

APOLLO

GUIDANCE, NAVIGATION AND CONTROL

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APOLLO GUIDANCE AND NAVIGATION PROGRAM

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E-1142
(Rev. 61)

SYSTEM STATUS REPORT

MAY 1969

MIT

**INSTRUMENTATION
LABORATORY**

CAMBRIDGE 39, MASSACHUSETTS

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The publication of this report does not constitute approval by the National Aeronautics and Space Administration of the findings or the conclusions contained therein. It is published only for the exchange and stimulation of ideas.

SYSTEM STATUS REPORT

ABSTRACT

The System Status Report is distributed quarterly. The areas of activity reported on in this revision include, but are not limited to, the following for the Block II Command Modules and Lunar Module equipment: reliability failure rates, computer programming status, and G&N status.

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.

NOTICE

MIT/IL feels that the System Status Report (E-1142) has served its purpose. Unless there is sufficient response from the distribution requesting continuation, this will be the final issue of this report.

TABLE OF CONTENTS

<u>Section</u>		<u>Page</u>
1	Reliability - Failure Rates	1-1
2	Guidance and Navigation Systems Status	2-1
3	G&N System Test	3-1
4	G&N Computer Status	4-1
5	Guidance Computer Programming	5-1
6	List of "E" and "R" Notes Published During Reporting Period	6-1

INTRODUCTION

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

Section 1	Reliability - Failure Rates
Section 2	Guidance and Navigation Systems Status
Section 3	G&N System Test
Section 4	G&N Computer Status
Section 5	Guidance Computer Programming
Section 6	List of "E" and "R" Notes Published During Reporting Period

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

All Tables, Graphs and Schematics are dated as of their last revision.

SECTION 1

RELIABILITY - FAILURE RATES

The current status of reliability analysis is reported in summary form in Table 1.1. This table 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 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.

TABLE 1.1 G&N MISSION RELIABILITY ANALYSIS

FAILURE RATES EXPRESS IN "FAILURES PER 10⁶ HOURS"

MISSION	IMU Assembly		IMU Electronics (PSA)		Optics Assembly		Optics Electronics (PSA)		IMU CDU		Optics CDU		ACC		DSKY		D&C		Mission Reliability
	ON	STBY	ON	STBY	ON	OFF	ON	OFF	ON	STBY	ON	OFF	ON	STBY	ON	OFF	ON	OFF	
CM	13.8	55.6	13.8	55.6	9.1	60.3	9.1	60.3	13.8	55.6	13.8	55.6	13.8	55.6	13.8	55.6	13.8	55.6	0.9840
DES REF	λ	129	10.2	110	6.3	94	77	-	155	-	91	-	235	60.5	2.3	-	2.3	-	
LM	3.25	66.3	3.25	66.3	3.25	-	3.25	-	3.25	-	3.25	-	3.25	-	3.25	-	3.25	-	0.9969
DES REF	λ	129	1.6	110	-	38	-	1.33	155	-	112	-	235	-	110	-	1.2	-	

DATE: 1 October 1968

SECTION 2

GUIDANCE AND NAVIGATION SYSTEMS STATUS

The status of delivered G & N Systems are shown in tabular form. Table 2.1 shows the status of G & N Systems progressing from installation to final test at KSC.

Table 2.2 shows the configuration for major units comprising the G & N Systems assigned to LM-7 and subsequent LM Vehicles at GAEC.

Table 2.3 shows the configuration for major units comprising the G & N Systems assigned to CM-109 and subsequent Command Modules at NAR.

Table 2.4 shows the configuration for major units comprising the G & N Systems at KSC.

TABLE 2.1 DELIVERED G&N SYSTEM STATUS

OPERATION	LOCATION									
	GAEC		NAR		KSC					
	LM-7 System 610	LM-8 System 611	CM-109 System 212	CM-110 System 214	CM-106 System 206	CM-107 System 210	CM-108 System 211	LM-4 System 606	LM-5 System 609	LM-6 System 607
INSTALLATION	X	X	X	X	X	X	X	X	X	X
SUBSYSTEM CHECKOUTS/C	X		X		X	X	X	X	X	X
INTEGRATED TEST S/C					X	X	X	X	X	X
COMPLETE TESTING AT KSC										

DATE: 1 April 1969

1. CM-107, G&N System 210, completed all G&N testing at S/C contractors and vehicle was shipped to KSC on 22 January 1969.
2. CM-108, G&N System 211, completed all G&N testing at S/C contractors and vehicle was shipped to KSC on 28 March 1969.
3. CM-104, G&N System 209, successfully completed Apollo Mission 9 on 13 March 1969.
4. LM-3, G&N System 605, successfully completed Apollo Mission 9 on 13 March 1969.
5. LM-5, G&N System 609, completed all G&N testing at S/C contractors and vehicle was shipped to KSC on 8 January 1969.
6. LM-6, G&N System 607, completed all G&N testing at S/C contractors and vehicle was shipped to KSC on 24 March 1969.

TABLE 2.2 LM G&N SYSTEM CONFIGURATION

S/C	LM-7		LM-8	
COMPONENT NOMENCLATURE	System 610		System 611	
	Part Number	S/N	Part Number	S/N
LGC	2003993-031	46	2003993-031	49
DSKY	2003994-071	61	2003994-091	96
IMU	2018601-221	28	2018601-221	37
ECDU	2007222-241	37	2007222-221	26
AOT	2011000-111	20	2011000-111	21

DATE: 1 April 1969

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

LM-5, G&N System 609

Vehicle was shipped to KSC on 8 January 1969.

LM-6, G&N System 607

A - DSKY part number 2003994-051 updated to -091. Incorporated ECP adding ALT-VEL legends on IL panel and change to increase safety margin of E/L panel.

B - AOT part number 20011000-081 updated to -111. Addition of AOT harness protective shield.

C - Vehicle shipped to KSC on 24 March 1969.

LM-7, G&N System 610

A - DSKY part number 2003994-051 updated to -071. Incorporated ECP adding ATL-VEL legends on IL panel.

B - IMU changed from part number 2018601-221 S/N 37 to S/N 28. IMU changed due to Y-PIPA O. O. S. condition.

TABLE 2.3 CM G&N SYSTEM CONFIGURATION AT NAR

S/C	CM-109		CM-110	
COMPONENT NOMENCLATURE	System 212		System 214	
	Part Number	S/N	Part Number	S/N
AGC	2003993-031	38	2003993-031	35
DSKY (Main)	2003994-051	72	2000994-051	77
DSKY (Navigation)	2003994-051	79	2003994-051	69
IMU	2018601-231	29	2018601-231	34
CDU	2007222-231	42	2007222-231	39
OPTICS	2011000-081	18	201000-081	21

DATE: 1 April 1969

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

CM-107, G&N System 210

Vehicle shipped to KSC on 22 January 1969.

CM-108, G&N System 211

Vehicle shipped to KSC on 28 March 1969.

CM-109, G&N System 212

- A - AGC part number 2003993-031, S/N 50 replaced with S/N 38. Computer changed due to restart and lock-up. Computer returned to Raytheon.
- B - DSKY (NAV) part number 2003994-051, S/N 51 replaced with S/N 79. DSKY changed when gimbal lock light became inoperative.

TABLE 2.4 G&N System Configuration at KSC

S/C COMPO- NENT NOMEN- CLATURE	CM-106		CM-107		CM-108		LM-4		LM-5		LM-6							
	System 206	Part Number	S/N	System 210	Part Number	S/N	System 211	Part Number	S/N	System 606	Part Number	S/N	System 609	Part Number	S/N	System 607	Part Number	S/N
AGC	2003993-041	40	2003993-031	44	2003993-031	34	2003993-031	31	2003993-031	42	2003993-031	45	2003993-031	42	2003993-031	45	2003993-031	45
DSKY (Main)	2003994-121	43	2003994-121	53	2003994-051	67	2003994-121	65	2003994-091	54	2003994-121	56	2003994-091	54	2003994-091	56	2003994-091	56
DSKY (Nav)	2003994-121	62	2003994-121	66	2003994-051	74												
IMU	2018601-231	45	2018601-231	17	2018601-231	20	2018601-221	27	2018601-221	32	2018601-221	33	2018601-221	32	2018601-221	33	2018601-221	33
CDU	2007222-181	22	2007222-231	40	2007222-231	41	2007222-241	38	2007222-241	31	2007222-241	32	2007222-241	31	2007222-241	32	2007222-241	32
OPTICS	2011000-071	22	2011000-081	20	2011000-081	26	6011000-111	16	6011000-111	15	6011000-111	19	6011000-111	15	6011000-111	19	6011000-111	19

Note: Listing will be revised if major units are changed. Explanatory notes will describe reason for change. DATE: 1 April 1969

LM-3, G&N System 605

Successfully completed Apollo Mission 9 on 13 March 1969.

LM-4, G&N System 606

DSKY part number 2003994-051 updated to -121. Incorporated aluminum pushbutton caps and redesigned leaf springs in cap housings; change to increase safety margin of E/L panel.

TABLE 2.4 (Cont.)

LM-5, G&N System 609

DSKY part number 2003994-051 updated to -091. Incorporated ECP; ALT-VEL legend on I/L panel.

CM-104, G&N System 209

A - IMU part number 2018601-201, S/N 22 replaced with 2018601-231, S/N 14, ADIA "x" O. O. S.

B - Successfully completed Apollo Mission 9 on 13 March 1969.

CM-106, G&N System 206

A - IMU part number 2018601-201, S/N 24 replaced with 2018601-231, S/N 45. RRT noise on 28 volt S/C bus caused I, M, and O gimbal servo error and torque motor current measurements to be erratic.

B - DSKYs part numbers 2003994-051 updated to -121 incorporated ECP's adding ALT-VEL legends on I/L panel and change to increase safety margin of E/L displays. Incorporated aluminum push-button caps and redesigned leaf springs in cap housings.

CM-107, G&N System 210

A - DSKYs part number 2003994-051 updated to -121 incorporated ECP's adding ALT-VEL legends on I/L panel and change to increase safety margin of E/L displays. Incorporated aluminum push-button caps and redesigned leaf springs on cap housings.

B - IMU part number 2018601-231, S/N 30 replaced with 2018601-231, S/N 17. Scale factor shift, Y PIPA O. O. S.

SECTION 3

G&N SYSTEM TEST

SYSTEM TEST LABORATORY

A. G&N 5

No operating hours.

B. G&N 104

No operating hours.

C. G&N 200

1. Program Tests

- a. Level .3 and level 5 testing of COMANCHE Rev. 45 was completed.
- b. Continued checkout of Sunflight test for S/C 104.
- c. Performed a special test of "S/C Control of Saturn" program.
- d. Performed preliminary testing of a special STARTRAK program. STARTRAK is a modification of COLOSSUS 249 to provide automatic IMU realignment with the star tracker.
- e. Supported Apollo 9 flight.
- f. Verified the following K-START tapes for use with program assemblies indicated.

SUNDISK

FO8C101-K00089-00

PIPA Bubble Test

SUNDANCE

FO7L003-K00067-07-13

Launch Load

COLOSSUS IA

FO9C104-K00067-02-15

Launch Load

FO9C104-K00079-01
FO9C106-K00079-00
FO9C106-K00078-00
FO9C106-K00091-00
FO9C106-K00068-00
FO9C106-K00067-00

TVC/RCS DAP Polarity Test
TVC/RCS DAP Polarity Test
Simflight Test
VHF Ranging Test
Mission Load
Launch Load

COLOSSUS II

F11C106-K00083-00
F11C106-K00081-00
F11C106-K00079-00
F11C106-K00093-00
F11C106-K00078-00
F11C106-K00094-00
F11C106-K00068-00
F11C106-K00067-00

IRIG Scale Factor Test
IMU Performance Test
TVC/RCS DAP Polarity Test
G&N/Launch Vehicle Polarity Test
Simflight Test
Simflight Test (ABRV. G&N LV)
Mission Load
Launch Load

LUMINARY

F10L004-K00068-02
F10L004-K00067-02

Mission Load
Launch Load

2. Hardware Test

- a. Investigated and verified reason for CDU trunnion problem which occurred during Apollo 8 flight.
- b. Measured harmonic content of all IMU and Optics resolver primary and secondary windings. Results published in STG Memo No. 1321.
- c. Checkout of Restart Monitor Module was satisfactory.
- d. In support of a field problem with G&N 216 at NAR, set up and tested system response to noise on CDU ZERO line from computer to CDU. Report presently being written.

3. Failures

- a. Replaced IMU thermostat. Low temperature alarm thermostat was open.
- b. Replaced the #1 button on DSKY S/N 17. Failure was due to fracture of the old style spring that is in all STG DSKY's.
- c. Y PIPA bias exceeded compensation limits. S/N 113 was replaced with S/N 183. Removal of Y PIPA required replacement of the following:

AC DIFF AMP
DC DIFF AMP
BINARY CUR SW
CALIB MOD

S/N 259 with S/N 258
S/N 259 with S/N 201
S/N 253 with S/N 263
S/N 251 with S/N 256

4. Modifications

a. CMC Standby Push Button updated to Standby/PROCEED operation.

D. G&N 600

1. Program Tests

a. Completed LUMINARY Level 5 tests on Rev. 69.

b. Performed various tests of flagword bits status on Core Rope Simulator for KSC.

c. Ran P 57 checkout of AOT functional accuracy test for KSC.

d. Ran P 51 test to be used on LM-5 in the VAB. The test uses only one target during an optical alignment in an AOT functional accuracy test.

e. Continued development of the LUMINARY Level 5 DAP Polarity Test.

f. Ran tests with Aurora 88 using flight tape patches for landing radar. The tests were performed using flight test data recorded at White Sands. Data evaluation will be made by Group 23N.

g. Conducted Level 3 STG verification tests on LUMINARY IA, Revisions 83 to 92.

h. Completed development of LUMINARY 69 Simflight.

i. Completed testing of RR#9 with DANCE 306 and LUMINARY IA.

j. Verified the following K-START Tapes for use with Program assemblies indicated:

SUNDANCE

F07L003-K00068-06-07

Mission Load

F07L003-K00067-06-07

Launch Load

COLOSSUS IA

F09C104-K00068-02

Mission Load

F09C104-K00067-02

Launch Load

LUMINARY

F10L004-K00061-00-01

IMU Performance Test

F10L004-K00083-00

IRIG Scale Factor Test

F10L004-K00082-00-01

AGS Initialization

F10L004-K00084-00

IMU/ASA Mechanical Alignment

F10L004-K00085-00

RCS/TVC DAP Polarity Test

F10L004-K00068-00-01

Mission Load

F10L004-K00067-00-01	Launch Load
F10L004-K00078-01	Simflight
F10L005-K00067-00	Launch Load
F10L005-K00078-00	Simflight
F10L005-K00068-00	Mission Load
F10L005-K00085-00	RCS/TVC DAP Polarity Test
F10L005-K00095-00	LR Data Accuracy Read Routine

2. Hardware Tests

- a. Continued testing the Auxiliary Memory Unit. The erasable program is now operating using DANCE 306 and AMDANCE Rev. 10.
- b. Ran a Transient Response test of current and voltage variations in the Standby bus return lines for MSC. Transient current flow (150-200 ma peak) can occur in LM structure due to voltage step changes occurring when heater power is switched on or off.
- c. Removed IMU from ROTAB and mounted it on RR frame. Installed new flight RR Electronics Assy #9, and Antenna Assy #7 from RCA on the same fixture.
- d. Ran a series of tests to evaluate Radar Designation and Search with various simulated gyro failures. The tests were run with DANCE 306 to support the Apollo 9 mission. Test data was forwarded to MSC.

FIELD OPERATIONS

A. GAEC

1. LM-5 (Mission AS 506) G&N System 609
Shipped to KSC.
2. LM-6 (Mission AS 507) G&N System 607
Completed FEAT testing, OCP 61018. Vehicle shipped to KSC.
3. LM-7 (Mission AS 508) G&N System 610
Completed Individual System Test, OCP 62000.
4. LM-8 (Mission AS 509) G&N System 611
Completed system installation in the Spacecraft.

B. KSC

1. S/C 104 (Mission 504) G&N System 209 - Apollo 9
Completed Flight Readiness Test, TCP-K-0028. Completed Apollo 9 flight on 13 March 1969.

2. S/C 106 (Mission AS 505) G&N System 206
Integrated test, TCP-K-0005 and all VAB testing have been completed. Spacecraft located at LC.
3. S/C 107 (Mission AS 506) G&N System 210
Completed abbreviated Combined Systems Test. TCP-K-0070 and Altitude Chamber Test, TCP-K-0034.
4. LM-3 (Mission AS 504) G&N System 605 - Apollo 9
Completed Flight Readiness Test, TCP-K-0005. Completed Apollo 9 flight on 13 March 1969.
5. LM-4 (Mission AS 505) G&N System 606
Combined Systems Test, TCP-K-0033 and all VAB testing have been completed. Spacecraft located at LC.
6. LM-5 (Mission AS 506) G&N System 609
Completed Combined Systems Test. TCP-K-0039 and Altitude Chamber Test, TCP-K-0013.

C. MSC

1. Completed analysis of Apollo 8 post flight data.
2. Monitored Simflights.
3. Supported Apollo 9 Mission.
4. Analyzing Apollo 9 post flight data.

D. NAR

1. CM-107 (Mission AS 506) G&N System 210
Vehicle shipped to KSC.
2. CM-108 (Mission AS 507) G&N System 211
Vehicle has completed all tests at NAR and was shipped to KSC.
3. CM-109 (Mission AS 508) G&N System 212
Individual Systems Test, OCP 6504; Integrated Test, OCP 131; and Combined System Test, OCP 126 have been completed.
4. CM-110 (Mission AS 509) G&N System 214
Phase III installation and Individual System Test. OCP 6504 have been completed.

5. CM-III (Mission AS 510) G&N System 215
Completed Phase III installation.

SYSTEM ENGINEERING

A. Program Testing

1. SUNDANCE

- a. Supported testing of the SUNDANCE 306 program with the flight type radar.
- b. Testing was performed on radar and optics routines in line with the additional LUMINARY test requested by NASA.

2. COLOSSUS

- a. The Colossus II Level 3 testing has been completed. Level 5 testing is complete except for the optics operational programs. Level 3 documentation has been completed and Level 5 documentation is 50% complete.
- b. COLOSSUS IIA testing has not begun. A limited effort is planned.
- c. A special program for computing shaft and trunnion during tests of the prelaunch alignment verification was completed. (STG Memo. No. 1314.)

3. LUMINARY

- a. The LUMINARY I Level 5 testing has been completed. Documentation was completed except for tests of P52 and P57 (AAP3, AAP4 and AAP7). The report on P57 (AAP7) will not be issued since this program is not in the mission for which LUMINARY I is planned and significant changes were made in LUMINARY IA.
- b. LUMINARY IA Level 3 testing has been completed except for 7 of 16 radar (RP) tests. Documentation on all but 5 of the completed tests is complete.

4. SFRR

The Mission D SFRR was supported and preparation for support of Mission D was initiated.

B. S/C Test Programs

1. Changes have been made to the GAP assembler and the new K-START generation program. These changes will allow all necessary information for the generation of K-START tapes to be stored on one magnetic tape instead of approx-

imately 15 tapes previously required.

2. Segments were generated for the COMANCHE IMU Performance Test and the IRIG SF Test. K-START tapes were generated and verified.
3. Segments were generated for the LUMINARY IA IMU Performance Test and the IRIG SF Test. K-START tapes were generated and verified.
4. STG Memo. No. 1297 was distributed describing XSM changes required for LUMAGS at other azimuths.
5. STG Memo. No. 1293 was distributed indicating a simplified method for performance of the AOT functional accuracy test.
6. Continued work on the PIPA bubble test.
7. A special landing Radar downlink program was checked out and debugged.

C. Flight Support

1. The Apollo 9 flight was supported with personnel at KSC, MSC and 24 hours a day at the MIT SCAMA room.
2. An analysis of the PIPA anomalies in Apollo 9 was performed and a report is being prepared. (STG Memo. No. 1326)
3. The planned use of P57 in the G Mission was analyzed particularly with regard to gyro drift measurements. Further work is required and a report is being prepared.

D. Miscellaneous

1. Supported testing of the effects of gyro failure modes with the flight type radar.
2. A program, STARTRAK, for use of a star tracker in the P52 alignment program was generated and is being debugged in the lab.
3. The work on CROSSLINK was supported and the implementation, impact on displays, and time sharing were investigated.

SIMULATION AND CHECKOUT

A. K-START Tape Verification on the Digital Simulation.

1. A one-for-one comparison of the plots and edited listings obtained from a digital simulation of the SUNDANCE 302, 292 and 306 LM RCS/TVC DAP Polarity Test have been compared with actual test results obtained at KCS on LM-3. These comparisons support the decision not to rerun a polarity test on LM-3 following installation of flight ropes.
2. The plots and edited listings from a digital simulation of the LUMINARY 69 RCS/TVC DAP Polarity Test have been provided to KSC.

3. The plots and edited listings obtained from digital simulations of the COLOSSUS 237 and COLOSSUS IA RCS/TVC DAP Polarity Tests have been provided to KSC for comparison with actual test results. A comparison of the COLOSSUS 237 simulation results with the COLOSSUS IA simulation results indicated that, in terms of the polarities, they are identical.
4. The simulation of SUNDANCE 306 K-START tapes provided by AC Electronics has been completed.
5. The capability to perform digital simulations of both CM and LM RCS/TVC DAP Polarity Tests is now fully operational. Edited listed and plotted results permit rapid test evaluation. These data are used to support test evaluation and the definition retest requirements at KSC. In addition, these simulation results are now being used to support test design, thus relieving required lab verification time.
6. The digital simulation of LUMINARY 69 K-START tapes provided by AC Electronics has been completed. (STG Memo. No. 1317.)
7. The digital simulation of COLOSSUS IA K-START tapes provided by AC Electronics has been completed. (STG Memo. No. 1324.)
8. COLOSSUS II K-START tapes provided by AC Electronics are currently being simulated.
9. RCS/TVC DAP Polarity Test K-START tapes provided to KSC to support LM and CM polarity tests have been simulated. The listed and plotted results are available.
10. The capability to simulate the G&N/LV Polarity Test K-START tape is being developed.

B. Test Design

1. Effective for CM-106 VAB testing (and all subsequent submittals of CM RCS/TVC DAP Polarity Test K-START tapes) a number of changes have been made in the RCS/TVC DAP Polarity Test. The Pitch and Yaw RCS tests were changed to incorporate the 7.25 degree offset angle between the vehicle body axes and the RCS DAP control axes. The DAP maneuver rate of the YAW RCS test was changed from 0.5 deg/sec to 0.4 deg/sec and the CDU incrementing portions of the Auto-Maneuvers were eliminated.
2. A new K-START tape has been provided for CM-106 VAB tests. This is for the VHF Ranging Test (F09C106-K00091-00). Subsequent revisions or new releases of this K-START Tape will be the responsibility of AC Electronics.

3. The AOT Functional Accuracy Test has been simplified to require only one target positioned in the portion of the field-of-view which overlaps for two detent positions. Running this test in the SLA with LUMINARY 69 ropes obviates the need for a special K-START tape loaded program to calculate angles.
4. A number of changes have been made to the TSCD to reflect actual test specifications for the CM RCS/TVC DAP Polarity Tests. These changes are consistent with actual test results and simulation results.
5. Two K-START tapes are being prepared to support Launch Vehicle Spacecraft Guidance Interface Testing. One of these tests is the polarity of IMU error signals to the engine actuators and the other is for an abbreviated simulated mission to test the takeover capability.
6. The G&N/LV Polarity Test and Simflight have been designed. The K-START tapes needed to perform these tests at KSC on CM-106 have been provided.
7. A LR Data Accuracy Read Routine has been designed to enable strobing of the Landing Radar at the flight strobe rate. A K-START tape needed to perform this function at KSC will be provided to support LM-5 tests in the VAR.
8. Several changes are now being considered for the IMU Performance Test. These would provide automatic calls to the specific downlist, and would add a routine to curve fit CDU data to provide an independent measure of gyro-drift. A decision on these proposed changes will be made early in April.
9. A new K-START tape is being designed to provide a Radar Simflight capability in the MSOB for LM-6 and subsequent vehicles. Previously this testing was supported with F10L004-K00078-01, the simulated mission tape.

C. K-START Tape Manufacture and Delivery

1. The following K-START Tapes have been manufactured and sold-off for use with ropes indicated:

SUNDISK 282

F08C101-K00089-01 PIPA Bubble Test

SUNDANCE 306

F07L003-K00067-06	Launch Load, LM-3 FRT
F07L003-K00068-06	Mission Load, LM-3 FRT
F07L003-K00067-07	Launch Load, LM-3 PAD
F07L003-K00068-07	Mission Load LM-3 PAD
F07L003-K00067-08-13	Contingency Launch Load , LM-3, PAD

COLOSSUS IA

F09C104-K00067-01	Launch Load, CM-104 FRT
F09C104-K00068-01	Mission Load CM-104 FRT
F09C106-K00079-00	RCS/TVC DAP Polarity Test, CM-106 VAR
F09C106-K00091-00	VHF Ranging Test, CM-106 VAR
F09C106-K00078-00	Simflight, CM-106 VAB
F09C104-K00067-02	Launch Load, CM 104, PAD
F09C104-K00068-02	Mission Load, CM-104 PAD
F09C104-K00067-03-08	Contingency Launch Loads, CM-104 PAD
F09C106-K00067-00	Launch Load, CM-106. VAR
F09C106-K00068-00	Mission Load, CM-106. VAB
F09C104-K00067-09-16	Final and Contingency Launch Loads, CM-104, PAD

COLOSSUS II

F11C106-K00081-00	IMU Performance Test Colossus II
F11C106-K00083-00	IRIG Scale Factor Colossus II
F11C106-K00079-00	RCS/TVC DAP Polarity Test, CM-106 PAD
F11C106-K00078-00	Simflight CM-106 PAD
F11C106-K00093-00	G&N/LV Polarity Test CM-106 PAD
F11C106-K00094-00	G&N/LV Simflight CM-106 PAD
F11C106-K00067-00	Launch Load CM-106 PAD
F11C106-K00068-00	Mission Load CM-106 PAD

LUMINARY 69

F10L004-K00081-00	IMU Performance Test
F10L004-K00082-00	AGS Initialization, Earth Orbit
F10L004-K00082-01	AGS Initialization, Lunar Orbit
F10L004-K00083-00	IRIG Scale Factor Test
F10L004-K00084-00	IMU/ASA Mech. Alignment Test
F10L004-K00085-00	RCS/TVC DAP Polarity Test
F10L004-K00067-00	Launch Load, LM-4 VAR
F10L004-K00068-00	Mission Load, LM-4 VAR
F10L004-K00078-00	Simflight, LM-4 VAB
F10L004-K00078-01	Simflight, LM-4, PAD
F10L004-K00067-01	Launch Load, LM-4, PAD
F10L004-K00068-01	Mission Load, LM-4, PAD
F10L004-K00081-01	IMU Performance Test
F10L005-K00085-00	RCS/TV DAP Polarity Test LM-5 VAR
F10L005-K00078-00	Simflight LM-5 VAB
F10L005-K00067-00	Launch Load LM-5 VAB
F10L005-K00068-00	Mission Load LM-5 VAB
F10L004-K00067-02	Launch Load LM-4 PAD
F10L004-K00068-02	Mission Load LM-4 PAD

2. One K-START Tape, the IMU Performance Test, is now being generated directly from segments. This has necessitated a slight change in the format of the K-START tape listing. Copies of the new listing format are being pro-

vided to all users. Other K-START tapes are also being converted to this new manufacturing concept.

TEST EQUIPMENT

A. Uplink-Downlink Timer

1. A change was made in the uplink-downlink timer to initiate downlink recording upon a reset command.
2. Increased downlink recording intervals have been provided. The laboratory is now capable of recording downlink for intervals up to five minutes at a pre-selected time.

B. Uplink Transmitter

The logic has been completely built and is approximately 40% checked out on the bench. The interface cables must still be fabricated. It is expected that the unit will be operational in the laboratory by late April.

C. Trace

1. The logic design has been completed. the wire wrap data has been generated. and the logic trays are at Gardner Denver for wire wrap. The wire trays are due back in mid-April.
2. All of the NAFI PC boards have been received and the finished NAFI assemblies should be completed in mid-April.
3. The Coroner front panels have been assembled and wiring is nearly complete.
4. Data has been generated to verify the 360 computer printout programs and is in the process of being coded.
5. Project documentation is proceeding satisfactorily.
6. In all, the major program delays and difficulties would appear to be in the past.

D. Equipment Breakdown

Equipment Breakdowns during January have included but are not limited to:

Oscillograph Console Plug-Ins	(5)
Tape Readers	(2)
Tape Perforator	(1)
Scope Plug-Ins	(2)
Commercial Counters	(3)
DAC Monitor	(1)
Coolant Pumps	(1)

Blowers	(2)
DVM	(3)
CRS	(2)

All of the equipment has been repaired. The frequency of failures indicates a need for review of our maintenance procedures and some special attention to having adequate spare parts on hand (especially long lead items). This area will receive special attention in the coming months.

E. DAC Monitor

The DAC Monitor was revised to provide a readout in degrees rather than volts.

F. Resolver Error Analysis

A study of rate induced quadrature error in resolvers was completed. The effect was shown to be negligible for present design.

MISCELLANEOUS

1. Submitted results of MIT review of KSC process specifications. (ND 1002379 and ND 1002380).
2. Supported LM and CM checkout coordination meetings.
3. A study of methods to optimize non-linear systems by the adjustment of a control function is underway. Techniques under study include transition matrix and steepest descent methods. True aim of these investigations is to provide enough information to write a computer program to determine a control function that provides an optimum solution to two point boundary value problems.
4. The launch of Apollo 9 was supported at KSC, MSC and MIT.
5. Presentation of system test activities and results was made to NASA at the Quarterly Status Review.
6. System integration problems and requirements for various improved subsystem designs were reviewed.
7. Two programs utilizing steepest descent and transition matrix techniques for the solution of two point boundary problems have been written. They are now being debugged and documented.
8. Prepared Engineering change proposals for Lunar Exploration Program hardware modifications.

SECTION 4

G&N COMPUTER STATUS

DESIGN ANALYSIS & SUPPORT

A. Analysis Facility Activities

The equipment continued to be used in support of the auxiliary memory tests in pursuant of the requirements of T. O. #36 and for testing of the Portafam Assembly of T. O. #37. The progress under both T. O. #36 and T. O. #37 is reported separately.

B. Design Support

1. The testing of rope modules in a computer while being subjected to thermal environment and vacuum environment has been introduced in order to detect failures of the nature that were detected during S/C testing, that is the failure due to slow diode switching and the workmanship failure in vacuum tests of LM4. To detect these failure modes requires continuous monitoring of the rope module as it is being subjected to changes in environmental conditions. The previous test procedure, using the module test station, checks the operation at the extremes of temperature but not during transition and had no requirement for vacuum testing. These new tests are being documented and will be released as a new Purchase Specification. In the interim all ropes are being tested to the requirements of the new documentation.
2. The EL light failure mechanism is the result of marginal glass strength when subjected to spacecraft environment of vacuum and high temperature. A design change to bond safety glass to the surface has been made and the qualification tests are completed. A separation of the safety glass and EL glass surface that occurred during the qualification tests was analyzed and corrective action taken in the process of bonding the glass. The separation is not considered serious since if it occurred in flight the panel is still functional.
3. A minor effort was expended working with a tiger team to investigate the flight failures in the Entry Monitoring System of the spacecraft. One of the meetings of the tiger team was attended, the second one could not be attended because of weather conditions.

4. The proposal to use modules from computers of the 2003200 configuration in computers of the 2003993 configuration was evaluated. Initially document changes in the 2003993 configuration was proposed to make the usage an either or type of configuration for the modules used. This was rejected at MIT because there is a reliability risk even though it may be difficult or impossible to identify the magnitude of the risk. The procedure that was finally adopted was to write a waiver identifying the use of the older module and stating the differences thus flagging and permitting the evaluation of each case individually when the use of the computer is known.

5. Several proposals for expanding the storage capability of the computer were studied. Two of these were carried to sufficient detail to make it possible for a preliminary cost proposal to be submitted. One proposal was to design an external black box using Apollo type modules which would have a capacity of 2K additional words of erasable storage. The second proposal was to redesign Tray B and increase the capacity of the erasable memory designed for the Portafam system.

C. Documentation

1. A new Purchase Specification for the sale of ropes was submitted to DRB and is being reviewed. This will include the new tests with the modules operating in a computer.

2. The documentation for the new EL light design and the various Purchase Specification changes were reviewed at DRB and passed.

D. Component Problems

Two computer failures (C-27 and C-34) have been analyzed. One failure (C-34) was the result of contamination in the flatpacks. This was verified by reproducing intermittent failures on the suspected module output during module vibration. The gate that was most likely the one with the contamination was opened accidentally before reliability analysis was performed thus destroying any evidence to confirm the failure. The other failure (C-27) was the result of bond failures of the type called gold rich. This type of failure mode is extremely serious and it is the first to be detected after computer sale. The history of this type failure mode is being reviewed again to see if there is anything significant about this particular failure. Some of the reports that deal with this subject are a Raytheon RAL Test File Report #2985 and MIT letter AG403-67. So far there are no new conclusions or recommendations that can be drawn.

SECTION 5

APOLLO GUIDANCE COMPUTER PROGRAMMING SUMMARY

MISSION "C PRIME" - COLOSSUS I (Rev 237) MANNED CSM WITH LUNAR CAPABILITY

In an historic first, this country sent men to the moon in Apollo 8 with MIT's Guidance, Navigation and Control System sharing in a remarkable performance of Apollo spacecraft, flight crew, and ground operations.

The liftoff of Saturn launch vehicle 503 occurred 7:50 am EST on 21 December 1968, and injected astronauts Borman, Lovell, and Anders in Spacecraft 103 towards the moon which they orbited ten times on Christmas Eve before returning to recovery in the Pacific on the morning of 27 December after a 147 hour flight.

Few problems and superb performance were experienced with the GN&C. Both the inertial subsystem and the computer were left operating the whole mission. The crew, using the optics, made periodic IMU alignment checks and many navigation measurements. For long periods of time the navigation state vector was kept up to date only by the on-board measurements. In a different location in the computer an MSFN ground tracking determined state vector was held and renewed periodically by up-telemetry. Although these two had no significant difference, mission control overwrote the on-board navigation data with the MSFN values before each maneuver so that they would be accomplished on the basis of the ground tracking initial conditions. All major maneuvers and entry were guided and controlled automatically by our system and monitored by the crew.

The inertial measurement unit was given two major realignments by crew star sightings to set up new preferred orientations, first for lunar operations and then for earth return. Many star sighting alignment corrections were performed, typically several hours apart and requiring correction angles of the order of only a few hundredths of a degree. These realignments gave the data required to check IMU drift for each of the three gyros. The drift was uniformly consistent and matched the low values measured on the ground before launch. Likewise, accelerometer output during free fall gave a most satisfying measure of accelerometer bias stability. Dr. Draper's prognosis of superior inertial component performance in space has surely been demonstrated.

The mission plan for translunar navigation was to (1) confirm the on-board navigation capability, (2) confirm independently that the lunar arrival would be safe, and (3) to calibrate Captain Lovell's use of the earth horizon as a navigation

target. Loss of communication would require on-board sightings alone to be used on the return to assure safe atmospheric entry.

The crew was aided in optics star acquisition by the automatic pointing feature of the IMU realignment program (P52). Likewise, automatic acquisition pointing of both landmark and star lines in the midcourse navigation program (P23) allowed Lovell to make quickly each of over 200 cislunar earth and lunar horizon sextant navigation sightings. MIT had preselected the best visible stars of the 37 in the computer's star catalog for navigation use. His superposition of the star in the sextant on the earth's illuminated limb was at a remarkably uniform altitude above sea level but about 8 kilometers lower than he selected as his subjective target a few weeks before the flight on the MIT simulator. This horizon bias was determined independently during the first part of the outbound leg by both MSC and MIT. His performance with the optics was excellent even when fatigue was otherwise evident. The consistency of all his "marks", except when the spacecraft was close to the target body, was rarely greater than the 10 arc second quantization size of the sextant trunnion angle readout.

The sextant data were processed in the flight computer with Dr. Battin's recursive estimation formulation and as they approached the moon this on-board navigation was for all intents the same as the MSFN ground tracking data. There was no reason, then, why they couldn't have used this on-board state vector to initialize the lunar orbit insertion maneuver. This would have been an impressive demonstration of the actual complete on-board capability. However, the flight plan specified a state vector update before lunar orbit insertion, and the Flight Controller chose to proceed with this plan, since there was no overriding argument for deviation.

The Saturn guided translunar injection errors and the subsequent manual maneuvers needed to separate from a persistent SIVB they couldn't seem to shake, required a 25 ft/sec correction using the main SPS engine. This was made at 11 hours into the mission. The next two scheduled midcourse corrections were not necessary and were not made. The final translunar midcourse correction, made at 8 hours before lunar orbit insertion was only 3 ft/sec using the small reaction control jets.

The anxious wait for the spacecraft to make its first reappearance from in back of the moon on Christmas Eve following the out-of-sight lunar orbit insertion maneuver was rewarded with the report from the crew that the on-board computer gave their orbit as 60.5 by 169,1 nautical miles altitude. . . so close to the planned 60 by 170 orbit that the unavoidable emotional tension was broken with

unrestrained cheers. About 25 minutes later the ground reported that radar tracking had established an orbit comparing favorably with the on-board data. Two orbits later, after the circularization maneuver, the spacecraft emerged in sight with the satisfying report of a 60.6 by 60.7 nautical mile lunar orbit.

During lunar orbit, Lovell used the sextant and scanning telescope to track known lunar reference points, including potential landing sites. These data were telemetered to earth for post flight analysis.

The critical 3500ft/sec return-to-earth maneuver early Christmas morning was guided so accurately that only a single 5 ft/sec correction, made five hours later, was required to hit the center of the atmospheric entry corridor 42 hours later.

Our MIT teams of experts at Florida, Houston and Cambridge who provided support to mission control, were constantly monitoring and checking the progress of the flight and were called upon several times for consultation and recommendations.

A false alarm hardware problem which acquired the nickname "travelling trunnion" was manifest by a transient change of the optics trunnion indication in the computer and was associated with the procedure of starting optical sightings. In each case it occurred, Lovell merely rezeroed and proceeded without hesitation or concern. With the limited data we had available it took some ingenious sleuthing by our team to be able to certify confidently continued safe use of the optics. The curious action of the trunnion indication was finally understood completely only after discussing with Lovell the details of the procedures he used. The phenomenon involves the way in which the optics behave with power off in the free-fall environment of space flight. There was no failure or degradation of any GN&C hardware in the mission.

Considering the huge workload of GN&C use, which successfully exercised all functions except rendezvous, it is surprising so few operational problems were experienced in this flight. In the several cases which did occur, the computer gave proper alarm indication and the astronauts were able to recover without help from the ground. In three cases of question, MIT examined the contents of the erasable memory and was able to verify that corrections did not need to be telemetered up.

On the way back from the moon the on-board and the ground tracking navigation were essentially identical. Both were well within the tolerance needed for entry control. Lovell was still using the same altitude horizon for his P23 navigation he used on the way out. Our system controlled automatically the 36, 20⁰

ft/sec atmospheric entry to a spectacular landing next to the recovery carrier. The ship has reported splashdown coordinates within a third of a mile of the target coordinates in the flight computer.

MISSION "D" - COLOSSUS IA REV 249 and SUNDANCE REV 306

During the reporting period level 6 "Mission Performance Testing" was completed by MIT/IL in preparation for Mission "D" APM#9. The level 6 testing of Colossus IA consisted of approximately 60 mission oriented tests and approximately 55 on Sundance. The results of these tests were summarized and reported at The Apollo Flight Software Readiness Review (FSRR) held on January 27-28, 1969 at MSC. At this meeting, it was determined that the command module program (Colossus IA), and the LM program (Sundance) were capable of performing the Apollo 9 mission in a satisfactory manner.

During the actual flight MIT/IL flight support was given from the Cambridge Facility and residents at KSC and MSC. Subsequent to the flight, post flight analysis of the flight data received from MSC has been performed at MIT/IL.

COLOSSUS 2 - MANNED CSM (LUNAR CAPABILITY)

During the reporting period level 3 and level 4 testing was completed on the Colossus 2 program. The Colossus 2 program was released to rope manufacturing on 2/11/69 with the nomenclature Comanche Rev 44. On 3/3/69 Comanche was re-released at Rev. 45 which include a modification to the B3 module. Since that time the level 3 and 4 tests have been re-run on the latest version of Comanche Rev 45 and a test plan for Mission "F" type testing has been developed.

The Software Flight Readiness Review for Mission "F" is scheduled for 30 April 1969.

COLOSSUS 2A - MANNED CSM (LUNAR CAPABILITY)

During the period of 3 March 1969 to 15 March 1969 eight (8) Program Change Requests (PCR's) and eight (8) Comanche Rev 45 anomalies were incorporated into and fixed in the Comanche assembly. A Colossus 2A program which was re-tested by running the level 3 and 4 tests was released to rope manufacturing on 15 March 1969 as Comanche Rev. 51. Level 5 testing of Comanche Rev. 50 and 51 have been completed.

LUMINARY 1 - Rev 69 MANNED LM (LUNAR CAPABILITY)

During the reporting period a level 6 test plan has been developed and testing started in support of Mission "F". The planned completion of this effort is sched-

uled for mid-April 1969. The Software Flight Readiness Review for Mission "F" is scheduled for 30 April 1969 at MSC.

LUMINARY 1A - MANNED LM (LUNAR CAPABILITY)

During the reporting period another version of the Luminary 1 program was coded and level 2, 3 and 4 tested. This new version corrected approximately twenty (20) anomalies found in Luminary 1 and incorporated approximately forty-five (45) Program Change Requests. A PRE-FACI review by MIT/IL and MSC personnel was held at MIT/IL on March 24 and 25 to review the changes made in Luminary 1A. The schedule for release to rope manufacturing is set for the first of April 1969. Level 5 testing will be conducted on the Luminary 1A assembly after that date.

TABLE 5.1

COLOSSUS CMC PROGRAM

FIXED MEMORY ALLOCATION CHART

(Actuals at Assembly Rev. 51)

I. Utility and Service Programs

Interpreter, Single-Precision Subroutines, Fixed-Fixed Constant Pool	2206
Executive	337
Waitlist, Longcall	252
Interrupt Lead Ins	58
Interbank Communication	76
T4RUPT	791
SXT Angle Monitor	42
Keyrupt-Uprupt	68
Downlink Program and 5 Lists	399
Fresh Start and Restart	430
Alarm and Abort	99
Delayjob	30
Restart Routine and Tables	434
Phase Table Maintenance	179
Pinball Program and Noun Tables	2940
Displays, Priolarm	676
Program Select (V37, POO, ROO)	433
Self Check	314
Extended Verbs	746
RTBOP Codes	181
SXTMARK	315
IMU Mode Switching	560
IMU Compensation	247
AGC Startup	32
AGC Power Down (P06)	47
IMU Status Check	17
Systems Test (P07)	551
Interpretive Constants	35
Flagup, Flagdown	59

GENTRAN	15
DAP Data Load (R03)	50
End Bank Markers	68
TOTAL UTILITY AND SERVICE PROGRAMS	12687
II. Autopilot and Maneuver Programs	
Entry DAP	813
BOOST	61
RCS	1816
TVC	1424
TWINGIMB S40. 6	70
KALCMANU	713
Attitude Maneuver (R60)	86
Crew Defined Maneuver (R62)	11
Vecpoint	130
Rendezvous Final Attitude (R63)	41
Middle Gimbal Display	61
CM Body Attitude	195
TOTAL AUTOPILOT AND MANEUVER PROGRAMS	5421
III. Basic Math Routines	
Inflight Alignment Routines	225
Powered Flight Subroutines	187
CSM Geometry	253
Time of Free Fall	268
Conic Subroutines	1079
Orbital Integration	1531
PERIAPO	78
Latitude, Longitude, Altitude	159
Initial Velocity	174
Lunar and Solar Ephemeris	71
Planetary Inertial Orientation	204
TOTAL BASIC MATH ROUTINES	4229
IV. Targeting Routines	
Transfer Phase Initiation Search	322
Coelliptic Sequence Initiation	672
Central Angles Subroutine	46

	TOTAL TARGETING ROUTINES	1040
V.	Navigation Routines	
	Measurement Incorporation	385
	Preferred Tracking Attitude (R61)	269
	Lunar Landmark Selection (R35)	-
	Rendezvous Tracking Sighting Mark & Backup (R21, R23)	57
	Rendezvous Tracking Data Processing & Backup (R22, R24)	500
	Landmark Table	-
	TOTAL NAVIGATION ROUTINES	1211
VI.	Powered Guidance Routines	
	Servicer	375
	Desired Thrust Direction (S40. 1, S40. 2, 3)	275
	Cross Product Steering (S40. 8)	129
	VG Calculation (S40. 9)	85
	Time of Burn Calculation (S40. 13)	73
	Initial VG (S41. 1)	14
	Entry Guidance	1172
	TOTAL POWERED GUIDANCE	2123
VII.	Alignment Routines	
	Coarse Align (R50)	119
	Fine Align (R51)	114
	Auto Optics (R52)	140
	Sighting Mark (R53)	63
	Star Data Test (R54)	-
	Gyro Torquing (R55)	27
	Pick-A-Pair	127
	Star Catalog	223
	Alternate LOS Sighting Mark (R56)	117
	Optics Calibration (R57)	53
	TOTAL ALIGNMENT ROUTINES	983
VIII.	Miscellaneous Programs and Routines	
	P27 - Update Program	280
	R36 - Rendezvous Out of Plane Display	126

P30 - P31 EXT DELTA V & General Lambert Maneuver	343
R05 - S Band Antenna Display	80
R30 - Orbit Parameter Display	283
R31 - R34 Rendezvous Parameter Display Routine 1 & 2	218
R33 - CMC/LGC Clock Synchronization	26
TOTAL MISCELLANEOUS PROGRAMS AND ROUTINES	1356

IX Mission Control Programs

P01 - Prelaunch or Service Initialization	47
P02 - Prelaunch or Service Gyrocompassing	331
P03 - Optical Verification of Gyrocompassing	184
P11 - Earth Orbit Insertion Monitor	474
P17 - TPI Search	75
P20 - Rendezvous Navigation	135
P21 - Ground Track Determination	108
P22 - Orbital Navigation	976
P23 - Cislunar Midcourse Navigation	593
P32, P72 CSI Prethrust	99
P33, P73 CDH Prethrust	111
P34, P74 TPI Prethrust	} 657
P35, P75 TPM Prethrust	
P37 - Return to Earth	1368
P38, P78 SOR Prethrust	} 225
P39, P79 SOM Prethrust	
P40 - SPS Thrusting	} 788
P41 - RCS Thrusting	
P47 - Thrust Monitor	58
P51, P53 IMU Orientation Determination & Backup	255
P52, P54 IMU Realign and Backup	415
P61 - Maneuver to CM/SM Sep Attitude	309
P62 - CM/SM Sep and Pre-Entry Maneuver	91
P63 - Entry Initialization	22
P64 - Post 0.05G	6
P65 - Upcontrol	27
P66 - Ballistic	4
P67 - Final Phase	36
P76 - Target Delta V	96
P77 - LM TPI Search	-

TOTAL MISSION CONTROL PROGRAMS	7490
GRAND TOTAL	36540
REMAINING FIXED MEMORY	324

TABLE 5. 2

LUMINARY LGC PROGRAM

FIXED MEMORY ALLOCATION CHART

(Actuals at Assembly Rev. 92)

I. Utility and Service Programs

Interpreter, Single Precision Subroutines } Fixed-Fixed Constant Pool }	2211
Executive	345
Waitlist, Longcall	267
Interrupt Lead Ins	54
Interbank Communication	76
T4rupt (R10, R25)	634
Keyrupt - Uprupt	69
Downlink Program and 7 Lists	415
Fresh Start and Restart	476
Alarm and Abort	126
Delayjob	31
Restart Routine and Tables	317
Phase Table Maintenance	164
Pinball Program and Noun Tables	2975
Displays, Priolarm	693
Program Select Check (V37, P00, R00)	338
Self Check	314
Extended Verbs	762
RTB OP Codes	130
Radar Rupts	262
AOTMARK (R53)	439
Backup Marking (COAS)	-
IMU Mode Switching	564
IMU Compensation	282
LGC Startup	32
LGC Power Down (P06)	47
IMU Status Check	17
System Test (P07)	637
Interpretive Constants	35
Flagup, Flagdown	32
GENTRAN	15

DAP Data Load (R03)	169
Radar Subroutines	741
End Bank Markers	68
TOTAL UTILITY AND SERVICE PROGRAMS	13737
II. Autopilot and Maneuver Programs	
Digital Autopilot	3506
KALCMANU	670
Find CDU W	441
Attitude Maneuver (R60)	99
Crew Defined Maneuver (R62)	11
Vecpoint	136
Rendezvous Final Attitude (R63)	65
Ball Angle Display	50
Middle Gimbal Display	54
TOTAL AUTOPILOT AND MANEUVER PROGRAMS	5032
III. Basic Math Routines	
Inflight Alignment Routines	184
Powered Flight Subroutines	267
LM Geometry	112
Time of Free Fall	268
Conic Subroutines	1088
Orbital Integration	1510
PERIAPO	78
Latitude, Longitude, Altitude	159
Initial Velocity	189
Lunar and Solar Ephemeris	126
Planetary Inertial Orientation	206
TOTAL BASIC MATH ROUTINES	4187
IV. Targeting Routines	
Coelliptic Sequence Initiation	} 650
Constant Delta Altitude	
TOTAL TARGETING ROUTINES	650

V.	Navigation Routines	
	Measurement Incorporation	384
	Preferred Tracking Attitude (R61)	126
	Rendezvous Navigation (LSR22.3, RADARANG)	534
	LUNAR SURFACE NAVIGATION (LSR22.4)	
	RR Search, Designate and Read	758
	(R21, R22, R23, R24, LPS20.1, LPS20.2, LRS22.1, LRS22.2, LRS24.1, CALCXY)	
	TOTAL NAVIGATION ROUTINES	1802
VI.	Powered Guidance Routines	
	Servicer (R12)	1224
	Desired Thrust Direction (S40.1, S40.2, 3)	129
	Cross Product Steering (S40.8)	57
	VG Calculation (S40.9)	202
	Time of Burn Calculation (S40.13)	103
	Descent Guidance (R11, R13)	920
	Throttle Logic	135
	Ascent Guidance	533
	TRIMGIMB (S41.1, S40.6)	44
	TOTAL POWERED GUIDANCE ROUTINES	3347
VII.	Alignment Routines	
	Coarse Align (R50)	64
	Fine Align (R51)	135
	Auto Optics (R52)	68
	Star Data Test (R54)	41
	Gyro Torquing (R55)	26
	Pick-A-Pair (R56)	132
	Lunar Surface Sighting Routine	221
	Star Catalog	223
	TOTAL ALIGNMENT ROUTINES	910
VIII.	Miscellaneous Programs and Routines	
	R47 - AGS Initialization	138
	R36 - Rendezvous Out of Plane Display	93
	P27 - Update Program	270
	P30 - External Delta V Prethrust	70

P31 - General Lambert Maneuver	61
R04 - RR/LR Self Test	} 188
R77 - LR Spurious Return Test	
R05 - S Band Antenna Display	118
R29 - Rendezvous Radar Flight Designate	335
R30 - Orbit Parameter Display	265
R31 - Rendezvous Parameter Display	204
R33 - CMC/LGC Clock Synchronization	27
R10 - Landing Analog Display Monitor	473
R11 - Abort Discretes Monitor	52
R13 - Auto Modes Monitor	74
TOTAL MISCELLANEOUS PROGRAMS AND ROUTINES	2368

IX. Mission Control Programs

P12 - Ascent Guidance	187
P20, P22 - Rendezvous Navigation	373
P21 - Ground Track Determination	115
P25 - Preferred Tracking Attitude	37
P32, P72 - CSI Prethrust	119
P33, P73 - CDH Prethrust	140
P34, P74 - TPI Prethrust	656
P38, P78 - SOR Prethrust	} 233
P39, P79 - SOM Prethrust	
P40 - DPS Thrust	918
P41 - RCS Thrust	78
P42 - APS Thrust	22
P47 - Thrust Monitor	52
P51 - IMU Orientation Determination	262
P52 - IMU Realign	198
P57 - Lunar Surface Align	579
P63 - Landing Braking	} 181
P64 - Landing Approach	
P65 - Landing (AUTO)	} 42
P66 - Landing (ROD)	
P67 - Landing (Manual)	
P68 - Landing Conformation	---

P70 - DSP Abort }	252
P71 - APS Abort }	
P76 - Target Delta V	98
TOTAL MISSION CONTROL PROGRAMS	4542
GRAND TOTAL	36575
REMAINING FIXED MEMORY	289

MIT/IL MASTER APOLLO SOFTWARE DEVELOPMENT PLAN

Title	1968									1969			
	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	Jul	Aug	
MISSION "D" APM-9 COLOSSUS 1A (REV 249) Level 6 Testing SUNDANCE (REV 306) Level 6 Testing Mission Support & Post-Flight Analysis					8 25		5 27						
MISSION "F" APM-10 COLOSSUS 2 (COMANCHE REV 45) Level 6 Testing LUMINARY 1 (REV 69) Level 6 Testing Mission Support & Post-Flight Analysis							4 25						
MISSION "G" APM-11 COLOSSUS 2A (COMANCHE REV 51) Coding & Testing Level 6 Testing							3 15	27 (RELEASED)	15 28			27	

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