BELLCOMM, INC.
1100 Seventeenth Street, N.W. Washington, D.C. 20036

SUBJECT: Simplified Software for the Apollo Guidance Computer - CSM Powered Flight Programs
Case 310

DATE: March 11, 1968

FROM: D. A. Corey

ABSTRACT

A substantially simplified software budget is discussed for the powered flight related portions of the Apollo Guidance Computer programs. Maximum dependence on ground computation facilities has been assumed and on board capability is retained only where absolutely required for mission execution and safety. It is felt that this budget, which requires about half of the current MIT non erasible budget, would have a negligible impact on the probability of mission success.

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MEMORANDUM FOR FILE

INTRODUCTION

This memorandum describes the basic philosophy and implementation of a simplified software package for the Apollo Guidance Computer insofar as the powered flight portions of the Apollo Lunar Missions are concerned. Some of the computer programs and routines are also used in other phases of the mission; these requirements are reflected in the figures presented.

The basic philosophy of the simplifications relates to maximum dependence on ground assistance during all powered flight maneuvers. Generally speaking, there is no actual increase in the amount and type of ground computation requirements, although specific parameters to be computed and uplinked differ from current requirements in several cases.

It is this writer's opinion that the impact of the simplified powered flight programs on the probability of mission success is virtually negligible. There is some loss of backup capability, but under current mission planning this capability would only be used in the event of highly unlikely situations, for example, loss of all ground communications with both the CSM and the LM for an extended period of time.

Table II presents a list of the powered flight related programs and routines currently programmed for the AGC based on the list of routines for MIT's version called COLOSSUS Rev. 135. Three estimates of the number of fixed memory words required are presented: (a) MIT's budget, (b) the current count of the actual number of words used, and (c) the proposed budget for the simplified programs. The following paragraphs will explain the changes proposed for the routines which would have a word count different from MIT's budget.

DESCRIPTION OF PROGRAM AND ROUTINE CHANGES

P11 - EOI Monitor - The portion of the program related to computation of the launch vehicle attitude deviations from a prescribed pitch polynomial during the interval from 10 to 133 seconds after launch has been removed. The attitude as displayed by the "8 Ball" will remain and the DSKY displays will be unchanged.

P15 - TLI Monitor - No on-board guidance computations will be done. The magnitude of ΔV and the current attitude rate will be displayed on the DSKY.

P17 - TPI Search - This program has been eliminated. The ground or the LM will do the targeting.

P30 - External ΔV Prethrust - This program has been simplified considerably. The compensation of $\vec{\Delta V}$ for maneuver angle is removed. State vector extrapolation to ignition time less 30 seconds and to ignition time is done on the ground. ΔV is sent up in platform coordinates, eliminating the conversion from local vertical. The Tgo routine is not called.

P31 - General Lambert Maneuver - All powered flights are to be performed in the External ΔV mode. There are no Lambert maneuvers so this program is not required.

P34/P74 - TPI Prethrust - The TPI maneuver will be targeted from the ground or by the LGC and executed in the External ΔV mode. TPI Prethrust becomes the same as External ΔV prethrust.

P35/P75 - TPM Prethrust - This maneuver is targeted on the ground or by the LGC and executed in the External ΔV mode. No on-board targeting capability is retained.

P37 - Return to Earth - Only an extremely limited on-board targeting capability is retained, consisting basically of astronaut controlled iteration using the Kepler routine.

P38 - SOR Prethrust - The maneuver, if done at all, will be performed in the External ΔV mode with external targeting.

P39 - SOM Prethrust - See P38.

P49 - SPS Thrusting - Some words have been eliminated due to the simpler operation. IMU orientation will always be the same with respect to nominal thrust direction. Some restart protection would be eliminated. Items related to Lambert steering and the Lambert aim point are removed. The estimated reduction is 25% of the current estimates.

P47 - Thrust Monitor - This task will be done by the astronaut. Some of the functions may still be required (for example turning the ullage off automatically) but basic operations such as switch settings will be done before ignition. If steering computations are to be performed at all they will be done from the first call to the routines.

S40.1, S40.2,3 - Desired Thrust Direction - The preferred IMU alignment computations are removed. The computations of initial engine bell trim and the resulting desired gimbal angles are retained. Portions dealing with time of burn are simplified or eliminated. The routine really only needs to be told which propulsion system is to be used. It is estimated that 100 words can be saved.

S40.8 - Cross Product Steering - The equations can be simplified somewhat since C = 0 and $Cb\Delta t = 0$ in all cases.

S40.9 - VG Calculation - This routine is used with Lambert steering and can be eliminated.

S40.13 - Time of Burn Calculation - This function is done on the ground, eliminating the need for this routine.

Time of Free Fall Routines - These are basically eliminated since they are rather redundant. The Conic routines do substantially the same job. A small budget has been retained to manipulate the Conic routines when certain parameters are required for display purposes.

Conic Routines - The Lambert routine is not required.

Periaps Routine - This function will be done by calling subroutine APSIDES directly.

Latitude Longitude Altitude Routine - If the astronaut needs these quantities, he can ask the ground.

Initial Velocity Routine - This routine is the entry point for Lambert operations, which are not used. Consequently, the routine is not required.

TPI Search Routine - Basic Targeting for CSM/LM Rescue will be done on the ground, with the LGC serving as a backup. A profile for LM rescue is available which places TPI at such a location that sufficient tracking time and computing time are available such that the CSM can receive TPI targeting from the ground. TPI is then performed in the External ΔV mode.

Return to Earth Routines - See P37 Return to Earth.

IMPLICATIONS OF NO LAMBERT STEERING

The impact of External ΔV mode powered flights on mission fuel requirements and on maneuver accuracy appears to be negligible. In the first place, current planning already utilizes the External ΔV mode for everything but the first part of LOI (and maybe TEI). Strong consideration is being given to using it everywhere. In the second place, studies have shown that very little penalty is incurred by using the External ΔV mode in place of Lambert Steering. Reference 1 compares the two steering methods for insertion into an elliptical orbit (first part of LOI). For a 10.15 degree plane change into a 95 x 80 mile orbit, the External ΔV mode required 10 fps more fuel nominally (3274 vs. 3264). A one degree plane change into a 200 x 80 mile orbit required .3 fps more fuel in the External ΔV mode.

Generally, error analysis studies performed at MSC have shown that for direct insertion into a circular lunar parking orbit, the External ΔV mode produces significantly larger errors than does the Lambert steering. The errors are acceptable at the 3σ level, however. The difference between the two methods is much smaller for insertion into a 170 x 60 ellipse, which is the current plan. Reference 2 presents the results of a 550 run Monte Carlo Error Analysis comparing the two methods. The trajectory involved a plane change of 10° and a final nominal orbit of 60 x 170 miles. Table II is extracted from Reference 2 and presents a summary of the results of that error analysis. The following data is extracted from that table, and assumes that the statistics were gaussian and that + 3σ = 98%.

	EXTERNAL ΔV	LAMBERT
	3σ Errors	3σ Errors
Apolune Altitude (N.Mi)	5.3	5.3
Perilune Altitude (N.Mi)	.66	.67
Inclination (deg)	.25	.25
Longitude of ASC. Node (deg)	.25	.26
Burn Time (Sec)	3.51	3.41

The differences in the errors are obviously negligible.

SUMMARY

The simplified powered flight non-erasible word budget presented in this memorandum is principally based on the philosophy that everything that can be done on the ground is done on the ground. On-board backup capability has been retained only where absolutely necessary for mission operations and safety. The on-board capabilities to compute and display various parameters to the astronaut have largely been retained in order to assist them in making decisions where either time or safety is critical.

The proposed complete reliance on the External ΔV mode for powered flight maneuvers actually differs very little from current mission plans, although more parameters would be computed on the ground in the simplified plan.

Close coordination between the AGC programming and the RTCC programming is, of course, especially important in the case of the simplified on-board system. This is a matter of degree, however, since close coordination is also required under current plans. The program impact on the RTCC is judged to be relatively small. Most of the computations required by the simplified system are already made for the current system. Some changes are required in particular parameters to be uplinked.

Substantial non-erasible memory savings have also been obtained by removing most of the on-board maneuver targeting capabilities. It is felt, however, that they would only be required in the most remote of circumstances and the actual impact on the probability of mission success and safety is negligible.

Non-erasible core requirements are completely meaningful only in terms of totals for the entire computer since many routines are used for more than one function. However, the estimated core savings for the powered flight related programs is in the neighborhood of 50% of the current MIT requirements.

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2011-DAC-vh

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Attachments
Table I
Table II

REFERENCES

1. Comparison of the Sensitivity of Lambert and External ΔV Guidances to Dispersions in the LOI Burns of Missions F and G. U. S. Government Memorandum, Robert F. Wiley, NASA/MSC (not yet a published memorandum).

2. A Comparison Analysis Between the External ΔV and Lambert Guidance for the Lunar Orbit Insertion (LOI) Maneuver. U. S. Government Memorandum 68-FM73-81, February 21, 1968, Richard M. Moore, Jr., and Aldo J. Bordano NASA/MSC.

TABLE I

AGC WORD COUNTS OF PROGRAMS AND ROUTINES DEALING WITH CSM POWERED FLIGHTS

ROUTINE IDENTIFICATION	TITLE	WORD COUNT		
		MIT BUDGET	MIT CURRENT ESTIMATE	SIMPLIFIED BUDGET
PROGRAMS AND MISC. ROUTINES				
P11	EOI MONITOR	380	376	325
P15	TLI MONITOR	250	-*	150
P17	TPI SEARCH	150	-	0
P30	EXTERNAL ΔV PRETHRUST	250	244	50
P31	GENERAL LAMBERT MANEUVER	120	-	0
P34/P74	TPI PRETHRUST	450	138	0
P35/P75	TPM PRETHRUST	100	502	0
P37	RETURN TO EARTH	250	240	50
P38	SOR PRETHRUST	50	-	0
P39	SOM PRETHRUST	50	-	0

*Where no current estimate is available, MIT Budget figures are used in the totals.

TABLE I Contd.

		WORD COUNT		
ROUTINE IDENTIFICATION	TITLE	MIT BUDGET	MIT CURRENT ESTIMATE	SIMPLIFIED BUDGET
PROGRAMS AND MISC. ROUTINES				
P40	SPS THRUSTING	560	563	422
P41	RCS THRUSTING	150	128	150
P47	THRUST MONITOR	100	72	0
P51/P53	IMU ORIENT & BACKUP	265	259	265
P52/P54	IMU REALIGN & BACKUP	260	240	260
R30	ORBIT PARAMETER DISPLAY	115	290	290
R31-R34	RENDEZVOUS PARAMETER DISPLAY	100	158	100
POWERED GUIDANCE ROUTINES				
	SERVICER	500	401	500
S40.1, S40.2,3	DESIRED THRUST DIRECTION	350	338	238
S40.8	CROSS PRODUCT STEERING	140	128	100
S40.9	VG CALCULATION	100	99	0
S40.13	TIME OF BURN CALCULATION	80	68	0
S41.1	INITIAL GC	20	17	20

TABLE I Contd.

ROUTINE IDENTIFICATION	TITLE	WORD COUNT MIT BUDGET	MIT CURRENT ESTIMATE	SIMPLIFIED BUDGET
BASIC MATH ROUTINES				
	POWERED FLIGHT SUBROUTINES	156	156	156
	TIME OF FREE FALL	300	266	50
	CONIC SUBROUTINES	1050	1082	800
	PERIAPO	100	78	0
	LATITUDE LONGITUDE ALTITUDE	170	159	0
	INITIAL VELOCITY	175	175	0
	INFLIGHT ALIGNMENT ROUTINES	287	225	225
TARGETING ROUTINES				
	TPI SEARCH	320	304	0
	RETURN TO EARTH	1200	888	0
UTILITY AND SERVICE ROUTINES				
	IMU MODE SWITCHING	580	573	580
	IMU COMPENSATION	250	246	100
	IMU STATUS CHECK	30	17	17
	TOTALS	9408	9050	4848

TABLE II

(Extracted from Reference 2)

LOI DISPERSION ANALYSIS SUMMARY

Guidance for LOI	Resulting Apocynthion (n. mi.)	Resulting Pericynthion (n. mi.)	Resulting Inclination (deg)	Resulting Longitude of Ascending Node (deg)	Burn Time (sec)
External ΔV					
Nominal	170.00	59.98	157.99	178.74	381.48
Mean	170.07	59.99	157.98	178.73	381.57
Largest Sample	178.52	60.97	158.34	179.11	388.03
98%	175.65	60.62	158.22	178.97	385.04
2%	164.85	59.41	157.72	178.48	378.03
Smallest Sample	162.53	59.16	157.58	178.35	377.18
Lambert					
Nominal	169.55	60.21	157.99	178.74	381.73
Mean	169.68	60.21	157.98	178.72	381.76
Largest Sample	176.87	69.19	158.35	179.03	386.80
98%	175.05	60.89	158.25	178.98	385.17
2%	164.55	59.56	157.73	178.47	378.25
Smallest Sample	162.40	59.04	157.54	178.28	376.62

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From: D. A. Corey

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