases to 50% of nominal RR data-not-good discrete occurs during LGC data read sequence LR altitude data-not-good discrete or LR velocity data-not-good discrete occurs during LGC data read sequence.
	3DS15	COMPTR ACTY condition indicator (white)	Indicates that LGC is in program other than dummy job and that LGC is not in standby mode (LGC is processing data.)	N/A	N/A	
	3M1	PROG display indicator	Indicates program is being processed by LGC.	N/A	N/A	

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 4 (cont)					
3M2	VERB display indicator	Indicates verb code entered at key- board or commanded by LGC.	N/A	N/A	
3M3	NOUN display indicator	Indicates noun code entered at key- board or commanded by LGC.	N/A	N/A	
3M4 3M5 3M6	DATA display registers	Indicate numerical data entered at keyboard or commanded by LGC. Sign is associated only with decimal data.	N/A	N/A	The three data display registers are designated R1, R2, R3 from top to bottom of DSKY.
3S3	VERB pushbutton (momentary)	Conditions LGC to interpret next two numerical characters as verb code and extinguishes verb numerical display.	N/A	N/A	
3S4	NOUN pushbutton (momentary)	Conditions LGC to interpret next two numerical characters as noun code and extinguishes noun numerical display.	N/A	N/A	
3S5	CLR pushbutton (momentary)	Used during data loading to blank data register being used; loading can then be resumed.	N/A	N/A	First component load verbs are cleared by pressing CLR pushbutton once. Second and third component load verbs are cleared by pressing the pushbutton twice or three times, as required. The data registers clear in R3, R2, R1 order.
3S6	PRO pushbutton (momentary)	Commands LGC to proceed without DSKY inputs. Also commands LGC to enter standby mode if pressed when program is in progress.	N/A	N/A	

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 4 (cont)					
3S7	KEY REL pushbutton (momentary)	Releases DSKY to LGC for use with internal sequences.	N/A	N/A	Operator should release DSKY by pressing pushbutton when he is temporarily finished with DSKY.
3S8	ENTR pushbutton (momentary)	Informs LGC that assembled data are complete and that requested function is to be executed. Used in two ways: to execute the VERB/ NOUN code appearing on the VERB and NOUN display and to accept data just loaded and appearing in data display registers (R1, R2, R3).	N/A	N/A	
3S9	RSET pushbutton (momentary)	Turns off DSKY condition indicator after condition has been corrected.	N/A	N/A	
3S10 thru 3S19	0 through 10 pushbuttons (momentary)	Enter numerical data, noun codes, and verb codes into DSKY displays.	N/A	N/A	
3S21 3S20	+ and - pushbutton (momentary)	Inform LGC that following numerical data are decimal and indicate sign of data.	N/A	N/A	

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 5 1S5	DES RATE switch + -	Permits establishing LM rate of descent under PGNS control in fixed increments. Each switch actuation provides a discrete pulse, changing the rate of descent by 1 fps. Decreases rate of descent by 1 fps in the +X direction. Increases rate of descent by 1 fps in -X direction.	N/A	N/A	Response to switch commands is monitored on the altitude rate scale of the Range/Range Rate; Alt/Alt Rate indicator. Plus sign denotes increase in engine thrust. Minus sign denotes decrease in engine thrust.
1S3	Engine STOP pushbutton	Provides discrete stop signals to descent and ascent engines, independent of setting of ENG ARM switch.	STAB/CONT: ENG ARM (panel 16)	LMP's 28-vdc bus	Pushbutton is pressed on lunar landing, after LUNAR CONTACT lights go on. When pressed, pushbutton remains pressed and illuminated (red). It is reset by pressing it again.
1S2	Engine START pushbutton	Permits immediate manual firing of descent or ascent engine, depending upon setting of ENG ARM switch.	STAB/CONT: ENG START OVRD (panel 11)	CDR's 28-vdc bus	When pressed, pushbutton remains pressed and illuminated (red). Actuation of either engine STOP pushbutton interrupts override function, the engine stops, and the START pushbutton light goes out.
1S12	+X TRANSL pushbutton (momentary)	When held pressed, switch provides four-jet translation in +X-direction by energizing RCS direct (secondary) coils. Upon release of pushbutton, signal is removed from coils, terminating jet firings.	STAB/CONT: ATT DIR CONT (panel 11)	CDR's 28-vdc bus	
9S19	MISSION TIMER: TIMER CONT switch START	Provides discrete signals to MISSION TIMER indicator. Enables indicator to count upward from number preset with SLEW CONT switches.	FLIGHT DISPLAYS: MISSION TIMER (panel 11)	CDR's 28-vdc bus	

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 5 (cont)	STOP	Stops and holds indicator count until START or RESET is selected.			
	RESET	Resets indicator to zero.			
	9S22 SLEW CONT HOURS switch	Provides slewing function for HOURS columns of MISSION TIMER indicator.	FLIGHT DISPLAYS: MISSION TIMER (panel 11)	CDR's 28-vdc bus	Hundreds-column digit of HOURS columns is also controlled by the tens position, at rate of one digit per 5 seconds. All digits change in increasing direction.
	TENS	Slews tens-column digit of HOURS columns at rate of two digits per second as long as switch is held in this position.			
	Center	Disables slewing function.			
	UNITS	Slews units-column digit of HOURS columns at rate of two digits per second as long as switch is held in this position.			
	9S21 SLEW CONT MIN switch	Provides slewing function for MIN columns of MISSION TIMER indicator.	FLIGHT DISPLAYS: MISSION TIMER (panel 11)	CDR's 28-vdc bus	All digits change in increasing direction.
	TENS	Slews tens-column digit of MIN columns at rate of two digits per second as long as switch is held in this position.			
	Center	Disables slewing function.			
	UNITS	Slews units-column digit of MIN columns at rate of two digits per second as long as switch is held in this position.			

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 5 (cont)	9S20	<p>SLEW CONT SEC switch</p> <p>TENS</p> <p>Center</p> <p>UNITS</p>	<p>Selects inputs to MISSION TIMER indicator.</p> <p>Slews tens-column digit of SEC columns at rate of two digits per second as long as switch is held in this position.</p> <p>Disables slewing function.</p> <p>Slew units-column digit of SEC columns at rate of two digits per second as long as switch is held in this position.</p>	<p>FLIGHT DISPLAYS: MISSION TIMER (panel 11)</p> <p>CDR's 28-vdc bus</p>	
	16S4	<p>OVERRIDE ANUN switch</p> <p>ON</p> <p>OFF</p>	<p>Provides full voltage bypass of C/W array and component caution light portion of ANUN/NUM control.</p> <p>Bypasses ANUN/NUM control and applies 5 volts dc directly to annunciators of C/W array, to component caution lights, and to incandescent illuminated pushbuttons.</p> <p>C/W array and component caution lights are controlled with ANUN/NUM control.</p>	<p>N/A</p> <p>CDR's 28-vdc bus</p>	
	16S5	<p>OVERRIDE NUM switch</p> <p>ON</p> <p>OFF</p>	<p>Provides full voltage override of brightness control of numeric portion of ANUN/NUM control.</p> <p>Supplies full power (115 volts ac) directly to integrally illuminated EL numerics and time-shared displays.</p> <p>Disconnects full power; EL numeric readouts are controlled with ANUN/NUM control.</p>	<p>AC BUS B: NUM LTG: (panel 11)</p> <p>CDR's 115-vac bus</p>	<p>Portion of autotransformer associated with numeric readouts is disconnected from circuit.</p>

LM790-3-LM 3
APOLLO OPERATIONS HANDBOOK
CONTROLS AND DISPLAYS

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 5 (cont)					
16S3	<p>OVERRIDE INTEGRAL switch</p> <p>ON</p> <p>OFF</p>	<p>Supplies full voltage to low-level integrally illuminated EL markings and displays.</p> <p>Disconnects INTEGRAL control from power circuit and applies 115 volts ac directly to EL markings and displays.</p> <p>Disconnects 115-volt a-c power. Low-level integrally illuminated EL markings and displays are controlled with INTEGRAL control.</p>	AC BUS A: INTGL LTG: (panel 11)	CDR's 115-vac bus	Full voltage is 115 volts ac, 400 cps
16S1	<p>SIDE PANELS switch</p> <p>ON</p> <p>OFF</p>	<p>Permits control of EL lighting on Commander's side panels, independently of lighting of forward panel.</p> <p>Permits regulation of CDR's side panel EL lighting with INTEGRAL control and OVERRIDE INTEGRAL switch.</p> <p>Disconnects INTEGRAL control, and OVERRIDE INTEGRAL switch from their respective circuits.</p>	AC BUS A: INTGL LTG: (panel 11)	CDR's 115-vac bus	
16R1	<p>FLOOD OVHD/FWD control</p> <p>DIM to BRIGHT</p>	<p>Controls the brightness of the Commander's overhead and forward floodlights.</p> <p>Controls intensity level of floodlights continuously from dim to bright.</p>	LTG: FLOOD (panel 16)	LMP's 28-vdc bus	Control operates only when FLOOD OVHD/FWD switch (panel 16) is set to OVHD/FWD or ALL, and the overhead hatch is closed. If overhead hatch is open, FLOOD OVHD/FWD switch is bypassed and FLOOD OVHD/FWD control enabled.

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 5 (cont) 16R2	ANUN/NUM control	Regulates brightness of all annunciators except C/W PWR in C/W array, component caution lights, EL numeric readouts, incandescent illuminated pushbuttons, and time-shared displays (temporary).	LTG: NUM (panel 11)	CDR's 115-vac bus	If either portion of ANUN/NUM control fails, separate override switch provides maximum voltage for annunciators and component caution lights (ANUN OVERRIDE switch) and for EL numeric readouts (NUM OVERRIDE switch). Maximum voltage supplied on BRIGHT position: 5 volts dc for annunciators and component caution lights; 115 volts ac for numeric readouts.
	16R3 INTEGRAL control	Regulates brightness of low-level integrally illuminated EL markings and displays from DIM to BRIGHT.	LTG: INTGL (panel 11)	CDR's 115-vac bus	If control fails or brightness range is inadequate, control may be bypassed with INTEGRAL OVERRIDE switch.

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 6					
1S4	Engine STOP switch	Provides discrete stop signals to descent and ascent engines, independent of setting of ENG ARM switch.	STAB/CONT: ENG ARM (panel 16)	LMP's 28-vdc bus	Pushbutton is pressed on lunar landing, after LUNAR CONTACT lights go on. When pressed, pushbutton remains pressed and illuminated red. It is reset by pressing it again.
12S17	AGS STATUS switch OFF STANDBY OPERATE	Enables astronauts to place AGS in any one of three states. No power is supplied to AGS. Supplies power to ASA heaters. Applies full power to entire ASA and then places AEA in warmup mode. Applies full power to ASA and AEA.	STAB/CONT: AEA (panel 16) STAB/CONT: ASA (panel 16)	LMP's 28-vdc bus	
12DS1	OPR ERR condition indicator (white)	Goes on if astronaut presses incorrect number of pushbuttons for operation being performed, if + or - keys are not pressed first in entering data, and if "8" or "9" is used in entering address (which is limited to octal digits).	N/A	N/A	If too few pushbuttons are pressed, indicator goes on after ENTR or READOUT pushbutton is pressed. If too many pushbuttons are pressed, indicator goes on before ENTR or READOUT pushbutton is pressed. Indicator goes off when CLR pushbutton is pressed.
12M1	Address indicator	Displays digits that identify AEA computer address selected by astronaut via keyboard.	N/A	N/A	Three octal digits must be set on this indicator, using keyboard, before each DEDA operation.
12M2	Data indicator	Displays data to be entered into AEA computer address displayed on address indicator. Displays data selected for readout from AEA computer location identified on address indicator, if READOUT pushbutton is pressed.	N/A	N/A	Five-digit numeric indicator and + and - indicator. Data to be entered are selected by astronaut via keyboard. Updating rate of any changing data selected for readout is limited to two times per second.

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 6 (cont) 12S1 thru 12S12 12S13 12S15 12S14 12S16	Keyboard pushbuttons	Enable astronauts to load shift register with necessary values (0 through 9) and signs (+ and -) to be transferred to AEA.	STAB/CONT: AEA (panel 16)	LMP's 28-vdc bus	Pressing pushbuttons successively fills address and data indicators in order, from left to right.
	CLR pushbutton (momentary)	Erases all numerals displayed on address and data indicators and cancels effect of HOLD switch.	N/A	N/A	When pressed, switch extinguishes OPR ERR indicator lamp.
	READOUT pushbutton (momentary)	Enables astronauts to call up AEA computer data from address set up on address indicator, for display on data indicator.	N/A	N/A	
	ENTR pushbutton (momentary)	Enables astronauts to enter data (set up on data indicator) into AEA computer at address set up on address indicator.	N/A	N/A	Address and data indicators are cleared for immediate reuse when AEA computer has accepted data.
	HOLD pushbutton (momentary)	Enables astronauts to interrupt updating of any continuously changing data displayed on data indicator.	N/A	N/A	Information displayed on data indicator remains unchanged until pushbutton is pressed again, enabling display of present value of data and continuance of updating.

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 8 10S9	DES PROPULSION FUEL VENT switch OPEN Center CLOSE	Enables venting of descent fuel and of helium pressurization section. Energizes fuel vent valve to open position. Fuel vent valve remains in last selected position. Energizes fuel vent valve to closed position.	PROPUL: DES He REG VENT (panel 11)	CDR's 28-vdc bus	
10FL5	DES PROPULSION FUEL VENT talkback Gray display Barber-pole display	Indicates position of descent fuel vent valve. Indicates fuel vent valve is latched open. Indicates fuel vent valve is latched closed.	PROPUL: TEMP/ PRESS DISP-FLAGS (panel 16)	LMP's 28-vdc bus	
10S10	DES PROPULSION OXID VENT switch OPEN Center CLOSE	Enables venting of descent oxidizer and of helium pressurization sec- tion. Energizes oxidizer vent valve to open position. Oxidizer vent valve remains in last selected position. Energizes oxidizer vent valve to closed position.	PROPUL: DES He REG VENT (panel 11)	CDR's 28-vdc bus	

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 8 (cont) 2S3 2S10 2FL1 2S2	ASC He SEL switch				
	TANK 1	Selects isolation valve of ascent helium tank No. 1 for firing.	ED: LOGIC PWR A (panel 11)	CDR's 28-vdc bus	Switch is locked in all positions.
	BOTH	Selects isolation valves of both ascent helium tanks for firing.	ED: LOGIC PWR B (panel 16)	LMP's 28-vdc bus	
	TANK 2	Selects isolation valve of ascent helium tank No. 2 for firing.			
	LDG GEAR DEPLOY switch				
	FIRE	Actuates explosive devices that release stowed landing gear.	ED: LOGIC PWR A (panel 11) and ED: LOGIC PWR B (panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	Switch is locked in, and spring-loaded to, SAFE position. When all four landing gear assemblies are deployed, positive feedback of landing gear deployment is provided by LDG GEAR DEPLOY talkback.
	SAFE	Removes power from landing gear explosive devices.			
	LDG GEAR DEPLOY talkback				
	Gray display	Indicates landing gear assemblies are deployed.	ED: LDG GEAR FLAG (panel 11)	CDR's 28-vdc bus	All four landing gear assemblies must deploy to generate this telemetry code.
	Barber-pole display	Indicates landing gear assemblies are stowed.			
	He PRESS RCS switch				
	FIRE	Actuates helium isolation valves that permit helium flow from RCS helium tanks to pressurize RCS.	ED: LOGIC PWR A (panel 11) and ED: LOGIC PWR B (panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	Switch is locked and spring-loaded to SAFE position. Positive indication of helium isolation valves actuation is provided by RCS PRESS indicator (panel 2).
	SAFE	Removes power from valves.			

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 8 (cont) 2S1 2S4 2S5 2DS1	He PRESS DES START switch		ED: LOGIC PWR A (panel 11) and ED: LOGIC PWR B (panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	Switch is locked in, and spring-loaded to, SAFE position. Positive indication of valve assembly actuation is provided by MAIN PROPULSION PRESS indicator (FUEL and OXID scales).
	FIRE	Fires ambient helium isolation and propellant compatibility valves that permit helium from descent ambient helium tank to prepressurize descent propulsion section.			
	SAFE	Removes power from valves.			
	He PRESS ASCENT switch		ED: LOGIC PWR A (panel 11) and ED: LOGIC PWR B (panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	Switch is locked in, and spring-loaded, to SAFE position. Positive indication of isolation valves firing is provided by MAIN PROPULSION PRESS indicator (FUEL and OXID scales).
	FIRE	Fires isolation valve of helium tank or tanks selected with ASC He SEL switch, to pressurize ascent propulsion section.			
	SAFE	Removes power from valves.			
	STAGE switch		ED: LOGIC PWR A (panel 11) and ED: LOGIC PWR B (panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	Switch is locked in, and spring-loaded to, SAFE position. Switch is used only when staging is desired without firing ascent engine.
	FIRE	Actuates explosive devices that separate descent and ascent stages.			
	SAFE	Removes power from explosive devices.			
	STAGE SEQ RELAYS SYS A component caution light	Indicates that EDS bus A is armed.	ED: LDG GEAR FLAG (panel 11)	CDR's 28-vdc bus	Light goes on after MASTER ARM switch is set to ON. If light goes on before MASTER ARM switch is set to ON, ED RELAYS caution light also goes on.

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks	
Panel 8 (cont)	2DS2	STAGE SEQ RELAYS SYS B component caution light	Indicates that EDS bus B is armed.	ED: LDG GEAR FLAG (panel 11)	CDR's 28-vdc bus	Light goes on after MASTER ARM switch is set to ON. If light goes on before MASTER ARM switch is set to ON, ED RELAYS caution light also goes on.
	2DS8	STAGE RELAY switch		ED: LOGIC PWR A (panel 11)	CDR's 28-vdc bus	If staging relays (K2) trip before MASTER ARM switch is set to ON, STAGE SEQ RELAYS SYS A and SYS B component caution lights go on. Setting STAGE RELAY switch to RESET, resets staging relays (K2) and extinguishes the component caution lights.
		RESET	Energizes reset coil of staging relays (K2)	ED: LOGIC PWR B (panel 16)	LMP's 28-vdc bus	
	15AS1	S-BAND TR switch		N/A	CDR's audio center	
		S-BAND T/R	Enables routing received S-band audio to headset amplifier, and microphone amplifier outputs to PMP for S-band transmission.			
		OFF	Inhibits routing of S-band transmit- ter and receiver outputs through CDR's audio control center.			
15AR14	S-BAND RCV	Enables routing received S-band audio to headset amplifier.				
	S-band VOLUME thumbwheel	Permits continuous adjustment level of received S-band audio fed to headset amplifier.	N/A	CDR's audio center		

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 8 (cont)	15AS3 ICS T/R switch ICS T/R OFF ICS RCV	Enables routing microphone amplifier outputs to LMP's headset amplifier through intercom bus and audio from intercom bus to CDR's headset. Inhibits intercom capability. Enables routing audio from intercom bus to CDR's headset.	N/A	CDR's audio center	
	15AR17 ICS VOLUME thumbwheel	Permits continuous adjustment of level of audio fed from intercom bus to headset amplifier.	N/A	CDR's audio center	
	15AS4 Relay switch RELAY ON RELAY OFF	Enables voice conference capability with CSM and MSFN or with EVA and MSFN. Received VHF from CSM and EVA may be routed to MSFN via S-band transmitter. Inhibits conference capability.	N/A	Premodulation processor	LMP's and CDR's relay switches should not be set to RELAY ON simultaneously. Appropriate Communications subsystem switches are used to establish the desired relay mode.
	15AS6 VOX switch ICS/XMTR ICS PTT	Enables VOX control circuit in CDR's audio center to key intercom and selected transmitter(s). Enables VOX control circuit in CDR's audio center to key intercom. Disables VOX control circuit in CDR's audio center.	N/A	CDR's audio center	Selected transmitters are keyed only with push-to-talk (PTT) switches. All keying is accomplished with PTT switches.

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 8 (cont)					
15AR8	VOX SENS thumbwheel	Permits continuous adjustment of VOX sensitivity circuit threshold.	N/A	CDR's audio center	
15AS5	AUDIO CONT switch NORM BU	Selects CDR's audio center and microphone circuit. Selects LMP's audio center and microphone circuit for use by Commander.	COMM: CDR AUDIO COMM: LMP AUDIO	CDR's 28-vdc bus LMP's 28-vdc bus	
15AS2	VHF A switch T/R OFF RCV	Enables routing received VHF A audio to headset amplifier, and microphone amplifier outputs to VHF A transmitter for transmission. VOX keying voltage is routed to VHF A transmitter. Inhibits routing VHF A transmitter and receiver outputs through Commander's audio center. Enables routing received VHF A audio to headset amplifier.	N/A	CDR's audio center	
15AR12	VHF A VOLUME thumbwheel	Permits continuous adjustment of level of received VHF audio (channel A) fed to headset amplifier.	N/A	CDR's audio center	
15AS9	VHF B switch T/R	Enables routing received VHF B audio to headset amplifier, and microphone amplifier outputs to VHF	N/A	CDR's audio center	

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 8 (cont)	OFF	B transmitter for transmission. VOX keying voltage is routed to VHF B transmitter.			
	RCV	Inhibits routing VHF B transmitter and receiver outputs through CDR's audio center. Enables routing received VHF B audio to headset amplifier.			
	15ARI3 VHF B VOLUME thumbwheel	Permits continuous adjustment of level of received VHF audio (channel B) fed to headset amplifier.	N/A	CDR's audio center	
	15ARI5 MASTER VOL thumbwheel	Permits continuous, simultaneous adjustment of all audio output levels from headset amplifier.	N/A	CDR's audio center	
	16SI4 COAS switch	Energizes COAS connectors in docking windows.	LTG: COAS (panel 11)	CDR's 28-vdc bus	
	OVHD	Applies 28 volts dc to overhead docking window COAS connector.			
	OFF	Removes power from docking window COAS connectors.			
	FWD	Applies 28 volts dc to forward docking window COAS connector.			

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 11	AC BUS B circuit breakers				
4CB152	SE WIND HTR (2 amperes)	Applies a-c power to LMP's window heater.	N/A	115-vac bus	
4CB169	He/PQGS PROPUL DISP (2 amperes)	Applies a-c power to HELIUM indicator and to OXIDIZER and FUEL QUANTITY indicators.	N/A	115-vac bus	
4CB34	S-BD ANT (2 amperes)	Applies a-c power to S-band sterrable antenna electronics assembly.	N/A	115-vac bus	
4CB226	ORDEAL (2 amperes)	Applies a-c power to earth- or lunar-stay resolvers through EARTH-LUNAR switch.	N/A	115-vac bus	
4CB203	AGS (2 amperes)	Applies a-c power to AEA outputs to FDAI.	N/A	115-vac bus	
4CB214	AOT LAMP (2 amperes)	Applies a-c power to AOT lamp.	N/A	115-vac	On-off control for AOT lamp.
4CB210	SE FDAI (2 amperes)	Applies a-c power to LMP's FDAI.	N/A	115-vac bus	
4CB200	NUM LTG (2 amperes)	Applies a-c power to all numeric (digital displays) DSKY displays, RCS oxidizer and fuel displays, event and mission timers, MPS oxidizer and fuel displays, DEDA address and data displays.	N/A	115-vac	
4CB186	BUS TIE INV 2 (5 amperes)	Connects inverter No. 2 to a-c bus B through INVERTER switch.	N/A	115-vac bus	

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 11 (cont)					
4CB185	BUS TIE INV 1 (5 amperes)	Connects inverter No. 1 to a-c bus B through INVERTER switch.	N/A	115-vac bus	
4CB24	AC BUS A circuit breakers BUS TIE INV 2 (5 amperes)	Connects inverter No. 2 to a-c bus A through INVERTER switch.	N/A	115-vac bus	
4CB23	BUS TIE INV 1 (5 amperes)	Connects inverter No. 1 to a-c bus A through INVERTER switch.	N/A	115-vac bus	
4CB27	AC BUS VOLT (2 amperes)	Provides a-c bus voltage and frequency characteristics to IS for display and telemetry purposes.	N/A	115-vac bus	
4CB144	CDR WIND HTR (2 amperes)	Applies a-c power to CDR's window heater.	N/A	115-vac bus	
4CB202	TAPE RCDR (2 amperes)	Applies a-c power to DSEA tape drive motors.	N/A	115-vac bus	
4CB212	AOT LAMP (2 amperes)	Applies a-c power to AOT lamp.	N/A	115-vac bus	On-off control for AOT lamp.
4CB206	RNDZ RDR (2 amperes)	Applies a-c power to RR power supply.	N/A	115-vac bus	
4CB207	DECA GMBL (2 amperes)	Applies a-c power to GDA's within DECA.	N/A	115-vac bus	
4CB211	INTGL LTG (2 amperes)	Applies a-c power to low-level integral lighting; e.g., talkbacks, indicators, and displays.	N/A	115-vac bus	

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 11 (cont)					
4CB204	RNG/RNG RT; ALT/ALT RT (2 amperes)	Applies a-c power to range/altitude indicator.	N/A	115-vac bus	
4CB201	GASTA (2 amperes)	Applies a-c power to GASTA.	N/A	115-vac bus	
4CB209	CDR FDAI	Applies a-c power to CDR's FDAI.	N/A	115-vac bus	
4CB72	RCS SYS A circuit breakers MAIN SOV (5 amperes)	Applies d-c power to RCS system A main oxidizer and fuel shutoff valves through SYSTEM A MAIN SOV switch.	N/A	CDR's 28-vdc bus	Main shutoff valves control propellant flow between RCS tanks and RCS TCA's.
4CB60	QUAD 4 TCA (15 amperes)	Applies d-c power to primary coils of oxidizer and fuel valves of RCS system A, quad IV TCA's.	N/A	CDR's 28-vdc bus	TCA secondary coil power is applied when ACA is pushed to hard stop or when +X TRANSL pushbutton is pressed.
4CB61	QUAD 3 TCA (15 amperes)	Applies d-c power to primary coils of oxidizer and fuel valves of RCS system A, quad III TCA's.	N/A	CDR's 28-vdc bus	TCA secondary coil power is applied when ACA is pushed to hard stop or when +X TRANSL pushbutton is pressed.
4CB62	QUAD 2 TCA (15 amperes)	Applies d-c power to primary coils of oxidizer and fuel valves of RCS system A, quad II TCA's.	N/A	CDR's 28-vdc bus	TCA secondary coil power is applied when ACA is pushed to hard stop or when +X TRANSL pushbutton is pressed.
4CB63	QUAD 1 TCA (15 amperes)	Applies d-c power to primary coils of oxidizer and fuel valves of RCS system A, quad I TCA's.	N/A	CDR's 28-vdc bus	TCA secondary coil power is applied when ACA is pushed to hard stop or when +X TRANSL pushbutton is pressed.

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 11 (cont)					
4CB67	ISOL VLV (5 amperes)	Applies d-c power to RCS system A oxidizer and fuel isolation valves, through SYSTEM A THRUSTER PAIR switches.	N/A	CDR's 28-vdc bus	
4CB231	ASC FEED 2 (5 amperes)	Applies d-c power to RCS system A ascent fuel and oxidizer interconnect valves, through SYSTEM A ASC FEED 2 switch.	N/A	CDR's 28-vdc bus	Interconnect valves permit propellant flow from ascent tanks to RCS tanks. SYSTEM A ASCENT FEED 1 switch must be set to ASCENT FEED 1.
4CB51	ASC FEED 1 (5 amperes)	Applies d-c power to RCS system A ascent fuel and oxidizer interconnect valves, through SYSTEM A ASC FEED 1 switch.	N/A	CDR's 28-vdc bus	Interconnect valves permit propellant flow from ascent tanks to RCS tanks. SYSTEM A ASCENT FEED 2 switch must be set to ASCENT FEED 2.
	FLIGHT DISPLAYS circuit breakers				
4CB168	THRUST DISP (2 amperes)	Applies d-c power to THRUST indicator power supply and to part of auxiliary switching relay box through THR CONT switch.	N/A	CDR's 28-vdc bus	
4CB159	MISSION TIMER (2 amperes)	Applies d-c power to MISSION TIMER.	N/A	CDR's 28-vdc bus	
4CB133	X-PNTR (2 amperes)	Applies d-c power to CDR's X-Pointer indicator, and to parts of auxiliary relay switching box through RATE/ERR MON and MODE SEL switches.	N/A	CDR's 28-vdc bus	
4CB123	RNG/RNG RT; ALT/ALT RT (2 amperes)	Applies d-c power to RANGE/RANGE RATE or ALT/ALT RATE indicator.	N/A	CDR's 28-vdc bus	

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 11 (cont)					
4CB88	GASTA (2 amperes)	Applies d-c power to GASTA.	N/A	CDR's 28-vdc bus	
4CB97	CDR FDAI (2 amperes)	Applies d-c power to CDR's FDAI and to parts of auxiliary switching relay box through RATE/ERR MON and ATTITUDE MON switches.	N/A	CDR's 28-vdc bus	
4CB188	COAS (2 amperes)	Applies d-c power to forward or overhead optical alignment sight via COAS switch.	N/A	CDR's 28-vdc bus	
4CB227	ORDEAL (2 amperes)	Applies d-c power to ORDEAL panel lighting circuits via LIGHT- ING switch.	N/A	CDR's 28-vdc bus	
4CB74	PROPUL: DES He REG/VENT circuit breaker (5 amperes)	Applies d-c power to latching helium solenoid valves No. 1 and 2, through DESCENT He REG switches No. 1 and 2, and to fuel and oxidizer vent valves DES PROPULSION FUEL VENT and OXID VENT switches.	N/A	CDR's 28-vdc bus	
4CB156	HEATERS circuit breakers RNDZ RDR STBY (7.5 amperes)	Applies d-c power to rendezvous radar heater control circuit to maintain temperature of crystal oven.	N/A	CDR's 28-vdc bus	
4CB155	RNDZ RDR OPR (5 amperes)	Applies d-c power to RR radar heater control circuit which main- tains temperature of antenna gyros, and to rendezvous radar electronics assembly.	N/A	CDR's 28-vdc bus	

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 11 (cont)					
4CB157	LDG RDR (5 amperes)	Applies d-c power to heater control circuit in LR electronic assembly.	N/A	CDR's 28-vdc bus	
4CB213	AOT (2 amperes)	Applies d-c power to AOT heaters.	N/A	CDR's 28-vdc bus	
4CB129	DOCK WINDOW (2 amperes)	Applies d-c power to docking window heater.	N/A	CDR's 28-vdc bus	
4CB131	INST: SIG CONDR 1 circuit breaker (2 amperes)	Applies d-c power to power buffers and conditioners in signal conditioner electronic replaceable assemblies of IS.	N/A	CDR's 28-vdc bus	
4CB3	STAB/CONT circuit breakers ABORT STAGE (5 amperes)	Applies d-c power to abort stage electronics through ABORT STAGE switch.	N/A	CDR's 28-vdc bus	
4CB81	ATCA (PGNS) (2 amperes)	Applies d-c power through GUID CONT switch to select PGNS, and redundant bias power to ATCA. Also applies d-c power through MODE CONTROL switch to ATCA primary preamplifiers to be used by PGNS for attitude control.	N/A	CDR's 28-vdc bus	
4CB40	AELD (7.5 amperes)	Applies d-c power to system A of AELD/S.	N/A	CDR's 28-vdc bus	

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 11 (cont) 4CB80	ENG CONT (2 amperes)	Applies d-c power for automatic switching from wide deadband to narrow deadband with descent engine on, for automatic switching from 2 to 4 jets with engine on, to CES for analog control of GDA when using AGS, to disable auto thrust control when using AGS, to reset engine START switch, and applies redundant power for manual engine stop when staging.	N/A	CDR's 28-vdc bus	
	4CB59	ATT DIR CONT (15 amperes)			
	4CB106	ENG START OVRD (2 amperes)	N/A	CDR's 28-vdc bus	ENG ARM switch derives primary d-c power from STAB/CONT: ENG ARM circuit breaker (panel 16).
	4CB69	DECA PWR (20 amperes)	N/A	CDR's 28-vdc bus	
	4CB149	ED circuit breakers			
		LDG GEAR FLAG (2 amperes)	N/A	CDR's 28-vdc bus	

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 11 (cont)	4CB76	LOGIC PWR A (2 amperes)	Applies d-c power to ASCENT He PRESS, ASC He SEL, DES PRESS, LDG GEAR DEPLOY, MASTER ARM, STAGE, RCS PRESS, and ABORT STAGE switches.	N/A	CDR's 28-vdc bus
	4CB146	LTG: ANUN DOCK/COMPNT circuit breaker (2 amperes)	Applies alternate d-c power to caution and warning annunciators, component caution lights, docking lights, and LUNAR CONTACT lights.	N/A	CDR's 28-vdc bus
	HEATERS RCS SYS A/B-1 circuit breakers				
	4CB221	QUAD 4 (2 amperes)	Applies d-c power to section No. 1 engine heaters of quad 4, systems A and B.	N/A	CDR's 28-vdc bus
	4CB220	QUAD 3 (2 amperes)	Applies d-c power to section No. 1 engine heaters of quad 3, systems A and B.	N/A	CDR's 28-vdc bus
	4CB219	QUAD 2 (2 amperes)	Applies d-c power to section No. 1 engine heaters of quad 2, systems A and B.	N/A	CDR's 28-vdc bus
	4CB218	QUAD 1 (2 amperes)	Applies d-c power to section No. 1 engine heaters of quad 1, systems A and B.	N/A	CDR's 28-vdc bus
	ECS circuit breakers				
	4CB138	SUIT FAN 1 (15 amperes)	Applies d-c power to suit fan No. 1 (suit circuit assembly) through SUIT FAN switch.	N/A	CDR's 28-vdc bus
	4CB107	CABIN FAN 1 (5 amperes)	Applies d-c power to cabin fan No. 1 through ECS relay box.	N/A	CDR's 28-vdc bus

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 11 (cont)					
4CB141	GLYCOL PUMP 2 (5 amperes)	Applies d-c power to glycol pump No. 2 through GLYCOL PUMP switch.	N/A	CDR's 28-vdc bus	
4CB117	GLYCOL PUMP 1 (5 amperes)	Applies d-c power to glycol pump No. 1 through GLYCOL PUMP switch.	N/A	CDR's 28-vdc bus	
4CB217	GLYCOL PUMP AUTO TRNFR (2 amperes)	Energizes transfer relay to auto- matically switch pumps when low Δ V develops.	N/A	CDR's 28-vdc bus	
4CB228	COMM circuit breakers UPDATA LINK (5 amperes)	When closed, data uplink is enabled; when opened voice uplink is enabled.	N/A	CDR's 28-vdc bus	
4CB137	SEC S-BD XMTR/RCVR (5 amperes)	Applies d-c power to power supply in S-band section of CS through XMTR/RCVR switch. Also applies backup d-c power through XMTR/ RCVR switch for BU voice/emerg- ency key.	N/A	CDR's 28-vdc bus	
4CB136	SEC S-BD PWR AMPL (7.5 amperes)	Applies d-c power to power supply No. 2 in S-band power amplifier assembly.	N/A	CDR's 28-vdc bus	
4CB162	VHF B XMTR (2 amperes)	Applies d-c power to VHF B trans- mitter-receiver, and to exciter- power amplifier and modulator in VHF B transmitter through VHF B XMTR switch.	N/A	CDR's 28-vdc bus	

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 11 (cont)					
4CB87	VHF A RCVR (2 amperes)	Applies d-c power to VHF A IF and audio amplifier in VHF A receiver through VHF A RCVR switch.	N/A	CDR's 28-vdc bus	
4CB86	CDR AUDIO (2 amperes)	Applies d-c power to regulated power supply in CDR's audio center, to CDR's microphone amplifier through CDR's AUDIO CONT switch (NORM position), and to LMP's microphone through LMP's AUDIO CONT switch (BU position).	N/A	CDR's 28-vdc bus	
	PGNS circuit breakers				
4CB154	SIG STR DISP (2 amperes)	Applies d-c power to radar SIGNAL STRENGTH indicator.	N/A	CDR's 28-vdc bus	
4CB105	LDG RDR (10 amperes)	Applies d-c power and acts as on-off switch to LR power supply.	N/A	CDR's 28-vdc bus	
4CB29	RNDZ RDR (15 amperes)	Applies d-c power and acts as on-off switch to RR electronic assembly.	N/A	CDR's 28-vdc bus	
4CB122	LGC/DSKY (7.5 amperes)	Applies d-c power and acts as on-off switch to LGC power supply, CDU, PTA, and PSA.	N/A	CDR's 28-vdc bus	
4CB161	IMU STBY (5 amperes)	Applies d-c power and acts as on-off switch to PGNS power and servo assembly (PIPA and IRIG heaters.)	N/A	CDR's 28-vdc bus	Serves as on-off switch for temperature alarm thermostat. Is used in conjunction with temperature signals generated in IMU and PSA.

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 11 (cont)					
4CB124	IMU OPR (20 amperes)	Applies d-c power and acts as on-off switch to IMU, PIPA and IRIG pre-amplifiers and excitation, and PSA gimbal servo amplifiers. Applies d-c power to IMU CAGE switch.	N/A	CDR's 28-vdc bus	
	EPS circuit breakers				
4CB18	BAT FEED TIE (100 amperes)	Ties battery No. 3 (descent) and battery No. 5 (ascent) (backup mode) to CDR's d-c bus.	N/A	N/A	
4CB26	BAT FEED TIE (100 amperes)	Ties battery No. 4 (descent) and battery No. 6 (ascent) (normal mode) to CDR's d-c bus.	N/A	N/A	
4CB184	CROSS TIE-BAL LOADS (30 amperes)	Ties CDR's feeder/bus system to LMP's d-c bus through LMP's CROSS TIE-BAL LOADS circuit breaker.	N/A	CDR's 28-vdc bus	
4CB20	CROSS TIE-BUS (100 amperes)	Ties CDR's feeder/ bus system to LMP's d-c bus through LMP's EPS: CROSS TIE-BUS circuit breaker.	N/A	CDR's 28-vdc bus	
4CB4	XLUNAR BUS TIE (50 amperes)	Ties CDR's d-c bus translunar loads to LM single-point ground.	N/A	N/A	
4CB8	DES ECA CONT (5 amperes)	Applies d-c power to low- and high-voltage contact coils in ECA No. 1 and 2 through HI VOLTAGE and LOW VOLTAGE switches.	N/A	CDR's 28-vdc bus	

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 11 (cont)					
4CB10	DES ECA (2 amperes)	Applies d-c power to power supplies of both descent ECA's.	N/A	CDR's 28-vdc bus	
4CB6	ASC ECA CONT (5 amperes)	Applies d-c power to normal and backup contact coils in ECA No. 3 and 4 through NORMAL FEED and BACK UP FEED switches.	N/A	CDR's 28-vdc bus	
4CB15	ASC ECA (2 amperes)	Applies d-c power to power supplies of both ascent ECA's.	N/A	CDR's 28-vdc bus	
4CB12	INV 1 (30 amperes)	Applies d-c power to inverter No. 1 for generation of 115-volt, 400-cps a-c power, through INVERTER switch.	N/A	CDR's 28-vdc bus	
4CB22	DC BUS VOLT (2 amperes)	Applies d-c power to IS for conditioning to monitor CDR's d-c bus voltage.	N/A	CDR's 28-vdc bus	Permits monitoring through caution and warning, pulse-code-modulation (telemetry), and voltmeter sections.
	EARTH ORBIT circuit breakers				
4CB36	SLA/LEM ANT TRNFR B (5 amperes)	Applies d-c power to secondary SLA/LEM antenna transfer switch.	N/A	CDR's 28-vdc bus	
4CB35	SLA/LEM ANT TRNFR A circuit breaker (5 amperes)	Applies d-c power to primary SLA/LEM antenna switch.	N/A	CDR's 28-vdc bus	
4CB229	R/D INST A circuit breaker (40 amperes)	Applies d-c power to DFI power and control box.	N/A	CDR's 28-vdc bus	

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 11 (cont) 19S1	C-BAND PWR switch	Selects tracking function for transmission via C-band transponder.	R/D INST A and R/D INST B	LM 28-vdc	
	ON	Activates C-band transponder circuitry.			
	OFF	Deactivates C-band transponder circuitry.			
	19S2	R/D TLM CALIBRATE switch	R/D INST A and R/D INST B	LM 28-vdc	
	ON	Activates calibration circuitry. (Twelve seconds completes one calibration cycle.)			
	OFF	Deactivates calibration circuitry.			
4CB181	R/D INST B circuit breaker (40 amperes)	Applies d-c power to DFI power and control box.	N/A	CDR's 28-vdc bus	
SLA attach- ment point	SLA/LEM antenna transfer switches	Automatic make-before-break switch that provides communications via SLA antennas before SLA separation and via LEM antennas after SLA separation.	SLA/LEM ANT TRNFR A and SLA/ LEM ANT TRNFR B	LM 28-vdc	

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 12 15BS1 15BR14 15BS3 15BR7	S-BAND T/R switch S-BAND T/R OFF S-BAND RCV	Enables routing received S-band audio to headset amplifier, and microphone amplifier outputs to PMP for S-band transmission. Inhibits routing S-band transmitter and receiver outputs through LMP's audio center. Enables routing received S-band audio to headset amplifier.	N/A	LMP's audio center	
	S-band VOLUME thumbwheel	Permits continuous adjustment of level of received S-band audio fed to headset amplifier.	N/A	LMP's audio center	
	ICS T/R switch ICS T/R OFF ICS RCV	Enables routing microphone amplifier outputs to CDR's headset amplifier through intercom bus, and audio from intercom bus to LMP's headset. Inhibits intercom capability. Enables routing audio from intercom bus to LMP's headset.	N/A	LMP's audio center	
	ICS VOLUME thumbwheel	Permits continuous adjustment of level of audio fed from intercom bus to headset amplifier.	N/A	LMP's audio center	

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 12 (cont)	15BS4	Relay switch	N/A	Premod- ulation proces- sor	LMP's and CDR's relay switches should not be set to RELAY ON simultaneously.
	RELAY ON	Enables voice conference capability between CSM and earth, or with EVA and MSFN. Received VHF from CSM and EVA may be routed to MSFN via S-band transmitter.			
	RELAY OFF	Inhibits conference capability.			Appropriate Communications Sub-system switches are used to establish the desired relay mode.
	15BS5	AUDIO CONT switch	COMM: SE AUDIO (panel 16)	LMP's 28-vdc bus	
	NORM	Selects LMP's audio center and microphone circuit.			
	BU	Selects CDR's audio center and microphone circuit for use by LMP.	COMM: CDR AUDIO (panel 11)	CDR's 28-vdc bus	
	15BS6	VOX switch	N/A	LMP's audio center	Selected transmitters are keyed only with push-to-talk (PTT) switches. All keying is accomplished with PTT switches.
	ICS/XMTR	Enables VOX control circuit in LMP's audio center to key intercom and selected transmitter(s).			
	ICS	Enables VOX control circuit in LMP's audio center to key intercom.			
	PTT	Disables VOX control circuit in LMP's audio center.			
	15BR8	VOX SENS thumbwheel	N/A	LMP's audio center	
		Permits continuous adjustment of VOX sensitivity circuit threshold.			

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 12 (cont) 15BS2	VHF A switch		N/A	LMP's audio center	
	T/R	Enables routing received VHF A audio to headset amplifier, and microphone amplifier outputs to VHF A transmitter for transmission. VOX keying voltage is routed to VHF A transmitter.			
	OFF	Inhibits routing VHF A transmitter and receiver outputs through LM Pilot's audio center.			
	RCV	Enables routing received VHF A audio to headset amplifier.			
15BR12	VHF A VOLUME thumbwheel	Permits continuous adjustment of level of received VHF audio (channel A) fed to headset amplifier.	N/A	LMP's audio control center	
15BS9	VHF B switch		N/A	LMP's audio center	
	T/R	Enables routing received VHF B audio to headset amplifier, and microphone amplifier outputs to VHF B transmitter for transmission. VOX keying voltage is routed to VHF B transmitter.			
	OFF	Inhibits routing VHF B transmitter and receiver outputs through LMP's audio center.			
	RCV	Enables routing received VHF B audio to headset amplifier.			
15BR13	VHF B VOLUME thumbwheel	Permits continuous adjustment of level of received VHF audio (channel B) fed to headset amplifier.	N/A	LMP's audio center	

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 12 (cont)					
15BR15	MASTER VOL thumbwheel	Permits continuous, simultaneous adjustment of all audio output levels from headset amplifier.	N/A	LMP's audio center	
13S5	MODULATE switch PM FM	Enables PM control circuit in SPA and disables frequency modulator in S-band transmitter. Enables FM control circuit and disables phase modulator and range gate amplifier in S-band transmitter.	N/A	SPA	Normal setting of this switch is PM. Normally, FM setting is used for video transmissions.
13S8	XMTR/RCVR switch PRIM OFF SEC	Applies 28-volt d-c power to primary S-band transmitter-receiver power supply (dc-to-dc converter No. 1). Interrupts d-c power to S-band transmitter-receiver power supplies. Applies 28-volt d-c power to secondary S-band transmitter-receiver power supply (dc-to-dc converter No. 2).	COMM: PRIM S-BD XMTR/RCVR (panel 16) COMM: SEC S-BD XMTR/RCVR (panel 11)	LMP's 28-vdc bus CDR's 28-vdc bus	Enables S-band power amplifier. Enables S-band power amplifier.
13S2	PWR AMPL switch PRIM OFF	Enables power supply No. 1 of S-band power amplifier (minimum of 18.6 watts). Inhibits both S-band power-amplifier power supplies.	N/A	S-band power amplifier	S-band power amplifier is enabled only if XMTR/RCVR switch is set to PRIM or SEC. Primary power to power supply No. 1 is provided by LMP's 28-vdc bus through COMM: PRIM S-BD PWR AMPL circuit breaker.

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 12 (cont)	SEC	Enables power supply No. 2 of S-band power amplifier (minimum of 14.8 watts).			Primary power to power supply No. 2 is provided by CDR's 28-vdc bus through COMM: SEC S-BD PWR AMPL circuit breaker.
13S6	FUNCTIONS VOICE switch VOICE OFF VOICE BU	<p>Applies 24 volts dc to 1.25 mc control circuit in SPA.</p> <p>Disables all S-band voice transmission.</p> <p>Enables phase modulator section of S-band transmitter (regardless of setting of MODULATE switch) to transmit voice directly on S-band baseband, bypassing PMP.</p>	N/A	SPA	<p>Audio modulates 1.25-mc subcarrier and is routed to selected S-band transmitter, phase modulated or frequency modulated.</p> <p>Ranging or television function is interrupted in this position.</p>
13S4	FUNCTIONS PCM switch PCM OFF KEY	<p>Enables 1.024-mc data control circuit in SPA.</p> <p>Disables telemetry subcarrier transmission.</p> <p>Applies 28 volts dc to emergency key circuit in SPA. PTT switches on ECS umbilicals are enabled to serve as Morse code keyers for emergency transmissions.</p>	N/A	SPA	<p>Selects PM mode; automatically interrupts all other S-band modes of operation.</p>

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 12 (cont)					
13S1	FUNCTIONS RANGE switch RANGE OFF/RESET TV/CWEA ENABLE	Enables selection of ranging or TV functions for S-band transmission. PM transmitter retransmits received coded pseudorandom noise signals to MSFN. Inhibits range data transmission. Enables FM transmitter to transmit TV data and enables CWEA logic for S-BAND RCVR caution light.	N/A	S-band trans- mitter receiver assembly	
13S7	VHF A XMTR switch ON OFF	Applies 28-volt d-c power to VHF A transmitter power supply. Interrupts d-c power to VHF A transmitter power supply.	COMM: VHF A XMTR (panel 16)	LMP's 28-vdc bus	Transmitter frequency is 296.8 mc.
13S10	VHF A RCVR switch ON OFF	Applies 28-volt d-c power to +20-volt regulator in VHF A receiver. Interrupts d-c power to VHF A receiver.	COMM: VHF A RCVR (panel 11)	CDR's 28-vdc bus	Receiver frequency is 296.8 mc.
13R10	SQUELCH VHF A thumbwheel	Adjusts threshold level of received VHF A audio signal.	N/A	VHF A receiver	
13S12	VHF B XMTR switch VOICE	Applies 28-volt d-c power to VHF B transmitter power supply and activates data mute circuit.	COMM: VHF B XMTR (panel 11)	CDR's 28-vdc bus	Transmitter frequency is 259.7 mc.

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 12 (cont)	OFF	Interrupts d-c power to VHF B transmitter.			TELEMETRY PCM switch must be set to LO (1,600-bits-per-second data rate).
	DATA	Applies 28-volt d-c power to VHF B transmitter power supply and activates voice mute circuit.			
	13S15 VHF B RCVR switch				
	ON	Applies 28-volt d-c power to +20-volt regulator in VHF B receiver.	COMM: VHF B RCVR (panel 16)	LMP's 28-vdc bus	Receiver frequency is 259.7 mc.
	OFF	Interrupts d-c power to VHF B receiver.			
13R15	SQUELCH VHF B thumbwheel	Adjusts threshold level of received VHF B audio signal.	N/A	VHF B receiver	
13S3	TELEMETRY BIOMED switch		COM: PMP (panel 16)	LMP's 28-vdc bus	With this switch set to OFF and with FUNCTIONS VOICE switch set to VOICE BU, biomedical data transmission is interrupted, but voice intelligibility is increased because of additional speech-processing.
	LEFT	Applies d-c power to Commander's suit power supply for EKG monitoring and enables direct baseband voice/biomed transmission, phase modulated or frequency modulated.			
	OFF	Interrupts d-c power to Commander's and Systems Engineer's suit power supply.			
	RIGHT	Applies d-c power to LMP's suit power supply for EKG monitoring and enables direct baseband voice/biomed transmission, phase modulated or frequency modulated.			

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 12 (cont)					
13S13	TELEMETRY PCM switch				
	HI	Enables pulse-code-modulation programmer high-speed gates.	N/A	PCM pro-grammer	Low bit rate permits data transmission to CSM.
	LO	Disables high-speed gates; data rate is 1,600 bits per second.			
13S11	RECORDER switch		N/A	LMP's audio center	
	ON	Applies key supply voltage to VOX control circuit of DSEA.			
	OFF	Interrupts key supply voltage to DSEA.			
13FL1	RECORDER TAPE talkback		N/A	DSEA	
	Gray display	Indicates tape in DSEA is moving and that voice is being recorded.			
	Barber-pole display	Indicates tape is not moving.			
14S3	TRACK MODE switch		AC BUS B: S-BD ANT (panel 11)	CDR's 115-vac bus	
	AUTO	Applies a-c and d-c power to steerable antenna electronics power supply. Antenna is enabled to track received MSFN signal automatically.	COMM: S-BD ANT (panel 16)	LMP's 28-vdc bus	
	OFF	Interrupts a-c and d-c power to steerable antenna electronics power supply.			
	SLEW	Applies a-c and d-c power to steerable antenna electronics power supply. Antenna is positioned with PITCH and YAW controls through synchro transmitters.			

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 12 (cont)					
14B2	PITCH control	Positions S-band steerable antenna in pitch axis through synchro transmitter.	AC BUS B: S-BD ANT (panel 11)	CDR's 115-vac bus	Control has range of -75° to $+225^{\circ}$.
14M3	PITCH indicator	Displays pitch angle of S-band steerable antenna.	COMM: DISP (panel 16)	LMP's 28-vdc bus	Antenna pitch limits are 255° above and 75° below plane parallel to LM Y-Z plane.
14B1	YAW control	Positions S-band steerable antenna in yaw axis through synchro transmitter.	AC BUS B: S-BD ANT (panel 11)	CDR's 115-vac bus	Control has range of -75° to $+75^{\circ}$.
14M4	YAW indicator	Displays yaw angle of S-band steerable antenna.	COMM: DISP (panel 16)	LMP's 28-vdc bus	Antenna yaw limits are 75° to left and 75° to right of plane parallel to LM Y-Z plane.
14M1	SIGNAL STRENGTH indicator	Displays intensity of S-band signals received from MSFN. When peaked, it indicates that S-band steerable antenna is pointing at earth. Also indicates which of the two omni antennas is providing best communications link to MSFN.	COMM: DISP (panel 16)	LMP's 28-vdc bus	Used in conjunction with PITCH and YAW controls to establish contact with MSFN.
14S6	VHF selector switch		N/A	Selected transmitter or antenna	
	1/PLSS TEST	Selects VHF antenna No. 1 and, if hardline connection is made to PLSS, provides for test of EVA voice and telemetry transmission.			Switch is spring loaded and has lock mechanism. To change switch setting, switch first must be pulled out.
	2	Selects VHF antenna No. 2.			
	EVA	Position is not wired for LM 3. (Used for VHF communications between EVA and LM during lunar stay.)			

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 12 (cont) 14S5	S-BAND selector switch		N/A	Selected trans- mitter or antenna	Switch is spring loaded and has lock mechanism. To change switch set- ting, switch first must be pulled out.
	1 2 SLEW LUNAR STAY	Selects S-band antenna No. 1. Selects S-band antenna No. 2. Selects S-band steerable antenna. Position is not used for LM 3. (Selects S-band erectable antenna for use during lunar stay.)			

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 14 4DS2	DC BUS FAULT component caution light	Indicates a short in either a bus or a feeder line.	LTG: ANUN/ DOCK/ COMPNT (panel 11 and panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	
4M2	VOLTS indicator	Displays voltage of each of six EPS batteries, CDR's and LMP's d-c buses, a-c bus and the EDS batteries, depending on setting of POWER/TEMP MON switch.	EPS: DISP (panel 16)	LMP's 28-vdc bus	Green band (35.8 to 37.7 volts dc) on VOLTS indicator is equivalent to 112 to 118 volts ac. Range is 20 to 40 volts dc; 62.5 to 125 volts ac.
4M3	AMPS indicator	Indicates current flowing through each of six EPS batteries and the EDS batteries, depending on setting of POWER/TEMP MON switch.	EPS: DISP (panel 16)	LMP's 28-vdc bus	Range is 0 to 120 amperes. Amperage of descent batteries (No. 1, 2, 3, and 4) is obtained by halving indicator reading.
4DS1	BAT FAULT component caution light	Goes on when any malfunctioning battery is selected with POWER/TEMP MON switch.	LTG: ANUN/ DOCK COMPNT (panel 16)	LMP's 28-vdc bus	When lit indicates reverse-current, overcurrent or overtemperature, condition of any one of six EPS batteries.
4S17	ED VOLTS switch BAT A OFF BAT B	Selects voltage monitoring of EDS batteries. Selects monitoring EDS battery A. Disables voltage monitoring function. Selects monitoring EDS battery B.			POWER/TEMP MON selector switch must be set to ED/OFF.
4S15	POWER/TEMP MON selector switch	Enables monitoring of voltage and current of the six EPS batteries, two EDS batteries, monitoring of a-c and d-c bus voltage, and isolation of malfunctioning battery (overcurrent, reverse-current, and overtemperature condition).	EPS: DISP (panel 16)	LMP's 28-vdc bus	

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 14 (cont)	ED/OFF	Enables voltage monitoring of EDS batteries.			
	BAT 1	Selects battery No. 1 to be monitored on AMPS and VOLTS indicators, and on BAT FAULT component caution light.			
	BAT 2	Same as for BAT 1 position, except display is for battery No. 2.			
	BAT 3	Same as for BAT 1 position, except display is for battery No. 3.			
	BAT 4	Same as for BAT 1 position, except display is for battery No. 4.			
	BAT 5	Same as for BAT 1 position, except display is for battery No. 5.			
	BAT 6	Same as for BAT 1 position, except display is for battery No. 6.			
	CDR BUS	Voltage of CDR's d-c bus is displayed on VOLTS indicator.			
	AC BUS	Voltage of a-c bus is displayed on VOLTS indicator.			
	SE BUS	Voltage of LMP's d-c bus is displayed on VOLTS indicator.			
4S14	INVERTER switch	Controls application of a-c power to a-c bus.			
	OFF	Interrupts a-c inverter power is during space flight.	EPS: INV 1 (panel 11) and EPS: INV 2 (panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	A-C bus voltage is displayed on VOLTS indicator when POWER/TEMP MON switch is set to AC/BUS.

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 14 (cont)	1	Inverter No. 1 supplies power to a-c bus.			
	2	Inverter No. 2 supplies power to a-c bus.			
4S1	SE BAT 1 HI VOLTAGE switch	Controls high-voltage output from descent battery No. 1 to feeder line.	EPS: DES ECA CONT (panel 11 and/or panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	Before selecting ON position, OFF/RESET position must be selected so that ECA contactors are reset, thereby enabling battery power application to LMP's d-c bus. In event of overcurrent, ECA No. 1 takes battery No. 1 off line. SE BAT 1 gray/HI talkback is displayed. SE BAT 1 barber-pole talkback is displayed.
	ON	Connects high-voltage battery tap to line.			
	Center	Retains status of last initiated switch position.			
	OFF/RESET	Disconnects high-voltage battery tap from line.			
4S5	SE BAT 1 LOW VOLTAGE switch	Controls low-voltage output from descent battery No. 1 feeder line.	EPS: DES ECA CONT (panel 11 and/or panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	Before selecting ON position, OFF/RESET position must be selected so that ECA contactors are reset, thereby enabling battery-power application to LMP's d-c bus. In event of overcurrent, ECA No. 1 takes battery No. 1 off line. SE BAT 1 gray/LO talkback is displayed. SE BAT 1 barber-pole talkback is displayed.
	ON	Connects low-voltage battery tap to line.			
	Center	Retains status of last initiated switch position.			
	OFF/RESET	Disconnects low-voltage battery tap from line.			

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 14 (cont) 4 FL1	SE BAT 1 talkback				
	Gray/HI display	Indicates descent battery No. 1 is on line with high voltage tap.			
	Gray/LO display	Indicates descent battery No. 1 is on line with low voltage tap.			
	Barber-pole display	Indicates descent battery No. 1 is off line.			
4S2	SE BAT 2 HI VOLTAGE switch	Controls high-voltage output from descent battery No. 2 to feeder line.	EPS: DISP (panel 16)	LMP's 28-vdc bus	
	ON	Connects high-voltage battery tap to line.		CDR's 28-vdc bus	Before selecting ON position, OFF/RESET position must be selected so that ECA contactors are reset, thereby enabling battery-power application to LMP's d-c bus. In event of overcurrent, ECA No. 1 takes battery No. 2 off line.
	Center	Retains status of last initiated switch position.		LMP's 28-vdc bus	SE BAT 2 gray/HI talkback is displayed.
	OFF/RESET	Disconnects high-voltage battery tap from line.			SE BAT 2 barber-pole talkback is displayed.
4S6	SE BAT 2 LOW VOLTAGE switch	Controls low-voltage output from descent battery No. 2 to feeder line.	EPS: DES ECA CONT (panel 11 and/or panel 16)	CDR's 28-vdc bus	Before selecting ON position OFF/RESET position must be selected so that ECA contactors are reset, thereby enabling battery-power application to LMP's d-c bus. In event of overcurrent, ECA No. 1 takes battery No. 2 off line.
	ON	Connects low-voltage battery tap to line.		LMP's 28-vdc bus	SE BAT 2 gray/LO talkback is displayed.

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 14 (cont)	Center	Retains status of last initiated switch position.			
	OFF/RESET	Disconnects low-voltage battery tap from line.			SE BAT 2 barber-pole talkback is displayed.
4FL2	SE BAT 2 talkback		EPS: DISP (panel 16)	LMP's 28-vdc bus	
	Gray/HI display	Indicates descent battery No. 2 is on line with high voltage tap.			
	Gray/LO display	Indicates descent battery No. 2 is on line with low voltage tap.			
	Barber-pole display	Indicates descent battery No. 2 is off line.			
4S3	CDR BAT 3 HI VOLTAGE switch	Controls high-voltage output from descent battery No. 3 to feeder line.	EPS: DES ECA CONT (panel 11 and/or panel 16)	CDR's 28-vdc bus	Before selecting ON position, OFF/RESET position must be selected so that ECA contactors are reset, thereby enabling battery-power application to CDR's d-c bus. In event of battery overcurrent, ECA No. 2 takes battery No. 3 off line.
	ON	Connects high-voltage battery tap to line.			CDR BAT 3 gray/HI talkback is displayed.
	Center	Retains status of last initiated switch position.			
	OFF/RESET	Disconnects high-voltage battery tap from line.			CDR BAT 3 barber-pole talkback is displayed.
4S7	CDR BAT 3 LOW VOLTAGE switch	Controls low-voltage output from descent battery No. 3 to feeder line.	EPS: DES ECA CONT (panel 11 and/or panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	Before selecting ON position, OFF/RESET position must be selected so that ECA contactors are reset, thereby enabling battery-power application to CDR's d-c bus. In event of overcurrent, ECA No. 2 trips battery No. 3 off line.

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 14 (cont)	ON	Connects low-voltage battery tap to line.			CDR BAT 3 gray/LO talkback is displayed.
	Center	Retains status of last initiated switch position.			
	OFF/RESET	Disconnects low-voltage battery tap from line.			CDR BAT 3 barber-pole talkback is displayed.
4S4	CDR BAT 4 HI VOLTAGE switch	Controls high-voltage output from descent battery No. 4 to feeder line.	EPS: DES ECA CONT (panel 11 and/or panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	Before selecting ON position, OFF/RESET position must be selected so that ECA contactors are reset, thereby enabling battery-power application to CDR's d-c bus. In event of overcurrent, ECA No. 2 takes battery No. 4 off line.
	ON	Connects high-voltage battery tap to line.			CDR BAT 4 gray/HI talkback is displayed
	Center	Retains status of last initiated switch position.			
4S8	CDR BAT 4 LOW VOLTAGE switch	Controls low-voltage output from descent battery No. 4 to feeder line.	EPS: DES ECA CONT (panel 11 and/or panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	Before selecting ON position, OFF/RESET position must be selected so that ECA contactors are reset, thereby enabling battery-power application to CDR's d-c bus. In event of overcurrent, ECA No. 2 takes battery No. 4 off line.
	ON	Connects low-voltage battery tap to line.			CDR BAT 4 gray/LO talkback is displayed.
	Center	Retains status of last initiated switch position.			
	OFF/RESET	Disconnects low-voltage battery tap from line.			CDR BAT 4 barber-pole talkback is displayed.

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 14 (cont) 4FL4 4S9 4FL9	CDR BAT 4 talkback Gray/HI display Gray/LO display Barber-pole display	Indicates descent battery No. 4 is on line with high voltage tap. Indicates descent battery No. 4 is on line with low voltage tap. Indicates descent battery No. 4 is off line.	EPS: DISP (panel 16)	LMP's 28-vdc bus	
	DES BATS switch CONNECT Center DEADFACE	Enables interruption of power from descent batteries to ascent stage. Applies power from descent batteries to ascent stage. Retains status of last initiated switch position. Energizes deadface relays, isolating descent batteries on ascent stage side of staging guillotine.	EPS: ASC ECA CONT (panel 11 and/or panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	Switch is lever locked to center position. Momentary actuation of switch sets latching relays in descent ECA's. Descent batteries are normally connected to ascent stage. DES BATS gray talkback is displayed. DES BATS barber-pole talkback is displayed.
	DES BATS talkback Gray display Barber-pole display	Indicates whether descent stage deadface has been accomplished. Indicates descent batteries are connected to ascent stage. Indicates descent batteries are disconnected and deadfaced.	EPS: DISP (panel 16)	LMP's 28-vdc bus	

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 14 (cont) 4S10	BAT 5 NORMAL SE FEED switch	Controls connections of ascent battery No. 5 to LMP's bus.	EPS: ASC ECA CONT (panel 11 and/or panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	Switch is spring loaded to center position. Respective ECA controls battery connection to LMP's d-c bus; disconnects this battery in event of overcurrent. BAT 5 NORMAL SE FEED gray talkback is displayed. BAT 5 NORMAL SE FEED talkback is displayed.
	ON	Connects ascent battery No. 5 to bus.			
	Center	Retains status of last initiated switch position.			
4S11	OFF/RESET	Disconnects ascent battery No. 5 from bus; resets respective ECA contactors for overcurrent protection.	EPS: DISP (panel 16)	LMP's 28-vdc bus	
4FL5	BAT 5 NORMAL SE FEED talkback		EPS: ASC ECA CONT (panel 11 and/or panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	
	Gray display	Indicates ascent battery No. 5 is connected to LMP's bus.			
	Barber-pole display	Indicates ascent battery No. 5 is disconnected from LMP's bus.			
4S11	BAT 6 NORMAL CDR FEED switch	Controls connection of ascent battery No. 6 to CDR's bus.	EPS: ASC ECA CONT (panel 11 and/or panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	Switch is spring loaded to center position. Respective ECA controls battery connection to CDR's d-c bus; disconnects this battery in event of overcurrent. BAT 6 NORMAL CDR FEED gray talkback is displayed. BAT 6 NORMAL CDR FEED barber-pole talkback is displayed.
	ON	Connects ascent battery No. 6 to bus.			
	Center	Retains status of last initiated switch position.			
4S11	OFF/RESET	Disconnects ascent battery No. 6 from bus; resets respective ECA contactors for overcurrent protection.	EPS: ASC ECA CONT (panel 11 and/or panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 14 (cont) 4FL6 4S12 4FL7	BAT 6 NORMAL CDR FEED talkback Gray display Barber-pole display	Indicates ascent battery No. 6 is connected to CDR's bus. Indicates battery No. 6 is discon- nected from CDR's bus.	EPS: DISP (panel 16)	LMP's 28-vdc bus	
	BAT 5 BACK UP CDR FEED switch ON Center OFF/RESET	Controls connection of battery No. 5 to CDR's bus. Connects ascent battery to bus. Retains status of last initiated switch position. Disconnects ascent battery No. 5 from line; resets respective ECA contactors for overcurrent protec- tion.	EPS: ASC ECA CONT (panel 11 and/or panel 16)	CDR's 28-vdc bus LMP's 28-vdc bus	Switch is spring loaded to center po- sition. Respective ECA controls battery connection to CDR's d-c bus; disconnects this battery in event of overcurrent. If battery No. 6 or battery No. 5 feeder line fails, this switch is set to ON. BAT 5 BACK UP CDR FEED gray talkback is displayed. BAT 5 BACK UP CDR FEED barber-pole talkback is displayed.
	BAT 5 BACK UP CDR FEED talkback Gray display Barber-pole display	Indicates ascent battery No. 5 is connected to CDR's bus. Indicates ascent battery No. 5 is disconnected from CDR's bus.	EPS: DISP (panel 16)	LMP's 28-vdc bus	

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 16	FLT DISP circuit breakers				
4CB126	EVENT TIMER/FDAI (2 amperes)	Applies d-c power to EVENT TIMER and to LMP's FDAI and parts of auxiliary switching relay box, through RATE/ERR MON and ATTITUDE MON switches.	N/A	LMP's 28-vdc bus	
4CB134	X-PNTR (2 amperes)	Applies d-c power to LMP's X-Pointer indicator and to parts of auxiliary relay switching box through RATE/ERR MON switch.	N/A	LMP's 28-vdc bus	
	RCS SYS B circuit breakers				
4CB52	ASC FEED 1 (5 amperes)	Applies d-c power to RCS system B ascent fuel and oxidizer interconnect valves, through SYSTEM B ASC FEED 1 switch.	N/A	LMP's 28-vdc bus	Interconnect valves permit propellant flow from ascent tanks to RCS tanks. System B ASCENT FEED 2 switch must be set to ASCENT FEED 2.
4CB231	ASC FEED 2 (5 amperes)	Applies d-c power to RCS system B ascent fuel and oxidizer interconnect valves through SYSTEM B ASC FEED 2 switch.	N/A	LMP's 28-vdc bus	Interconnect valves permit propellant flow from ascent tanks to RCS tanks. System B ASCENT FEED 1 switch must be set to ASCENT FEED 1.
4CB49	ISOL VLV (5 amperes)	Applies d-c power to RCS system B oxidizer and fuel isolation valves through SYSTEM B THRUSTER PAIR switches.	N/A	LMP's 28-vdc bus	
4CB45	QUAD 1 TCA (15 amperes)	Applies d-c power to oxidizer and fuel valves of RCS system B, quad I TCA's.	N/A	LMP's 28-vdc bus	
4CB44	QUAD 2 TCA (15 amperes)	Applies d-c power to oxidizer and fuel valves of RCS system B, quad II TCA's.	N/A	LMP's 28-vdc bus	

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 16 (cont)					
4CB43	QUAD 3 TCA (15 amperes)	Applies d-c power to oxidizer and fuel valves of RCS system B, quad III TCA's.	N/A	LMP's 28-vdc bus	
4CB42	QUAD 4 TCA (15 amperes)	Applies d-c power to oxidizer and fuel valves of RCS system B, quad IV TCA's.	N/A	LMP's 28-vdc bus	
4CB54	CRSFD (5 amperes)	Applies d-c power to oxidizer and fuel crossfeed valves through CRSFD switch.	N/A	LMP's 28-vdc bus	
4CB50	TEMP/PRESS DISP-FLAGS (2 amperes)	Applies d-c power to REACTION CONTROL TEMP and PRESS indicators and to RCS talkbacks.	N/A	LMP's 28-vdc bus	
4CB121	PQGS DISP (2 amperes)	Applies d-c power to RCS system A and B pressure-volume-temperature (PVT) system.	N/A	LMP's 28-vdc bus	
4CB73	MAIN SOV (5 amperes)	Applies d-c power to RCS system B main oxidizer and fuel shutoff valves through SYSTEM B MAIN SOV switch.	N/A	LMP's 28-vdc bus	
	PROPUL circuit breakers				
4CB103	TEMP/PRESS DISP-FLAGS (2 amperes)	Applies d-c power to MAIN PROPULSION TEMP and PRESS indicators and to ASCENT and DESCENT He REG talkbacks.	N/A	LMP's 28-vdc bus	
4CB32	PQGS (2 amperes)	Applies d-c power to propellant quantity gaging system (PQGS) control unit through PRPLNT QTY MON switch.	N/A	LMP's 28-vdc bus	

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 16 (cont)					
4CB53	ASC He Reg (5 amperes)	Applies d-c power to latching helium solenoid valves No. 1 and 2 through ASCENT He REG switches.	N/A	LMP's 28-vdc bus	
4CB128	LTG circuit breakers FLOOD (5 amperes)	Applies d-c power to cabin flood-lights through FLOOD switch.	N/A	LMP's 28-vdc bus	
4CB160	TRACK (15 amperes)	Applies d-c power to tracking light electronic assembly.	N/A	LMP's 28-vdc bus	
4CB148	ANUN/DOCK COMPNT (2 amperes)	Applies alternate d-c power to caution and warning annunciators, component caution lights, docking lights, and LUNAR CONTACT lights.	N/A	LMP's 28-vdc bus	
4CB147	MASTER ALARM (2 amperes)	Applies d-c power to MASTER ALARM lights and master alarm tone generators.	N/A	LMP's 28-vdc bus	
4CB75	ED: LOGIC PWR B circuit breaker (2 amperes)	Applies d-c power to ASCENT He PRESS, ASC He SEL, DES PRESS, LDG GEAR DEPLOY, MASTER ARM, RCS PRESS, and ABORT STAGE switches.	N/A	LMP's 28-vdc bus	
4CB28	STAB/CONT circuit breakers AEA (10 amperes)	Applies main d-c power and acts as on-off switch to AGS.	N/A	LMP's 28-vdc bus	

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 16 (cont)					
4CB37	ENG ARM (2 amperes)	Applies d-c power to ENG ARM switch for arming ascent or descent engine.	N/A	LMP's 28-vdc bus	
4CB79	ASA (20 amperes)	Applies d-c power and acts as on-off switch to ASA.	N/A	LMP's 28-vdc bus	
4CB41	AELD (7.5 amperes)	Applies d-c power to system B of AELD/S.	N/A	LMP's 28-vdc bus	
4CB82	ATCA (7.5 amperes)	Applies d-c power to ATCA power supply.	N/A	LMP's 28-vdc bus	
4CB2	ABORT STAGE (2 amperes)	Applies d-c power to abort stage electronics through ABORT STAGE switch.	N/A	LMP's 28-vdc bus	
4CB230	ATCA (AGS) (2 amperes)	Applies d-c power through GUID CONT switch to select AGS, and bias power to ATCA. Also applies d-c power through MODE CONTROL and BAL CPL switches to ATCA primary preamplifiers.	N/A	LMP's 28-vdc bus	
4CB233	DES ENG OVRD (10 amperes)	Applies redundant d-c power to descent engine actuator valves.	N/A	LMP's 28-vdc bus	

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 16 (cont)	INST circuit breakers				
4CB99	CWEA (2 amperes)	Applies d-c power to CWEA.	N/A	LMP's 28-vdc bus	
4CB132	SIG SENSOR (2 amperes)	Applies d-c power to all preconditioned transducers throughout LM.	N/A	LMP's 28-vdc bus	
4CB125	PCM/TE (2 amperes)	Applies d-c power to PCMTEA.	N/A	LMP's 28-vdc bus	
4CB1	SIG CONDR 2 (2 amperes)	Applies d-c power to power buffers and conditioners in SCERA's.	N/A	LMP's 28-vdc bus	
4CB234	ECS circuit breakers SUIT FLOW CONT (2 amperes)	Applies d-c power to LMP's and CDR's SUIT ISOL valves.	N/A	LMP's 28-vdc bus	SUIT ISOL valves afford torn suit protection to the astronauts. If suit pressure falls below 3.1 psia, SUIT ISOL valves close, CABIN REPRESS valve opens, and remains open until cabin pressure is 4.1 psia or greater.
4CB235	SUIT/CABIN REPRESS (2 amperes)	Applies d-c power to CABIN RE-PRESS valve.	N/A	LMP's 28-vdc bus	
4CB153	COMM circuit breakers DISP (2 amperes)	Applies d-c power to SIGNAL STRENGTH indicator, and to PITCH and YAW indicators.	N/A	LMP's 28-vdc bus	

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 16 (cont)					
4CB85	SE AUDIO (2 amperes)	Applies d-c power to regulated power supply in LMP's audio center, to LMP's microphones amplifier through LMP's AUDIO CONT switch (NORM position), and to CDR's microphone through CDR's AUDIO CONT switch (BU position).	N/A	LMP's 28-vdc bus	
4CB115	VHF A XMTR (2 amperes)	Applies d-c power to VHF A transmitter-receiver and to exciter-power amplifier and modulator in VHF A transmitter through VHF A XMTR switch.	N/A	LMP's 28-vdc bus	
4CB114	VHF B RCVR (2 amperes)	Applies d-c power to VHF B IF and audio amplifier in VHF B receiver through VHF B RCVR switch.	N/A	LMP's 28-vdc bus	
4CB30	PRIM S-BD PWR AMPL (7.5 amperes)	Applies d-c power to power supply No. 1 in S-band power amplifier assembly.	N/A	LMP's 28-vdc bus	
4CB111	PRIM S-BD XMTR/RCVR (5 amperes)	Applies d-c power to power supply in S-band section of CS through XMTR/RCVR switch.	N/A	LMP's 28-vdc bus	
4CB110	S-BD ANT (2 amperes)	Applies d-c power to S-band steerable antenna power supply through TRACK MODE switch.	N/A	LMP's 28-vdc bus	
4CB102	PMP (2 amperes)	Applies d-c power to LMP's and CDR's communications umbilical assembly through TELEMETRY BIOMED switch and to PMP power supply.	N/A	LMP's 28-vdc bus	

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 16 (cont)					
4CB104	TV (2 amperes)	Applies d-c power to television camera (GFE) power supply.	N/A	LMP's 28-vdc bus	
4CB140	ECS circuit breakers DISP (2 amperes)	Applies d-c power to PART PRESS CO ₂ , ENVIRONMENTAL CONTROL TEMP, and PRESS, GLYCOL TEMP, and QUANTITY indicators.	N/A	LMP's 28-vdc bus	
4CB96	GLYCOL PUMP SEC (5 amperes)	Applies d-c power to backup glycol pump in coolant recirculation assembly.	N/A	LMP's 28-vdc bus	
4CB98	PRIM GLYCOL EVAP FLOW (5 amperes)	Applies d-c power to solenoid valve, that controls flow of water from water manifold to primary water boiler, via PRIM EVAP FLOW #2 switch.	N/A	LMP's 28-vdc bus	
4CB108	CABIN FAN 2 (5 amperes)	Applies d-c power to cabin fan No. 2 through ECS relay box.	N/A	LMP's 28-vdc bus	
4CB109	CABIN FAN CONT (2 amperes)	Applies d-c power to ECS O ₂ pressure regulator valves (PRESS REG A and PRESS REG B).	N/A	LMP's 28-vdc bus	
4CB113	CABIN REPRESS (2 amperes)	Applies d-c power to cabin repressurization emergency O ₂ valve (CABIN REPRESS).	N/A	LMP's 28-vdc bus	
4CB119	SUIT FAN 2 (15 amperes)	Applies d-c power to suit fan No. 2 (suit circuit assembly) through SUIT FAN switch.	N/A	LMP's 28-vdc bus	

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 16 (cont)					
4CB120	SUIT FAN Δ P (2 amperes)	Applies d-c power to fan differential pressure sensor.	N/A	LMP's 28-vdc bus	
4CB112	DIVERT VLV (2 amperes)	Applies d-c power to suit circuit diverter valve.	N/A	LMP's 28-vdc bus	
4CB84	CO ₂ SENSOR (2 amperes)	Applies d-c power to CO ₂ sensor in suit circuit assembly.	N/A	LMP's 28-vdc bus	
	HEATERS: RCS SYS A/B-2 circuit breakers				
4CB222	QUAD 1 (7.5 amperes)	Applies d-c power to section No. 2 engine heaters of quad I, systems A and B.	N/A	LMP's 28-vdc bus	
4CB223	QUAD 2 (7.5 amperes)	Applies d-c power to section No. 2 engine heaters of quad II, systems A and B.	N/A	LMP's 28-vdc bus	
4CB224	QUAD 3 (7.5 amperes)	Applies d-c power to section No. 2 engine heaters of quad III, systems A and B.	N/A	LMP's 28-vdc bus	
4CB225	QUAD 4 (7.5 amperes)	Applies d-c power to section No. 2 engine heaters of quad IV, systems A and B.	N/A	LMP's 28-vdc bus	
4CB68	DISP (2 amperes)	Applies d-c power to HTR CONT TEMP indicator.	N/A	LMP's 28-vdc bus	

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 16 (cont)					
4CB31	S-BD ANT (5 amperes)	Applies d-c power to four heaters in S-band steerable antenna electronics assembly.	N/A	LMP's 28-vdc bus	
4CB33	CAMR: SEQ circuit breaker (2 amperes)	Applies d-c power to sequence camera electrical outlet.	N/A	LMP's 28-vdc bus	
4CB16	EPS circuit breakers DISP (2 amperes)	Applies d-c power to AMPS and VOLTS indicators and to subsystem talkbacks.	N/A	LMP's 28-vdc bus	
4CB21	DC BUS VOLT (2 amperes)	Applies d-c power to IS for conditioning to monitor LMP's d-c bus voltage.	N/A	LMP's 28-vdc bus	Permits monitoring through caution and warning, pulse-code-modulation (telemetry), and voltmeter sections.
4CB13	INV 2 (30 amperes)	Applies d-c power to inverter No. 2 for generation of 115-volt 400-cps, a-c, power, via INVERTER switch.	N/A	LMP's 28-vdc bus	
4CB14	ASC ECA (2 amperes)	Applies d-c power to power supplies of both ascent ECA's.	N/A	LMP's 28-vdc bus	
4CB7	ASC ECA CONT (5 amperes)	Applies d-c power to normal and backup contact coils in ECA No. 3 and 4 through NORMAL FEED and BACK UP FEED switches.	N/A	LMP's 28-vdc bus	
4CB11	DES ECA (2 amperes)	Applies d-c power to power supplies of both descent ECA's.	N/A	LMP's 28-vdc bus	

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
Panel 16 (cont)					
4CB9	DES ECA CONT (5 amperes)	Applies d-c power to low- and high-voltage contact coils in ECA No. 1 and 2 through HI VOLTAGE and LOW VOLTAGE switches.	N/A	LMP's 28-vdc bus	
4CB5	XLUNAR BUS TIE (50 amperes)	Ties LMP's d-c bus translunar loads to LM single-point ground.	N/A	N/A	
4CB19	CROSS TIE-BUS (100 amperes)	Ties LMP's feeder/bus system to CDR's d-c bus through CDR's EPS: CROSS TIE-BUS circuit breaker.	N/A	LMP's 28-vdc bus	
4CB183	CROSS TIE-BAL LOADS (30 amperes)	Ties LMP's feeder/bus system to CDR's d-c bus through CDR's EPS: CROSS TIE-BAL LOADS circuit breaker.	N/A	LMP's 28-vdc bus	
4CB25	BAT FEED TIE (100 amperes)	Ties descent battery No. 1 and ascent battery No. 6 (backup mode) to LMP's d-c bus.	N/A	N/A	
4CB17	BAT FEED TIE (100 amperes)	Ties descent battery No. 2 and ascent battery No. 5 (normal mode) to LMP's d-c bus.	N/A	N/A	

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
ECS	7H8	SUIT GAS DIVERTER valve	ECS: DIVERT VLV (panel 16)	LMP's 28-vdc bus	Valve has provisions for automatic closure by signal from cabin pressure sensor when cabin pressure drops below 4.0 psia. Valve also closes automatically when PRESS REG A and PRESS REG B valves are set to EGRESS.
	PUSH-CABIN	Permits gas in suit circuit downstream of flow control valves to flow into cabin.			Enables suit circuit to maintain oxygen level of cabin within limits.
	PULL-EGRESS	Prevents gas in suit circuit from passing into cabin.			
	7H3	CABIN REPRESS valve	ECS: CABIN REPRESS (panel 16)	LMP's 28-vdc bus	CABIN PRESS indicator provides positive feedback of results of CABIN REPRESS valve actuation.
	MANUAL	Permits unregulated oxygen flow to cabin from oxygen manifold.			AUTO mode is disabled if PRESS REG A and PRESS REG B valves are set to EGRESS or if one valve is set to EGRESS and other valve is set to CLOSE.
	AUTO	Enables CABIN REPRESS valve to respond to inputs from cabin pressure switch and suit circuit low pressure sensor.			
	CLOSE	Prevents oxygen flow from oxygen manifold to cabin.			Valve opens fully when cabin pressure drops below 4.6 psia; it closes when pressure rises past 4.8 psia. Valve opens when suit circuit pressure drops to 3.12±0.18 psia; it closes when pressure rises past 4.1 psia.
	7H4	PLSS FILL valve	N/A	N/A	
	OPEN	Permits oxygen flow to primary oxygen storage tank in PLSS.			
	CLOSE	Prevents oxygen flow to tank.			

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
ECS (cont) 7H1 7H2 7H15 7H21 7H5	PRESS REG A and PRESS REG B valves		N/A	N/A	SUIT PRESS indicator provides positive feedback of results of PRESS REG A and PRESS REG B valve actuation. Both valves must be set to CABIN or EGRESS, simultaneously, to accomplish desired pressure regulation.
	DIRECT O ₂	Permits unregulated oxygen flow to suit circuit.			DIRECT O ₂ position is selected if both suit fans do not supply oxygen to suit circuits.
	CABIN	Permits regulated oxygen flow to suit circuit to maintain 4.8±0.2 psia.			CABIN position is selected during normal pressurized-cabin operations.
	EGRESS	Permits regulated oxygen flow to suit circuit to maintain 3.8±0.2 psia.			EGRESS position is selected during egress operations and when cabin is unpressurized.
	CLOSE	Prevents oxygen flow to suit circuit.			CLOSE position is selected only when one PRESS REG valve fails open.
	DES O ₂ valve		N/A	N/A	
	OPEN	Permits oxygen flow from descent oxygen tank to oxygen control valves.			
	CLOSE	Prevents oxygen flow from descent oxygen tank to oxygen control valves.			
	#1 ASC O ₂ and #2 ASC O ₂ valves		N/A	N/A	
	OPEN	Permits full oxygen flow from ascent oxygen tank to oxygen control valves.			Mechanical interlock in system prevents ascent oxygen flow to descent tank. If descent oxygen tank does not close, interlock override permits opening of ASC O ₂ valve after staging. DES O ₂ valve must be set to CLOSE.
	CLOSE	Prevents oxygen flow from ascent oxygen tank to oxygen control valves.			

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
ECS (cont) 7H6 7H7 7H18 7H16 7H14	SUIT ISOL valves	Controls flow of oxygen to space suit.	ECS: SUIT FLOW CONT (panel 16)	LMP's 28-vdc bus	SUIT ISOL valves afford the astronauts torn suit protection. If suit pressure falls below 3.1 psia, valves close, disconnecting suits from atmosphere revitalization section. CABIN REPRESS valve, which is operated by the same low pressure sensor as are the SUIT ISOL valves, opens, and remains open until cabin pressure rises above 4.1 psia.
	SUIT DISCONN	Disconnects suit from oxygen supply.			
	SUIT FLOW	Connect suit to oxygen supply.			
	SEC EVAP FLOW valve	Provides emergency means of cooling suit circuit.	N/A	N/A	Glycol temperature is read on GLYCOL TEMP indicator. CLOSE position is selected for normal operation.
	OPEN	Controls water flow to suit circuit water evaporator and to secondary water boiler when heat rejection by suit circuit heat exchanger is inadequate.			
	CLOSE	Prevents water flow to boiler.			
	PRIM EVAP FLOW No. 2 valve	Backup valve that controls water flow from the water manifold to the primary water boiler.	N/A	N/A	
	OPEN	Permits water (backup) flow to primary water boiler.			
	CLOSE	Shuts off water flow.			
	WATER TANK SELECT valve		N/A	N/A	During prelaunch, cooling is accomplished by Freon jacket in primary coolant system loop. After crew transfer, PRIM EVAP FLOW No. 2 valve is opened, permitting water from descent tank to flow to primary water boiler if WATER TANK SELECT valve is set to DES.

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
ECS (cont)	DES	Selects descent water tank to provide water for primary water boiler, and for DES H ₂ O valve for period between earth launch and staging.			
	ASC	Selects both ascent water tanks to provide water for primary water boiler and for ASC H ₂ O valve.			
	SEC	Prevents water flow from water tanks to primary water boiler. Diverts all water from water separators to secondary water boilers. Ruptures water isolation valve disk, thus replenishing emergency coolant system loop with water backup.			Safety trigger near WATER TANK SELECT valve must be tripped manually before setting valve to SEC.
	7H13	ASC H ₂ O valve	N/A	N/A	Water quantity is monitored by H ₂ O QTY indicator on panel 2.
		OPEN			
		CLOSE			
	7H26	DES H ₂ O valve	N/A	N/A	Water quantity is monitored by H ₂ O QTY indicator on panel 2.
		OPEN			
		CLOSE			

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
ECS (cont)	7H22	SUIT TEMP valve			
		Permits regulation of suit circuit temperature by varying rate of glycol flow to suit regenerative heat exchanger.	N/A	N/A	Modulating faucet control.
		DECR COLD			
		Decreases glycol flow to suit regenerative heat exchanger to decrease suit circuit gas temperature.			
		INCR HOT			
		Increases glycol flow to suit regenerative heat exchanger to increase suit circuit gas temperature.			
	7H17	CABIN GAS RETURN valve			
		Provides for return of cabin gas to suit circuit under normal operations or provides suit circuit integrity under rapid cabin decompression.	N/A	N/A	
	OPEN	Permits cabin gas to feed back to suit circuit for revitalization.			
	AUTO	Permits gas flow into, but not out of, suit circuit.			
	EGRESS	Closes valve, ensuring suit circuit integrity during unpressurized-cabin operations.			
	7H19	CO ₂ CANISTER SEL valve			
	PRIM	Permits suit circuit gas to be filtered through primary LiOH canister, thereby removing CO ₂ and noxious gases from suit circuit gas.	N/A	N/A	
	SEC	Permits suit circuit gas to be filtered through secondary LiOH canister to permit replacement of primary canister.			

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
ECS (cont)	7H9	SUIT CIRCUIT RELIEF valve	N/A	N/A	Positive feedback of suit circuit pressure is provided by SUIT PRESS indicator.
	OPEN	Fully opens valve, overriding AUTO mode.			
	AUTO	Permits valve to operate by aneroid device in response to suit circuit pressure.			
	CLOSE	Fully closes valve, overriding AUTO mode.			Valve is fully open when suit pressure is 4.7 psia or greater; fully closed when suit pressure is less than 4.3 psia.
	PRIMARY CO ₂ CANISTER VENT pushbutton	When button is pressed, gas in canister is vented, facilitating removal of canister from suit circuit.	N/A	N/A	Momentary pushbutton; associated with primary LiOH canister.
	7H23	PRIMARY CO ₂ CANISTER	N/A	N/A	After setting CO ₂ CANISTER SEL valve to SEC, PRIMARY CANISTER is set to OPEN, to remove cartridge.
	OPEN	Opens cover for removal of CO ₂ cartridge.			
	CLOSE	Closes cover after replacement of cartridge.			
	7H24	SECONDARY CO ₂ CANISTER			
	OPEN	Opens cover for removal of CO ₂ cartridge.			
	CLOSE	Closes cover after replacement of cartridge.			
	SECONDARY CO ₂ CANISTER vent pushbutton	When button is pressed, gas in canister is vented, facilitating removal of canister from suit circuit.	N/A	N/A	Momentary pushbutton; associated with secondary LiOH canister.

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
ECS (cont)	7H10	WATER SEP SEL valve	N/A	N/A	Normally separator No. 1 is on line.
	PUSH-SEP 1	Selects separator No. 1.			
	PUSH-SEP 2	Selects separator No. 2.			
	7H12	CABIN TEMP valve	N/A	N/A	Cabin temperature is monitored by CABIN TEMP indicator. Modulating faucet control.
	NORM	Regulates cabin temperature through adjustment of temperature of glycol supplied to cabin heat exchanger. Glycol temperature is adjusted auto- matically to maintain cabin gas at 70°±5° F.			
	MAX COOL	Diverts glycol of lower temperature into coolant flow.			
	MAX HEAT	Diverts higher temperature glycol into coolant flow.			
7H11 7H20	Cabin relief and dump valves	Provides means for automatic cabin depressurization and cabin pressure relief.	N/A	N/A	Trigger on cabin relief and dump valve lever on cabin side of hatch must be squeezed to unlock lever, before valve can be set to another position. Valve also has two-posi- tion PULL TO DUMP control lever on exterior side of hatch. Exterior lever is spring loaded to "in" posi- tion. Pulling and holding lever out for approximately 90 seconds dumps cabin pressure. "Out" position is comparable to DUMP position of in- terior lever; "in" position of ex- terior lever is comparable to AUTO position.
	DUMP	Overrides AUTO position and per- mits astronaut to dump cabin pres- sure.			

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
AOT					
3H3	Eyepiece adjust lever	Moves eyepiece toward, or away from, eye of observer for focusing.	N/A	N/A	
3S23	MARK X pushbutton (momentary)	Provides signal to LGC, indicating that navigation star is aligned on X-hairline of reticle.	N/A	N/A	
3S25	MARK Y pushbutton (momentary)	Provides signal to LGC, indicating that navigation star is aligned on Y-hairline of reticle.	N/A	N/A	
3S24	REJECT pushbutton (momentary)	Provides signal to LGC, erasing mark-X or mark-Y signal previously entered into LGC. New mark-X or mark-Y signal may be entered into LGC after mark-R REJECT pushbutton is pressed.	N/A	N/A	
3R1	Reticle illumination control	Controls brightness of reticle illumination.	AC BUS B: AOT LAMP (panel 11)	CDR's 115-vac bus	
3H1	Reticle control	Rotates reticle to superimpose spiral on target star, to zero the AOT counter, and to superimpose x-hairline on target star.	N/A	N/A	
3H2	Azimuth control	Rotates AOT prism to cover five 60° sectors, from left rear to right rear.	N/A	N/A	Image rotates as prism rotates.
	LR	Rotates prism to left rear position.			Right position (R) and right rear position (RR) are not usable at present.
	L	Rotates prism to left position.			
	F	Rotates prism to front position.			
	R	Rotates prism to right position.			

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
AOT (cont)	RR CL	Rotates prism to right rear position. Stores prism under protective cover.			
3M7	AOT indicator	Indicates position (in degrees) of reticle.	N/A	N/A	Four-place digital display. Extreme right digit is for tenths of a degree.
ACA 1A1 1A2	Attitude control assembly	Either astronaut can command vehicle attitude changes manually, using his ACA. ACA is installed with its longitudinal axis approximately parallel to LM X-axis; vehicle rotations correspond to astronaut hand movements in operating ACA. Clockwise or counterclockwise rotation of ACA about its longitudinal axis commands vehicle yaw right or yaw left about LM X-axis. Forward or aft movement of ACA commands vehicle pitch down or pitch up, respectively, about LM Y-axis. Left or right movement of ACA commands roll left or roll right about LM Z-axis.	STAB/CONT: ATT DIR CONT (panel 11)	CDR's 28-vdc bus	
15AS10 15BS10	Push-to-talk switch	Keys intercom and/or selected transmitters.	N/A	N/A	Located on ACA control grip.
TTCA 1X1 1X2	Thrust/translation controller	The thrust/translation controller is, functionally, an integrated translation and thrust controller used to command vehicle translations by reaction control jet firing, and to throttle the descent engine between 10% and 92.5% maximum thrust magnitude. It is a three-axis, tee-handle,	N/A	N/A	

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
TTCA (cont)		left-hand controller. Vehicle translations correspond approximately to astronaut movement of the tee-handle. Leftward or rightward movement commands translation along LM Y-axis; inward or outward movement commands translation along LM Z-axis; upward or downward movement commands translation along LM X-axis.			
1H1 1H2	Throttle/jets select lever	Lever mounted on TTCA affords integrated thrust and translation control capability.	N/A	N/A	Regardless of lever position, controller has translation command capability along the Y-axis and Z-axis.
	JETS	Provides RCS X-axis translation capability.			
	THROTTLE	Provides Y-axis translation by varying thrust magnitude of descent engine.			
1H3 1H4	Throttle friction controller	Varies force required to move tee-handle upward or downward. Controller is operative when THROTTLE/JETS select lever is set to THROTTLE.	N/A	N/A	Force required to move tee-handle varies from minimum of 0.25 to 1.0 pound to maximum of 2.5 to 3.5 pounds.
ORDEAL 9S23	FDAI switches 1 ORB RATE INRTL	Determines type of total attitude to be displayed on FDAI's. Selects inputs to CDR's FDAI. Enables CDR's FDAI to display total attitude with respect to local horizontal reference frame. Enables CDR's FDAI to display total attitude with respect to IMU.	N/A	N/A	

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
ORDEAL (cont) 9S24 9S25 9R1 9S26	2 ORB RATE INRTL	Selects input to LMP's FDAI. Enables LMP's FDAI to display total attitude with respect to local horizontal reference frame. Enables LMP's FDAI to display total attitude with respect to IMU.	N/A	N/A	
	EARTH-LUNAR switch EARTH PWR OFF LUNAR	Used in conjunction with ALT SET control, inserts appropriate scale factor into ORDEAL electronics. Supplies proper scale factor to ORDEAL electronics when LM is in earth orbit. Removes ac and dc power from ORDEAL. Same as EARTH position, except that scale factor applies to lunar orbit.	FLT DISP: ORDEAL (ac) (panel 11) FLIGHT DISPLAYS: ORDEAL (panel 11)	CDR's 115-vac bus CDR's 28-vdc bus	Switch is always set to either LUNAR or OFF.
	ALT SET control	Inserts LM orbital altitude into ORDEAL.	N/A	N/A	Control can be set from 10 to 310 nautical miles.
	LIGHTING switch BRT OFF DIM	Controls the brightness of the ORDEAL EL panel lighting. Selects bright light level. Turns off panel lighting. Selects dim light level.	FLIGHT DISPLAYS: ORDEAL (panel 11)	CDR's 28-vdc bus	

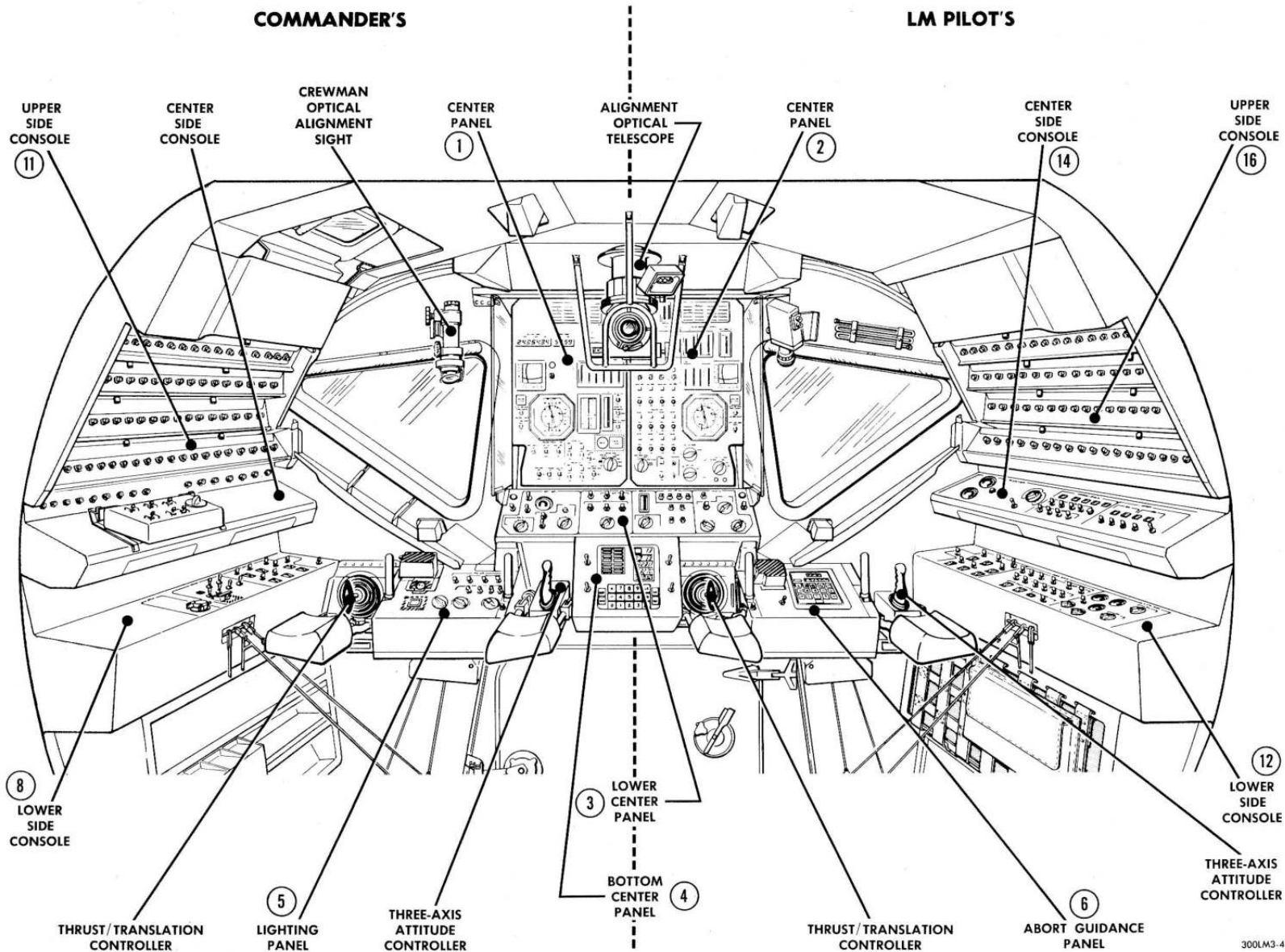
LMAT790-3-LM 3
APOLLO OPERATIONS HANDBOOK
CONTROLS AND DISPLAYS

Location/ Ref Des	Name and Position	Function	Circuit Breaker	Power Source	Remarks
ORDEAL (cont) 9S27	MODE switch	Inserts and maintains proper angular offset into FDAI's.	N/A	N/A	
	OPR/SLOW	When used with UP and DOWN positions of the SLEW switch, permits slewing the FDAI at 10X orbital rate in plus or minus direction. Used for fine adjustment.			
	HOLD/FAST	When used with UP and DOWN positions of SLEW switch, permits slewing FDAI at 200X orbital rate in plus or minus direction. Used for coarse adjustment.			
9S28	SLEW switch	Slews pitch indication on FDAI in plus (UP position) or minus (DOWN position) at rate dependent on setting of MODE switch. When switch is set to center position and MODE switch is set to OPR/SLOW, ORDEAL slews at orbital rate and FDAI displays total attitude with respect to local reference frame.			

LMA 790-3-LM3
APOLLO OPERATIONS HANDBOOK
CONTROLS AND DISPLAYS

INSTRUMENT BEHAVIOR

INSTRUMENT	TRANSDUCER		CONDITIONER		INSTRUMENT SIGNAL LINE		
	OPEN	SHORT	OPEN	SHORT	PWR FAILURE	OPEN	SHORT
X-Pointers (9M2, 9M3)	Zero or random	Last position	Off scale	Zero	Last position	Last position	Zero
FDAI's (9M1, 9M6)	Last position				DC - Flag AC - Last position	DC - Flag AC - Last position	DC - Flag AC - Last position
Mission Timer (9M12) Event Timer (9M11)	Last position					Continues Counting	
Helium Indicator (10M1) Propulsion Quantity Indicator (10M5)	Numeric Zero				No clock pulse random	Blank	Blank
Thrust Indicator (9M7)	Zero or random	Zero thrust < 0 cmd in manual - 10 in automatic	Last position	Last position	Last position. May move with vibration		
Range/Altitude Indicator (9M9)	Last position						
MPS Temperature and Pressure Indicators (10M3, 10M4) RCS Temperature Pressure and Quantity Indicator (8M1, 8M2, 8M4)	Zero or random	Zero	Random	Zero	Last position		
ECS Temperature and Pressure Indicators (7M2, 7M3)	Random	Off bottom of scale	Random	Off bottom of scale	Last position		
ECS Part Press CO ₂ , Glycol, and Quantity Indicators (7M1, 7M4, 7M5)	Zero or random	Zero	Last position				
Radar and Antennas Signal Strength Indicators (14M1, 17M1)	Zero or random	Zero	Last position				
Pitch and Yaw Indicators (14M3, 14M4)	Low end of scale or random point on scale		Last position				
VOLTS Indicator (4M2)	Below 20 or random point on scale	Below 20 or bottom of scale	Last position				
AMPS Indicator (4M3)	Zero	Zero	Last position				



300LM3-4

Figure 3-1. LM Cabin - Controls and Displays

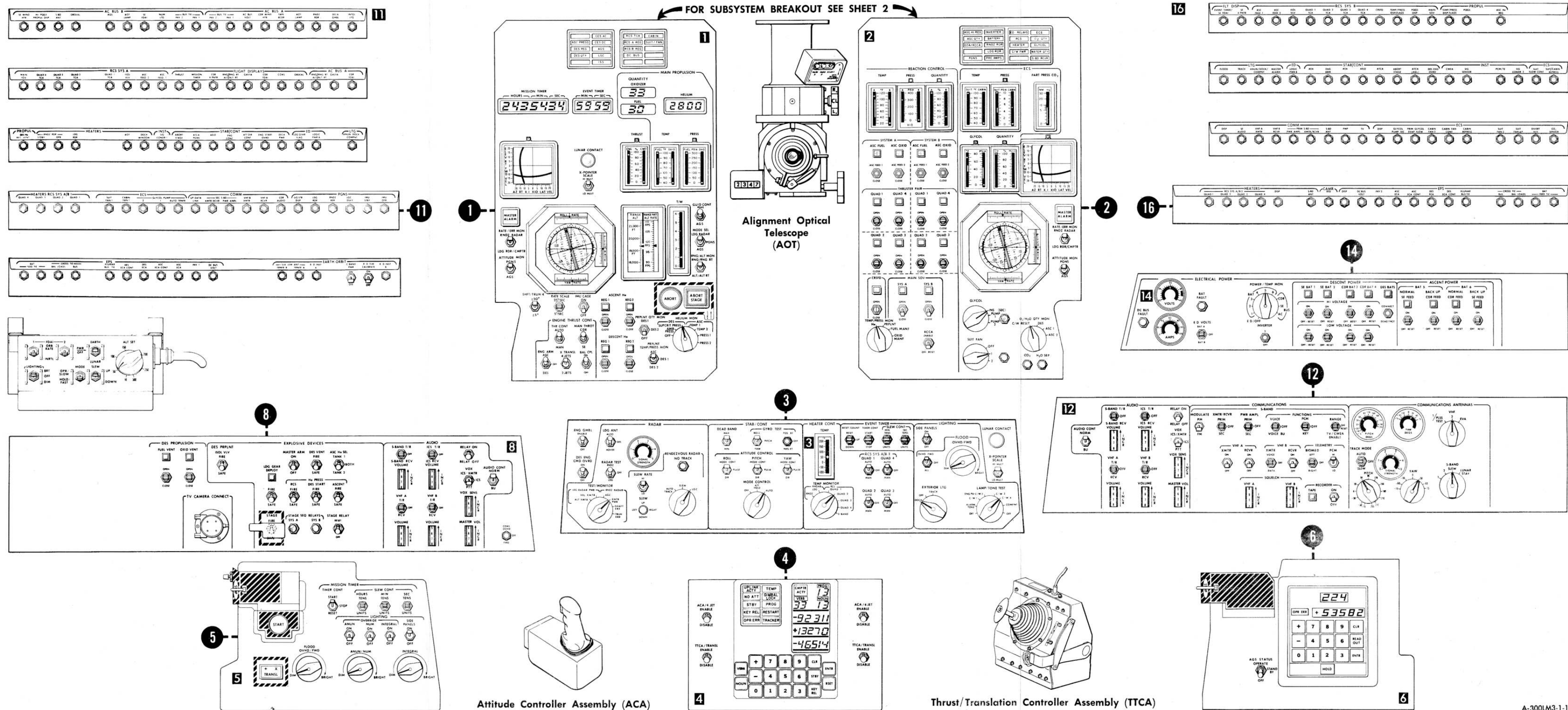


Figure 3-2. Main Display Console (Sheet 1 of 2)

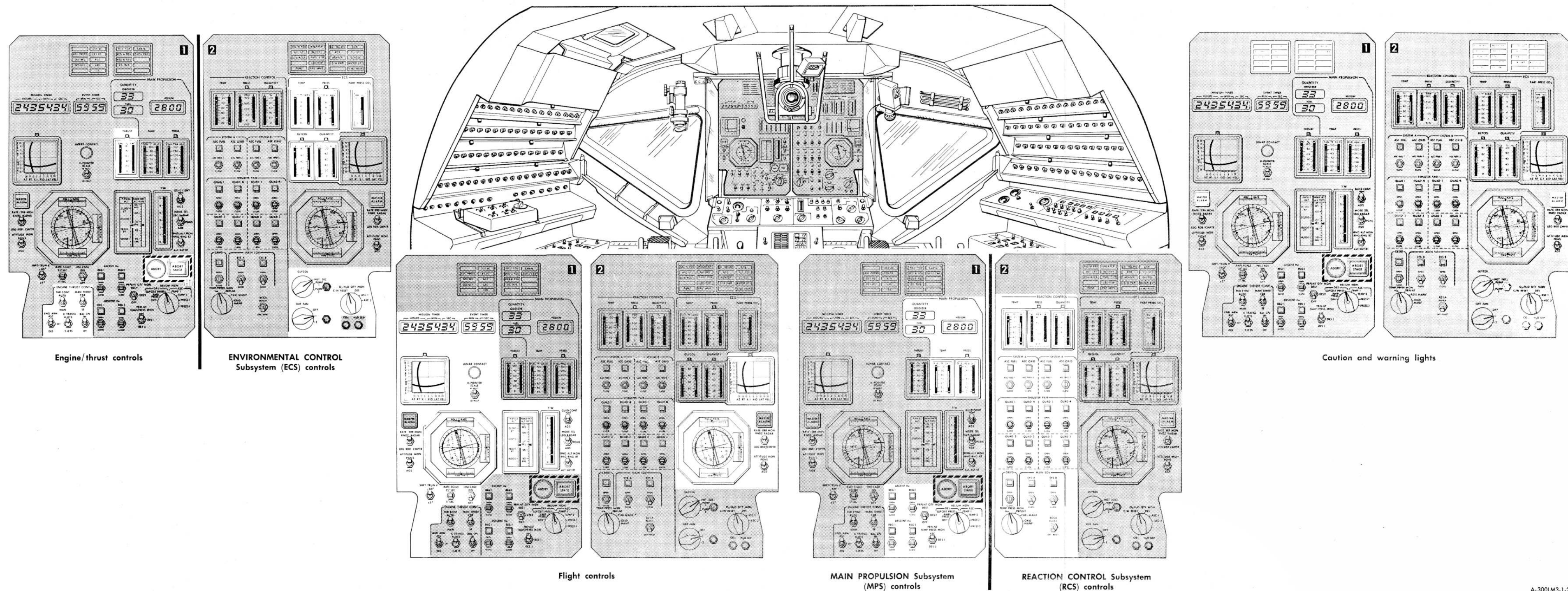


Figure 3-2. Main Display Console (Sheet 2 of 2)

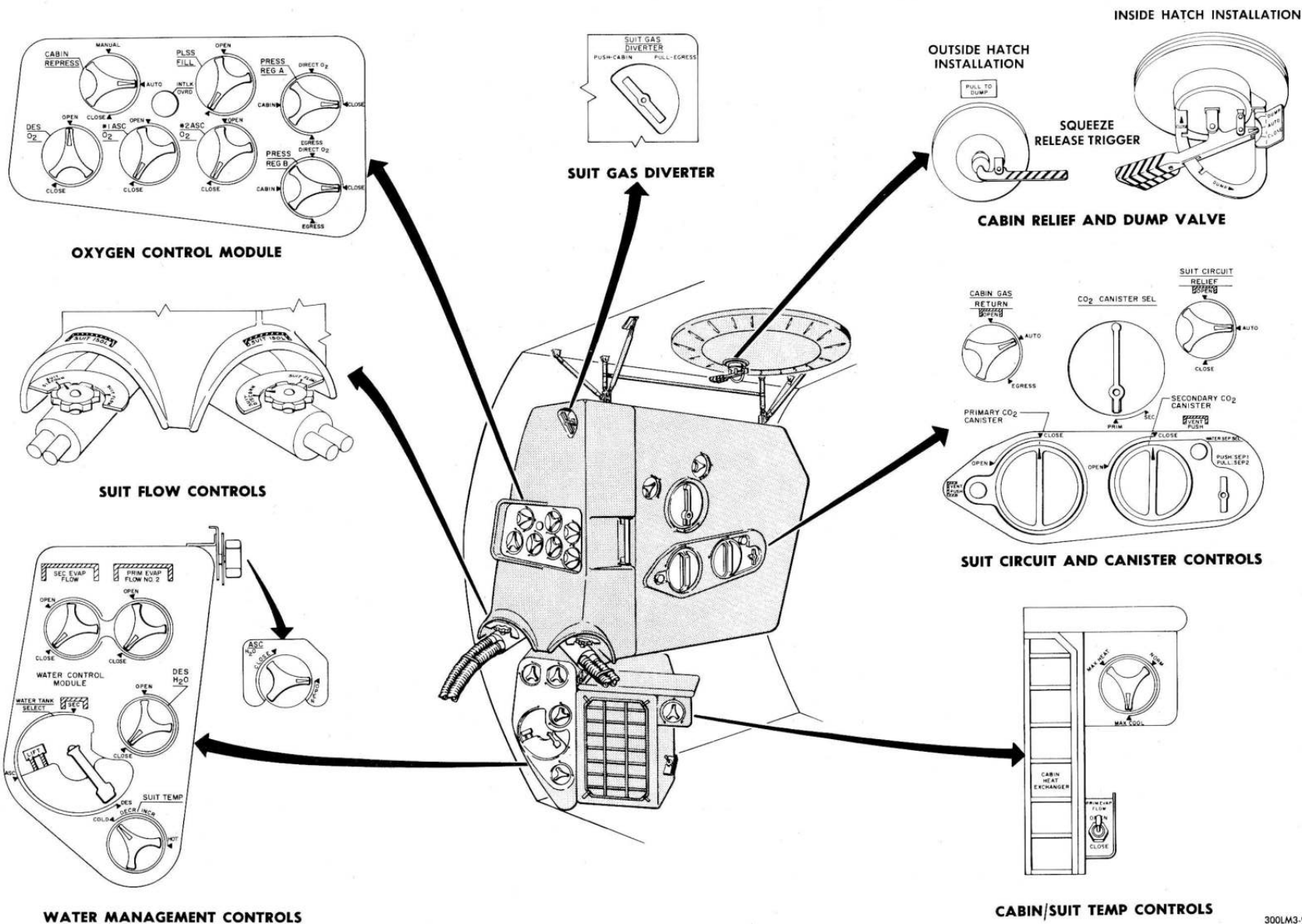


Figure 3-3. Environmental Control Subsystem Aft Bulkhead Controls

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

ABBREVIATION LIST

A

A/D	Analog-to-digital
AAP	Abort autopilot
abs	Absolute
ac	Alternating current (a-c, u. m.)
ACA	Attitude controller assembly
AEA	Abort electronics assembly
AEAA	Ascent engine arming assembly
AELD	Ascent engine latching device
AFC	Automatic frequency control
AGC	Automatic gain control
AGS	Abort guidance section
ALT	Altitude
amp	Amper(s)
AMPL	Amplifier
ANT	Antenna
ANUN	Annunciator
AOT	Alignment optical telescope
APS	Ascent propulsion section
ARS	Atmosphere revitalization section
ASA	Abort sensor assembly
ASC	Ascent
ASD	Apollo standard detonator
ASI	Apollo standard initiator
ASSY	Assembly
ATA	Abort timing assembly
ATCA	Attitude and translation control assembly
ATM	Altimeter transmitter multiplier
ATT	Attitude
AUTO	Automatic
AUX	Auxiliary

B

BAL	Balance
BAT	Battery
BD	Band
biomed	Biomedical
BIPRPLNT	Bipropellant
BPF	Band-pass filter
BU	Backup

C

cb	Circuit breaker
CBW	Constant bandwidth
CBX	C-band transponder
CDH	Constant delta altitude maneuver
CDR	Commander
CDU	Coupling data unit
CES	Control electronics section
cg	Center of gravity
CKT	Circuit
CLR	Clear
CMPTR	Computer
COAS	Crewman optical alignment sight
COMM	Communications
COMP	Comparator
CONDR	Conditioner
CONT	Control
cont	Continued
cos	Cosine
CO ₂	Carbon dioxide
CPL	Couple
cps	Cycles per second

C (cont)

CPS	Cold plate section
CRSFD	Crossfeed
CS	Communications Subsystem
CSI	Coelliptic sequence initiation maneuver
CSM	Command and Service module
CSS	Computer subsection
CT	Control transformer
CW	Continuous wave
C/W	caution and warning
CWEA	Caution and warning electronics assembly
CX	Control transmitter

D

D/A	Digital-to-analog
DAP	Digital autopilot
db	Decibel
dc	Direct current (d-c, u. m.)
DCA	Digital command assembly
DECA	Descent engine control assembly
DECR	Decrease
DEDA	Data entry and display assembly
DEG	Degree(s)
DEMOD	Demodulator
DES	Descent
DET	Detector
DFI	Developmental Flight Instrumentation
DFR	Deadface relay
DID	Display inertial data (discrete)
DIF	Differential
DISP	Display
DIST	Distribution
DN	Down
DPS	Descent propulsion section
DRB	Deadface relay box
DSEA	Data storage electronics assembly
DSKY	Display and keyboard

E

ECA	Electronic control assembly
ECI	Electrical circuit interrupter
ECS	Environmental Control Subsystem
ED	Explosive device
EDC	End detonator cartridge
EDS	Explosive Devices Subsystem
EKG	Electro-cardiograph
EL	Electroluminescent
EMI	Electromagnetic interference
EMP	Emphasis
EMU	Extravehicular mobility unit
ENG	Engine
ENTR	Enter
EOS	Emergency oxygen system
EPS	Electrical Power Subsystem
ERA	Electronic replaceable assembly
ERR	Error
EVA	Extravehicular astronaut
EVVA	Extravehicular visor assembly
Ex	X-component of attitude error
Ey	Y-component of attitude error
Ez	Z-component of attitude error

ABBREVIATION LIST (cont)

K (cont)

Page A-2 Mission LM 3 Basic Date 1 January 1968 Change Date

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

ABBREVIATION LIST (cont)

O (cont)

OCR Overcurrent relay
 OCPS Oxygen cabin pressure section
 OGA Outer gimbal axis
 OPR Operate
 OPR ERR Operator error
 ORDEAL Orbital rate display - earth and lunar
 OSC Oscillator
 OSCPCS Oxygen supply and cabin pressure control section
 OSS Optical subsection
 O/T Overtemperature
 OT Operational test
 OVED Overboard
 OVHD Overhead
 OXID Oxidizer
 O₂ Oxygen

P

P/O Part of
 p-p Peak-to-peak
 PAM Pulse amplitude modulation
 PA Power amplifier
 PBAT Pyro battery
 PBW Proportional bandwidth
 PCA Program coupler assembly
 PCM Pulse code modulation
 PCMTEA Pulse-code-modulation and timing electronics assembly
 PDA Power distribution assembly
 PGA Pressure garment assembly
 PGNC Primary guidance, navigation, and control section
 PGNS Primary guidance and navigation section
 PIP Pulse integrating pendulum
 PIPA Pulsed integrating pendulous accelerometer
 ø Phase
 PKG Package
 PLSS Portable life support system
 PM Phase modulation
 PMP Premodulation processor
 P/O Part of
 ppm Pulse(s) per minute
 pps Pulse(s) per second
 PQGS Propellant quantity gaging system
 PRA Program reader assembly
 PRE Program reader electronics
 PRESS Pressure
 PRF Pulse repetition frequency
 PRIM Primary
 PRM Pulse ratio modulator
 PRN Pseudorandom noise
 PRPLNT Propellant
 PS Power Supply
 PSA Power and servo assembly
 psi Pound(s) per square inch
 psia Pound(s) per square inch absolute
 psid Pound(s) per square inch differential
 PSK Phase-shift keyed
 PT Pressure transducer
 PTA Pulse torque assembly
 PTT Push-to-talk
 PVT Pressure-volume-temperature
 PWR Power

Q

QI Quantity indicator
 QTY Quantity
 quad Quadrant

R

R Rankine
 R/C Reverse current
 RC Resistance-capacitance
 RCCA Rough combustion cutoff assembly
 RCR Reverse-current relay
 RCS Reaction Control Subsystem
 RCVR Receiver
 RD Relay driver
 RH Right hand
 RDR Radar
 REF Reference
 REG Regulator
 RES Resolver
 RF Radio frequency
 RGA Rate gyro assembly
 RJB Relay junction box
 rms Root mean square
 RNDZ Rendezvous
 RNG Range
 RR Rendezvous Radar
 RRE Rendezvous radar electronics
 RT Resistance thermometer
 RZ Return-to-zero

S

S/S Subsystem
 S&C Stabilization and control
 SBASI Single bridgewire Apollo standard initiator
 SBPA S-band power amplifier
 SBX S-band transponder
 SC Signal conditioner
 SCEA Signal-conditioning electronics assembly
 SCERA Signal conditioner electronic replaceable assembly
 SE Systems Engineer
 SCO Signal-controlled oscillator
 sec Second(s); secondary
 SEL Select
 SENS Sensitivity
 SEP Separator
 SEQ Sequence
 SERVO- Servoamplifier
 AMPL
 SHe Supercritical helium
 SG Signal Generator
 SHFT Shaft
 SIG Signal
 ∑ Sum (summing)
 sin Sine
 SLA Spacecraft launch-vehicle adapter
 SOL Solenoid
 SMRD Spin motor rotation detector
 SOV Shutoff valve
 SP Static pressure
 SPA Signal-processing assembly
 SPDT Single-pole double-throw
 SS Speed sensor

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

ABBREVIATION LIST (cont)

S (cont)		V (cont)	
ST	Strain/temperature signal conditioner	VCO	Voltage-controlled oscillator
STBY	Standby	vdc	Volts, direct current
SYS	System	VEL	Velocity
T		VG	Magnitude of velocity to be gained
TAI	Absolute time	VGPS	Vehicle ground power supply
Tig	Time of ignition	VHF	Very high frequency
TN	Trim negative	VLV	Valve
Tp	Trim positive	VOL	Volume
TC	Thermocouple	VOX	Voice-operated relay
TCA	Thrust chamber assembly	VPI	Valve position indicator
TE	Timing electronics equipment	vrms	Volts root mean square
TEMP	Temperature	V _x	Altitude rate
TFF	Time of free fall to 300,000 ft	V _y	Lateral velocity
TFI	Time from Tig	V _z	Forward velocity
THR	Thrust	W	
TLE	Tracking light electronics	W/B	Water boiler
TM	Telemetry	WC	Weighted current
TPF	Transfer phase final maneuver	WCG	Weighted current gate
TPI	Transfer phase initiation maneuver	WMS	Water management section
TPM	Transfer phase midcourse	X	
T/R	Transmitter-receiver	XMTR	Transmitter
TRANSL	Translation	XPNDR	Transponder
TRUN	Trunnion	XTAL	Crystal
TS	Temperature sensor	∠	Angle
TT	Temperature transducer	Δh	Altitude differential
TTCA	Thrust/translation controller assembly	ΔP	Pressure differential
TTI	Time to initiate	Δro	Differential altitude in co-elliptic orbit
TTig	Time to ignition	ΔV	Velocity change (differential)
TV	Television	ΔV _m	Measured ΔV magnitude
TX	Telemetry transmitter	ΔR	Magnitude of difference between position state vectors before and after incorporation of mark data
U		Δθg	Change in gimbal angle
UDMH	Unsymmetrical dimethylhydrazine	Δθc	Gimbal angle change command
UHF	Ultrahigh frequency	1X	One-speed resolver
V		16X	Sixteen-speed resolver
V _{cx}	X component of CSM velocity		
V _{cy}	Y component of CSM velocity		
V _{cz}	Z component of CSM velocity		
vac	Volts, alternating current		

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

LIST OF SYMBOLS



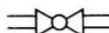
DIVERTER VALVE
(MANUAL OVERRIDE)



FILLERNECK
WITH FILTER SCREEN



BASIC VALVE



BALL VALVE



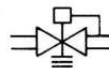
MANUAL VALVE



MOTOR CONTROL VALVE



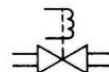
PRESSURE REGULATOR VALVE



PRESSURE REGULATOR VALVE
WITH RELIEF



RELIEF VALVE



SOLENOID VALVE



PYRO ISOLATION



PYRO GUILLOTINE
(S indicates sealing tube type)



ORIFICE OR RESTRICTOR



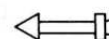
FILTER



CHECK VALVE



LOW-LEVEL SENSOR



LIQUID-LEVEL SENSOR



TEMPERATURE
CONTROL VALVE



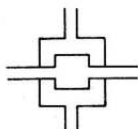
GLYCOL PUMP



PUMP (gear type)



PUMP (vane type)



CONDENSER, REGENERATOR
OR PREHEATER



ACCUMULATOR



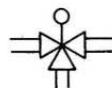
VENT



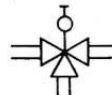
FILL OR DRAIN



ENGINE



MOTOR-DRIVEN
SELECTOR VALVE



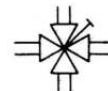
MOTOR-DRIVEN
SELECTOR VALVE
WITH MANUAL OVERRIDE



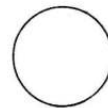
QUICK-DISCONNECT COUPLING



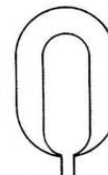
BURST DISK



SELECTOR VALVE
(4 WAY-2 POSITION)



TANK



TANK WITH BLADDER



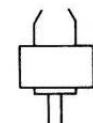
CYLINDER AND PISTON



WATER SEPARATOR



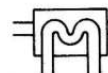
FREON BOILER



SECONDARY WATER BOILER



BLOWER



HEAT EXCHANGER



FAN



CO₂ AND ODOR REMOVAL
CANISTER AND CARTRIDGE



WATER EVAPORATOR

300LM3-340-1

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

LIST OF SYMBOLS (cont)

	CURRENT SENSOR		ELECTRICAL CONTACTORS (NON-LOCKING TYPE)		PUSHBUTTON SWITCH (MOMENTARY BREAK)
	FLOW TRANSDUCER		ANTENNA		SWITCH (SPDT)
	PARTIAL-PRESSURE SENSOR		CIRCUIT BREAKER (push-pull type)		BUS BAR
	PRESSURE TRANSDUCER		CIRCUIT BREAKER (switch type)		HEATER
	QUANTITY INDICATOR		FUSE		AMPLIFIER OR DRIVER (DC, Pre, or Buffer)
	SIGNAL CONDITIONER		DIODE		INVERTER AMPLIFIER (Inversion symbol is shown on inverted line)
	SPEED SENSOR		DIODE (zener)	LOGIC SYMBOLS	
	TEMPERATURE PROBE		GROUND		AND
	TEMPERATURE TRANSDUCER		POTENTIOMETER		NAND
	VIBRATION SENSOR		RESISTOR		OR
	VALVE POSITION INDICATOR		CAPACITOR		NOR
	VOLTAGE TRANSDUCER		BATTERY		EXCLUSIVE OR
	LOW-LEVEL SENSOR		RELAY CONTACTS		VARIABLE DELAY
	DIFFERENTIAL PRESSURE SENSOR		RELAY OR SOLENOID COIL		FLIP-FLOP
	GASEOUS OXYGEN		MOMENTARY LATCHING	SWITCH & RELAY CONTACTS	
	FUEL		SWITCH (SP3T)		SYNCHRO RESOLVER
	OXIDIZER		PUSHBUTTON SWITCH (MOMENTARY MAKE)		MOTOR
	GLYCOL - PRIMARY LOOP		SWITCH (SPST)		CONTROL TRANSMITTER
	GLYCOL - SECONDARY LOOP				CONTROL TRANSFORMER
	NITROGEN				CURRENT MONITOR
	HYDROGEN				ELECTRICAL CONTACTORS
	WATER				
	OXYGEN				
	HELIUM				

300LM3-340-2

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

ALPHABETICAL INDEX

	Paragraph
Communications Subsystem	2.7
Failure Modes	2.7.4
Functional Description	2.7.2
Data Operation	2.7.2.2
Ranging and Tracking	2.7.2.3
Subsystem Operation	2.7.2.4
Voice Operation	2.7.2.1
Introduction	2.7.1
Major Component/Functional Description	2.7.3
Antenna Equipment	2.7.3.3
S-Band In-Flight Antennas	2.7.3.3.1
S-Band Steerable Antenna	2.7.3.3.2
VHF In-Flight Antennas	2.7.3.3.3
Electrical Power Distribution	2.7.3.4
RF Electronic Equipment	2.7.3.1
S-Band Diplexer and RF Switch	2.7.3.1.3
S-Band Power Amplifier	2.7.3.1.2
S-Band Transmitter-Receiver Assembly	2.7.3.1.1
VHF Diplexer and RF Switch	2.7.3.1.5
VHF Transmitter-Receiver Assembly	2.7.3.1.4
Signal Processing Assembly	2.7.3.2
Audio Centers	2.7.3.2.2
Premodulation Processor	2.7.3.2.1
Operational Limitations and Restrictions	2.7.6
Antennas	2.7.6.1
Performance and Design Data	2.7.5
Telemetry Measurements	2.7.7
Crew Personal Equipment	2.11
Crew Life Support	2.11.4
EMU Waste Management System	2.11.4.2
Fecal Containment System	2.11.4.2.2
Waste Fluid Transfer	2.11.4.2.1
Food and Water	2.11.4.1
Crew Water System	2.11.4.1.1
Food Preparation and Consumption	2.11.4.1.2
Crew Miscellaneous Equipment	2.11.8
Alignment Optical Telescope Platform	2.11.8.4
In-Flight Data	2.11.8.1
Tool B	2.11.8.2
Window Shades	2.11.8.3
Crew Support and Restraint Equipment	2.11.6
Armrests	2.11.6.1
Handholds	2.11.6.2
Restraint Assembly	2.11.6.3
Docking Aids and Tunnel Hardware	2.11.7
CM Forward Hatch	2.11.7.6
Crewman Optical Alignment Sight	2.11.7.1
Operation (COAS)	2.11.7.1.1
Docking Target	2.11.7.2
Drogue Assembly	2.11.7.3
Probe Assembly	2.11.7.5

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

ALPHABETICAL INDEX (cont)

	Paragraph
Crew Personal Equipment (cont)	
. Tunnel Hardware	2.11.7.4
. Extravehicular Mobility Unit	2.11.2
. Communications Carrier	2.11.2.3
. EMU Maintenance Kit	2.11.2.7
. Integrated Thermal Micrometeoroid Garment	2.11.2.4
. Extravehicular Boots	2.11.2.4.2
. Extravehicular Gloves	2.11.2.4.1
. Extravehicular Visor Assembly	2.11.2.4.3
. Interim Oxygen Purge Systems	2.11.2.6
. Liquid-Cooled Garment	2.11.2.1
. Portable Life Support System	2.11.2.5
. Electrical System	2.11.2.5.5
. Feedwater Loop	2.11.2.5.3
. Liquid Transport Loop	2.11.2.5.4
. Oxygen Ventilating Circuit	2.11.2.5.2
. PLSS Donning	2.11.2.5.6
. Primary Oxygen System	2.11.2.5.1
. Pressure Garment Assembly	2.11.2.2
. Helmet	2.11.2.2.2
. Intravehicular Gloves	2.11.2.2.3
. Torso and Limb Suit	2.11.2.2.1
. Introduction	2.11.1
. Medical Equipment	2.11.5
. Bio Instrumentation	2.11.5.1
. Emergency Medical Equipment	2.11.5.3
. Personal Radiation Dosimeters	2.11.5.2
. Stowage Locations	2.11.9
. Umbilical Assembly	2.11.3
. Electrical Umbilical	2.11.3.2
. Oxygen Umbilical	2.11.3.1
Electrical Power Subsystem	2.5
. Failure Modes	2.5.4
. Functional Description	2.5.2
. A-C Section	2.5.2.3
. D-C Section	2.5.2.2
. EPS Stages of Operation	2.5.2.6
. Ascent Stage Power	2.5.2.6.5
. Descent Stage Power (High-Voltage Taps)	2.5.2.6.4
. Descent Stage Power (Low-Voltage Taps)	2.5.2.6.2
. Earth Orbit-CSM/LM Power	2.5.2.6.3
. GSE - Supplied Prelaunch Power	2.5.2.6.1
. Staging - Normal or Abort	2.5.2.6.6
. Power Distribution	2.5.2.4
. Power Monitoring	2.5.2.5
. Battery Status - Monitoring Circuits	2.5.2.5.1
. Battery Voltage - and Current - Monitoring Circuits	2.5.2.5.2
. Malfunctioning - Battery Isolation Circuitry	2.5.2.5.4
. Primary Bus Voltage - Monitoring Circuits	2.5.2.5.3
. Introduction	2.5.1
. Major Component/Functional Description	2.5.3
. Ascent Stage Batteries	2.5.3.2
. Ascent Stage Electrical Control Assemblies	2.5.3.4
. Circuit Breaker and EPS Control Panels	2.5.3.8

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
 SUBSYSTEMS DATA

ALPHABETICAL INDEX (cont)

	Paragraph
Electrical Power Subsystem (cont)	
. . . Deadface Relay Box	2.5.3.6
. . . Descent Stage Batteries	2.5.3.1
. . . Descent Stage Electrical Control Assemblies	2.5.3.3
. . . Inverters	2.5.3.7
. . . Relay Junction Box	2.5.3.5
. . . Sensor Power Fuse Assemblies	2.5.3.9
. . . Operational Limitations and Restrictions	2.5.6
. . . Performance and Design Data	2.5.5
. . . Telemetry Measurements	2.5.7
Environmental Control Subsystem	
. . . Failure Modes	2.6
. . . Functional Description	2.6.4
. . . Atmosphere Revitalization Section	2.6.2
. . . Cold Plates and Rails	2.6.2.1
. . . Heat Transport Section	2.6.2.5
. . . Oxygen Supply and Cabin Pressure Control Section	2.6.2.4
. . . Water Management Section	2.6.2.2
. . . Introduction	2.6.2.3
. . . Atmosphere Revitalization Section	2.6.1
. . . Heat Transport Section	2.6.1.1
. . . Oxygen Supply and Cabin Pressure Control Section	2.6.1.4
. . . Water Management Section	2.6.1.2
. . . Major Component/Functional Description	2.6.1.3
. . . Atmosphere Revitalization Section	2.6.3
. . . Cabin Recirculation Assembly	2.6.3.1
. . . Recirculation System	2.6.3.1.2
. . . Heat Transport Section	2.6.3.1.1
. . . Cabin Temperature Control Valve	2.6.3.4
. . . Cold Plates	2.6.3.4.4
. . . Coolant Accumulator	2.6.3.4.8
. . . Coolant Pumps	2.6.3.4.1
. . . Coolant Regenerative Heat Exchanger	2.6.3.4.3
. . . Primary Coolant Filter	2.6.3.4.5
. . . Sublimators	2.6.3.4.2
. . . Suit Temperature Control Valve	2.6.3.4.7
. . . Oxygen Supply and Cabin Pressure Control Section	2.6.3.4.6
. . . Ascent Stage Oxygen Tanks	2.6.3.2
. . . Cabin Pressure Switch	2.6.3.2.3
. . . Cabin Relief and Dump Valves	2.6.3.2.7
. . . Descent Oxygen Tank	2.6.3.2.6
. . . High-Pressure Oxygen Control Assembly	2.6.3.2.1
. . . Oxygen Control Module	2.6.3.2.2
. . . Oxygen Filters	2.6.3.2.5
. . . Water Management Section	2.6.3.2.4
. . . Ascent Stage Water Tanks	2.6.3.3
. . . Descent Stage Water Tanks	2.6.3.3.2
. . . Water Control Module	2.6.3.3.1
. . . Water Quantity Measuring Device	2.6.3.3.4
. . . Operational Limitations and Restrictions	2.6.3.3.3
. . . Performance and Design Data	2.6.6
. . . Telemetry Measurements	2.6.5
	2.6.7

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

ALPHABETICAL INDEX (cont)

	Paragraph
Explosive Devices Subsystem	2.8
Failure Modes	2.8.4
Functional Description	2.8.2
Introduction	2.8.1
Major Component/Functional Description	2.8.3
Ascent Propellant Tank Pressurization	2.8.3.10
Ascent Helium Tank Select Switch	2.8.3.10.1
Circuitry (EDS)	2.8.3.2
Descent Propellant Tank Prepressurization	2.8.3.8
ED Batteries	2.8.3.5
Explosive Devices	2.8.3.1
Explosive Devices Relay Boxes	2.8.3.6
Initiators	2.8.3.4
Landing Gear Uplock and Cutter Assembly	2.8.3.7
Master Arm Switch	2.8.3.3
Component Caution Lights	2.8.3.3.1
RCS Propellant Tank Pressurization	2.8.3.11
Stage-Separation Components	2.8.3.9
Circuit Interrupters (Deadface Connectors)	2.8.3.9.3
Interstage Structural Connections	2.8.3.9.1
Interstage Umbilical Cutters (Guillotine)	2.8.3.9.2
Stage-Sequencing Circuits	2.8.3.9.4
Operational Limitations and Restrictions	2.8.6
Performance and Design Data	2.8.5
Telemetry Measurements	2.8.7
Guidance, Navigation, and Control Subsystem	2.2
Failure Modes	2.2.4
Functional Description	2.2.2
Abort Guidance Path	2.2.2.2
LM and Primary Guidance and Navigation Section Axes	2.2.2.3
Alignment Optical Telescope Axes	2.2.2.3.4
IMU Axes	2.2.2.3.3
LM Vehicle Axes	2.2.2.3.1
Navigation Base Axes	2.2.2.3.2
Radar Antenna Axes	2.2.2.3.5
Primary Guidance Path	2.2.2.1
Introduction	2.2.1
Major Component/Functional Description	2.2.3
Abort Guidance Section	2.2.3.2
Abort Electronics Assembly	2.2.3.2.2
Abort Guidance Section - Guidance Routines	2.2.3.2.6
Abort Guidance Section - Modes of Operation	2.2.3.2.5
Abort Sensor Assembly	2.2.3.2.1
Data Entry and Display Assembly	2.2.3.2.3
General Operation of the Abort Guidance Section	2.2.3.2.4
Control Electronics Section	2.2.3.4
800-cps Synchronization Loop	2.2.3.4.7
Attitude and Translation Control Assembly	2.2.3.4.3
Attitude Controller Assemblies	2.2.3.4.1
Control Electronics Section - Modes of Operation	2.2.3.4.10
Descent Engine Control Assembly	2.2.3.4.5
Gimbal Angle Sequencing Transformation Assembly	2.2.3.4.9
Gimbal Drive Actuators	2.2.3.4.6
Rate Gyro Assembly	2.2.3.4.4

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

ALPHABETICAL INDEX (cont)

	Paragraph
Guidance, Navigation, and Control Subsystem (cont)	
S&C Control Assemblies	2.2.3.4.8
Thrust/Translation Controller Assemblies	2.2.3.4.2
LM Mission Programmer	2.2.3.5
Ascent Engine Arming Assembly	2.2.3.5.2
Digital Command Assembly	2.2.3.5.1
Orbital Rate Display - Earth and Lunar	2.2.3.6
Primary Guidance and Navigation Section	2.2.3.1
Computer Subsection	2.2.3.1.3
General Operation of the Primary Guidance and Navigation Section	2.2.3.1.6
Inertial Subsection	2.2.3.1.1
Optical Subsection	2.2.3.1.2
Primary Guidance and Navigation Section Operational Modes	2.2.3.1.4
Primary Guidance and Navigation Section Routines	2.2.3.1.5
Radar Section	2.2.3.3
Landing Radar	2.2.3.3.2
Rendezvous Radar	2.2.3.3.1
Operational Limitations and Restriction	2.2.6
Performance and Design Data	2.2.5
Telemetry Measurements	2.2.7
Instrumentation Subsystem	2.9
Failure Modes	2.9.4
Functional Description	2.9.2
Developmental Flight Instrumentation	2.9.2.2
Instrumentation Subsystem	2.9.2.1
Introduction	2.9.1
Major Component/Functional Description	2.9.3
Caution and Warning Electronics	2.9.3.4
AGS Warning Light	2.9.3.4.9
ASC HI REG Caution Light	2.9.3.4.14
ASC PRESS Warning Light	2.9.3.4.3
ASC QTY Caution Light	2.9.3.4.15
BATTERY Caution Light	2.9.3.4.19
C/W PWR Caution Light	2.9.3.4.25
CABIN Warning Light	2.9.3.4.1
CES AC Warning Light	2.9.3.4.11
CES DC Warning Light	2.9.3.4.10
DC BUS Warning Light	2.9.3.4.8
DES QTY Warning Light	2.9.3.4.4
DES REG Warning Light	2.9.3.4.5
ECS Caution Light	2.9.3.4.26
ED RELAYS Caution Light	2.9.3.4.30
Heater Caution Light	2.9.3.4.24
GDA/RCCA Caution Light	2.9.3.4.16
GLYCOL Caution Light	2.9.3.4.28
Inverter Caution Light	2.9.3.4.18
ISS Warning Light	2.9.3.4.13
LDG RDR Caution Light	2.9.3.4.21
LGC Warning Light	2.9.3.4.12
O ₂ QTY Caution Light	2.9.3.4.27
PGNS Caution Light	2.9.3.4.17
PRE AMPS Caution Light	2.9.3.4.22
RCS A REG and RCS B REG Warning Lights	2.9.3.4.6

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

ALPHABETICAL INDEX (cont)

	Paragraph
Instrumentation Subsystem (cont)	
RCS Caution Light	2.9.3.4.23
RCS TCA Warning Lights	2.9.3.4.7
RNDZ RDR Caution Light	2.9.3.4.20
S-BD RCVR Caution Light	2.9.3.4.31
SUIT/FAN Warning Light	2.9.3.4.2
WATER QTY Caution Light	2.9.3.4.29
Data Storage Electronics Assembly	2.9.3.5
Power Supply	2.9.3.5.1
Developmental Flight Instrumentations	2.9.3.6
Constant-Bandwidth Modulation Package D	2.9.3.6.6
DFI Communications Equipment	2.9.3.6.8
Ninety-Segment Time-Division Multiplexers	2.9.3.6.4
Power Control and Distribution Equipment	2.9.3.6.2
Proportional-Bandwidth Modulation Packages A, B, and C	2.9.3.6.7
Sensors	2.9.3.6.1
Strain/Temperature Signal Conditioners	2.9.3.6.3
Vibration Commutators	2.9.3.6.5
Pulse-Code-Modulation and Timing Electronics Assembly	2.9.3.3
Analog Multiplexer Gate Drivers	2.9.3.3.1
Analog-to-Digital Converter	2.9.3.3.3
Calibration	2.9.3.3.4
Digital Multiplexer	2.9.3.3.6
High-Level Analog Multiplexer and High-Speed Gates	2.9.3.3.2
Oscillator Failure-Detection Circuits (No. 1, No. 2 and No. 3)	2.9.3.3.10
Output Register and Data Transfer Buffers	2.9.3.3.7
Phase-Locked Oscillator and Doublers	2.9.3.3.9
Power Supply	2.9.3.3.8
Programmer	2.9.3.3.5
Time Accumulator and Serial Time Code Generator	2.9.3.3.12
Timing Generator	2.9.3.3.11
Sensing Equipment	2.9.3.1
Signal-Conditioning Electronics Assembly	2.9.3.2
AC- to- DC Converters	2.9.3.2.3
Analog Signal Isolating Buffer	2.9.3.2.4
Attenuators	2.9.3.2.2
D-C Amplifiers	2.9.3.2.1
Discrete Signal Isolating Buffers	2.9.3.2.5
Frequency-to-DC Converters	2.9.3.2.6
Phase-Sensitive Demodulators	2.9.3.2.8
Resistance-to-DC Converters	2.9.3.2.7
Operational Limitations and Restrictions	2.9.6
Performance and Design Data	2.9.5
Telemetry Measurements	2.9.7
Main Propulsion Subsystem (APS)	2.3
Failure Modes	2.3.10
Functional Description	2.3.8
Engine Assembly	2.3.8.3
Pressurization Section	2.3.8.1
Propellant Feed Section	2.3.8.2
Introduction	2.3.1
Major Component/Functional Description	2.3.9
Combustion Chamber Assembly	2.3.9.7
Explosive Valves	2.3.9.1

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

ALPHABETICAL INDEX (cont)

	Paragraph
Main Propulsion Subsystem (APS) (cont)	
Helium Pressure Regulator Assemblies	2.3.9.2
Injector Assembly	2.3.9.6
Propellant Storage Tanks	2.3.9.4
Relief Valve Assemblies	2.3.9.3
Valve Package Assembly	2.3.9.5
Operational Limitations and Restrictions	2.3.12
Performance and Design Data	2.3.11
Telemetry Measurements	2.3.13
Main Propulsion Subsystem (DPS)	2.3
Failure Modes	2.3.4
Functional Description	2.3.2
Engine Assembly	2.3.2.3
Pressurization Section	2.3.2.1
Propellant Feed Section	2.3.2.2
Propellant Quantity Gaging System	2.3.2.2.1
Introduction	2.3.1
Major Component/Functional Description	2.3.3
Combustion Chamber and Nozzle Extension	2.3.3.12
Cryogenic Helium Storage Vessel	2.3.3.2
Explosive Valves	2.3.3.1
Flow Control Valve	2.3.3.9
Fuel/Helium Heat Exchanger	2.3.3.3
Gimbal Ring and Gimbal Drive Actuator	2.3.3.13
Helium Pressure Regulators	2.3.3.5
Propellant Shutoff Valve Assemblies	2.3.3.10
Propellant Storage Tanks	2.3.3.7
Relief Valve Assemblies	2.3.3.6
Throttle Valve Actuator	2.3.3.8
Variable-Area Injector	2.3.3.11
Operational Limitations and Restrictions	2.3.6
Performance and Design Data	2.3.5
Telemetry Measurements	2.3.7
Miscellaneous	2.10
Failure Modes	2.10.4
Functional Description	2.10.2
Heating	2.10.2.1
Lighting	2.10.2.2
Introduction	2.10.1
Major Component/Functional Description	2.10.3
Heating	2.10.3.1
Alignment Optical Telescope Mirror Heaters	2.10.3.1.6
Forward and Docking Window Heaters	2.10.3.1.5
Landing Radar Antenna Heaters	2.10.3.1.1
Rendezvous Radar Antenna Heaters	2.10.3.1.2
RCS TCA Quad Heaters	2.10.3.1.3
S-Band Antenna Heaters	2.10.3.1.4
Lighting	2.10.3.2
Exterior Lighting	2.10.3.2.1
Interior Lighting	2.10.3.2.2
Operational Limitations and Restrictions	2.10.6
Heater Section	2.10.6.1
Lighting Section	2.10.6.2
Performance and Design Data	2.10.5
Telemetry Measurements	2.10.7

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

ALPHABETICAL INDEX (cont)

	Paragraph
Reaction Control Subsystem	2.4
Failure Modes	2.4.4
Functional Description	2.4.2
Helium Pressurization Section	2.4.2.1
Propellant Quantity Measuring Device	2.4.2.3
Propellant Section	2.4.2.2
Thrust Chamber Assembly	2.4.2.4
Heaters	2.4.2.4.2
Thrust Chamber Assembly Failure Detection System	2.4.2.4.1
Introduction	2.4.1
Major Component/Functional Description	2.4.3
Explosive Valves	2.4.3.1
Fuel and Oxidizer Tanks (RCS)	2.4.3.4
Pressure Regulator Assembly	2.4.3.2
Pressure Relief Valve Assemblies	2.4.3.3
Thrust Chamber Assembly	2.4.3.5
Combustion Chamber and Nozzle	2.4.3.5.3
Fuel and Oxidizer Valve Assemblies	2.4.3.5.1
Injector Head Assembly	2.4.3.5.2
Operational Limitations and Restrictions	2.4.6
Performance and Design Data	2.4.5
Telemetry Measurements	2.4.7
Spacecraft Ascent Stage	1.2
General Description	1.2.1
Structure	1.2.2
Aft Equipment Bay	1.2.2.3
Antenna Supports	1.2.2.5
Crew Compartment	1.2.2.1
Control and Display Panels	1.2.2.1.1
Docking Tunnel	1.2.2.2.1
Forward Hatch	1.2.2.1.2
Upper Hatch	1.2.2.2.2
Windows	1.2.2.1.3
Midsection	1.2.2.2
TCA Cluster Supports	1.2.2.4
Thermal and Micrometeoroid Shield	1.2.2.6
Spacecraft Descent Stage	1.3
General Description	1.3.1
Structure	1.3.2
Landing Gear	1.3.2.2
Drive-out and Downlock Mechanisms	1.3.2.2.5
Footpad	1.3.2.2.2
Ladder	1.3.2.2.7
Lunar-Surface Sensing Probe	1.3.2.2.6
Primary Strut	1.3.2.2.1
Secondary Struts	1.3.2.2.3
Uplock Assembly	1.3.2.2.4
Platform	1.3.2.3
Thermal and Micrometeoroid Shield	1.3.2.1
Spacecraft LM 3 Configuration	1.1
Spacecraft LM-CSM Interfaces	1.5
Crew Transfer Tunnel	1.5.1
Docking Aids	1.5.1.6
Docking Drogue	1.5.1.4

LMA790-3-LM 3
APOLLO OPERATIONS HANDBOOK
SUBSYSTEMS DATA

ALPHABETICAL INDEX (cont)

	Paragraph
Spacecraft LM-CSM Interfaces (cont)	
. . Docking Hatches	1.5.1.3
. . Docking Probe	1.5.1.5
. . Final Docking Latches	1.5.1.1
. . Umbilicals	1.5.1.2
Spacecraft LM-SLA-S-IVB Connections	1.4
Spacecraft Stowage Provisions	1.6
Subsystem Interface 2.1	
. Communications Subsystem	2.1.4.5, 2.1.6
. Electrical Power Subsystem	2.1.1.3, 2.1.2.3, 2.1.3.3, 2.1.5.1, 2.1.6.1
. Environmental Control Subsystem	2.1.4.4, 2.1.5
. Explosive Devices Subsystem	2.1.1.4, 2.1.2.5, 2.1.3.4, 2.1.4.6, 2.1.7
. Guidance, Navigation, and Control Subsystem	2.1.1, 2.1.2.1, 2.1.3.1, 2.1.4.1
. Instrumentation Subsystem	2.1.1.5, 2.1.2.5, 2.1.3.5, 2.1.4.7, 2.1.5.2, 2.1.6.2, 2.1.8
. LM Mission Programmer	2.1.9
. Main Propulsion Subsystem	2.1.1.1, 2.1.2, 2.1.3.2, 2.1.4.2
. Reaction Control Subsystem	2.1.1.2, 2.1.2.2, 2.1.3, 2.1.4.3

