

APOLLO

GUIDANCE AND NAVIGATION

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E-1142
(Rev. 50)

SYSTEM STATUS REPORT

April 1967



INSTRUMENTATION LABORATORY

CAMBRIDGE 39, MASSACHUSETTS

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ACKNOWLEDGEMENT

This report was prepared under DSR Project 55-23850, sponsored by the Manned Spacecraft Center of the National Aeronautics and Space Administration through Contract NAS 9-4065.

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E-1142
(Rev. 50)

SYSTEM STATUS REPORT

ABSTRACT

The System Status Report is normally distributed monthly. The areas of activity reported on in this month's revision include, but are not limited to, the following for the Block 1 100 Series and Block II Command Modules and Lunar Excursion Module equipment: configuration weight, weight trend information, reliability failure rates, electrical power requirements, computer programming status, and G&N Status.

by Apollo Staff
April, 1967

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ACCURACY

The accuracy of numerical values reported in this revision should not be considered to be within the tolerances implied by the significant figures quoted. The reported values, although based upon the most current information, are subject to slight variations from system to system.

INTRODUCTION

The areas of activity reported on in this month's revision include, in general, the following for the Block I 100 Series and Block II Command Modules and Lunar Module equipment:

- Section 1 - Configuration Weight
- Section 2 - Glossary and System Definition
- Section 3 - Reliability - Failure Rates
- Section 4 - Electrical Power Requirements
- Section 5 - Guidance and Navigation Systems Status
- Section 6 - G&N System Test
- Section 7 - G&N Computer Status
- Section 8 - Guidance Computer Programming

Additional material, not suited to this format, will be presented from time to time as an appendix when it is particularly significant.

SECTION 1

WEIGHTS

Weights are reported to the nearest tenth of a pound on a component level. Each component weight is identified as estimated, calculated, or measured in order of increasing accuracy. These terms are defined as follows: estimated weights (E) are based on rough calculations; calculated weights (C) are based on detailed calculations made from final production drawings that will be used to build flyable equipment; measured weights (M) are actual weights of equipment built to the production drawings.

Tables 1, 2, and 3, respectively, present the weight of all CM Block I 100 Series, CM Block II, and LM Guidance and Navigation equipment based upon the most current information. These tables offer a comparison of present component weight values with those listed in last month's revision of the System Status Report. The weights tabulated for Block II CM and LM configuration represent operational flight hardware.

Also included are the respective control and design load weights as assigned by NASA. The Control Weight is the maximum allowable total weight of the Apollo Guidance and Navigation equipment for which MIT/IL is responsible. Design Load Weights are restricted to individual components and should be considered as "not to exceed" weights. These values represent a maximum within which design variations may cause changes without need for renegotiation.

The row labeled "Bare Guidance System" is inserted to provide for comparisons with similarly specified systems.

When applicable, the tables will be followed by a discussion of reported weight changes and weight trend information. Each weight increase or decrease is accompanied with an explanation for the change and the effectivity by system number. Weight trend information describes future component changes presently being studied with an emphasis on weight reduction proposals.

North American Aviation and Grumman Aircraft Engineering Corporation will provide and be responsible for weights of cold plates that are not integral with guidance and control equipment.

Reported Weight Changes and
Weight Trend Information

Block I

An increase of 1.0 lbs for the optical subsystem is due to the reported measured weight of the APTPS.

Block II

1. An increase of 0.3 lbs for the CDU is due to the addition of a vibration damper plate.
2. An increase of 1.1 lbs for the optical subsystem is due to the measured weights of the APTPS and optics dust covers.
3. An increase of 0.5 lbs for the AGC is due to the weight of the installation kit. This mounting hardware had not been previously reported. The reported AGC weight remains estimated because flight configured rope weights are not yet available.
4. An increase of 2.9 lbs for the eyepiece storage assembly is due to the measured weights of the ESU and the eyepieces. This weight includes the SXT long relief Eyepiece which had been reported separately.
5. A decrease of 0.4 lbs for the SXT long relief eyepiece. This is being reported as part of the eyepiece stowage unit.

The weights of the eyepiece stowage unit and the G&N indicator control panel are expected to change because of a probable redesign using less flammable materials.

TABLE 1. CURRENT WEIGHT STATUS OF BLOCK I 100 SERIES
COMMAND MODULE G&N (LBS AT 1G)

Command Module G&N Equipment	Status 1/67	Change	Status 4/67	Design Load Weight *
LOWER EQUIPMENT BAY				18.0 #
CDU Assy	16.9 (M)	0.0	16.9 (M)	} 155.0 **
Optical Subsystem				
SXT and gearing	53.6 (E)	+1.0	54.6 (M)	
SCT and gearing				
Optical Base and gearing				
NVB and Resilient Mounts	25.7 (M)	0.0	25.7 (M)	
Bellows Assy	10.7 (M)	0.0	10.7 (M)	
IMU	61.2 (M)	0.0	61.2 (M)	
Coolant Hoses (Three)	1.4 (M)	0.0	1.4 (M)	
Power Servo Assy	65.4 (M)	0.0	65.4 (M)	
G&N Interconnection Assy	26.1 (M)	0.0	26.1 (M)	} 120.0
Optical Shroud	3.1 (M)	0.0	3.1 (M)	
G&N to S/C Interface Assy	90.8 (M)	0.0	90.8 (M)	4.5
AGC (with 6 rope modules)				100.0
Optical Eyepiece Storage Assy	12.7 (M)	0.0	12.7 (M)	} 15.0
Condition Annunciators				
SXT Normal Relief Eyepiece				
SCT Normal Relief Eyepiece				
SCT Long Relief Eyepiece				} 5.0
D&C Electronics Assy	2.6 (M)	0.0	2.6 (M)	
Control Electronics Assy	1.8 (M)	0.0	1.8 (M)	4.0

TABLE 1. CURRENT WEIGHT STATUS OF BLOCK I 100 SERIES
COMMAND MODULE G&N (LBS AT 1G) (CONT)

Command Module G&N Equipment	Status 1/67	Change	Status 4/67	Design Load Weight
G&N Indicator Control Panel	10.9 (M)	0.0	10.9 (M)	15.0
IMU Control Panel	2.9 (M)	0.0	2.9 (M)	5.0
Signal Conditioner Assy	4.8 (M)	0.0	4.8 (M)	8.0
DSKY	24.5 (M)	0.0	24.5 (M)	26.0
MAIN PANEL AREA				
DSKY	25.3 (M)	0.0	25.3 (M)	26.0
LOOSE STORED ITEMS				
Optics Cover	2.1 (M)	0.0	2.1 (M)	2.5
Horizontal Hand Holds (Two)	0.3 (M)	0.0	0.3 (M)	1.0
TOTAL	442.8	1.0	443.8	---
The reported total weight for this month is 13.8 pounds more than the 430.0 pound total control weight †				
Bare Guidance Systems - IMU, AGC, IMU portions of the CDU's and IMU Support electronics			206.4	---

* Design Load Weights are taken from ICD MH01-01256-416 signed 3 June 1965, submitted by MIT in letter AG 478-65.

** This design load weight includes only 1/2 the weight of the Bellows Assembly.

† The Total Control Weight is specified in NASA letter EG-151-44-65-55 dated 10 February 1965. This weight assignment does not include recognition of the Optical Eyepiece Storage Assembly.

This design load weight taken from IRN 3677, submitted by MIT in Letter AG 407-66 dated 9 May 1966.

TABLE 2. CURRENT WEIGHT STATUS OF BLOCK II
COMMAND MODULE GN&C (LBS AT IG)

Command Module GN&C Equipment	Status 1/67	Change	Status 4/67	Design Load * Weight
LOWER EQUIPMENT BAY				
CDU Assy	36.2 (E)	+0.3	36.5 (M)	50.0
Optical Subsystem				} 150.0
SXT and gearing	54.6 (E)	+1.1	55.7 (M)	
SCT and gearing	17.4 (M)	0.0	17.4 (M)	
Optical Base and gearing A PTPS and Dust Covers NVB and Mounts	10.7 (M)	0.0	10.7 (M)	
Bellows Assy	42.5 (M)	0.0	42.5 (M)	
IMU	1.2 (M)	0.0	1.2 (M)	
Coolant Hoses (Two)	49.4 (M)	0.0	49.4 (M)	58.0
Power Servo Assy	9.0 (E)	0.0	9.0 (M)	12.0
PIPA Electronics Assy	24.0 (M)	0.0	24.0 (M)	40.0
G&N Interconnect Harness Group	69.0 (E)	+0.5	69.5 (E)	80.0
AGC (with six(6) rope modules + mag. trays)	3.1 (M)	0.0	3.1 (M)	4.5
Optical Shroud				
Optical Eyepiece Storage Assy				} 15.0
SXT Normal Relief Eyepiece	11.1 (E)	+2.9	14.0 (M)	
SCT Normal Relief Eyepiece				
SCT Long Relief Eyepiece				
G&N Indicator Control Panel	11.5 (M)	0.0	11.5 (M)	17.0
DSKY	17.5 (M)	0.0	17.5 (M)	25.0
Signal Conditioner Assy (Operational Flights)	8.0 (E)	0.0	8.0 (E)**	8.0

TABLE 2. CURRENT WEIGHT STATUS OF BLOCK II
COMMAND MODULE GN&C (LBS AT 1G) (CONT)

Command Module GN&C Equipment	Status 1/67	Change	Status 4/67	Design Load Weight *
MAIN PANEL AREA				
DSKY	17.5 (M)	0.0	17.5 (M)	25.0
LOOSE STORED ITEMS				
Horizontal Hand Holds (Two)	0.3 (M)	0.0	0.3 (M)	1.0
SXT Long Relief Eyepiece	0.4 (E)	-0.4	0 (M)	---
TOTAL	383.4	+4.4	387.8	---
The reported total weight for this month is 12.2 pounds less than the 400.0 pound total control weight †				
Bare Guidance Systems - IMU, AGC, IMU portions of the CDUs and IMU support electronics			172.2	---

* Design Load Weights are taken from ICD MH01-01356-416 signed 16 July 1965 at Meeting #22A.

** The weight of a qualification flight signal conditioner assy is 9.6 (E) pounds.

† The Total Control Weight is specified in NASA letter EG-151-44-65-55 dated 10 February 1965. This weight assignment does not include recognition of the Optical Eyepiece Storage Assembly.

Reported Weight Changes and
Weight Trend Information

LM

1. The estimated AOT weight was changed to measured.
2. An increase of 0.5 lbs for the LGC is due to the weight of the installation kit. This mounting hardware had not previously been reported.
3. An increase of 0.3 lbs for the CDU is due to the addition of a vibration damper plate.

TABLE 3. CURRENT WEIGHT STATUS OF LM PGNCS (LBS AT 1G)

LM PGNCS Equipment	Status 1/67	Change	Status 4/67	Design Load Weight*
IMU	42.4 (M)	0.0	42.4 (M)	} 80.0
AOT (including eyepiece and bellows)	23.1 (E)	0.0	23.1 (M)	
NVB	5.1 (M)	0.0	5.1 (M)	
HARNES "B" Supported by the NVB	0.6 (E)	0.0	0.6 (E)	
HARNES "B" Supported by the PTA	0.8 (E)	0.0	0.8 (E)	
HARNES "B" Supported by the structure	3.1 (E)	0.0	3.1 (E)	
PTA	14.3 (M)	0.0	14.3 (M)	
HARNES "A"	14.6 (E)	0.0	14.6 (M)	
LGC (with six(6) rope modules + mag trays)	69.0 (M)	+0.5	69.5 (M)	
DSKY	17.5 (M)	0.0	17.5 (M)	
AOT Control Unit (CCRD)	1.6 (M)	0.0	1.6 (M)	} 2.0
CDU	37.2 (M)	+0.3	37.5 (M)	
PSA	17.5 (M)	0.0	17.5 (M)	} 37.0
SCA (Operational Flights)	7.2 (E)**	0.0	7.2 (E)	
TOTAL	254.0	+0.8	254.8	---
The reported total weight for this month exceeds the 245.0 pounds total control weight by 9.8 lbs.†				
Bare Guidance Systems - IMU, LGC, IMU portions of the CDUs and IMU support electronics			167.3	

* Design Load Weights are taken from ICD LIS-490-10001 as signed by Mr. R.A. Gardner (NASA/MS) on 29 March 1966.

** The weight of a qualification flight signal conditioner assy is 9.4 (E) pounds.

† The Total Control Weight is specified in Contract Technical Specification PS 6000000 - amended by NASA Letter EG 26-233-66-565 dated 18 August 1966.

SECTION 2

GLOSSARY AND SYSTEM DEFINITION

The description of what constitutes the MIT Guidance and Navigation equipment in Block I (100 series), Block II Command Modules and Lunar Modules has been defined in previous System Status reports. This Section will be updated when any significant changes are made in the systems.

SECTION 3

RELIABILITY ANALYSIS AND ASSESSMENT

The current status of reliability analysis is reported in summary form as a chart.

This chart contains tabulations of the failure rates associated with each major configuration of G&N systems. These have been derived from the parts count of each assembly using generic type part failure rates, modified only by the stress applied to each part and its singular application in the system. From these data, estimations of mission success probabilities may be calculated. Continual updating is accomplished and will be reported monthly in this report.

G&N MISSION RELIABILITY ANALYSIS
 FAURE RATES EXPRESS IN "FAILURES PER 10⁶ HOURS"

MISSION	IMU Assembly		IMU Electronics (PSA)		Optics Assembly		Optics Electronics (PSA)		IMU		CDU		Optics		CDU		AGC		DSKY		D&C		Mission Reliability
	ON	STBY	ON	STBY	ON	OFF	ON	OFF	ON	STBY	ON	OFF	ON	STBY	ON	OFF	ON	STBY	ON	OFF	ON	OFF	
AGE #12 FLIGHT 204 MANNED	Oper Hrs λ	49 185	266 10.2	49 224	266 6.3	13 94	302 -	13 84	302 -	49 111	266 -	13 68	302 -	50 257	265 66.3	50 3.2	265 -	50 66.3	50 3.2	265 -	49 26	266 -	.9580
AGE#122 FLIGHT 501 UNMANNED	Oper Hrs λ	8.63 195	- -	8.63 224	- -	- -	- -	- -	- -	8.63 111	- -	- -	- -	8.63 257	- -	8.63 12	- -	8.63 -	8.63 -	8.63 6	- -	- -	.9931
AGE 603 FLIGHT 206 UNMANNED LM	Oper Hrs λ	9.6 129	- -	9.6 110	- -	- -	- -	- -	- -	9.6 155	- -	- -	- -	9.6 235	- -	9.6 12	- -	9.6 -	9.6 -	- -	- -	- -	.9938
C/M DES. REF.	Oper Hrs λ	13.8 129	55.6 10.2	13.8 110	55.6 6.3	9.1 94	60.3 -	9.1 77	60.3 -	13.8 155	55.6 -	13.8 91	55.6 -	13.8 235	55.6 60.5	13.8 2.3	55.6 -	13.8 2.3	55.6 -	13.8 2.3	55.6 -	55.6 -	.9840
LM DES. REF.	Oper Hrs λ	3.25 129	66.3 1.6	3.25 110	66.3 -	3.25 38	- -	3.25 -	- -	3.25 155	- -	3.25 112	- -	3.25 235	- -	3.25 110	- -	3.25 -	3.25 -	3.25 1.2	- -	- -	.9969

SECTION 4

ELECTRICAL POWER AND ENERGY

Electrical power and energy reporting is based upon the inflight spacecraft sequence of events for the Design Reference Mission as developed by the Apollo Mission Planning Task Force (AMPTF). (Reference GAEC Report Volume III - LED-540-12, dated 30 October 1964.)

The accompanying tables present the magnitude and distribution of power dissipated on a subsystem level. It is assumed that power is drawn from the spacecrafts' primary +28VDC supply and a 400 cps - 115 VAC single phase inverter.

Intermittent power peaks can exist, particularly during operation of displays and controls at random times. The energy content in these peaks is considered negligible.

All values (except those mentioned above) are actual expected levels of power. No margin factor has been applied to protect against possible differences between actual loads which will be experienced and the calculated levels quoted. Thus, these values should not be taken as "not to exceed" extremes.

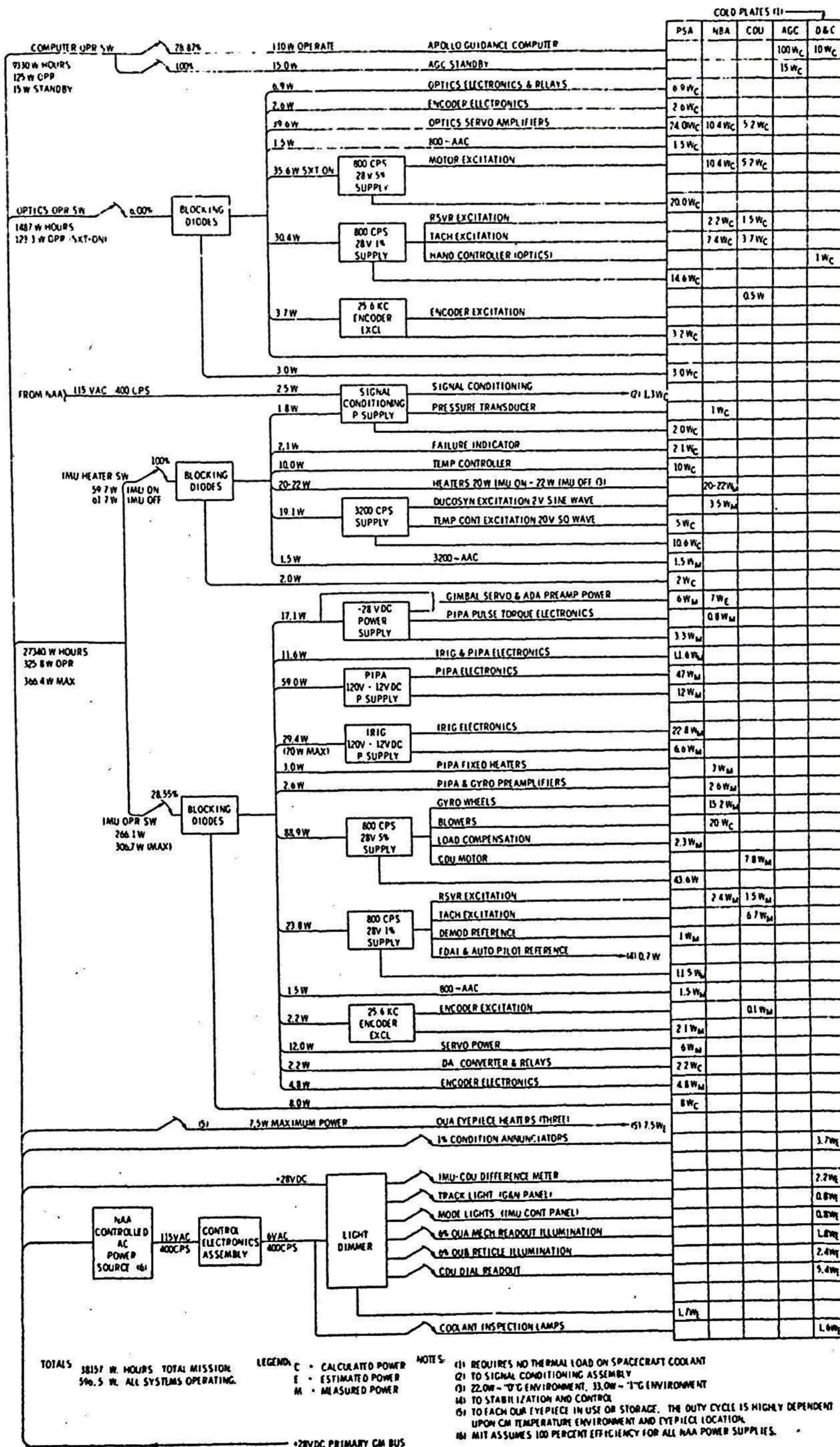
Interface Control Documents serve as the guidelines for reporting power figures.

CM Block I 100 Series	MH01-01227-216 "G & N Electrical Input Power" signed 11 June 1965
CM Block II	MH01-01327-216 "G & N Electrical Input Power" signed 15 July 1965
LEM	LIS-390-10002 "PGNCS Prime Power Requirements and Characteristics" signed 30 July 1965

BLOCK I - 100 SERIES GUIDANCE AND NAVIGATION LOAD ON PRIMARY +28 VDC COMMAND MODULE

BASED UPON 198.5 HOUR (8.27 DAY) LUNAR MISSION
DESIGN REFERENCE MISSION

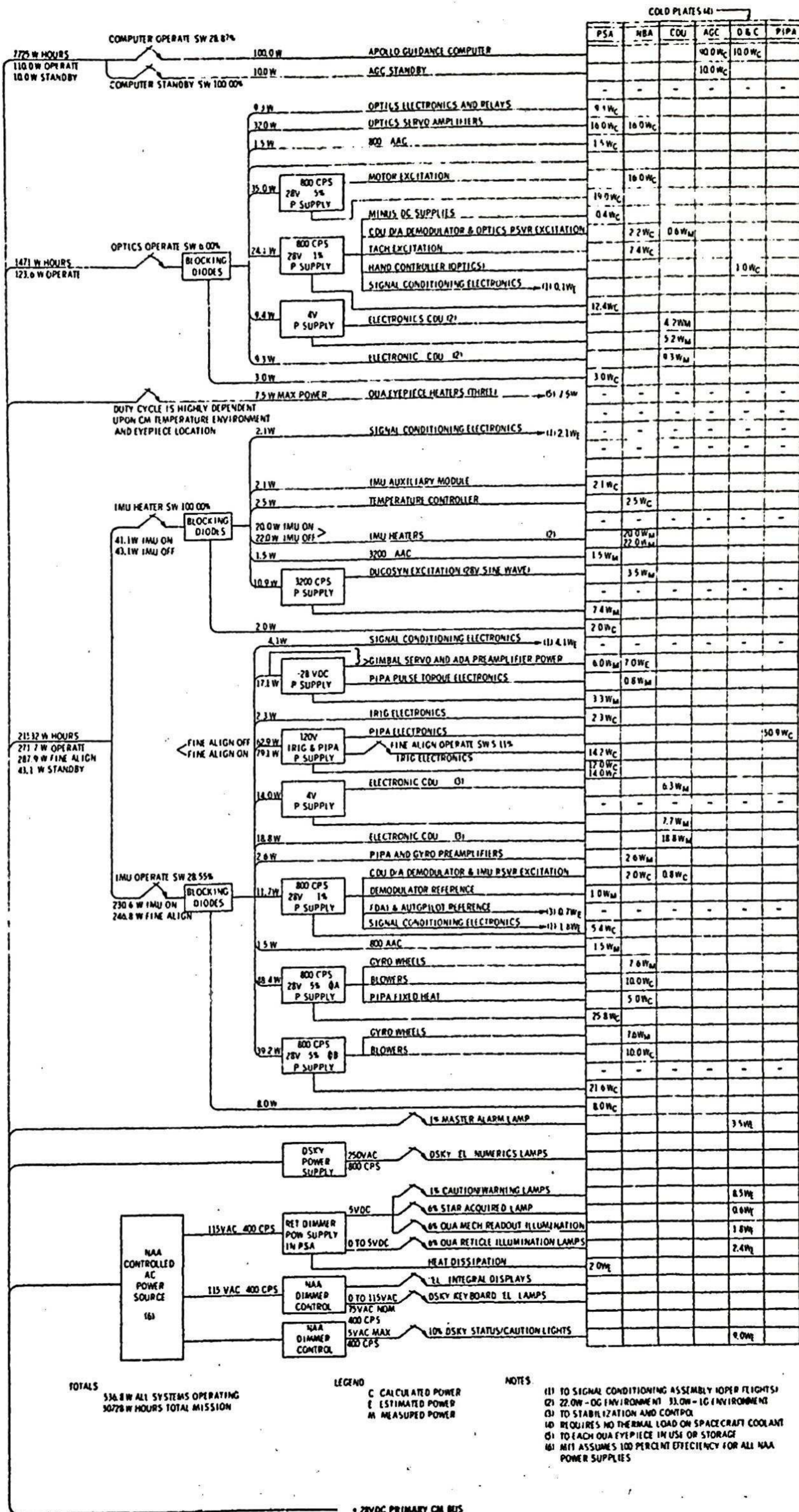
REFERENCE GAEC REPORT LED 540-12, 30 OCTOBER 1964
APOLLO MISSION PLANNING TASK FORCE



BLOCK II GUIDANCE AND NAVIGATION LOAD ON PRIMARY +28 VDC COMMAND MODULE

BASED UPON 198.5 HOUR 18 27 DAY LUNAR ORBIT MISSION
DESIGN REFERENCE MISSION

REFERENCE CALC REPORT LED 540 17 30 OCTOBER 1964
APOLLO MISSION PLANNING TASK FORCE



TOTALS
536.8 W ALL SYSTEMS OPERATING
30278 W HOURS TOTAL MISSION

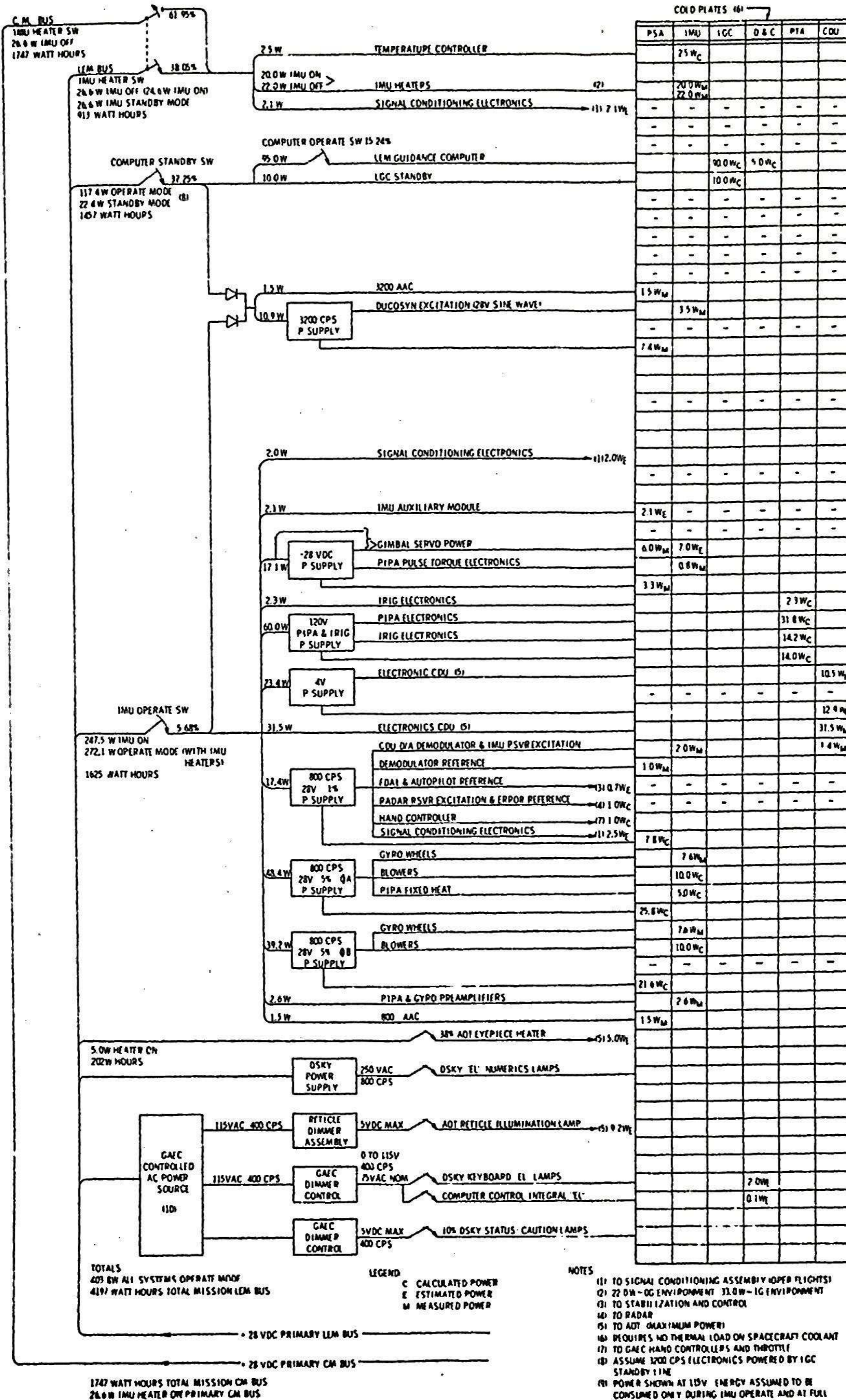
LEGEND
C CALCULATED POWER
E ESTIMATED POWER
M MEASURED POWER

NOTES
(1) TO SIGNAL CONDITIONING ASSEMBLY (OPER FEIGHTS)
(2) 22.0W - 0G ENVIRONMENT 33.0W - 1G ENVIRONMENT
(3) TO STABILIZATION AND CONTROL
(4) REQUIRES NO THERMAL LOAD ON SPACECRAFT COOLANT
(5) TO EACH OVA EYEPIECE IN USE OR STORAGE
(6) MIT ASSUMES 100 PERCENT EFFICIENCY FOR ALL NAA POWER SUPPLIES

• 28VDC PRIMARY CM BUS

LUNAR EXCURSION MODULE GUIDANCE AND NAVIGATION LOAD ON +28 VDC PRIMARY

BASED UPON 106.02 HOURS 14.42 DAY LUNAR LANDING MISSION REFERENCE GAEC REPORT - LEO 540-12, 30 OCTOBER 1964
DESIGN REFERENCE MISSION APOLLO MISSION PLANNING TASK FORCE



SECTION 5

GUIDANCE AND NAVIGATION SYSTEMS STATUS

The status of delivered G&N Systems are shown in tabular form. Table I shows the status of G&N Systems progressing from installation to final test at KSC.

Table II shows the configuration for major units comprising the G&N Systems assigned to LTA-8 and subsequent LM Vehicles at GAEC.

Table III shows the configuration for major units comprising the G&N Systems assigned to CSM-20 and subsequent Command Modules at NAA.

Table IV shows the configuration for major units comprising the G&N Systems at KSC.

TABLE 1

LOCATION										
OPERATIONS	GAEC				NAA					KSC
	LTA-8 602	LM-1 603	LM-2 605	LM-3 606	CSM-20 502	CSM98 2TV-1 202	CSM-101 204	CSM-102 205	CSM-103 206	CSM-17 122
INSTALLATION	X	X	X		X	X	X	X		X
SUBSYSTEM CHECKOUT S/C	X	X			X	X				X
INTEGRATED TEST S/C	X									X
COMPLETE TESTING AT KSC										

TABLE II

LM G&N SYSTEM CONFIGURATION

S/C	LTA-8		LM-1		LM-2	
COMPONENT NOMENCLATURE	System 602		System 603		System 605	
	Part No.	S/N	Part No.	S/N	Part No.	S/N
AGC	2003100-041	14	2003200-021	22	2003993-011	24
DSKY	2003985-051	13	2003950-011	28	2003950-011	19
IMU	2018699-021	2	2018601-051	13		
ECDU	2010744-021	9	2007222-131	12	2007222-081	10
AOT	6011000-012	8	6011000-021	9	6011000-041	11

NOTE: Listing will be revised if major units are changed. Explanatory notes will described reason for changes.

The following changes affect the previous listing:

1. LTA-1, G&N System 601
Shipped to Houston.
2. LTA-8, G&N System 602
 - A. Replaced AGC 2003100-021 S/N 8 with AGC 2003100-041, S/N 14. MSC requested change. S/N 8 did not include Thermal Vacuum Test fixes.
 - B. Replaced AOT 6011000-011, S/N 8 with 6011000-012, S/N 8. Configuration change of AOT seal and screws.
3. LM-1, G&N System 603
Replaced CDU 2007222-081, S/N 11 with CDU 2007222-131, S/N 12 to incorporate ECP's 499 and 515. Damper plate added between Trays X and S. Correct Gimbal Dump problem, changed trigger level of coarse detector.
4. LM-2, G&N System 605
 - A. Replaced AGC 2003200-031, S/N 20 with 2003993-011, S/N 24. Restart condition existed during OCP 37025 Self -test sequence. Problem traced to wire routing in Tray A. Computer returned to Raytheon.
 - B. Removed IMU 2018601-051, S/N 21. IMU power off for indeterminate period due to short in 800 ~5%.

TABLE III

CSM G&N SYSTEM CONFIGURATION AT NAA

S/C	CSM-20		CSM-98		CSM-101		CSM-102	
COMPONENT NOMEN- CLATURE	System 123		System 202		System 204		System 205	
	Part No.	S/N	Part No.	S/N	Part No.	S/N	Part No.	S/N
AGC	1003700-051	13	2003100-031	9	2003200-031	18	2003200-031	19
DSKY (Main)	1003563-051	9	2003985-041	26	2003994-011	37	2003999-011	35
DSKY (Nav.)	1003706-051	7	2003985-041	15	2003994-011	40	-	
IMU	1001500-111	4	2018699-011	5	2018601-081	17	2018601-081	14
CDU	1021304-011	6	2010744-031	13	2072222-161	17	2007222-091	16
OPTICS	2011000-023	9	2011000-035	13	2011000-034	15	2001100-034	16

NOTE: Listing will be revised if major units are changed. Explanatory notes will describe reason for change.

The following changes affect the previous listing.

1. CSM-101, G&N System 204

Replaced CDU 2072222-071, S/N 15 with CDU 2072222-161, S/N 17 to incorporate ECP's 499 and 515. Damper plate added between Trays X and S. Correct Gimbal Dump problem, changed trigger level of coarse detector.

2. CSM-102, G&N System 205

DSKY (Nav.) 2003999-011, S/N 32 removed and sent to MSC.

TABLE IV

G&N SYSTEM CONFIGURATION AT KSC

S/C	17	
COMPONENT NOMENCLATURE	System 122	
	Part. No.	S/N
AGC	1003700-051	14
DSKY (Main)	1003563-051	2
DSKY (Navigation)	1003706-051	10
IMU	1001500-091	11
CDU	1021304-011	4
OPTICS	2011000-024	7

NOTE: Listing will be revised if major units are changed. Explanatory notes will describe reason for change.

SECTION 6

G&N SYSTEM TEST

A. System Test Laboratory

1. G&N 5

System has been operating in the Space Navigator Facility approximately 34 hours during February and March.

2. G&N 104

a. Ran 501 Simflight and experimented with extended times to SIVBSMSEP.

b. Collected monthly G&N performance data.

c. Conducted special gyrocompass tests to obtain baseline data at high, low, and normal buss voltages in preparation for testing with regulated PIPA torque power supply.

d. Field Support

(1) S/C 20 at NAA

(a) Investigated marking routine for optics slew rate test and fine align test.

(b) Investigated random triggering of night watchman due to noise.

(c) Confirmed optics proportional problem via AGC command.

(2) S/C 14 at KSC

(a) Verified two (2) K-Start tapes.

3. G&N 200

a. Verification of fix to Sundial "C and D" gyrocompass program incorporation into Sundial "E" was completed.

b. Various changes to the IMU performance test (JDC 12217) were and are still under investigation. Present change being evaluated in the incorporation of small-angle offset to platform prior to start of vertical drift test.

c. Problems associated with single phase drive of sextant trunnion motor and error build-up due to drive rate at optics were resolved. CDU read counters can accommodate maximum optic drive without any loss of information. Sextant motor single-phase drive is caused by a build-up of back EMF into the anti-creep circuit which appears to the motor drive winding as a high-impedance tuned circuit when MDA is off.

d. More tests were run to evaluate the effects of a pulse disturbance on the CDU with the 0 VDC (CDU) tied to the chassis ground. The fix showed a marked improvement in the error counter resistance to a pulse applied between the 0 VDC line and the chassis.

e. A number of IMU Performance Tests were run and the stability of the IRIG drift terms was good.

4. G&N 600

a. Continued checkout of Sunburst (AS 206) through the official release of Rev. 113. Verified system test programs and mission programs per Simflight.

b. Continued Simflight development of improved targeting and optimizing the program for use at KSC.

c. Completed the LGC processing of all Landing Radar flight test tapes received to date. Preliminary data from the early profile appear satisfactory.

d. Checked rendezvous radar subroutines in Sunburst (radar enabled) and Sundance.

e. Verified four (4) K-Start tapes; 3 with Sunburst and 1 with Aurora.

B. Test Programming

1. Mission 278

a. IMU Performance test program verified on digital simulator.

b. Gyro compass program in process of verification; problem with digital simulator gyro torquing simulation and VERB 37 entry.

2. Mission 504

a. Command module program coding is complete.

b. LM performance tests and lunar erection programs are coded. Lunar system tests are completed.

C. Field Operations

1. KSC Site

CSM 17 (Mission AS 501) G&N 122: Completed OCP K-0005 except for Simulated Flight. Except testing to resume 6 May 1967.

2. GAEC Site

a. LTA-8 (Thermo Vacuum) G&N 602: FEAT completed; preparing to ship.

b. LM-1 (Mission AS 206) G&N 603: OCP 61017 completed.

c. LM-2 (Mission AS 208) G&N 605: Holding at OCP 37025.

d. LM-3 (Mission AS 503) G&N 606: System awaiting installation; AOT installed.

3. MSC Site

- a. Preparing for Block II System to be used for CSM simulations.
- b. Reviewing flight test objectives for A-2.
- c. K-START kluge is operating on the bench.

4. NAA Site

- a. CSM-20 (Mission AS 502) G&N 123: Awaiting start of OCP-131.
- b. CSM-98 (2 TV-1 Thermo Vacuum) G&N 202: Awaiting start of Integrated Test, OCP-131.
- c. CSM-101 (Mission AS 207) G&N 204: System awaiting start of retest of OCP-6504, which is scheduled for 15 April 1967.
- d. CSM-102 (Mission AS 503) G&N 205: The System is installed and awaiting the start of OCP 6504.
- e. CSM-103 (Mission AS 504) G&N 206: System awaiting start of Phase III Installation.
- f. CSM-104 (Mission AS 505) G&N 207: Awaiting start of Phase II Installation.

D. Checkout Planning

Subprogram Checkout and Analysis

1. Phase A:

The following subprograms were analyzed and program descriptions were issued:

Axis Rot. Program
1/ACCS Program
Alarm and Abort Program
SQRT Program
Selected Portions of T4RUPT Program
GP Matrix
General Stalling Routine
Subroutine SXTNB
Routine SCTANG, including SXTANG1
Subroutine CDULOGIC
Routine CALCSXA
Subroutine SMNB
Trans P1, Trans P2 Subroutines

The appropriate portions of these descriptions are being added to the listings. The testing of the programs has been delayed so that a maximum number of descriptions can be issued.

2. Phase B:

The major part of this effort has continued to be the study of the operation of the Optx programs with the system. The work done for Mission 204 is being updated to be compatible with Mission 258. A brief study of spacecraft altitude control for landmark tracking was conducted and a memo describing the results (STG Memo No. 945) was written.

The G&N-SCS Interface Test K-START Tape (F04C017-K00014-02) has been sold off. This revision includes changes to prevent recurrence of TC Traps associated with a previous revision.

The CNTDN G&N SCS Interface Test K-START Tape F04C017-K00057-00 has been verified in the STB Lab and sold off.

The G&N SCS End-to-End Ramp Test K-START Tape F04C017-K00072-00 has been prepared for verification in the STG Lab. The test requirements for this tape have not yet been firmly established with MIT/KSC and NAA/KSC.

Level III Support

In support of the Level III testing by Group 23B a program is being prepared to simulate the AOT on a CRT during tests of LM alignment programs.

As a result of this and other studies the need for a "Resolved" Mode in the LM DAP during in-flight alignment was identified. Suggested specifications for this are being provided to mission programmers.

System Analysis

Data sheets which define expected flight parameters for quick comparison with actual flight data to support the analysis of AS-501 mission phases are being prepared. This work is about 75% complete.

Based on a review of data from flight AS-202 a number of calculations and changes of format to the data processing programs have been identified.

Discussions have been held with members of the SGA Group who need data from AS-258 to analyze performance during the "stroking" test. After discussing what data is available during a flight it was determined what data and format would be needed to support this analysis. This requires analog information from the RCS system processed in a form to input to a MAC-MH1800 program.

A set of mathematical models were developed which serve to resolve DAP attitude maneuvers with respect to the AOT coordinate system. (See STG #972.)

Support is being provided to the Mission Operations Group in preparing definitions, timing, etc. concerning selected Mnemonics on downlist as a source for GSOP. This would be done for AS-206 and AS-258.

E-Memory Programming

An erasable memory program to provide an IRIG Scale Factor Test for Mission 504 and subsequent testing with flight ropes was designed. A test tape will be prepared in April. Some effort was also expended to identify any other tests which MIT/IL should program from E-Memory.

Phase I Testing (Computer Software)

The following subroutines have been or are currently being analyzed and documented:

NBSM
AOTSM
MASSMON
LONGCALL
STALL
ALTOUT
ALTROUT

Testing these and previously documented programs on the Digital Simulation is currently underway.

A listing showing the status of documentation of computer software for Mission 278 was prepared.

Phase II Testing (Computer Software)

A test specification for the Mission 208 optics programs testing in the STG Lab was prepared. A similar plan for other Phase II tests will be prepared.

Sim-Flight Evaluation

A downlink data recording from the Mission 501 Compressed Sim-Flight run in the STG Lab has been obtained. These data are being analyzed to provide the ground controllers with information relevant to observations which can be made during a Sim-Flight, and a partial set of predicted results.

Support to Digital Simulation Group

Support is being provided to the Digital Simulation Group in the Preparation of edit programs to process digital simulation output. Currently being prepared are the Platform Alignment Edit Routine, AGC Edit Routine, Discrete Events Edit Routine (see STG #965). These routines are in a checkout phase to be followed by integration and verification, and should be ready by 31 March 1967.

Data Processing Support

The following summary of data requests relates to the reporting period. Eight data requests were submitted during this period and ten uncompleted requests were carried over from the last reporting period leaving a total of 18 in-house requests. Ten requests were processed to completion during the period.

SECTION 7

G&N COMPUTER STATUS

Design Analysis

No design analysis activity was scheduled during this period due to work load solving field problems and lack of test equipment (i. e., fixed core rope monitor).

Design Changes

The design changes reported as under investigation in the January Report (DOWNLINK information, PROCEED button, and "DINC" counter problem) were checked out functionally on the AGC-600M (Ref.: AG 63-67, dated 6 February 1967). The drawing changes required for the latter two have been processed through MIT DRB. The Downlink change is on hold per NASA direction.

Miscellaneous AGC Related Activity

Much of the activity for February consisted of investigating the following problems:

Shorting Test Connector

The problem with the shorting test connector first appeared with AGC C6. With the shorting plug installed, the AGC experienced constant restarts, whereas without the shorting plug AGC operation was normal. The cause of the problem was traced to inductive coupling between signals MDT08 (a test connector input) and +28 COM (the 28 volt internal power buss). Large amounts of noise were found on +28 COM between modules A30 and A31 (power supplies). Reworking the grounding configuration of the power supply modules reduced this noise by an order of magnitude on both +28 COM and MDT08. For noise immunity from power supply switching spikes and immunity from capacitively coupled noise, a 270 ohms resistor inserted between each test connector input and OVDC provided the best results.

A fix effective AGC C-12 requiring modification of the power supply module and re-routing the 28V COM wire in Tray A has been released.

Restarts During Gyro Compassing

Restarts occurring during gyro compassing, using Sundial ropes, were investigated in the System Test Lab with G&N 200. The restarts were traced to a program "bug" in the Sundial ropes. A new Sundial tape for module B-3 has been manufactured and forwarded to Raytheon. Direction from NASA to make the change to all Sundial assemblies is pending.

Standby Switching Problem (C Series AGCs)

During power transient of standby switching the 4V switched line is forced below ground which causes unusually high overloads on key logic signals, affecting external timing signals. In particular, the 1 mc spacecraft synchronizing signal is interrupted for the order of 1 ms. Also the scaler that maintains real time during standby may be interrupted and lose up to 0.5 sec. A fix has been instrumented (power module and Tray A) effective AGC C-12 to sequence turning off 4V and 14V.

Double entries from "Mark" button

Double entries from the optics "Mark" button were experienced during checkout of the S/C 020 G&N System. This problem was duplicated in the System Test Lab. In order for a double "Mark" to be generated, the "Mark" relay contact must return to the "Mark" reset and then back to "Mark", or a noise pulse injected into the "Mark" reset line while "Mark" is a binary one.

Investigation has shown that the relay contact when energized transmits a "Mark," then a "Mark" reset pulse is generated while the "Mark" signal is experiencing contact bounce resulting in multiple "Mark" entries. This will not be a problem when flight ropes are installed. The "Mark" routine utilizes the same program that the DSKY pushbuttons use. Therefore, the key code double entry fix is the same fix required for the "Mark" double entries.

Night Watchman Noise Problems

Experiments with the Block I system showed that the night watchman module is sensitive to input noise when the input is a logical one (i. e., the G&N fail light should be illuminated). A noise transient at the input will cause the circuit to trigger, thus extinguishing the lamp for the 1.5 sec. Experience with other systems at NAA (S/C 14, S/C 20) indicates that noise transients of sufficient amplitude to trigger the circuit are very infrequent. In order to gain further information about the amplitude of these transients at MIT/IL, an erasable program was loaded which would flash on and off four DSKY relays (KeyRel, CompAct, CheckFail, and ProgAlarm) every 10 msec. This increased the relative frequency of the noise to a point

where the G&N fail lamp would be extinguished about every 10 seconds, and it became feasible to wait for the transient with a differential oscilloscope at the input to the module.

Oscilloscope measurements showed about 50 mv at the input when the DSKY was quiescent. During the operation of the erasable program mentioned above, ringing noise of about 400 mv to 600 mv was observed and photographed. This noise was coincident with the extinguishing of the G&N fail lamp. The ringing frequency was about 1 megacycle. A 0.01μ f capacitor inserted between +13 VDC and the input point reduced the noise to a level which would not trigger the circuit. The capacitor did not impair normal operation of the circuit when the night watchman program was running.

Since no amount of transient noise can turn the G&N fail lamp on, and since under normal circumstances in flight with the night watchman program running the lamp should be extinguished by the 24μ sec pulse train, the noise sensitivity of the night watchman module should not endanger the mission. Noise which would turn the G&N fail lamp on with the night watchman program running must be noise "transients" of 13 volts, 24μ sec wide, and occurring every $3/4$ second; i. e., the noise must be exactly coincident with the night watchman programmed pulse train and of opposite sign. If this kind of "noise" is present, the mission should probably be aborted anyway.

Channel 77 Alarm Box

The idea of having electronics built into the test connector to enable the monitoring of certain alarms through the display of the DSKY is being studied. Logical designs have been initiated and a test connector is being fabricated.

Erasable Memory Failures

Information loss has been induced in certain of the erasable memories by the simultaneous application of a program designed to disturb all of the words in a memory while the memory is being vibrated. Early evaluation of the test results seems to indicate that the difficulty is not due to the magnetic fields which surround the shake table or to currents which might be induced by the shaker drive into the memory. Indications are that the particular supplier has lost control of his core manufacturing process and is now producing cores which lose their stored state after the application of several millions of disturb signals.

All procurements from the vendor in question have been placed on hold. Replacement memories may be procured from the alternate (prime vendor). The vendor responsible for furnishing the defective material is conducting a parallel investigation into the problem.

ICD Changes (LIS 370-10004)

Two changes were made to this ICD this month because GAEC hardware was incorrectly specified and a program change was easier than a hardware change.

Sign Convention Change

1. The altitude note output is essentially a magnitude plus sign bit transmission. The sign convention has been changed so that a "1" in the position indicates the altitude is increasing.

Trim Signal Change

1. The trim signals to the descent engine are now defined so that a plus pitch trim signal will rotate the engine negatively about the engine pitch axis.

SECTION 8

GUIDANCE COMPUTER PROGRAMMING

Appendix A to this report is a summary of the Mission Software Development organization. Appendices B through G to this report reflect an updated version of mission program development status.

Apollo Guidance Computer Programming Summary
for the Month of March

Mission AS-501

Continued analysis of the released program for Mission AS-501 has been preformed. From this analysis ground procedure have been revised and program limitation defined.

Mission AS-206

Final verification of the computer program for Mission AS-206 was completed during the month of February. The program tape was released for rope manufacturing on 1 March 1967 except for modules 1, 3 and 5. Program release for modules 1, 3, and 5 was on 31 March 1967.

Mission AS-258 (Formerly AS-278)

During the reporting period the computer program for Mission AS-258 underwent Level III testing. The "A" release of the tape for rope manufacturing is expected by 8 June 1967.

Mission AS-504

The Guidance Software Operation Plan for Mission AS-504 is under preparation with complete publication expected by mid-June 1967. Selected portion of Sections 4 and 5 of the GSOP were submitted to NASA/MSC for comment. Work is underway on the formulation and equation testing for the computer program. The "A" release of the program for rope manufacturing is expected by mid-November 1967.

MISSION	ITEM	1965				1966				1967											
		S	O	N	D	J	F	M	A	M	J	J	A	M	J	J	A	S	O	N	D
202	COMPUTER PROGRAM DEVELOPMENT				(3)																
	GUIDANCE SYSTEM OPERATIONS PLAN				(1)				UPDATING												
204	COMPUTER PROGRAM DEVELOPMENT								(2)												
	OPERATIONS HANDBOOK								(1)												
	GUIDANCE SYSTEM OPERATIONS PLAN								UPDATING												
501/502	COMPUTER PROGRAM DEVELOPMENT								(3)												
	GUIDANCE SYSTEM OPERATIONS PLAN								(1)				UPDATING								
206	COMPUTER PROGRAM DEVELOPMENT												(3)								
	GUIDANCE SYSTEM OPERATIONS PLAN								(1)				UPDATING								
258	COMPUTER PROGRAM DEVELOPMENT												(3)								
	OPERATIONS HANDBOOK								(1)												
	GUIDANCE SYSTEM OPERATIONS PLAN												(1)				UPDATING				
504A	COMPUTER PROGRAM DEVELOPMENT																(3)				
	OPERATIONS HANDBOOK																(1)				

(1) NASA APPROVAL (2) "B RELEASE" = PRELIMINARY VERSION OF THE SPACECRAFT COMPUTER PROGRAM
(3) "A RELEASE" = FLIGHT VERSION OF THE SPACECRAFT COMPUTER PROGRAM RELEASED FOR FLIGHT ROPE MANUFACTURE

Appendix A

Organization of Mission Software Development

I. Mission Software Design Control

The ultimate responsibility of specifying Apollo mission requirements to the MIT/IL rests with the MSC Software Control Panel. Within the MIT/IL organization, the Apollo mission designs are controlled through the actions of the Mission Design Review Board (MDRB). The functions of this board are (1) to provide a formal MIT/IL point of contact with the MSC Software Control Panel for submittal and approval of the Guidance System Operation Plans (GSOPs), prelaunch crasable load listings, and other mission-related control documentation that requires MSC approval and (2) to provide a mechanism for internal coordination and change control of mission related activities.

The GSOP is published when the chairman of the MDRB decides that the concepts are both approved by MSC and firm enough to permit a formal release. This publication constitutes a baseline to which no informal changes may be made. Formal documentation of changes by the MDRB is accomplished by the use of the "MIT/IL Mission Design Review Board Record of Change and Document Release Form."

A. Guidance System Operation Plan

The Guidance System Operation Plan is a Type 1 controlled document which includes

1. Guidance and Navigation equations,
2. MSC/Crew/Computer interface for S/C and Mission Control,
3. Computer logic and timeline for S/C and Mission Control,
4. RTCC/Computer interface (digital uplink and downlink), and
5. Spacecraft and trajectory data stored in the computer and used in simulations.

In addition it is an information document for

1. G&N system configuration,
2. Error analysis (effect of G&N errors),
3. Performance analysis (effect of L/D dispersions and S/C performance variations),
4. Telemetry and recording instrumentation, and
5. MSFN tracking requirement.

The organization of the Guidance System Operation Plan (GSOP) is:

Volume I CM GNCS Operations

- Section 1 Introduction (GSOP Scope and Authority, Operational Concept, etc.)
- Section 2 GNCS Data Links (Uplink, Downlink, Analog Telemetry)
- Section 3 GNCS Digital Autopilots (includes Saturn Steering)
- Section 4 GNCS Operational Modes (Major Program Logic, C&W System, etc.)
- Section 5 CMC Guidance Equations

Volume II LM PGNCS Operations

- Section 1 Introduction (GSOP Scope and Authority, Operational Concept, etc.)
- Section 2 PGNCS Data Links (Uplink, Downlink, Analog Telemetry)
- Section 3 PGNCS Digital Autopilots
- Section 4 PGNCS Operational Modes (Major Program Logic, C&W System, etc.)
- Section 5 LGC Guidance Equations

Volume III

- Section 6 Control Data (Mission, Vehicle, Memory and Carry-on Data, ICDs and IRNs, Systems Configuration, etc.)

Volume IV

- Section 7 Error Analysis

The Space Guidance Analysis Division is responsible for the preparation of the guidance equations section (Section 5) of the GSOP. The autopilot control analysis and design performed by the SGA Division is coordinated with other Apollo groups engaged in similar control tasks in support of the GSOP Section 3. In addition to these sections, Program Definition Memos, presenting more detailed computation logic diagrams and scaling, are prepared for internal use by the Guidance Programming Group.

The Systems Engineering Division and the Display and Human Factor Division are responsible for the preparation of the Apollo computer logic and crew procedures checklist Section 4 of the GSOP. The information contained in Sections 4 and 5 are necessary before the detailed programming of the Apollo computer can begin.

The G&N System Operations Plan is also the basis for other MIT/IL mission software control documentation. For example, the environment programs required in the all-digital simulation are controlled through the GSOP. Other examples are the prelaunch operational check out-procedures, erasable load tapes, core rope simulator load tapes, flight program listings, and hybrid simulation reports.

B. Programming Test Packages

The purpose of the Programming Test Package is to identify and define a set of tests to ensure that guidance computer programs correspond satisfactorily to the analytical procedures defined in the GSOP for each mission. There are five basic levels of testing required during the development of a mission program:

Level I: Using the guidance equation material of Section 5 in the GSOP, computational difficulties, such as loss of accuracy and overflows, are identified. Numerical examples are developed to check the adequacy of the coded AGC program to handle sufficient ranges of variables. These check solutions are generated using a general purpose algebraic compiler (MAC) and based on AGC program block diagrams.

Level II: Using the data obtained from the Level I package, actual tests on the coded programs are performed. The flight computer solutions are checked against the sample MAC solutions.

The first two test levels include the analytical processes associated with trajectory computations, displays, steering equations, navigation, and targeting programs as described in Section 5 of GSOP.

Level III: At the third level of testing, complete programs and routines, using sufficient environment to verify the performance of the system under flight simulated conditions, are checked out on the all-digital simulator.

Level IV: The testing of program sequences, which require use of several of the programs tested at the third level, constitute the fourth stage in the evolution of a fully verified mission program. As an example, a sequence might include attitude and alignment determination, re-alignment, targeting, burn, trim, and return to the idle mode.

Level V: The final and most comprehensive testing occurs when complete mission sequences are tested; e.g., a concentric flight plan rendezvous maneuver or translunar injection.

The testing at Levels IV and V is conducted on both the hybrid and the all-digital simulators.

FIXED MEMORY ALLOCATION COMPARISON FOR MISSIONS AS-257 AND AS-504

This chart incorporates the agreed-upon changes that were itemized in Lists I and II of the January 1967 System Status Report, except as noted.

	<u>CMC</u>	
I. Control Programs	AS-258 (actual)	AS-504A (estimated)
A. DSKY		
Pinball	2843	3000
Extended Verbs	471	1000
Keyrupt and Urupt	80	80
Display and Service	670	700
Down Telemetry List	78	400
Program Select Check	179	185
Down Telemetry Program	194	260
B. Interpreter and Executive		
Interpreter	2271	2271
Waitlist	220	220
Executive	312	335
Phase Tables	115	350
Restart Control	179	180
Fresh Start and Restart	298	310
Phase Change and New Phase	158	158
T4 Rupt	715	731
Alarm and Abort	72	72
Self Check	986	966
Interrupt Lead In	52	52
RTB OP Codes	211	250
End Bank Marks	108	36
Interbank Communication	88	88
C. Other		
Digital Auto-Pilot	3762	3800
Saturn and CM Tests	550	----
Transformations	600	600
Gyro Torquing (R-55)	40	44
Total - DSKY and Interpreter and Executive and Other	15252	16088

II. <u>CMC Routines</u>	AS-258 (actual)	AS-504A (estimated)
A. Basic Routines		
Conic Subroutines	879	1300
Orbital Integration	1118	1200
Latitude and Longitude Altitude	216	200
Lunar and Solar Ephemeris	127	100
Lunar Rotation	----	150
Initial Velocity	188	188
Rendezvous Parameters	----	100
Maneuver Specification	199	205
Maneuver Calculation	829	560
Attitude Drive	166	175
Mid Gimbal Display	33	68
B. Targetting		
TPI	275	290
Midcourse Maneuver (S35.1)	53	54
Return to Earth (Near Earth)	----	1000
LOPC	----	150
TPI Search	----	200
Landing Time Prediction	----	200
C. Navigation		
Cislunar Midcourse	----	300
Rendezvous	391	440
Lunar Orbit	555	555
Measurement Incorporation	408	450
Preferred Tracking Attitude	342	350
Sight Mark (R-53)	39	40
SXT Mark	326	330
D. Entry		
Entry Calculations	1310	1300
Preentry Computations (S61.2)	129	140
Gimbal Angles for Separation (S61.3)	34	35
IMU Entry Status (S61.1)	72	80
Trim Gimbal Angles (S62.3)	31	40
Apogee, Perigee and T_{FF}	312	320

	AS-258 (actual)	AS-504A (estimated)
E. Powered Guidance		
Cross Product Steering (S40.8)	124	125
Vg Calculation (S40.9)	77	100
Time of Burn Calculation (S40.13)	66	77
Servicer	401	500
Desired Thrust Direction (S40.1)	149	270
F. IMU and Optics		
IMU Compensation	258	258
IMU Status Check (R02)	17	20
Coarse Align Cal 53A	64	64
Fine Align (R51)	78	75
Auto-Optics Positioning (52 and SR52.1)	304	305
Pick-a-Pair	131	135
Star Data Test (R54)	53	53
IMU Mode Switching	531	561
Star Catalog	260	263
Landmark Catalog	----	150
G. Boost		
Boost Routine	83	100
Saturn Takeover	91	100
Total CMC Routines	10719	13676
III. <u>CMC Programs</u>		
P-00 CMC Idling	21	50
P-01-P03 Prelaunch Align Calib.	865	1082
P-05 GNCS Startup	57	65
P-06 CMC Power Down	61	65
P-07 System Test	2489	----
P-11 EOI Monitor	133	150
P-15 TLI	----	250
P-17 TPI Search	----	50
P-20 Rendezvous Navigation	107	110
P-21 Ground Track Det.	35	50
P-22 Lunar Orbit Navigation	270	270
P-23 Cislunar Midcourse Navigation	74	75
P-25 Predicted Lunar Landing	----	50
P-27 CMC Update	220	250
P-30 External Delta V	249	250
P-31 General Lambert	----	120

	AS-258 (actual)	AS-504A (estimated)
P-32 Lunar Orbit Insertion (LOI)	----	120
P-33 Lunar Orbit Plane Change (LOPC)	----	120
P-34 Transfer Phase Initiation (TPI)	262	265
P-35 Transfer Phase Midcourse (TPM)	82	100
P-37 Return to Earth (Near Earth)	----	100
P-40 SPS	720	730
P-41 RCS	154	155
P-47 Thrust Monitor	124	125
P-51 IMU Orientation Determination	136	140
P-52 IMU Realign	164	164
P-53 IMU Realign Backup	----	*
P-61 Maneuver to CM/SM Sep. Att.	50	50
P-62 CM/SM Sep. and Preentry Maneu.	120	120
P-63 Entry Initialization	8	20
P-64 Post 0.05 G	8	20
P-65 Up Control	----	20
P-66 Ballistic	----	20
P-67 Entry Final Phase	30	35
P-70 Safe Perilune Targetting	----	120
P-74 LM TPI Targetting	11	25
P-75 LM TPM Targetting	10	25
P-77 LM TPI Search	----	25
R-03 Load DAP Data	32	40
R-05 S-Band Pointing	----	*
R-23 Rendezvous Tracking Data Process (Dock Ret)	----	*
R-30 Orbital Parameter Display	110	110
R-31 Rendezvous Parameter Display	32	35
R-32 Target Delta V	89	100
R-33 CMC/LGC Clock Sync.	----	**
R-62 Crew Defined Maneuvers	----	**
Total - CMC Programs	6723	5671
GRAND TOTAL	32694	35435
Remaining Fixed Memory	4170	1429

* - These items were contained in List II of the January report, but word estimates are not available.

** - Newly identified requirement, word estimates are not available.

LGC

I. Control Programs	AS-258 (actual)	AS-504A (estimated)
A. DSKY		
Pinball	2843	3000
Extended Verbs	694	1000
Keyrupt and Uprupt	80	80
Display and Servicer	670	700
Down Telemetry List	157	500
Program Select Check	202	205
Down Telemetry Program	194	260
B. Interpreter and Executive		
Interpreter	2271	2271
Waitlist	220	220
Executive	312	335
Phase Table	111	350
Restart Control	179	180
Fresh Start and Restart	306	310
Phase Change and New Change	158	158
T4 Rupt	679	1000
Alarm and Abort	72	72
Self Check	986	966
Interbank Communications	88	88
Interrupt Lead In	52	52
RTB OP Codes	211	250
End of Bank Marks	108	36
C. Other		
Digital Auto-Pilot	4008	4100
LM Flight Control Sys. Test	360	----
Transformations	821	825
Gyro Torquing (R55)	40	44
Total - DSKY and Interpreter and Executive and other	15822	17002
II. LGC Routines		
A. Basic Routines		
Conic Subroutines	879	1300
Orbital Integration	1118	1200
Latitude, Longitude, & Altitude	216	200
Lunar and Solar Ephemeris	131	100
Lunar Rotation	----	150

	AS-258 (actual)	AS-504A (estimated)
Initial Velocity	188	188
Rendezvous Parameters	----	100
Maneuver Specification	212	215
Maneuver Calculation	840	560
Attitude Drive	166	175
Mid Gimbal Display	33	68
Radar Subroutines	783	785
B. Targetting		
Predicted Landing Time	----	200
DOI	----	150
Predicted Launch Time (CFP)	----	400
Predicted Launch Time (TPI)	----	100
CSI	540	540
CDH	387	390
TPI	275	290
Midcourse Maneuver (S35.1)	53	54
TPI Search	----	200
C. Navigation		
Rendezvous	498	520
RR Lunar Surface	----	300
Measurement Incorp	408	425
Preferred Tracking Attitude (RGILEM)	56	60
AOT Mark	367	370
Radar Test	59	60
RR Search Designation Read.	552	560
D. Powered Guidance		
Cross Product Steering (S40.8)	186	190
Vg Calc (S40.9)	77	77
Servicer	557	600
Desired Thrust Direction (S40.1)	137	270
Time of Burn Calc (S40.13)	98	100
E. IMU and Optics		
IMU Compensation	258	258
IMU Status Check (R02)	17	20
Coarse Align Cal 53A	64	64
Fine Align (R-51)	75	75

	AS-258 (actual)	AS-504A (estimated)
Auto-Optics (R-52)	42	42
Pick-A-Pair	127	135
Star Data Test (R-54)	52	52
IMU Mode Switch	531	561
Anytime Align	----	100
Star Catalog	223	225
Total - CMC Routines	10205	12 429

III. LGC Programs

P-00 LGC Idling	24	50
P-02 AGS Initialization	100	100
P-04 Lunar Surface Checkout	----	260
P-05 LGC Startup	57	65
P-06 LGC Power Down	61	65
P-07 System Tests	2864	725 (See Note 3)
P-10 Predicted Launch Time (CFP)	----	100
P-11 Predicted Launch Time (TPI)	----	100
P-12 Powered Ascent Guidance	----	700
P-17 TPI Search	----	50
P-20 Rendezvous Navigation	157	160
P-21 Ground Track Determination	35	50
P-22 RR Lunar Surface Navigation	----	50
P-25 Preferred Tracking Attitude	46	50
P-27 LGC Update	220	250
P-30 External ΔV	143	150
P-32 CSI	145	145
P-33 CDH	77	146
P-34 TPI	251	255
P-35 TPM	82	100
P-40 DPS	750	750
P-41 RCS	124	250
P-42 APS	13	25
P-47 Thrust Monitor	107	120
P-50 Docked IMU Align	----	*
P-51 IMU Orientation Determination	120	120
P-52 IMU Realign	157	160
P-53 IMU Realign (Backup)	----	*
P-54 Lunar Surface Align (Post Landing)	----	**
P-55 IMU Surface Align (Normal)	----	400

	AS-258 (actual)	AS-504A (estimated)
P-56 IMU Surface Align (Backup)	----	50
P-57 Anytime Launch Align	----	50
P-60 Predicted Lunar Landing	----	50
P-61 DOI	----	100
P-63 Braking Phase	----	} 1500
P-64 Approach Phase	----	
P-65 Landing Phase (Automatic)	----	
P-66 Landing Phase (Rate of Descent)	----	
P-67 Landing Phase (Manual)	----	
P-70 DPS Abort	----	} 100
P-71 APS Abort	----	
P-72 CSM CSI Targetting	22	30
P-73 CSM CDH Targetting	32	35
P-74 CSM TPI Targetting	8	25
P-75 CSM TPM Targetting	7	25
P-76 TEI Backup	----	120
R-03 Load DAP Data	138	140
R-04 RR Self Check	----	*
R-05 S-Band Pointing	----	*
R-30 Orbit Parameter Display	110	110
R-31 Rendezvous Parameter Display	32	35
R-32 Target ΔV	89	100
R-33 CMC/LGC Clock Sync	----	**
R-62 Crew Define Maneuver	----	**
Total LGC Programs		5971
GRAND TOTAL		7866
Remaining Fixed Memory		31998
		4866
		-433

1. * - These terms were contained in List II of the January report, but word estimates are not available.
2. ** - Newly identified requirements, word estimates are not available.
3. IMU Performance Tests.

Appendix B

I Earth Pre-Launch Phase

CMC

A) Service Programs

- P-05 CMC Start-Up
- P-01 Pre-Launch Initialization
- P-02 Gyro Compass
- P-03 Optics Verification
- P-07 System Test
- P-00 CMC Idling
- P-27 CMC Update
- P-06 GNCS Power Down

II Earth Orbit Injection (EOI) Phase

CMC

A) Nominal

- P-11 EOI Monitor

B) Abort to Entry

- P-61 Entry Maneuver to Separation
- P-62 Entry Separation Maneuver
- P-63 Entry Initialization
- P-64 Entry Post .05 G Phase
- P-67 Entry Final Phase

III Earth Orbit Phase

CMC

A) Nominal

1. Mission Programs

P-15 TLI Program (Pre-Thrust Mode)

R-30 Orbit Parameter Display

B) Aborts - To Earth Entry

1. RTCC Controlled Abort

P-30 External ΔV Pre-Thrust (de-orbit)

P-31 Lambert Aim Point Pre-Thrust (de-orbit) ^{or}

P-40 } SPS or RCS Thrust Program
P-41 }

P-61

P-62

P-63 } Entry Programs

P-64

P-67

2. Spacecraft Controlled Abort

P-22 Lunar Orbit Navigation Program (Earth Mode)

P-21 Ground Track Program

P-37 Return to Earth Program (Targeting and Pre-Thrust)

P-40 } SPS or RCS Thrust Programs
P-41 }

P-61

P-62

P-63 } Entry Programs

P-64

P-67

C) Service Programs (Nominal and Abort Cases)

P-27 CMC Update

P-52 IMU Realignment Program

P-00 CMC Idling

IV Trans-Lunar Injection (TLI) Maneuver

CMC

A) Nominal

- P-15 TLI Program (CMC Controlled Maneuver)
or
- P-47 Thrust Monitor Program (Saturn Controlled Maneuver)

B) Aborts to Earth Entry

1. RTCC Controlled Abort

- P-27 CMC Update
- P-30 External ΔV Pre-Thrust Program
- P-31 Lambert Aim Point Pre-Thrust Program

P-40 }
P-41 } SPS or RCS Thrust Programs

P-61 }
to } Entry Programs
P-67 }

2. Spacecraft Controlled Abort

- P-23 Cis-Lunar Navigation Program
- P-37 Return to Earth Program (Targeting and Pre-Thrust)

P-40 }
P-41 } SPS or RCS Thrust Programs

P-61 }
to } Entry Programs
P-67 }

C) Service Programs used in Abort Cases

- P-51 IMU Alignment Determination
- P-52 IMU Realignment Program
- P-06 GNCS Power Down
- P-05 CMC Start-Up
- P-00 CMC Idling

V

Trans-Lunar Phase

CMC

A) Nominal

P-27 CMC Update Program

P-30 External ΔV Pre-Thrust Program

P-31 Lambert Aim Point Pre-Thrust Program

P-40 }
P-41 } SPS or RCS Thrust Programs

P-47 Thrust Monitor (Manual Transposition & Docking Maneuver)

} MCC

B) Aborts to Earth Entry

1. RTCC Controlled Abort

Same as nominal case

2. Spacecraft Controlled Abort

P-23 Cis-Lunar Navigation Program

P-70 Safe Perilune Targeting Program

P-37 Return to Earth Program (Targeting and Pre-Thrust)

P-40 }
P-41 } SPS or RCS Thrust Maneuver Programs

P-61 }
to } Entry Programs
P-67 }

C) Service Programs for Nominal and Abort Cases

P-05 CMC Start-Up

P-06 GNCS Power Down

P-51 IMU Alignment Determination

P-52 IMU Realignment Program

P-00 CMC Idling

VI Lunar Orbit Insertion (LOI) Phase

CMC

A) Nominal

- P-27 CMC Update Program
- P-32 Lunar Orbit Insertion Pre-Thrust
- P-40 SPS Thrust Maneuver Program

B) Aborts to Return Earth Trajectory

1. RTCC Controlled Abort

- P-27 CMC Update Program
- P-30 External ΔV Pre-Thrust Program (Safe Lunar Orbit)
- P-31 Lambert Aim Point Pre-Thrust Program (TEI)
- P-40 SPS Thrust Program

2. Spacecraft Controlled Abort

- P-22 Lunar Orbit Navigation Program
- P-21 Ground Track Program
- P-70 Safe Perilune Targeting Program (If Required)
- P-37 Return to Earth Program (TEI Targeting and Pre-Thrust)
- P-40 SPS Thrust Program

C) Service Programs for Nominal and Abort Cases

- P-52 IMU Realignment Program

VII Lunar Orbit Phase Prior to LM Descent Orbit Injection

	<u>CMC</u>	<u>LGC</u>
A)	<u>Nominal</u>	
	P-22 Lunar Orbit Navigation Program	P-01 LGC Initialization
	P-21 Ground Track Program	P-60 Landing Time Prediction Program
	P-25 Landing Time Prediction Program	P-02 AGS Initialization
	P-26 LGC Initializaiton	P-21 Ground Track Program
	R-32 Target ΔV Routine	P-47 Thrust Monitor Program (Manual Separation Man.)
	P-20 Rendezvous Navigation Program (Tracking Mode for LM RR Check-Out)	P-20 Rendezvous Navigation Program (Pre DOI RR Check-Out)
		R-30 Orbit Parameter Display
B)	<u>Aborts to Return Earth Trajectory</u>	
	1. <u>RTCC Controlled Abort</u>	
	P-27 CMC Update Program	P-76 TEI Back-Up Program
	P-31 Lambert Aim Point Pre-Thrust (TEI)	P-30 External ΔV Pre-Thrust Program (Cis-Lunar MCC targeted from RTCC)
	P-40 SPS Thrust Program	P-40 DPS Thrust Program
	2. <u>Spacecraft Controlled Abort</u>	
	P-22 Lunar Orbit Navigation	P-76 TEI Back-Up Program
	P-21 Ground Track Program	P-40 DPS Thrust Program
	P-37 Return to Earth Program (TEI Targeting and Pre-Thrust)	
	P-40 SPS Thrust Program	
	P-47 Thrust Monitor (TEI by DPS)	
C)	<u>Service Programs for Nominal and Abort Cases</u>	
	P-05 CMC Start Up	P-05 LGC Start Up
	P-06 GNCS Power Down	P-51 IMU Alignment Determination
	P-51 IMU Alignment De-termination	P-52 IMU Realignment
	P-52 IMU Realignment Prog.	P-00 LGC Idling
	P-00 CMC Idling	

VIII Descent Orbit Injection (DOI) Maneuver and LM Descent Coast Phase

<u>CMC</u>	<u>LGC</u>
A) <u>Nominal</u>	
P-20 Rendezvous Navigation (Monitoring only)	P-61 DOI Pre-Thrust Program
	P-40 DPS Thrust Program
	R-30 Orbit Parameter Display Routine
	P-20 Rendezvous Navigation Program (Descent Monitor- ing)
	P-02 AGS Initialization Program
	P-21 Ground Track Program
	P-63 Landing Maneuver Braking Program (Pre-Ignition Mode)
B) <u>Aborts to Rendezvous Condition</u>	
1. <u>LM Active Vehicle</u>	
P-20 Rendezvous Navigation Program	P-20 Rendezvous Navigation Program <u>or</u>
R-32 Target ΔV Routine	P-25 Preferred Tracking Attitude Program
P-74 TPI Pre-Thrust (LM) (Monitoring or Commands via Voice Link)	P-30 External ΔV Pre-Thrust Program (from CMC or RTCC)
P-75 TPM Pre-Thrust (LM) (Rendezvous MCC Moni- toring or Commands via Voice Link)	P-32 CSI Pre-Thrust Program P-33 CDH Pre-Thrust Program P-34 TPI Pre-Thrust Program P-35 TPM (MCC) Pre-Thrust Prog.
P-77 TPI Search Program (LM) (CMC Commands via Voice Link)	P-36 TPF Maneuver Program P-17 TPI Search Program P-40 DPS Thrust Program
P-73 AGS Back-Up Initializa- tion	P-41 RCS Thrust Program P-42 APS Thrust Program
P-21 Ground Track Program	P-21 Ground Track Program

(continued)

VIII Descent Orbit Injection (DOI) Maneuver and LM Descent Coast Phase (cont)

CMC

LGC

2. CSM Active Retrieval

P-27	CMC Update Program	P-20	Rendezvous Navigation Program <u>or</u>
P-20	Rend. Navigation Prog.		
P-30	External ΔV Pre-Thrust (from RTCC or LGC)	P-25	Preferred Tracking Attitude Program
P-17	TPI Search Program	R-32	Target ΔV Routine
P-21	Ground Track Program		
P-34	TPI Pre-Thrust Program	P-72	CSI Pre-Thrust (CSM)
P-35	TPM Pre-Thrust Program	P-73	CDH Pre-Thrust (CSM)
P-36	TPF Maneuver Program	P-74	TPI Pre-Thrust (CSM)
P-40	SPS Thrust Program	P-75	TPM Pre-Thrust (CSM)
P-41	RCS Thrust Program		

C) Service Programs

P-52	IMU Realignment	P-52	IMU Realignment Program
R-31	Rendezvous Parameter Display Routine	R-31	Rendezvous Parameter Display Routine
P-00	CMC Idling	P-00	LGC Idling

IX Powered Lunar Landing Maneuver to Touchdown

	<u>CMC</u>	<u>LGC</u>
A)	<u>Nominal</u>	
	P-20 Rendezvous Navigation Program (Tracking Attitude and Monitoring)	P-63 Landing Braking Phase
		P-64 Landing Approach Phase
		P-65 Automatic Final Landing Phase
		P-66 Rate of Descent Final Phase
		P-67 Manual Final Phase (Post Landing Sequence included in P-65, P-66, and P-67)
		P-52 IMU Realignment Program
		P-06 PGNCS Power Down
B)	<u>Abort to Safe Orbit</u>	
	For rendezvous from safe orbit. See Section VIII Aborts	P-70 DPS Abort Sequence Program
		P-71 APS Abort Sequence Program
		P-12 Powered Ascent Guidance Program

X

Lunar Surface Phase to 3 Orbits before LM Launch

CMC

LGC

A) Nominal

No Active Program Req't.

No Active Program Req't.

P-22 Lunar Orbit Navigation
Program for Landing site
Surveillance if desired

B) Emergency Aborts to Safe Orbit

P-05 CMC Start Up

P-05 LGC Start Up

P-51 IMU Align't Determina-
tion

P-57 Any-Time Launch
Alignment Program

P-52 IMU Realignment Program

P-12 Powered Ascent Guidance
Program

P-27 CMC Up Date

R-30 Orbit Parameter Display

XI Lunar Pre-Launch Phase (Final 3 CSM Orbits before LM Launch)

	<u>CMC</u>	<u>LGC</u>
A)	<u>Nominal</u>	
	P-22 Lunar Orbit Navigation or	P-22 RR Lunar Surface Navigation
	P-27 CMC Update Program	P-10 Prediction Launch Time or (CFP) Program
	P-21 Ground Track Program	P-11 Prediction Launch Time (TPI) Program
	P-33 Lunar Orbit Plane Change (LOPC) Pre-Thrust Prog.	P-02 AGS Initialization Program
	P-40 SPS Thrust Program	
	P-20 Rendezvous Navigation Program (Tracking Attitude and Monitoring)	
	P-71 LM IMU Launch Alignment Determination	
B)	<u>Abort Cases Prior to LM Ascent</u>	
	P-72 AGS Back-Up Azimuth Alignment Program	P-56 Back-Up IMU Surface Alignment Program
	P-73 AGS Back-Up Initialization Program	
C)	<u>Service Programs</u>	
	P-05 CMC Start-Up	P-05 LGC Start-Up
	P-51 IMU Alignment Determination	P-55 IMU Surface Alignment (Normal)
	P-52 IMU Realignment Program	P-00 LGC Idling
	P-00 CMC Idling	

XII LM Powered Ascent Phase

CMC

LGC

A) Nominal

P-20 Rendezvous Navigation
(Preferred Tracking At-
titude Mode)

P-12 Powered Ascent Guidance
Program

B) Aborts

None

None

XIII Rendezvous Phase

	<u>CMC</u>	<u>LGC</u>
A)	<u>Nominal</u>	
	P-20 Rendezvous Navigation Program	P-20 Rendezvous Navigation Program
	R-32 Target ΔV Routine	P-32 CSI Pre-Thrust Program
	P-74 TPI Pre-Thrust (LM) (Monitoring)	P-33 CDH Pre-Thrust Program
	P-75 TPM Pre-Thrust (LM) (Monitoring)	P-34 TPI Pre-Thrust Program
		P-35 TPM Pre-Thrust Program
		P-36 TPF Maneuver Program
		P-21 Ground Track Program
		P-41 RCS Thrust Program
		P-42 APS Thrust Program
		R-31 Rendezvous Parameter Display Routine
		P-02 AGS Initialization Program
B)	<u>Aborts to Rendezvous</u>	
	1. <u>LM Active Vehicle</u>	
	Same a nominal plus:	Same as nominal plus:
	P-73 AGS Back-Up Initialization	P-17 TPI Search Program
	P-77 TPI Search Program (LM)	P-30 External ΔV Pre-Thrust (CMC or RTCC targeted)
	P-21 Ground Track Program	P-41 RCS Thrust Program
		P-42 APS Thrust Program

(continued)

XIII Rendezvous Phase (cont)

CMC

LGC

2. CSM Active Retrieval

P-20	Rendezvous Navigation Program	P-20	Rendezvous Navigation Program
P-21	Ground Track Program	R-32	Target ΔV Routine
P-27	CMC Update Program (RTCC controlled abort)	P-25	Preferred Tracking Attitude Program
P-30	External ΔV Pre-Thrust (LGC or RTCC targetted)	P-72	CSI Pre-Thrust (CSM)
P-17	TPI Search Program	P-73	CDH Pre-Thrust (CSM)
P-34	TPI Pre-Thrust Program	P-74	TPI Pre-Thrust (CSM)
P-35	TPM Pre-Thrust Program	P-75	TPM Pre-Thrust (CSM)
P-36	TPF Maneuver Program		
R-31	Rendezvous Parameter Display		
P-40	SPS Thrust Program		
P-41	RCS Thrust Program		

C) Service Programs

P-52	IMU Realignment Program	P-52	IMU Realignment Program
------	-------------------------	------	-------------------------

XIV Lunar Orbit Phase Prior to TEI

CMC

A) Nominal

P-22 Lunar Orbit Navigation Program

P-21 Ground Track Program

P-52 IMU Realignment Program

P-00 CMC Idling

B) Abort Conditions Prior to TEI

P-27 CMC Update Program

XV Trans-Earth Injection (TEI) Phase

CMC

A) Nominal

P-31 Lambert Aim Point Pre-Thrust Program
(TEI RTCC Targeted)

P-40 SPS Thrust Program

B) Abort to Earth Return Trajectory

P-37 Return to Earth Program (TEI Mode)

P-40 SPS Thrust Maneuver

XVI Trans-Earth Phase

CMC

A) Nominal

P-27 CMC Update Program

P-30 External ΔV Pre-Thrust Program
(RTCC Targeted)

P-31 Lambert Aim Point Pre-Thrust Program
(RTCC Targeted)

P-40 SPS Thrust Program

P-41 RCS Thrust Program

} MCC

B) Aborts to Maintain Earth Return Trajectory

P-23 Cis-Lunar Navigation Program

P-37 Return to Earth Program

P-40 SPS Thrust Program

P-41 RCS Thrust Program

C) Service Programs for Nominal and Abort Cases

P-05 CMC Start-Up Program

P-06 GNCS Power Down

P-51 IMU Alignment Determination Program

P-52 IMU Realignment Program

P-00 CMC Idling

XVII Entry Phase

CMC

A) Nominal

P-61 Entry Maneuver to Separate

P-62 Entry Separation Maneuver

P-63 Entry Initialization

P-64 Entry Post 0.05 G Phase

P-65 Entry Up Control Phase

P-66 Entry Ballistic Phase

P-67 Entry Final Phase

Appendix C

CMC PROGRAM AND ROUTINE DESCRIPTION

This is a description of the Mission 504A Command Module Computer (CMC) routines and programs.

The routines and programs are presented as listed on the Mission 504A "CMC" Program/Routine Size and Relationship Chart".

In general, programs are callable by the astronaut via the keyboard and routines are not.

These descriptions are organized as follows:

	<u>CATEGORY</u>	<u>PAGE NO.</u>
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II	Targeting Routines	78
III	Navigation Routines	79
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VI	IMU and Optics Routines	82
VII	Display and Keyboard Routines	83
VIII	Interpretive and Executive Routines	84
IX	Other Routines	86
P-0X	Prelaunch and Servicer Programs	87
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P-3X	Prethrust Programs	89
P-4X	Thrust Programs	90
P-5X	IMU Align Programs	90
P-6X	Entry Programs	90
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R-3X	Callable Routines	92

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AS-504A

CMC ROUTINES

I BASIC ROUTINES

Conic Routines

A group of routines to provide solutions to the following conic problems (two body problems):

1. Lambert Routine (required velocity to achieve aim point and time of arrival).
2. Kepler Routine (determines new state vector after a given time of flight).
3. Time-Theta (determines time of flight between a given transfer angle).
4. Final Pos. & Vel. (determines final state vector from Lambert or Time-Theta Routine or from initial state and a given transfer angle).
5. Orbital Parameters (computes orbital parameters from state vector).
6. Perigee and Apogee (computes periapsis and apoapsis radii and altitude from orbit parameters).
7. Various miscellaneous routines.

Orbital Integration

A routine to extrapolate a vehicle (CSM or LM) state vector during a coasting phase of the mission. The extrapolation may include a statistical error matrix (W matrix) of six or nine dimensions. The subroutine operates in Earth Orbit, Lunar Orbit, or Cislunar Space.

Lat - Lon - Alt

A routine to transform vectors from basic reference coordinate system to latitude, longitude, altitude and vice versa. Subroutine has two modes: Earth and Moon.

Lunar and Solar Ephemerides

A routine to compute position and velocity of moon and sun relative to earth.

Lunar Rotation

A routine to transform position vectors from the basic reference coordinate system to a selenographic coordinate system and vice versa.

Initial Velocity

A routine to calculate a precision or conic velocity required to cause the trajectory to hit an aim vector in a given time of flight. Accounts for the 180 degree singularity.

Rendezvous Parameters

A routine to compute estimated relative range, range rate, and an angle θ relating the body X axis (CSM) or Z axis (LM) to the local horizontal plane.

Vecpoint

A routine which calculates the required gimbal angles to point a specified vector within the spacecraft in a desired direction. Roll about this vector is arbitrary.

Calc Maneuvers

A routine which calculates the vector rotation which avoids gimbal lock and achieves desired vehicle orientation.

Attitude Maneuver

A routine which sends appropriate commands to a DAP to carry out the desired maneuver.

Middle Gimbal Display

A routine to compute and display the approximate IMU Middle Gimbal Angle for a desired ΔV vector which is used as an indication of potential gimbal lock conditions.

II TARGETING ROUTINES

TPI (Transfer Phase Initiation)

A rendezvous targeting routine used to initiate a direct intercept trajectory to the passive vehicle. The routine has two input data modes:

- 1.) Desired ignition time and transfer trajectory time of flight, Δt , to intercept.
- 2.) Desired line-of-sight elevation angle at ignition time and transfer trajectory time of flight, Δt .

Either of these two inputs are used to compute the impulsive velocity vector correction required to establish the intercept trajectory.

Midcourse Maneuver

A rendezvous targeting routine which computes the impulsive velocity vector correction required to maintain the intercept point initiated by the TPI routine. This rendezvous midcourse correction is computed for a time 10 minutes from the current time.

Return to Earth (near Earth and near Moon)

A routine which provides fuel critical or time critical targeting for:

- 1.) Returning from earth orbit.
- 2.) Returning from trajectories resulting from a TLI powered maneuver failure.
- 3.) Returning from cislunar midcourse.
- 4.) A safe perilune passage.
- 5.) Returning from trajectories resulting from LOI or TEI powered maneuver failures.
- 6.) Normal returns from lunar orbit.
- 7.) Midcourse corrections for transearth midcourse.
- 8.) Changes in transit time during transearth midcourse.

LOPC (Lunar Orbit Plane Change)

A routine which determines the required ignition time and aim vector for the CSM plane change maneuver required two orbits prior to LM launch and ascent.

TPI Search (Transfer Phase Initiation Targeting Search)

A routine which iteratively searches and displays acceptable TPI targeting parameters and resulting velocity requirements to achieve a direct transfer trajectory to the passive vehicle. The direct transfer trajectory selected by the routine is made on the basis of minimum total ΔV (TPI and TPF) and safe perilune criteria.

Landing Time Prediction

A routine to determine the following target and alignment parameters:

- 1.) Predicted landing time (This time determines the LM IMU alignment for the descent and landing phases).
- 2.) Landing maneuver target parameters for ignition, Hi-gate and Low-gate.
- 3.) Nominal landing maneuver ignition time.
- 4.) Descent orbit injection time desired.

III NAVIGATION ROUTINES

Cis-Lunar Midcourse Navigation

A routine to acquire and process star-earth/lunar landmark or horizon angle measurement data to improve CMC position and velocity estimates. This routine is a back-up navigation method used in the event of loss of communication with ground. Return to earth and this routine provide CMC with the capability of guiding CSM back to earth and safe entry conditions.

Rendezvous Navigation

A routine to acquire and process CSM-LM optics tracking data to improve the selected vehicle's state vector. The routine is the prime CMC rendezvous navigation method if LM retrieval is necessary, and is used to monitor all LM coasting and rendezvous phases.

This routine also maintains the CSM attitude such that the optics and the radar transponder cover the estimated line of sight to the LM either in free fall or on the lunar surface.

Lunar Orbit Navigation

A routine to acquire and process lunar landmark tracking data. The routine operates in nine dimensions improving vehicle position and velocity and landmark coordinate estimates. The following modes are available:

- 1.) Mapped landmark
- 2.) Landing site designation or unmapped landmark
- 3.) Landing site offset

This routine is the prime CMC navigation method during lunar orbit.

Measurement Incorporation

A routine to incorporate measurement data into the estimate of CSM and LM state vector. The routine has six and nine dimensional modes, and is used in Rendezvous, Lunar Orbit and Cis-Lunar Navigation programs.

Preferred Tracking Attitude

The preferred attitude routine commands the CSM attitude so as to align a specified body-fixed reference vector to the estimated line-of-sight of the Lunar Module. The routine maintains this alignment to within $\pm 5^\circ$ throughout the free-fall rendezvous phases. Since the reference vector lies within the SXT and RR transponder coverage sectors, this enables simultaneous tracking with the SXT and RR.

Sighting Mark

A routine which controls input-output for the Sextant Mark routine.

Sextant Mark

A routine which interfaces with the Keyboard and Optics and requests and receives optical sighting data.

IV ENTRY

Entry Calculations

Routines which provide steering commands to the entry DAP throughout the entire entry.

Pre-Entry Computation

A routine which computes six pertinent quantities for display to the astronaut prior to entry.

Separation Gimbal Angles

A routine to determine the desired separation attitude.

IMU Entry Status

A routine which starts Servicer, if required, and checks for gimbal lock.

IMU Gimbal Angles

A routine to determine the desired entry attitude.

Range To Go - Lat - Lon

A routine which computes the range to go, the present latitude and longitude when the vehicle velocity drops below 1000 fps.

Apogee, Perigee, Time of Free Fall

A routine which computes apogee, perigee and time of free fall to a specified altitude for a given vehicle state vector.

V POWERED GUIDANCE

Cross-Product Steering

A routine which computes the required thrusting direction given the velocity-to-be-gained.

Velocity to be Gained

A routine to compute the velocity to be gained vector for two guidance modes.

- 1.) Lambert Aim Point Maneuver Guidance
- 2.) LOI Maneuver Guidance

Time of Burn Calculation

A routine to estimate the required duration of burn in order to decide whether to steer or hold attitude.

Servicer

A routine which:

- 1.) Reads and compensates PIPA's
- 2.) Integrates PIPA ΔV via "Average G"
- 3.) Connects velocity to be gained and steering computations
- 4.) Monitors thrust and "run-away" PIPA's.

Desired Thrust Direction

A routine which computes the required orientation of the vehicle for ignition.

SIVB Attitude Error (Fast Loop)

A routine which:

- 1.) Meters out the desired attitude and differences this with actual attitude at 40 ms rate.
- 2.) Monitors for cut-off (in Boost Mode only)

VI IMU AND OPTICS

IMU Compensation

A routine which compensates PIPA readings for gyro and PIPA scale errors, bias and drifts.

IMU Status Check

A routine which determines if (1) computer knowledge of Stable Member is correct (2) if IMU ready for use.

Coarse Alignment

A routine which drives the IMU Stable Member to a desired orientation relative to the vehicle.

Fine Alignment

A routine which accurately aligns the IMU Stable Member based on star sightings.

Automatic Optics Positioning

A routine which drives the CSM optics to the estimated line-of-sight of an object such as the Lunar Module, a navigation landmark, or a star. The purpose of this routine is to aid the astronaut in visually acquiring the above objects.

Pick A Pair

A routine which selects the best pair of stars for fine alignment sightings.

Star Data Test

A routine which checks to determine if angle between sighted stars is equal to the true angle.

IMU Mode Switching

A set of routines utilized when changing the IMU modes. Contains such subroutines as IMU Zero, IMU Coarse, IMU Fine, PIPA Pulse, IMUpulse, IMU end .

Star Catalog

A catalog of star locations used for navigation and alignment.

Landmark Catalog

25 selected lunar landmarks used for lunar orbit navigation.

VII DISPLAY AND KEYBOARD ROUTINES

Pinball

A routine which:

- 1.) Processes input data from Key-rupt and Up-rupt routines.
- 2.) Processes requests for display of data initiated by internal programs or key-board activity.

- 3.) Processes Verb-Noun combination from various sources and passes control to appropriate program.

Extended Verbs

A set of routines callable by the astronaut which perform certain tasks such as parameter display, alteration of AGC clock, back-up functions and IMU modings via a special verb.

Key Rupt and Up Rupt

Routines which process the input and are initiated in the interrupt modes by an Uplink or Keyboard activity.

Display and Service

Routines which (1) provide interface between astronaut and pinball (2) sets and resets flag-word bits (3) provides various other service functions.

Down Telemetry List

A list of erasable locations which will be down-linked.

Program Selection Check

A routine which insures proper transfer between programs.

Down Telemetry Routine

A routine initiated by a T4Rupt which sends the down telemetry information.

VIII INTERPRETIVE AND EXECUTIVE ROUTINES

Interpreter

A set of routines which processes interpretive instructions.

Waitlist

A routine which controls the timing of program execution.

Executive

A routine which controls the program priorities.

Phase Tables

A list of restart locations within the Mission Program.

Restart Control

A routine activated when a restart occurs which chooses the correct items from phase table lists for the routines to be restarted. Does bookkeeping required for the restart.

Fresh Start and Restart

Routines which initialize the computer to allow operation.

Phase Change and New Phase

A routine which maintains the current restart information.

T4Rupt

A set of routines which cycle at a predetermined frequency to monitor input-output channels.

Alarm and Abort

A routine which displays alarms and effects a programmed abort.

Self Check

A routine which performs six computer checks:

- 1.) Pulse check
- 2.) Rope check
- 3.) Erasable check
- 4.) Counter check
- 5.) Showsum check
- 6.) DSKY check

Interrupt Lead-In

A routine which dispatches control to appropriate interrupt routine.

Return to Basic Opcodes

Routines written in basic language callable when in the interpretive mode.

End of Bank Mark

Provides check sum at end of each bank for Self Check.

IX OTHER

DAPS (Digital Autopilots)

1. TVC Provide digital filters (sampled data) for stable operation of the CSM/CSM-LEM vehicle during SPS firing.
2. Roll Keep outer gimbal angle within 5° of initial value during thrust vector control (SPS).
3. RCS Provide attitude control of the CSM/CSM-LEM vehicle by selecting appropriate combinations of jet firings. The autopilot must respond to both manual and automatic control.
4. Entry Provide attitude and roll control of the CM in pre-entry and during entry.

Saturn and CM Tests

A set of routines which test the Saturn and CSM interfaces prior to launch.

GEN 3 DAP

A generalized third order autopilot (filter) for thrust vector control (LM-Off). Organization of the filter permits a great measure of flexibility. Can be used to replace current first order design.

Transformations

A set of useful transforms such as 1s to 2s and 2s to 1s, stable member to navigation base, etc.

Gyro Torquing

Torques gyros to a desired orientation.

CMC PROGRAMS

P-00 Idling

This program indicates that the computer is not engaged in control or computational operations and maintains the computer in a ready condition for usage. Manual attitude maneuvers can be made by the crew while this program is active.

P-01 Prelaunch Initialization

This program initializes the computer for the prelaunch programs and orients the stable member of the IMU for gyrocompassing.

P-02 Gyrocompassing

This program controls the orientation of the stable member to the proper azimuth and local vertical for launch.

P-03 Optical Verification

This program provides an optical verification of the azimuth alignment of the IMU during gyrocompassing by means of sightings on internal targets.

P-05 GNCS Startup

This program transfers the ISS and computer from the standby to the operate condition.

P-07 System Test

This program carries out a series of IMU performance tests to verify that the IMU subsystem is performing correctly.

P-11 Earth Orbit Insertion Monitor

This program generates attitude error and trajectory parameter data for display during earth orbit insertion.

P-15 Translunar Injection (Prethrust and Thrust)

This program uses target data previously loaded to reorient the SIVB to the ignition attitude, sends the injection sequence start discrete to the SIVB, initializes the servicer routine, and provides guidance signals to SIVB during the burn.

P-17 Transfer Phase Initiation Search (Prethrust)

This program controls the TPI search targeting routine and interfaces with the astronaut.

P-20 Rendezvous Navigation

This program controls the CSM attitude to meet SXT tracking and RR beacon orientation requirements and provides for the processing of optics tracking data.

P-21 Ground Track Determination

This program computes and displays spacecraft latitude, longitude and altitude for any given time.

P-22 Lunar Orbit Navigation

This program provides for automatic or manual landmark acquisition and tracking and controls the lunar orbit navigation routine. It also provides the coordinates of the landing site from angle and time data obtained during tracking of the landing site.

P-23 Cislunar Midcourse Navigation

This program controls the Cislunar Navigation Routine.

P-25 Predicted Lunar Landing Time

This program controls the Landing Time Prediction Routine.

P-26 LGC Initialization

This program sequences the display of the parameters needed for initialization of the LGC.

P-27 CMC Update

This program controls the insertion of data into the CMC erasable memory via the keyboard or uplink.

P-30 External Delta V (Prethrust)

This program accepts external ΔV targeting parameters and displays pertinent dependent variables associated with the desired maneuver.

P-31 General Lambert (Prethrust)

This program accepts Lambert aimpoint targeting parameters and displays pertinent dependent variables associated with the desired maneuver.

P-32 Lunar Orbit Insertion (Prethrust)

This program accepts lunar orbit insertion targeting parameters and displays pertinent dependent variables associated with this maneuver.

P-33 Lunar Orbit Plane Change (Prethrust)

This program controls the LOPC targeting routine and interfaces with the astronaut.

P-34 Transfer Phase Initiation (Prethrust)

This program controls the TPI targeting routine and interfaces with the astronaut.

P-35 Transfer Phase Midcourse (Prethrust)

This program controls the TPM targeting routine and interfaces with the astronaut.

P-36 Transfer Phase Final (Prethrust)

This program displays rendezvous parameters and monitors the manual braking and docking maneuvers.

P-37 Return to Earth (Prethrust)

This program controls the RTE targeting routine and interfaces with the astronaut.

P-40 SPS (Thrust)

This program computes the desired initial vehicle and IMU orientation, orients the vehicle, determines the method of steering, initializes Servicer Routine, provides steering commands to the autopilot during the burn, and terminates the burn.

P-41 RCS (Thrust)

This program computes the desired vehicle and IMU orientations, orients the vehicle, initializes the Servicer Routine, displays the velocity to be gained and permits manual execution of the maneuver.

P-47 Thrust Monitor

This program monitors the acceleration and displays the velocity change during a non-GNCS controlled maneuver.

P-51 IMU Orientation Determination

This program determines the orientation of the IMU.

P-52 IMU Realign

This program aligns the IMU from a known orientation to a preferred orientation, and trims the stable member to correct for drift.

P-61 Maneuver to Separation (Entry)

This program initiates the Servicer Routine if necessary and controls the Pre-Entry displays and maneuver to the CM/SM Separation Attitude.

P-62 CM/SM Separation and Pre-Entry Maneuver

This program initiates the Servicer Routine if necessary and controls the displays and maneuver to the entry trim attitude after CM/SM separation.

P-63 Entry Initialization

This program initializes entry steering, maintains the CM entry trim attitude, and detects the onset of aerodynamic force.

P-64 Post 0.05 G

Initiation of this program indicates that .05g has occurred. The functions started in P-63 are continued.

P-65 Up Control

This program provides control during the Skip-Up phase of the entry.

P-66 Ballistic

This program provides control during the Ballistic phase of the entry.

P-67 Entry-Final Phase

This program provides entry steering after occurrence of 0.2G atmospheric drag acceleration following P-66 (or P-64 in the case of aborts from boost or earth orbit).

P-70 Safe Perilune (Prethrust)

This program provides access to the safe perilune mode of the RTE targeting routine and interfaces with the astronaut to permit a safe perilune burn on an abort trajectory when ground communication is lost.

P-71 LM IMU Launch Alignment Determination

This program determines the LM IMU launch alignment from the CSM state vector and the predicted launch time which is determined by the LGC or RTCC. This program is required for P-73 (AGS back-up initialization) since all state vector data voice-linked to the AGS must be referenced to this alignment after the landing phase.

P-72 AGS Back-Up Azimuth Alignment

This program is used in case of a LM PGNCS failure while the LM is on the lunar surface. It is used to compute an azimuth alignment correction due to lunar stay time so that the AGS can correct the landing azimuth for launch.

P-73 AGS Back-Up Initialization

This program provides CSM and LM state vector data in launch alignment coordinates that can be used by the LM AGS. This data would be voice-linked to the LM in the case of LM PGNCS failure if it were desired to control the LM maneuvers with the AGS.

P-74 Transfer Phase Initiation - LM (Prethrust)

This program is the same as CMC P-34 except the LM is the active vehicle.

P-75 Transfer Phase Midcourse - LM (Prethrust)

This program is the same as CMC P-35 except the LM is the active vehicle.

P-77 Transfer Phase Initiation Search - LM (Prethrust)

This program is the same as CMC P-17 except the LM is the active vehicle.

Selected CMC Callable Routines

R-30 Orbit Parameters Display

This routine displays apogee, perigee and TFF.

R-31 Rendezvous Parameter Display

This routine displays range, range rate and theta.

R-32 Target Delta

This routine provides the computer the velocity change applied to the other vehicle to enable an updating of the other vehicle state vector.

APPENDIX D
CMC PROGRAM/ROUTINE
RELATIONSHIP AND SIZES

APPENDIX E

CMC PROGRAM UTILIZATION

CMC PROGRAM UTILIZATION AS-504

MISSION PHASES	CMC CONTROL PROGRAMS AS-504	
	CMC Utilization	Program Required
1. Earth Prelaunch	P00 CMC Utilization	
2. Earth Orbit Injection (EOI)	P01 Pre-launch Initialization P02 Optics Verification P03 CMC Startup P04 CMC Power Down	
3. Earth Orbit Phase		
4. Translunar Injection (TLI)	P11 EOI Monitor	
5. Translunar Phase		
6. Lunar Orbit Insertion & LOI Prethrust & Maneuver	P12 TLI Prethrust & Thrust	
7. Lunar Orbit Phase Prior to LOI	P17 TLI Search	
8. Descent Orbit Injection & Descent Coast Phase	P20 Rendezvous Navigation P21 Ground Track P22 Lunar Orbit Navigation P23 Ctl-Lunar Navigation	
9. Powered Lunar Landing		
10. Lunar Surface Phase to 3 orbits before LM Launch	P24 Lunar Landing Time Prediction	
11. Lunar Prelaunch Phase (Final 3 orbits before LM Ascent)	P27 CMC Update P30 External AV P31 Lunar Orbit Insertion (LOI) P32 Lunar Orbit Change (LORC) P34 Transfer Phase Initiation (TPI) P35 Transfer Phase Mid-Corr. (TMC)	
12. LM Powered Ascent	P37 Return to Earth Target (RTT) P40 SPS Thrust Maneuver P41 RCS Thrust Maneuver	
13. Rendezvous Phase (LM Active)	P42 Thrust Monitor	
14. Lunar Orbit Pre TEI	P43 LMU Alignment Determination P44 LMU Re-assignment P45 LMU Reassign (Backup)	
15. Transearth Injection (TEI) Prethrust & Maneuver	P47 Entry Maneuver to Separate P48 Entry Sep. Maneuver P49 Entry Initiation P50 Entry Post-OSG Phase P51 Entry LIP-Control P52 Entry Ballistic Phase P53 Entry Final Phase	
16. Transearth Phase	P54 Entry Final Phase (RTT)	
17. Entry Phase		
18. LM Rescue (CSM Active)		
19. Abort from Earth Orbit Prethrust & Maneuver		
20. Abort from TL, LO, or TE Phase Prethrust & Maneuver		
	P77 TPI Search P78 TPA LMI P79 TPA LMI P80 5-Band Pointing P81 Rendezvous Tracking P82 Rend Tra (DOCS RFI) P83 Orb Parameter Display P84 Rendezvous Parameter Display P85 Target AV P86 CM/CC Clock Sync P87 Lunar Landing Selection P88 Crew Delta Maneuvers	

KEY:
 * Program Required
 S Program required for self-contained capability only.
 P Program required for ground navigation target capability only.
 G Capability only.

Appendix F

LMC PROGRAM AND ROUTINE DESCRIPTIONS

This is a description of the Mission 504A Lunar Module Computer (LMC) routines and programs.

The routines and programs are presented as listed on the Mission 504A "LMC" Program/Routine Size and Relationship Chart"

In general, programs are callable by the astronaut via the keyboard and routines are not.

These descriptions are organized as follows:

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LMC ROUTINES

I BASIC ROUTINES

Conic Routines

See CMC definitions

Orbital Integration

See CMC definitions

Lat -Lon -Alt

See CMC definitions

Lunar And Solar Ephemerides

See CMC definitions

Lunar Rotation

See CMC definitions

Initial Velocity

See CMC definitions

Rendezvous Parameters

See CMC definitions

Vecpoint

See CMC definitions

Calculate Maneuvers

See CMC definitions

Attitude Maneuver

See CMC definitions

Radar Subroutines

A set of routines which service the interface between the radars and the computer and aid in data reading and control of the radar systems.

II TARGETING ROUTINES

PLDT (Predicted Landing Time)

See CMC definitions

DOI (Decent Orbit Insertion)

A routine which determines DOI ignition time from the parameters supplied by the Lunar Time Prediction routine.

PLHT (Predicted Launch Time) (CFP)

A routine to determine the following target and alignment parameters for a LM launch followed by a CFP rendezvous:

1. Predicted Launch Time (This time determines the IMU alignment for the powered ascent and rendezvous phases)
2. Desired injection parameters for the powered ascent maneuver

This routine uses the CFP routines to iterate for the required launch time such that a desired differential altitude, Δh , can be achieved at the CDH maneuver. All CFP target parameters must be supplied by the astronaut.

PLHT (Predicted Launch Time) (TPI)

A routine which determines the following target and alignment parameters for a LM launch followed by a direct transfer rendezvous in which the TPI maneuver is initiated immediately after ascent injection:

1. Predicted Launch Time (This time determines the IMU alignment for the powered ascent and rendezvous phases).
2. Desired injection parameters for the powered ascent maneuver.

This routine uses the TPI search routine to iterate for the required launch time.

CSI (Concentric Sequence Initiation)

A CFP rendezvous routine to provide the horizontal impulsive velocity correction which results in the desired TPI relative geometry at the given TPI time.

CDH (Constant Differential Altitude)

A CFP rendezvous routine which achieves a constant differential altitude orbit relative to the passive vehicle's orbit. Given both vehicle state vectors, the routine computes:

- 1) The active vehicle state vector at the CDH time.
- 2) The passive vehicle radial rate, \dot{r} , and position vector magnitude, r_P , when r_P is aligned with r_A given in 1).
- 3) The passive vehicle semi-major axis, A_P .

To provide the impulsive velocity correction such that the following two equalities are realized:

$$a) \quad A_A = A_P - (r_P - r_A)$$

$$b) \quad \dot{r}_A = \dot{r}_P \left(\frac{A_P}{A_A} \right)^{3/2}$$

TPI (Transfer Phase Initiation)

See CMC definitions

Midcourse

See CMC definitions

TPI Search

See CMC definitions

III NAVIGATION ROUTINES

Rendezvous Navigation

A routine to acquire and process RR tracking data to improve the selected vehicle's state vector. The routine is the primary navigation method for rendezvous.

This routine also controls the LM attitude about the line of sight such that the optical beacon can be seen by the CSM, and so that the RR angle relative to the LM + Z axis is less than 30° for RR bias angle estimation. The preferred tracking attitude routine can be separately called by a difficult program in the LM for those cases not involving RR tracking where CSM optical tracking is required.

RR Lunar Surface Navigation

A routine to acquire and process RR tracking data while the LM tracks the CSM overpass from the lunar surface to improve CSM state vector and/or landing site coordinates for launch time determination and rendezvous targeting.

Preferred Tracking Attitude

This routine commands the attitude of the LM so as to point the LM +Z axis along the estimated line-of-sight to the CSM. This preferred tracking attitude is required for RR designation and tracking, and to direct the LM optical beacon for CSM SXT tracking during free fall phases.

AOT Mark (Alignment, Optical Telescope Mark)

A routine which processes the Optical Marks, in two modes (Free Fall and Lunar Surface) and determines the star location in the IMU Stable Member Coordinate System. This routine performs an averaging function on star data.

Radar Test

A routine which reads the data from the Landing and Rendezvous Radar System during self test of these systems. Data is downlinked and displayed.

RR Search, Designate and Read

1. RR Search Routine

This routine commands the rendezvous radar in an angular search pattern about the estimated line-of-sight to the CSM. The routine may be used by the astronaut if there is failure to achieve target acquisition with the Radar Designate Routine.

2. RR Designate Routine

This routine commands the rendezvous radar along the estimated line-of-sight to the CSM for target acquisition.

3. RR Read Routine

This routine periodically obtains data (range, range rate, and line-of-sight angles) from the rendezvous radar. The routine insures that the RR data is not read or used to update the navigation equations unless certain conditions (data good, etc.) are met with regard to using the rendezvous radar for rendezvous navigation.

IV POWERED GUIDANCE ROUTINES

Cross-Product Steering

See CMC definitions

Velocity To Be Gained

A routine to compute the velocity-to-be-gained vector in the following two operation modes:

1. Lambert Aim Point Maneuver Guidance Maneuvers.
2. Descent Orbit Injection (DOI) Maneuver Guidance Maneuvers.

Servicer

See CMC definitions

Desired Thrust Direction

See CMC definitions

Time of Burn Calculation

See CMC definitions

V IMU AND OPTICS ROUTINES

IMU Compensation

See CMC definitions

IMU Status Check

See CMC definitions

Course Align

See CMC definitions

Fine Align

See CMC definitions

Automatic Optics Positioning

A routine which controls the orientation of the vehicle to point the Optical Telescope in a desired direction.

Pick A Pair

See CMC definitions

Star Data Test

See CMC definitions

IMU Mode Switching

See CMC definitions

Anytime Launch Alignment

A routine which provides the "quick" alignment from stored CDU angles at landing plus any alignment correction due to lunar stay time.

Star Catalog

See CMC definitions

VI DISPLAY AND KEYBOARD ROUTINES

All same as CMC

VII INTERPRETER AND EXECUTIVE ROUTINES

All same as CMC

VIII OTHER ROUTINES

DAPS (Digital Autopilots)

1. P - Axis RCS Provide control around the vehicle X axis using RCS jets to hold the attitude within $\pm .3$ degree or ± 5 degrees (as selected by astronaut).
2. Q-R Axes RCS Provide control around the vehicle Y or Z axes using RCS jets. Holds attitude and satisfies attitude commands in powered and coasting flight phases.
3. Kalman Filter & GTS During powered descent provides control around the vehicle Y and Z axes using the Gimballed descent engine. Limited control in this mode minimizes propellant consumption.
4. SPS Backup Provides control of the combine LM-CSM in event of SP5 failure.
5. Rate Command A submode of the LM Digital Autopilot which permits astronaut control via the hand controller. Operational only in the attitude hold position of the SCS Mode Switch.
6. X Axis Override Allows astronaut control of rotation about the X axis in all modes up to the visibility phase.
7. X-Y-Z Translation In attitude hold mode, astronaut can control vehicle translation using the RCS.
8. Minimum Impulse Mode DSKY selected sub-mode which causes a 14 ms RCS jet firing about an astronaut-selected axis. Uses the hand controller as an input.
9. Rate of Descent Permits astronaut control of the velocity along the local vertical by ± 1 foot per second increments.

Transformations

See CMC definitions

Gyro Torquing

See CMC definitions

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LMC PROGRAM DESCRIPTIONS

P-00 LGC Idling

P-01 LGC Initialization

This program sequences the DSKY operations which provides the following:

- 1) Synchronization of the LGC clock with the CMC clock (G. E. T.)
- 2) CSM-LM state vector
- 3) Lunar landing site position vector
- 4) Ephemeris time defined as the time between zero GET and 1 July of the reference Besselian year.

P-02 AGS Initialization

This program commands a special down telemetry list from which the Abort Guidance System computer (AEA) is initialized. This special downlink list consists of the CSM and LM state vectors (position and velocity) with reference times modified by a time bias established at the start of the AGS initialization procedure.

P-05 LGC Start Up (See CMC)

P-06 PGNCS Power Down (See CMC)

P-07 System Test (See CMC)

P-10 Predicted Launch Time (CFP)

This program computes the launch time based on the CFP rendezvous profile by iterating on the desired constant differential altitude, Δh , at the CDH maneuver point. This launch time is also required for PGNCS and AGS ascent alignment.

P-11 Predicted Launch Time (TPI) Program

Computes the launch time for a rendezvous profile in which the TPI maneuver is to be initiated as soon as possible after ascent injection to achieve a "quick" return to the CSM.

P-12 Powered Ascent Guidance

This program controls the LM powered ascent maneuver.

P-17 TPI Search Targeting

(See CSM)

P-20 Rendezvous Navigation

This program controls the rendezvous navigation process including rendezvous radar (RR) tracking data processing for state vector updating and LM attitude control to meet RR and light beacon orientation requirements.

P-21 Ground Track Program (See CSM)

P-22 RR Lunar Surface Navigation

This program controls the RR Lunar Surface Navigation Routine to process RR tracking data of the CSM prior to launch.

P-25 Preferred Tracking Attitude

This program is used to control the LM +Z axis to within 30° of the estimated line of sight so that the CSM can track the LM optical beacon. The program is used when P-20 is not desired, such as in the case of a RR failure.

P-30 External ΔV Pre-Thrust (See CMC)

P-32 CSI Pre-Thrust

This program uses the Concentric Sequence Initiation routine to determine the required vector velocity for the first maneuver of a CFP rendezvous profile.

P-33 CDH Pre-Thrust

This program controls the Constant Differential Altitude routine to establish an orbit at an essentially constant altitude above or below the CSM orbit prior to the TPI maneuver.

P-34 TPI Pre-Thrust (See CMC)

P-35 TPM Pre-Thrust (See CMC)

P-36 TPF Maneuver

This program maintains the estimate of the LM state vector during the manual terminal rendezvous maneuver, and calls the Rendezvous Parameter Display routine to display range, range rate and angle Θ .

P-40 DPS Thrust

This program controls the LM Descent Propulsion System (DPS) maneuvers nominally targeted from P-30, P-32, P-33, P-34 for abort rendezvous cases.

P-41 RCS Thrust

This program controls LM RCS maneuvers nominally targeted from P-30, P-32, P-33, P-34, and P-35.

P-42 APS Thrust

This program controls LM Ascent Propulsion System (APS) maneuvers which could be targeted from P-30, P-32, P-33, P-34 and P-35 if APS propellant is available.

P-47 Thrust Monitor (See CMC definition)

P-51 IMU Alignment Determination (See CMC)

P-52 IMU Realignment (See CMC)

P-55 IMU Surface Alignment (Normal)

This program aligns the LM IMU on the lunar surface using two star sightings with the AOT.

P-56 IMU Surface Alignment (Back-up)

This program aligns the LM IMU on the lunar surface in the case of AOT failure (no star visible) by leveling the IMU using the accelerometers and driving azimuth to a prestored value at landing or a direction found by sighting on the sun.

P-57 Any Time Launch Alignment

This program performs a course IMU alignment by driving the IMU gimbal angles to values derived from the angles stored soon after landing. Azimuth is corrected for lunar stay time. This program is only used in time critical launch cases in which a normal alignment (P-55) could not be completed.

P-60 Predicted Landing Time

This program uses the Predicted Landing Time routine to determine the nominal lunar landing time, the LM IMU descent alignment, the nominal ignition time for the landing maneuver, and the desired DOI injection time.

P-61 DOI Pre-Thrust

This program determines the LM descent orbit injection (DOI) maneuver parameters to establish the Hohmann descent trajectory. It then controls the IMU realignment to the landing orientation, the attitude maneuver to the ignition attitude and the countdown, ignition, thrusting and cut-off of the DOI Maneuver.

P-63 Landing Braking

This program controls the lunar landing pre-ignition calculations, the IMU realignment to the landing orientation, the attitude maneuver to the ignition attitude, and the countdown, ignition and thrusting of the powered maneuver to Hi Gate.

P-64 Landing Approach

This program controls the landing final approach or visibility phase from Hi Gate to Low Gate.

P-65 Landing (Automatic)

This program automatically controls the terminal landing maneuver from Low Gate to DPS shut-off upon landing on the moon.

P-66 Landing (Rate of Descent)

This program controls a landing maneuver in which the DPS throttle is LGC controlled to maintain a desired vertical rate of descent while the astronaut manually controls the LM attitude.

P-67 Landing (Manual)

This program maintains the LM state vector estimation by IMU and LR data while the vehicle attitude and DPS throttle are under astronaut manual control for a landing maneuver.

P-70 DPS Abort

This program controls the abort sequence, guidance and displays for DPS abort from the powered landing maneuvers.

P-71 APS Abort

This program controls the abort sequence guidance and displays for APS abort from the powered landing maneuvers.

P-72 CSI Pre-Thrust (CSM)

This program is used to compute a CSI maneuver for a CSM retrieval profile.

P-73 CDH Pre-Thrust (CSM)

This program is used to compute a CDH maneuver for a CSM retrieval profile.

P-74 TPI Pre-Thrust (CSM)

This program is used to compute a TPI maneuver for a CSM retrieval.

P-75 TPM Pre-Thrust (CSM)

This program is used to compute a CSM rendezvous midcourse correction maneuver.

P-76 TEI Back-Up

This program uses the Lambert Aim Point Pre-Thrust routine to control an SPS back-up maneuver for trans-earth injection (TEI). This Program is targeted from the CMC Return to Earth program (P-37) or the RTCC.

R-30 Orbit Parameters

(See CMC definitions)

R-31 Rendezvous Parameters

(See CMC definitions)

R-32 Target ΔV

(See CMC definition)

APPENDIX G
LGC PROGRAM/ROUTINE
RELATIONSHIP AND SIZES

LGC PROGRAM / ROUTINE RELATIONSHIPS & SIZES

MARCH, 1967

LCC CONTROL PROGRAMS	AS-204		AS-206		TOTAL
	APR 204	APR 206	APR 204	APR 206	
LCC ROUTINES					
CONTROL PROGRAMS					
BASIC ROUTINES					
Bank Subroutines					
Orbital Integration					
Lk. Comp. AC					
Lunar & Solar Eph					
Lunar Elevation					
Initial Velocity					
Redundant Parameters					
Maneuver Spectr. (R10, R20)					
Maneuver Calculation					
Maneuver Calc. Display					
Bank Subroutines					
TARGETING					
PLUT (Pred. Lmid Time)					
D00					
PURP (C/P)					
PURP (P/T)					
C51					
C24					
P21					
Maneuver Manuever					
NAVIGATION					
Redundant					
R8 Lunar Surface					
Max. Inertia					
Pre. Track Adj. (R11)					
ADT Murt					
Star Test					
R8 Search Box, Bank, R11, R10					
POWERED GUIDANCE					
Cross Product Steering					
V8 DMK					
Servitor					
Devised Thrust Dir.					
Time of Burn Calc.					
IMU & OPTICS					
IMU Compensation					
IMU Status Check (R22)					
Course Align Cal. S1A					
Five Align (R51)					
Audi Optics (R52)					
Pick-N-Pole					
Star Data Test (R54)					
IMU Moon Switch					
Any Time Align					
Star Catalog					
LCC CONTROL PROGRAMS					
P00 LCC Testing					
P02 AOS Initialization					
P04 Lunar Surface Checkout					
P06 LCC Power Down					
P08 Systems Test					
P10 Predicted Launch Time (C/P)					
P11 Predicted Launch Time (P/T)					
P12 Power Axioms Guidance					
P17 Search					
P20 Redundant Navigation					
P21 Ground Track Determination					
P22 R8 Lunar Surface Navigation					
P23 Predicted Tracking Attitude					
P25 Guide Program					
P30 Error AV Prediction					
P32 CS1 Prediction					
P33 COH Prediction					
P34 TPI Prediction					
P35 TPA Prediction					
P40 OPS Thrust Prog.					
P41 RCS Thrust Prog.					
P42 APS Thrust Prog.					
P47 Thrust Monitor					
P50 Data IMU Align					
P51 IMU Orientation Determination					
P52 IMU Heading					
P53 IMU Heading Backup					
P54 Lunar Surface Align (Post Landing)					
P55 Lunar Surface Align (Pre-Flight)					
P56 Lunar Surface Align (Backup)					
P57 Any Time Launch Align					
P60 Predicted Launch Time					
P61 D01 Manuever					
P63 Landing Bearing					
P64 Landing Approach					
P65 Landing Lvlts					
P66 Landing Manual					
P70 DPS Abort					
P71 APS Abort					
P72 CS1 (CSMU)					
P73 COH (CSMU)					
P74 TPI (CSMU)					
P75 TPA (CSMU)					
P76 Transmittance Input (TPI) Backup					
P83 Load OAP Data					
P84 88 Star Test					
P85 5-Star Printing					
P86 OPA Parameter Display					
P87 Redundant Parameter Display					
P88 Target AV					
P89 CMC/ACC Check Sync					
P92 Crew Diring Manuevers					

112

* No estimate of storage available.

AS-204 AS-206
740 3000
694 1000
80 40
639 700
157 500
202 200
114 200
271 2771
220 220
312 335
111 300
175 180
306 310
138 138
67 1000
72 72
72 72
98 68
58 58
52 52
211 250
128 36
428 4100
360
81 85
40 44
TOTAL 1527 1020
GRAND TOTAL 3198 3297
PAD REMAINING 686 -43

DAYS
LM Flight Control System Test
Transformations
Ops Targeting (R53)
TOTAL 1527 1020
GRAND TOTAL 3198 3297
PAD REMAINING 686 -43

OTHER
DAYS
LM Flight Control System Test
Transformations
Ops Targeting (R53)
TOTAL 1527 1020
GRAND TOTAL 3198 3297
PAD REMAINING 686 -43

INTERP & DEC
Interpreter
Reboot
Executive
Phase Table
Restart Control
Fresh Start & Restart
Phase Change & Test Change
TP1 Prnt
Alert & Abort
Self Check
Interbank Communications
Interrupt Test In
RTB OP Codes
End Bank Marks
TOTAL 1527 1020
GRAND TOTAL 3198 3297
PAD REMAINING 686 -43

DAYS
LM Flight Control System Test
Transformations
Ops Targeting (R53)
TOTAL 1527 1020
GRAND TOTAL 3198 3297
PAD REMAINING 686 -43

APPENDIX H
LGC PROGRAM UTILIZATION

LGC PROGRAM UTILIZATION AS-504

March, 1966

MISSION PHASES LGC CONTROL PROGRAMS	LGC PROGRAM UTILIZATION AS-504																																																							
	P00	P02	P04	P05	P06	P10	P11	P12	P17	P20	P21	P22	P25	P27	P30	P31	P32	P33	P34	P35	P40	P41	P42	P47	P50	P51	P52	P53	P57	P60	P61	P63	P64	P65	P66	P67	P70	P71	P72	P73	P74	P75	P76	P77	R03	R04	R05	R30	R31	R32	R33	R34				
1. Lunar Orbit (Pre DOI)	✓								✓																✓	✓																														
2. DOI and Descent Coast	✓								✓																✓	✓																														
3. Powered Lunar Landing Maneuver	✓								✓																	✓	✓																													
4. Lunar Surface Phase	✓								✓																✓	✓																														
5. Lunar Prelaunch Phase	✓								✓																	✓	✓																													
6. Powered Ascent Phase	✓								✓																	✓	✓																													
7. Rendezvous (LM Active-Self Contained)																										✓	✓																													
8. Rendezvous (LM Active-External Calc)																										✓	✓																													
9. Rendezvous (CSM Active-LGC Passive)																										✓	✓																													
10. Rendezvous (CSM Active-LGC Calc)																										✓	✓																													
11. Trans Earth Injection (TEI) Backup																										✓	✓																													
12. Descent Orbit Abort (DORA-Self Contained)																										✓	✓																													
13. Descent Orbit Abort (DORA-Ext Calc)																										✓	✓																													
14. Powered Landing Aborts*																										✓	✓																													
15. AGS Aborts*																										✓	✓																													
16. Aborts from Translunar (Prethrust & Maneuver)																											✓	✓																												

* Refer to Items (7) - (10) for subsequent rendezvous.

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