APOLLO

GUIDANCE AND NAVIGATION

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E-1142

(Rev. 49)

SYSTEM STATUS REPORT

January, 1967

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E-1142
(Rev. 49)

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 I 100 Series and Block II Command Modules and Lunar Excursion Module equipment: configuration weight, weight trend information, centers of gravity, moments of inertia, reliability failure rates, electrical power requirements, computer programming status, and G&N Status.

by Apollo Staff
January 30, 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 - Centers of Gravity
Weight Trend Information

Section 2 - Centers of Gravity
Moments of Inertia

Section 3 - Glossary and System Definition

Section 4 - Reliability - Failure Rates

Section 5 - Electrical Power Requirements

Section 6 - Guidance and Navigation Systems Status

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.

Weight Changes

The previously reported number and weight of coolant hoses has been revised from two hoses weighing 0.9 pound to three hoses weighing 1.4 pounds.

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

Command Module G&N Equipment	Status 9/66	Change	Status 1/67	Design Load Weight*
LOWER EQUIPMENT BAY				
CDU Assy	16.9 (M)	0.0	16.9 (M)	18.0#
Optical Subsystem				
SXT and gearing SCT and gearing Optical Base and gearing	53.6 (E)	0.0	53.6 (E)	
NVB and Resilient Mounts	25.7 (M)	0.0	25.7 (M)	155.0**
Bellows Assy	10.7 (E)	0.0	10.7 (M)	
IMU	61.2 (M)	0.0	61.2 (M)	
Coolant Hoses (Three)	0.9 (M)	+0.5	1.4 (M)	
Power Servo Assy	65.4 (M)	0.0	65.4 (M)	120.0
G&N Interconnection Assy	26.1 (M)	0.0	26.1 (M)	
Optical Shroud	3.1 (M)	0.0	3.1 (M)	4.5
G&N to S/C Interface Assy AGC (with 6 rope modules)	90.8 (M)	0.0	90.8 (M)	100.0
Optical Eyepiece Storage Assy Condition Annunciators SXT Normal Relief Eyepiece SCT Normal Relief Eyepiece SCT Long Relief Eyepiece	12.7 (M)	0.0	12.7 (M)	15.0
D&C Electronics Assy	2.6 (M)	0.0	2.6 (M)	5.0
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 9/66	Change	Status 1/67	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	442.3	+0.5	442.8	---
The reported total weight for this month is 12.8 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 1G)

Command Module GN&C Equipment	Status 9/66	Change	Status 1/67	Design Load Weight*
LOWER EQUIPMENT BAY				
CDU Assy	36.2 (E)	0.0	36.2 (E)	50.0
Optical Subsystem SXT and gearing SCT and gearing Optical Base and gearing	54.6 (E)	0.0	54.6 (E)	
NVB and Mounts	17.4 (M)	0.0	17.4 (M)	
Bellows Assy	10.7 (M)	0.0	10.7 (M)	150.0
IMU	42.5 (M)	0.0	42.5 (M)	
Coolant Hoses (Two)	1.2 (M)	0.0	1.2 (M)	
Power Servo Assy	49.4 (M)	0.0	49.4 (M)	58.0
PIPA Electronics Assy	9.0 (E)	0.0	9.0 (M)	12.0
G&N Interconnect Harness Group	24.0 (M)	0.0	24.0 (M)	40.0
AGC (with six(6) rope modules + mag. trays)	69.0 (E)	0.0	69 0 (E)	80.0
Optical Shroud	3.1 (M)	0.0	3.1 (M)	4.5
Optical Eyepiece Storage Assy SXT Normal Relief Eyepiece SCT Normal Relief Eyepiece SCT Long Relief Eyepiece	11.1 (E)	0.0	11.1 (E)	15.0
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 9/66	Change	Status 1/67	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)	0.0	0.4 (E)	---
TOTAL	383.4	+0.0	383.4	---
The reported total weight for this month is 16.6 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

A change to add a vibration damping plate to the Block II Command Module CDU has been approved. This change will result in an increase at three-tenths (0.3) pound.

The LM CDU weight estimate has been increased two-tenths (0.2) pound to reflect the recently shipped LM/G&N Systems 603,604,605,606,607 and a spare. An additional change to add a vibration damping plate to the LM CDU has been approved. This change will result in an increase at three-tenths (0.3) pound.

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

LM PGNCS Equipment	Status 9/66	Change	Status 1/67	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 (E)	
NVB	5.1 (M)	0.0	5.1 (M)	
HARNESS "B" Supported by the NVB	0.6 (E)	0.0	0.6 (E)	
HARNESS "B" Supported by the PTA	0.8 (E)	0.0	0.8 (E)	21.0
HARNESS "B" Supported by the structure	3.1 (E)	0.0	3.1 (E)	
PTA	14.3 (M)	0.0	14.3 (M)	
HARNESS "A"	14.6 (E)	0.0	14.6 (E)	22.0
LGC (with six(6) rope modules + mag trays)	69.0 (M)	0.0	69.0 (M)	65.0
DSKY	17.5 (M)	0.0	17.5 (M)	20.0
AOT Control Unit (CCRD)	1.6 (M)	0.0	1.6 (M)	2.0
CDU	37.0 (M)	+0.2	37.2 (M)	37.0
PSA	17.5 (M)	0.0	17.5 (M)	28.2
SCA (Operational Flights)	7.2 (E)**	0.0	7.2 (E)	
TOTAL	253.8	+0.2	254.0	---
The reported total weight for this month exceeds the 245.0 pounds total control weight by 9.0 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/MSC) on 29 March 1966.

**The weight of a qualification flight signal conditioner assy is 9.2 (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

CENTERS OF GRAVITY AND MOMENTS OF INERTIA

The centers of gravity and moments of inertia are summarized in tabular form. This data has been prepared for MIT/IL designed equipment with respect to the reference axes of the Block II Command Module and the Lunar Excursion Module. MIT assumes that all hardware is in the proper configuration for Thrusting Modes; therefore, the eyepieces (3) will be located in the Optical Eyepiece Storage Assembly. North American Aviation will provide storage for the astronaut's Horizontal Handholds (2). Since this storage information is not available at MIT/IL, it is suggested that NAA supply the centers of gravity and moments of inertia for these items.

MIT Letter AG 261-66 dated 23 March 1966, proposed that NAA provide storage for the SXT Long Relief Eyepiece in the Block II Command Module.

TABLE 4. COMMAND MODULE BLOCK II GN&C MASS PROPERTY DATA

Command Module G&N Equipment	Center of Gravity - Inches				Moment of Inertia - Slug-ft^2			
	$\bar{x}$	$\bar{y}$	$\bar{z}$	±Error	I_x	I_y	I_z	±Error
CDU Assy	39.0	15.6	42.3	5%	17.85	28.78	15.34	2%
Optical Subsystem SXT & gearing SCT & gearing Optical Base & gearing	69.7	0	33.6	10%	11.77	61.99	50.25	2%
NVB & Mounts Bellows Assy	65.5	0	39.8	10%	10.02	35.56	26.15	5%
IMU Coolant Hoses (two)	55.8	0	40.9	10%	15.41	43.96	28.67	5%
Power Servo Assy	44.2	0	44.4	5%	22.77	44.04	22.09	1%
PIPA Electronics Assy G&N Interconnect Harness Assy	64.2	-14.0	37.6	5%	3.12	10.70	8.39	2%
AGC Optical Shroud	38.0	-4.0	46.2	5%	32.11	52.93	21.49	1%
Optical Eyepiece Storage Assy SXT Normal Relief Eyepiece SCT Normal Relief Eyepiece SCT Long Relief Eyepiece								
G&N Indicator Control Panel	54.5	0	36.5	5%	3.61	11.27	7.91	4%
DSKY (L.E.B.)	61.5	17.1	36.5	5%	6.14	19.31	15.39	1%
Signal Conditioner Assy	72.5	15.1	31.6	5%	2.12	10.79	9.46	2%
DSKY (Main Panel)	68.0	-13.9	-20.5	5%	2.32	19.06	18.21	2%
Horizontal Handholds (Two) SXT Long Relief Eyepiece		See text on the preceeding page.						
TOTAL								

TABLE 5. LUNAR MODULE PGNCS MASS PROPERTY DATA

LM GN&C EQUIPMENT	Center of Gravity - Inches				Moment of Inertia - Slug-ft^2			
	$\bar{x}$	$\bar{y}$	$\bar{z}$	±Error	I_x	I_y	I_z	±Error
IMU	307.0	0	49.9	5%	22.90	886.76	863.97	1%
Navigation Base	309.0	0	54.4	5%	2.57	3.39	0.86	1%
AOT								
AOT Control Unit (CCRD)								
PTA								
Harness "B"								
DSKY	254.0	0	58.6	10%	12.98	256.47	243.50	1%
LGC	266.0	0	-22.9	5%	8.24	1034.57	1027.81	1%
CDU	252.2	0	-22.8	10%	4.69	553.63	549.28	2%
PSA (not integral unit) } Signal Conditioner Assy }	240.0	0	-22.8	5%	3.04	308.63	305.88	5%
Harness "A"								
TOTAL								

SECTION 3

GLOSSARY AND SYSTEM DEFINITION

The description at 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 4

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

FAIURE RATES EXPRESS IN "FAILURES PER 10^6 HOURS"

MISSION		IMU Assembly ON/STBY	IMU Electronics (PSA) ON/STBY	Optics Assembly ON/OFF	Optics Electronics (PSA) ON/OFF	IMU CDU ON/STBY	Optics CDU ON/OFF	AGC ON/STBY	DSKY ON/OFF	D&C ON/OFF	Mission Reliability
AGE #12 FLIGHT 204 MANNED	Oper Hrs	49 266	49 266	13 302	13 302	49 266	13 302	50 265	50 265	49 266	.9580
	λ	185 10.2	224 6.3	94 -	84 -	111 -	68 -	257 66.3	3.2 -	26 -	
AGE#122 FLIGHT 501 UNMANNED	Oper Hrs	8.63 -	8.63 -	- -	- -	8.63 -	- -	8.63 -	8.63 -	8.63 -	.9931
	λ	195 .-	224 -	- -	- -	111 -	-	257 -	12 -	6 -	
AGE 603 FLIGHT 206 UNMANNED LM	Oper Hrs	9.6	9.6	-	-	9.6	-	9.6	9.6		.9938
	λ	129	110	-	-	155	-	235	12		
C/M DES. REF.	Oper Hrs	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	.9840
	λ	129 10.2	110 6.3	94 -	77 -	155 -	91 -	235 60.5	2.3 -	2.3 -	
LM DES. REF.	Oper Hrs	3.25 66.3	3.25 66.3	3.25 -	3.25 -	3.25 -	3.25 -	3.25 -	3.25 -	3.25 -	.9969
	λ	129 1.6	110 -	38 -	1.33 -	155 -	112 -	235 -	110 -	1.2 -	

SECTION 5

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.

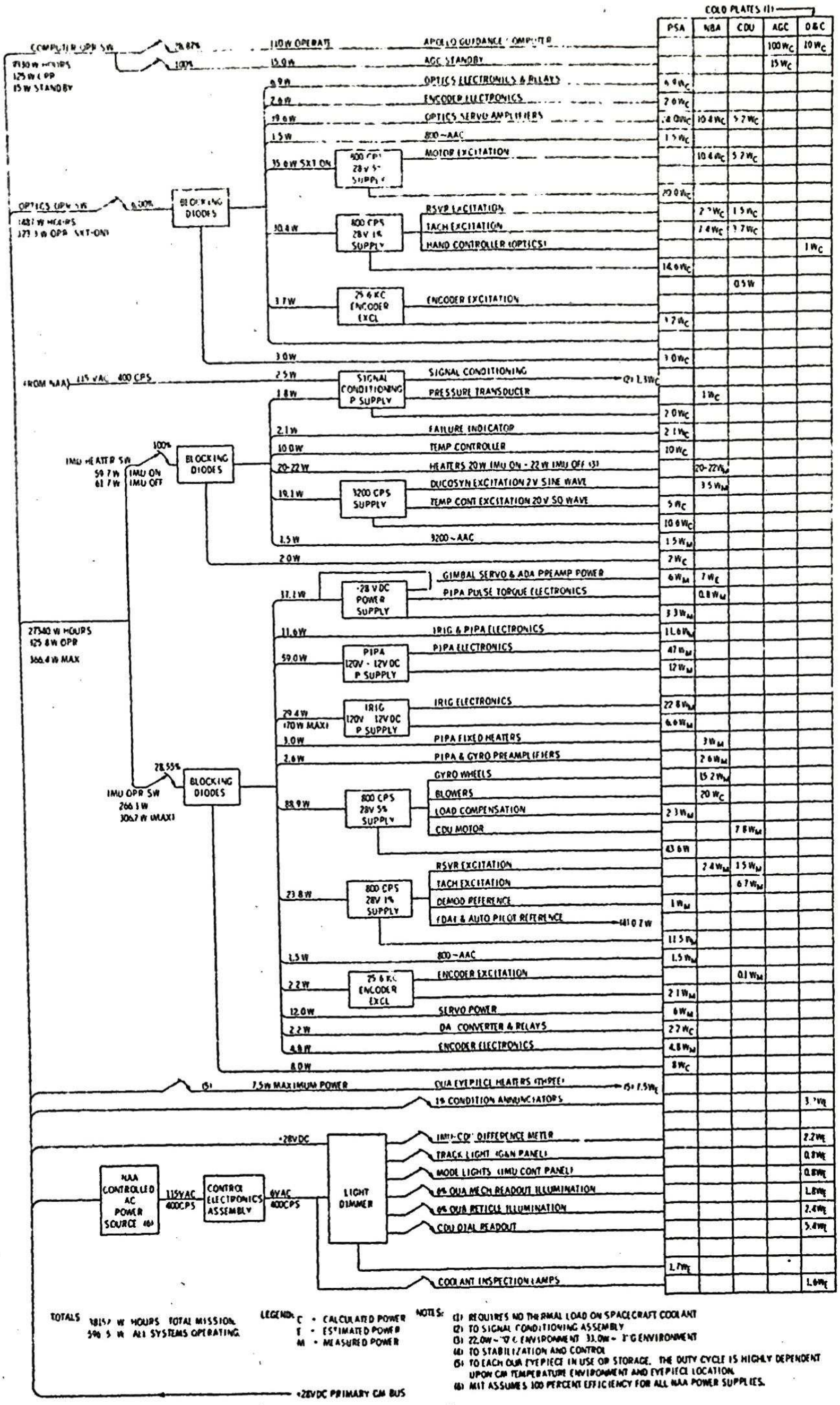
Interface Control Documents serve as the guidelines for reporting power figures.

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 1085 HOUR (8.27 DAY) LUNAR MISSION
DESIGN REFERENCE MISSION

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



TOTALS 18157 W HOURS TOTAL MISSION
596.5 W ALL SYSTEMS OPERATING

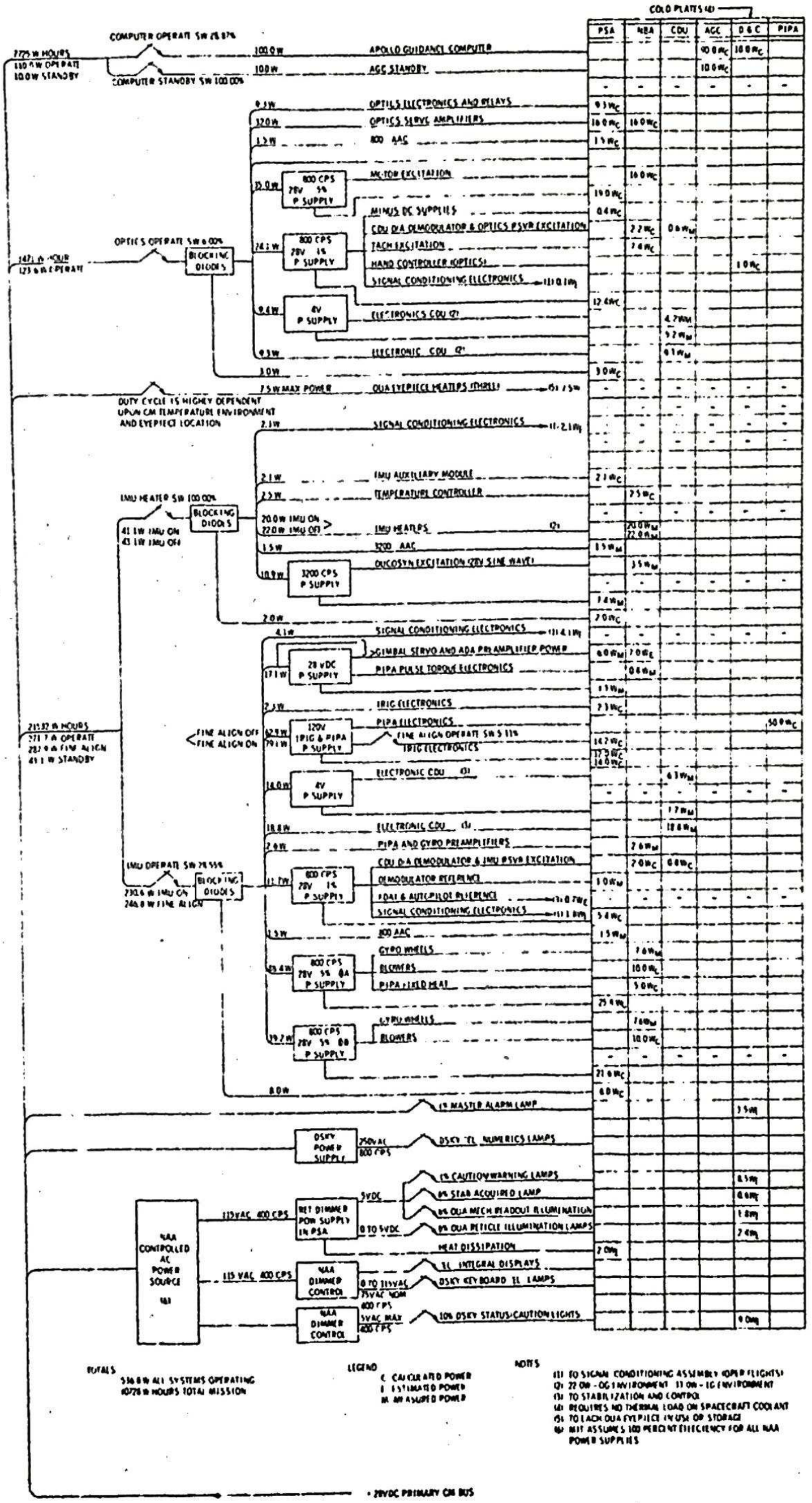
LEGEND: C - CALCULATED POWER
E - ESTIMATED POWER
M - MEASURED POWER

NOTES:
(1) REQUIRES NO THERMAL LOAD ON SPACECRAFT COOLANT
(2) TO SIGNAL CONDITIONING ASSEMBLY
(3) 22.0W - 0°C ENVIRONMENT 33.0W - 5°C ENVIRONMENT
(4) TO STABILIZATION AND CONTROL
(5) TO EACH OUA EYEPIECE IN USE OR STORAGE. THE DUTY CYCLE IS HIGHLY DEPENDENT UPON CM TEMPERATURE ENVIRONMENT AND EYEPIECE LOCATION.
(6) MIT ASSUMES 100 PERCENT EFFICIENCY FOR ALL NAA POWER SUPPLIES.

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

BASED UPON 1983 HOUR (82.7 DAY) LUNAR ORBIT MISSION
DESIGN REFERENCE MISSION

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



TOTALS
536.8 W ALL SYSTEMS OPERATING
10728 W HOURS TOTAL MISSION

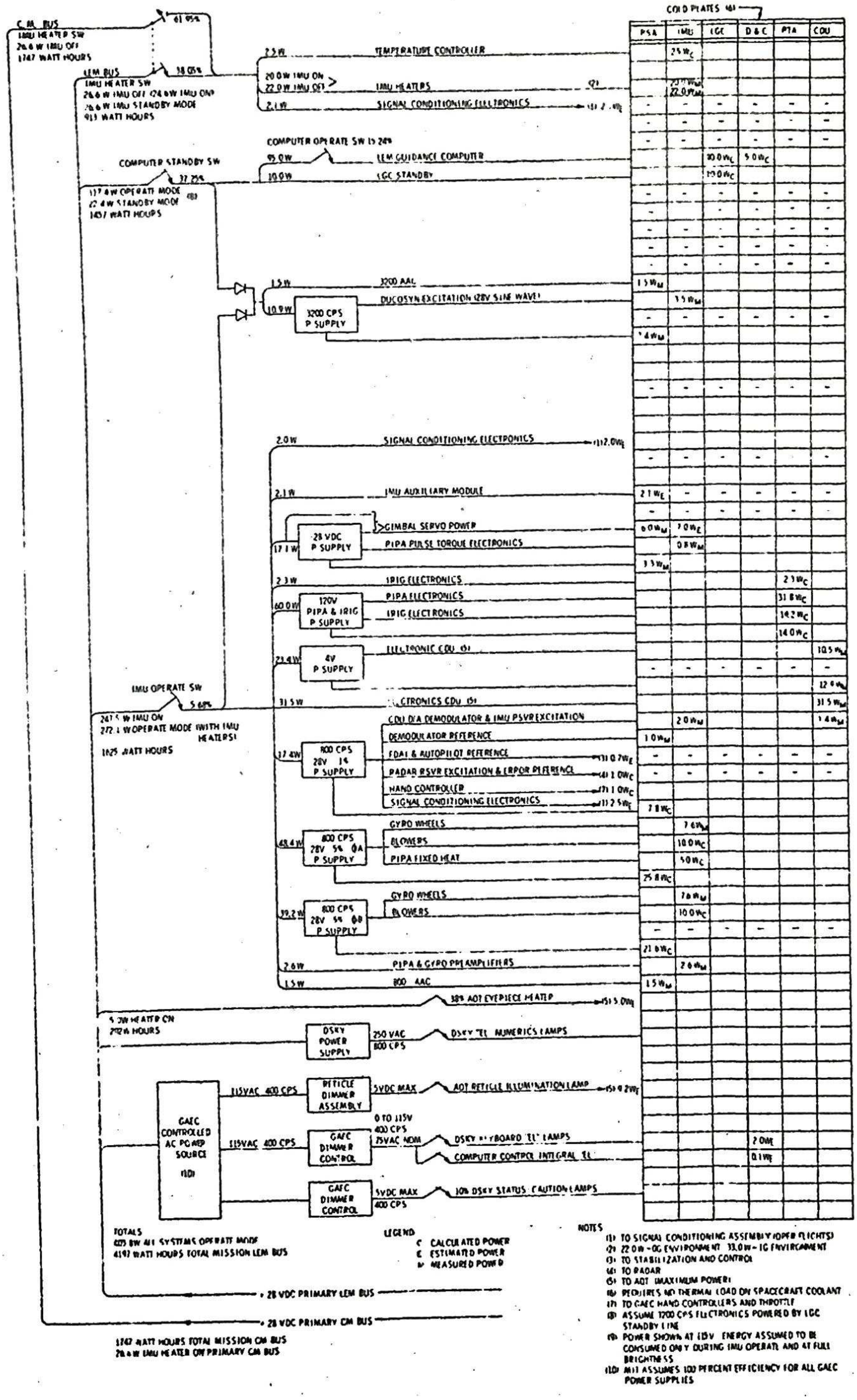
LEGEND
C CALCULATED POWER
E ESTIMATED POWER
M MEASURED POWER

NOTES
(1) TO SIGNAL CONDITIONING ASSEMBLY (OPER FLIGHT)
(2) 22 ON - OG ENVIRONMENT 11 ON - 1G ENVIRONMENT
(3) TO STABILIZATION AND CONTROL
(4) REQUIRES NO THERMAL LOAD ON SPACECRAFT COOLANT
(5) TO EACH QUA EYEPIECE (IN USE OR STORAGE
(6) MIT ASSUMES 100 PERCENT EFFICIENCY FOR ALL NAA POWER SUPPLIES

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

BASED UPON 108 02 HOURS 14 42 DAY LUNAR LANDING MISSION
DESIGN REFERENCE MISSION

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



SECTION 6

GUIDANCE AND NAVIGATION SYSTEMS STATUS

The Status of delivered G&N Systems are shown in tabular form. Table I shows the configuration for major units comprising the G&N Systems assigned to LTA-8 and subsequent LM vehicles. The next issue of this report will also include the configuration status of G&N System assigned to the Command Module vehicles.

Table II reflects the Status of G&N Systems progressing from installation to final test at KSC.

TABLE I

LM G&N SYSTEM CONFIGURATIONS

Component Nomenclature	LTA-1 System 601 Part Number	S/N	LTA-2 System 602 Part Number	S/N	LM-1 System 603 Part Number	S/N	LM-2 System 605 Part Number	S/N
AGC	2003100-021	1	2003100-021	8	2003200-021	22	2003200-031	20
DSKY	2003985-051	11	2003985-051	13	2003950-011	28	2003950-011	19
IMU	2018601-011	1	2018699-021	2	2018601-051	13	2018601-051	21
ECDU	2007222-041	5	2010744-021	9	2007222-081	11	2007222-081	10
AOT	Dummy		6011000-011	8	6011000-021	9	6011000-041	11

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

TABLE II

OPERATION	LOCATION																	
	GAEC			NAA						KSC								
	LTA-8 602	LM-1 603	LM12 605	LM-3 606	CSM17 501	CSM20 502	CSM98 2TV-1 202	CSM101 204	CSM102 205	CSM103 206	CSM11 17	CSM12 12	CSM17 122					
Installation	X	X	X		X	X	X	X	X		X	X	X					
Subsystem Checkout S/C	X	X			X		X				X	X	X					
Integnated Test S/C					X						X	X	X					
Complete Testing at KSC											X							

SECTION 7

G&N COMPUTER STATUS

Design Analysis

Design analysis of the Block II AGC, utilizing AGC-200, has not progressed as rapidly as planned due to time required to investigate field problems, design changes and having to share the monitor. Testing to date has consisted of the following:

1. Internal noise margins.
2. Power transient susceptibility.
3. STANDBY transient problems.

The design analysis has shown the Block II AGC to be adequately protected against noise generated internally and from power line transients. A problem exists when going into STANDBY (momentary loss of AGC timing) for which several possible solutions are being investigated.

Design Change Feasibility

The following design changes are being investigated:

1. DOWNLINK information.
2. PROCEED button.
3. DINC counter problem.

The DOWNLINK and PROCEED button investigations are requested by the NASA. The changes required are feasible and relatively easy. The change will affect the hardware in both cases (Tray A wiring changes) and, in addition, a software change will be required for the PROCEED button. The DINC counter problem could be eliminated by a programming change or an AGC hardware change. Investigation is continuing and no change action has been initiated.

Miscellaneous AGC Related Acctivity

During this reporting period the Analysis Facility has investigated the following AGC field problems and in-house development:

1. Field problems involving BL II RESTARTS, several of which are still not resolved, and BL 100 DOWNLINK.
2. Braid Memory/AGC Interfacing. A braid memory of 32,000 words (Program Aurora) has been operating with AGC-600M. It is planned to test this memory in the ISS Laboratory with a system in the near future.
3. Testing and integration with a computer of an IL light DSKY. The only relays required are those for S/C outputs.

SECTION 8

GUIDANCE COMPUTER PROGRAMMING

During the reporting period a presentation was given by MIT/IL to NASA/MSC on January 12, 1967 at MIT/IL.

The subject of the presentation was a review of the AS-504 spacecraft computer storage capability.

The presently defined programs exceeded memory storage capability by about 2,000 words in both CMC and LGC.

NASA/MSC and MIT identified programs which are to be deleted now or when more storage is needed. As a result a potential pad was obtained of about 4,100 words in the LGC and 5,300 words in the CMC. This pad would result from making all thirteen deletions noted below in List I. Also identified were a number of potential changes and additions noted below in List II. These changes would decrease the pad by an undefined amount.

Appendices A through F to this report were used by MIT/IL at the above referenced presentation. These Appendices reflect the AS258 and AS504 program status prior to any changes reflected by Lists I and II below, which were generated at the meeting.

Apollo Guidance Computer Programming Summary
for the Month of January

Mission AS-204A

The Hybrid and Digital Computer Facilities have continued to evaluate the released program. From this analysis crew procedures have been revised and program limitations defined.

Mission AS-501

The Hybrid and Digital Computer Facilities have continued to evaluate the released program. From this analysis ground procedures have been revised and program limitations defined.

Mission AS-206

The computer tape for the manufacturing of flight ropes has been undergoing final verification. The anticipated release date of the program tape is 15 February 1967.

Mission AS-258

The computer tape for the manufacturing of flight ropes has been in the final stages of formulation and coding. During the month a detailed Verification Plan was published. The verification to the computer program is now in the initial phase. 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. Work has been underway on the formulation and equation testing for the computer program. "A" release of the tape for rope manufacturing is expected by mid-November 1967.

The following chart gives a summary of the software development status.

List I - Possible Deletions

Categories:

A. Program to be removed immediately - no further effort to be expended.

B. Routine to remain in the program now but subject to later deletion; work to continue but on a low priority.

C. Routine to remain in the program now but subject to later deletion; no further effort required since the work is complete at this time.

		AS-258		AS-504		Program	
		LGC	CMC	LGC	CMC	Nos.	Deleted
1.	Gimbal lock avoidance	C*	C*	A	A		
2.	AGS back-up initialization	-	A	-	A	(P71,P72,P73)	
3.	Ground track determination	B	B	B	B		
4.	TPI search	-	-	B	B		
5.	LGC initialization	A	A	A	A	LGC (P01)	CMC (P02)
6.	Prelaunch Interface and system tests	-	-	A	A		
7.	Return to earth from within lunar sphere	-	-	-	A	Part of (P37)	
8.	Self check	C	C	C	C		
9.	Lunar orbit plane change	-	-	-	B		
10.	RR lunar surface navigation	-	-	B	-		
11.	Auto RCS steering	A	-	A	-		
12.	Rendezvous search routine	B	-	B	-		
13.	Landing time prediction	-	-	B	B		

* This capability is being temporarily retained to expedite AS-258 program development. Provision shall be made for deactivation of this routine for manufacture of crew training tapes and final AS-258 verification.

List II - Proposed Requirements

Categories. Updated to understandings as of 2/2/67

D. Candidates for addition - new requirement.
AS-258 - MDRB to be issued.
AS-504 - To be included in GSOP.

E. Definite new requirements. (To be in original issue of GSOP but in some cases may also have effect on GSOP or programming schedule.)

F. Considered but deleted

		AS-258		AS-504	
		LGC	CMC	LGC	CMC
1.	Simplified DAP initialization	F	F	E	E
2.	Entry - display g instead of bank angle	-	D	-	F
3.	r, r, $_{SXT}$ option (R31)	-	F	-	F
4.	Change displays from V's in IMU to V's in body axis and delete P36	D	D	E	E
5.	EMS initialization in erasable memory	-	D	+	D
6.	CALCMANU maneuver from DSKY input gimbal angles	F	F	E	E
7.	Transformation routine in LGC to align LM IMU docked	F	-	D	-
8.	IMU align using reticle (to provide DSKY mark capability)	-	D	D	D
9.	Rendezvous navigation using reticle (Also with DSKY mark capability)	-	D	-	E
10.	External targeting of Lambert steering	-	F	-	D
11.	Erasable memory onto downlist	D	D	E	E
12.	Trim option to P-40 and 42	D	D	D	D
13.	Perform desk calculator type function	F	F	F	F
14.	S-band pointing angle display	-	-	E	E
15.	Uplink	-	-	D	-
16.	LR reasonableness check	-	-	E	-
17.	Entry displays to be referenced to oblate earth	-	D	-	E

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

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)

or

P-31 Lambert Aim Point Pre-Thrust (de-orbit)

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

P-61, P-62, P-63, P-64, P-67 } Entry Programs

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, P-41 } SPS or RCS Thrust Programs

P-61, P-62, P-63, P-64, P-67 } Entry Programs

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 P-67 } Entry Programs

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 P-67 } Entry Programs

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 } MCC

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)

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 P-67 } Entry Programs

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

	CMC	LGC
A) Nominal		
	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-21 Ground Track Program
	P-26 LGC Initializaiton 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) Aborts to Return Earth Trajectory		
1. RTCC Controlled Abort		
	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. Spacecraft Controlled Abort		
	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) Service Programs for Nominal and Abort Cases		
	P-05 CMC Start Up	P-05 LGC Start Up
	P-06 GNCS Power Down	P-51 IMU Alignment Determination
	P-51 IMU Alignment Determination	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

	CMC	LGC
A)	Nominal	
	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 Monitoring)
		P-02 AGS Initialization Program
		P-21 Ground Track Program
		P-63 Landing Maneuver Braking Program (Pre-Ignition Mode)
B)	Aborts to Rendezvous Condition	
1.	LM Active Vehicle	
	P-20 Rendezvous Navigation Program	P-20 Rendezvous Navigation Program or
	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 Monitoring 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-41 RCS Thrust Program P-42 APS Thrust Program
	P-73 AGS Back-Up Initialization	
	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 or
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

	CMC	LGC
A) Nominal		
	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) Abort to Safe Orbit		
	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 Determination	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)

	CMC		LGC	
A)	Nominal			
	P-22	Lunar Orbit Navigation	P-22	RR Lunar Surface Navigation
	or			
	P-27	CMC Update Program	P-10	Prediction Launch Time (CFP) Program
			or	
	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)	Abort Cases Prior to LM Ascent			
	P-72	AGS Back-Up Azimuth Alignment Program	P-56	Back-Up IMU Surface Alignment Program
	P-73	AGS Back-Up Initialization Program		
C)	Service Programs			
	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 Attitude Mode)	P-12 Powered Ascent Guidance Program
B) Aborts		
	None	None

XIII Rendezvous Phase

	CMC	LGC
A) Nominal		
	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) Aborts to Rendezvous		
1. LM Active Vehicle		
	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)	MCC
P-31	Lambert Aim Point Pre-Thrust Program (RTCC Targeted)	MCC
P-40	SPS Thrust Program	
P-41	RCS Thrust Program	

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 B

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:

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 $\pm 5^{o}$ 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 bookeeping required for the restart.

Fresh Start and Restart

Routines which initilize 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

Interupt Lead-In

A routine which dispatches control to appropriate interupt routine.

Return to Basic Opcodes

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

End of Bank Mark

Provids 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^{o} 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 occurence 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 C

CMC PROGRAM/ROUTINE RELATIONSHIP AND SIZES

Appendix C

CMC PROGRAM / ROUTINE RELATIONSHIPS & SIZES

January 13, 1967

CMC Programs (control programs) and word counts

Program	Name	Word Count
P00	CMC Idling	50
P01	Prelaunch Initialization	← 3862-X →
P02	Gyro Compass	
P03	Optics Verification	
P05	CMC Startup	50
P06	CMC Power Down	80
P07	System Test	X
P11	EOI Monitor	150
P15	TLI Prethrust & Thrust	250
P17	TPI Search	50
P20	Rendezvous Navigation	80
P21	Ground Track	50
P22	Lunar Orbit Navigation	50
P23	Cis-Lunar Navigation	50
P29	Lunar Landing Time Prediction	50
P76	LGC Initialization	50
P27	CMC Update	250
P30	External ΔV	150
P31	Lambert Aim Point	120
P32	Lunar Orbit Insertion (LOI)	120
P33	Lunar Orbit Plane Change (LOPC)	120
P34	Transfer Phase Initiation (TPI)	750
P35	Transfer Phase Mid. Corr. (TPM)	100
P36	Transfer Phase Final (TPF)	80
P37	Return to Earth Target (RTE)	100
P40	SPS Thrust Maneuver	640
P41	RCS Thrust Maneuver	67
P47	Thrust Monitor	75
P51	IMU Alignment Determination	104
P52	IMU Realignment	154
P61	Entry Maneuver to Separate	50
P62	Entry Sep. Maneuver	100
P63	Entry Initialization	20
P64	Entry Post .05 G Phase	70
P65	Entry Up-Control	70
P66	Entry Ballist. Phase	70
P67	Entry Final Phase	35
P70	Safe Perilune Target (RTE)	120
P71	LM IMU Launch Alignment Determination	50
P72	AGS Backup Azimuth Alignment	50
P73	AGS Backup Initialization	50
P74	TPI (LM)	25
P75	TPM (LM)	25
P77	TPI Search	25
R30	Orbit Parameter Display	65
R31	Rendezvous Parameter Display	25
R32	Target ΔV	100

CMC Routines: word counts and the programs checked (✓) as using them

CMC Routines	Word Count AS-501	Word Count AS-258	Programs (✓)
CONTROL PROGRAMS	8,021		
BASIC ROUTINES			
Conic Subroutines	1,300	863	P15, P17, P20, P21, P22, P23, P29, P30, P31, P32, P33, P34, P35, P37, P40, P41, P52, P61, P70, P71, P72, P73, P74, P75, P77, R30, R31, R32
Orbital Integration	1,200	1,127	P17, P20, P21, P22, P23, P29, P30, P31, P32, P33, P34, P35, P37, P40, P41, P61, P70, P71, P72, P73, P74, P75, P77, R32
Lat., Long., Alt.	200	229	P21, P22, P23, P37, P67
Lunar & Solar Eph.	100	129	P23, P37, P52, P70
Lunar Rotation	150	-	P21, P22, P23, P29, P33, P71, P72
Int. Vel.	185	185	P15, P31, P34, P35, P40, P41, P74, P75
Rendezvous Parameters	100		P34, P35, P36, P74, P75, R31
Vec Point	100	100	P20
Calc. Maneuver	753	751	P15, P20, P40, P41, P61
Attitude Drive	460	460	P20, P40, P41, P61
Mid. Gimbal Display	68	68	P15, P30, P31, P32, P33, P34, P35, P37, P70
TARGETING			
TPI	290	290	P34, P74
Midcourse Maneuver	54	54	P35, P75
Return to Earth (Near Earth)	1,000	--	P37, P70
Return to Earth (Near Moon)	1,800	-	P37
LOPC	150	--	P33
TPI Search	200	--	P17, P77
Landing Time Pred.	200	--	P29
NAVIGATION			
Cislunar Midcourse	300	--	P23
Rendezvous	440	440	P20
Lunar Orbit	500	500	P22
Meas. Incorp.	450	432	P20, P22, P23
Preferred Track Att.	300	240	P20
Sight Mark (R53)	35	30	P22, P23, P51, P52
SXT Mark	293	293	P20, P22, P23, P51, P52
ENTRY			
Entry Calculations	1,200	1,200	P64, P65, P66, P67
Preentry Comp.	112	112	P63
Sep. Gimbal Angles	25	25	P61
IMU Entry Status	50	50	P61, P62
Trim Gimbal Angles	40	40	P62, P63
Apogee, Perigee, T_{ff}	350	350	P11, P40, P41, R30
POWERED GUIDANCE			
Cross Product Steering	117	117	P15, P40
VG Calc	100	77	P15, P40, P41
Time of Burn Calc	77	77	P30, P31, P32, P33, P34, P35, P37
Servicer	370	370	P15, P36, P40, P41, P47, P61, P62, P63, P64, P65, P66, P67
Desired Thrust Direction	270	177	P15, P40, P41
SIVB Att. Error Fast Loop	100	100	P15
IMU & OPTICS			
IMU Comp.	251	251	P01, P02, P15, P40, P41, P51, P52, P61, P62, P63, P64, P65, P66, P67
IMU Status Check (R02)	15	15	P15, P20, P22, P40, P41, P51, P52
Coarse Align	54	54	P01, P51, P52
Fine Align	64	64	P01, P51, P52
Auto Optics Positioning	200	200	P20, P22, P52
Pick-A-Pair	135	135	P52
Star Data Test	52	52	P51, P52
IMU Mode Switching	54	541	P01, P20, P22, P51, P52
Star Catalog	253	253	P23, P51, P52
Landmark Catalog	150	0	P22, P23
	15,174	20,447	

	AS-258	AS-501
DSKY		
Pinball	2,796	3,000
Extended Verbs	712	1,000
Keyrupt & Uprupt	79	79
Display & Service	170	500
Down Telemetry List	320	400
Prog. Select Check	100	100
Down Telemetry Prog.	260	260
INTERP & EXEC.		
Interpreter	2,271	2,271
Wait List	216	216
Executive	335	335
Phase Tables	300	350
Restart Control	175	175
Fresh SL & Restart	289	289
Phase Change & New Phase	158	158
T4 Rupt	731	731
Alarm & Abort	62	62
Self Check	966	986
Interrupt Lead In	51	51
RTB OP Codes	210	250
End Bank Marks	108	36
Interbank Communication	83	83
OTHER		
DAPS	3,600	3,600
Gen 3 DAP	191	191
Transformations	560	575
Gyro Torquing	44	44
	14,792	15,727

38,922

APPENDIX D

CMC PROGRAM UTILIZATION

CMC PROGRAM UTILIZATION

Appendix D

January 13, 1967

LUNAR LANDING MISSION PHASE / CMC PROGRAMS AS-501	P00 CMC Idling	P01 Prelaunch Initialization	P02 Gyro Compass	P03 Optics Verification	P05 CMC Startup	P06 CMC Power Down	P07 System Test	P11 EOI Monitor	P15 TLI Prethrust & Thrust	P17 TPI Search	P20 Rendezvous Navigation	P21 Ground Track	P22 Lunar Orbit Navigation	P23 Cis-Lunar Navigation	P25 Lunar Landing Time Prediction	P26 LGC Initialization	P27 CMC Update	P30 External ΔV	P31 Lambert Aim Point	P32 Lunar Orbit Insertion (LOI)	P33 Lunar Orbit Plane Change (LOPC)	P34 Transfer Phase Initiation (TPI)	P35 Transfer Phase Mid Corr. (TPM)	P36 Transfer Phase Final (TPF)	P37 Return to Earth Target (RTE)	P40 SPS Thrust Maneuver	P41 RCS Thrust Maneuver	P47 Thrust Monitor	P51 IMU Alignment Determination	P52 IMU Re-Alignment	P61 Entry Maneuver to Separate	P62 Entry Sep. Maneuver	P63 Entry Initialization	P64 Entry Post 05 G Phase	P65 Entry Up-Control	P66 Entry Ballistic Phase	P67 Entry Final Phase	P70 Safe Perilune Target (PTT)	P71 LM IMU Launch Alignment Determination	P72 AGS Backup Azimuth Alignment	P73 AGS Backup Initialization	P74 TPI (LM)	P75 TPM (LM)	P77 TPI Search	R10 Orbit Parameter Display	R11 Rendezvous Parameter Display	R12 Target ΔV
1. Earth Prelaunch	✓	✓	✓	✓	✓	✓	✓										✓																												
2. Earth Orbit Injection (EOI)								✓																																				
3. Earth Orbit Phase	✓								✓								✓													✓												✓		
4. Translunar Injection (TLI)									✓																			✓															
5. Translunar Phase	✓				✓	✓								✓S			✓G	✓G	✓G								✓	✓	✓	✓											✓		
6. Lunar Orbit Insertion (LOI) Prethrust & Maneuver																	✓			✓							✓			✓													
7. Lunar Orbit Phase Prior to DOI	✓										✓	✓S	✓		✓	✓	✓G																								✓		✓
8. Descent Orbit Injection & Descent Coast Phase	✓										✓																															✓	
9. Powered Lunar Landing	✓										✓																																
10. Lunar Surface Phase to 3 orbits Before LM Launch	✓				✓	✓						✓S	✓S				✓G												✓	✓												✓		
11. Lunar Prelaunch Phase (Final 3 orbits before LM Ascent)	✓				✓							✓S	✓S				✓G				✓S					✓			✓	✓											✓		
12. LM Powered Ascent											✓																																
13. Rendezvous Phase (LM Active)											✓	✓S					✓G												✓												✓S	✓	✓
14. Lunar Orbit Pre TEI	✓											✓S	✓S				✓G												✓												✓		
15. Transearth Injection (TEI) Prethrust & Maneuver																	✓G	✓G									✓S	✓	✓														
16. Transearth Phase	✓				✓	✓								✓S			✓G	✓G	✓G								✓S	✓	✓	✓	✓											✓	
17. Entry Phase																																✓	✓	✓	✓	✓	✓	✓					
18. LM Rescue (CSM Active)										✓S	✓	✓S					✓G	✓G	✓G		✓	✓	✓				✓S	✓	✓		✓											✓	
19. Abort From Earth Orbit Prethrust & Maneuver																	✓G	✓G	✓G								✓S	✓	✓		✓												
20. Abort from TL, LO, or TE Phase Prethrust & Maneuver																	✓G	✓G	✓G								✓S	✓			✓										✓S		

KEY ✓ • Program Required

S • Program required for self-contained capability only.

G • Program required for ground navigation target capability only.

Appendix E

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:

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 $\underline{r}_P$ when $\underline{r}_P$ is aligned with $\underline{r}_A$ given in 1).
3) The passive vehicle semi-major xis, A_P

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

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

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

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^{o} 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 j ets to hold the attitude within ±. 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 Overide	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.	Minirnum Impulse Mode	DSKY selected sub-mode which causes a 14 ms RCS jet f iring 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

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^{o} 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 preforms 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

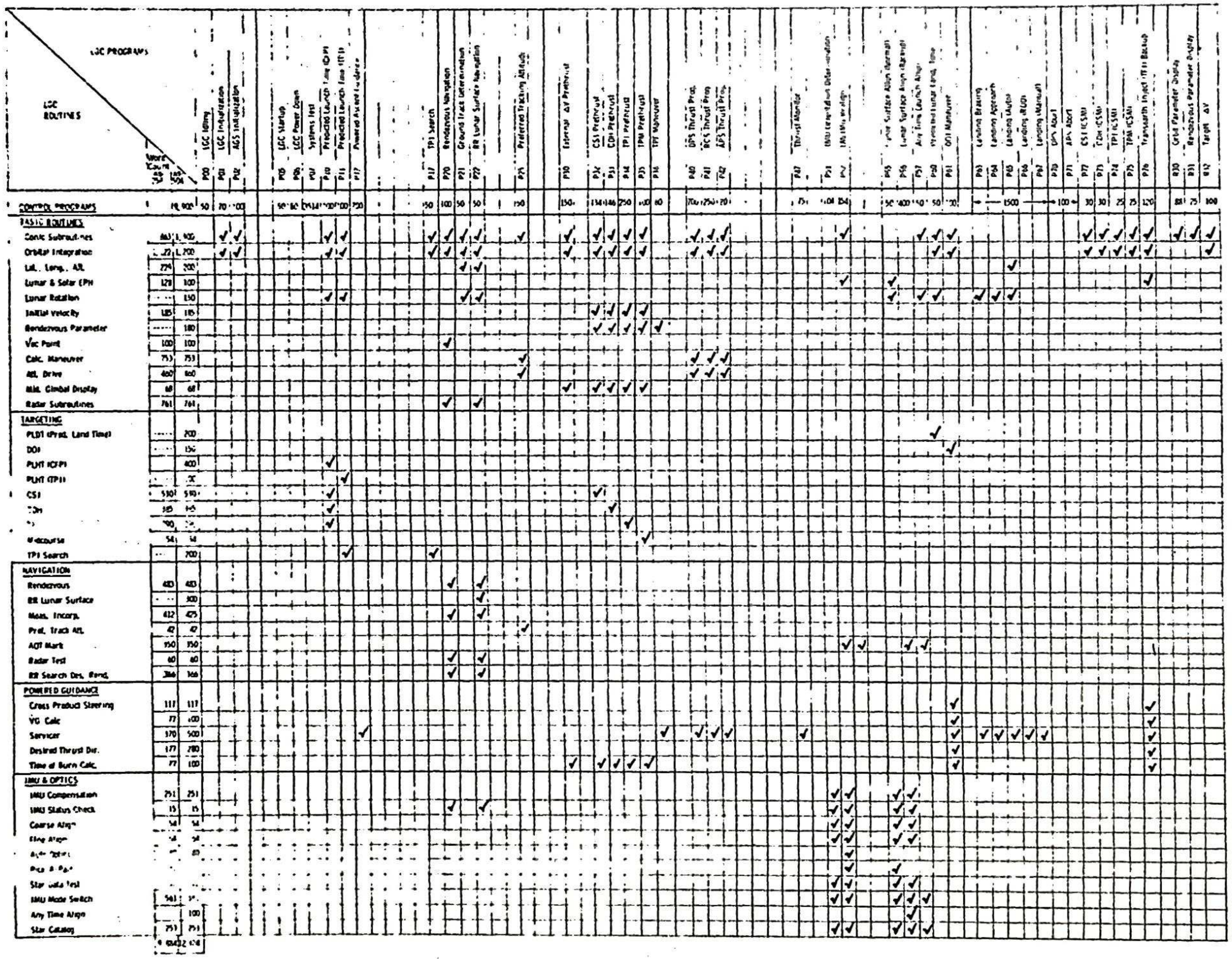
(See CMC definition)

APPENDIX F

LGC PROGRAM/ROUTINE RELATIONSHIP AND SIZES

Appendix F

LGC PROGRAM / ROUTINE RELATIONSHIPS & SIZES



January 13, 1967

DSKY	
Pinball	30000
Extended Verbs	1,680
Keyrupt & Uprupt	98
Display & Service	500
Down Telemetry List	500
Prog. Selec. Checks	100
Down Telemetry Prog.	760
INTERP & EXEC.	
Interpreter	2,271
Wait List	716
Executive	935
Phase Table	350
Restart Control	375
Fresh Start & Restart	289
Phase Change & New Phase	158
T4 Rupt	1,000
Alarm & Abort	65
Self Check	466
Interbank Commun.	88
Interrupt Lead In	91
RTB OP Codes	750
End Bank Marks	56
OTHER	
DAPS	3,400
Transformations	575
Gyro Torquing	44
	14,725
	38,429

APPENDIX G

LGC PROGRAM UTILIZATION

LGC PROGRAM UTILIZATION

January 13, 1967

MISSION PHASE \ LGC PROGRAMS	P00 LGC Idling	P01 LGC Initialization	P02 AGS Initialization	P05 LGC Startup	P06 LGC Power Down	P07 Systems Test	P10 Predicted Launch Time (CSM)	P11 Predicted Launch Time (TPI)	P12 Powered Ascent Guidance	P17 TPI Search	P20 Rendezvous Navigation	P21 Ground Track Determination	P22 RR Lunar Surface Navigation	P25 Preferred Tracking Attitude	P30 External ΔV Prethrust	P32 CSI Prethrust	P33 CDH Prethrust	P34 TPI Prethrust	P35 TPM Prethrust	P36 TPF Maneuver	P40 DPS Thrust Prog.	P41 RCS Thrust Prog.	P42 APS Thrust Prog.	P47 Thrust Monitor	P51 IMU Orientation Determination	P52 LM/IMU Realign	P55 Lunar Surface Align (Normal)	P56 Lunar Surface Align (Backup)	P57 Any Time Launch Align	P60 Predicted Lunar Land. Time	P61 DOI Maneuver	P63 Landing Braking	P64 Landing Approach	P65 Landing (Auto)	P66 Landing (ROD)	P67 Landing (Manual)	P70 DPS Abort	P71 APS Abort	P72 CSI (CSM)	P73 CDH (CSM)	P74 TPI (CSM)	P75 TPM (CSM)	P76 Transearth Inject (TEI) Backup	P40 Orbit Parameter Display	P31 Rendezvous Parameter Display	R32 Target ΔV
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 (PGNCS-Self Contain)*											✓					✓	✓	✓	✓	✓	✓	✓	✓																			✓	
13. Descent Orbit Abort (PGNCS-Ext. Calc)*															✓					✓		✓	✓	✓																			✓	
14. Powered Landing Aborts*																																					✓	✓					✓	
15. AGS Aborts*																								✓																				
16. Aborts from Translunar (Prethrust & Maneuver)		✓			✓	✓									✓					✓																							

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

E-1142 (Rev. 49)

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