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SUMMARY

RCS propellant usage studies for the Apollo CSM, primary control system, have been made to update data used in propellant calculations, and to determine the propellant penalty caused by inexact inertia values in the CMC. These results are presented and the digital simulation used in the study is described. Briefly, the results indicate that previously used RCS propellant consumption rate data was low for single-axis automatic maneuvers. Also, it is shown that computer values of inertia in error by more than 25 percent can cause a sizable (20 percent or higher) propellant penalty for automatic maneuvers.

INTRODUCTION

This internal note presents PGNCs CSM RCS propellant usage data resulting from two studies. The first study arose from a data request (reference 1) requesting a verification and update of the PGNCs CSM RCS propellant usage data found in the Mission Modular Data Book (MMDB). The second study, concerning the propellant penalty caused by inaccurate values of inertia in the CMC (RCS DAP), was prompted by a need to know when to update mass property parameters (e.g., inertias) not tracked automatically by the CMC (reference 2).

The simulator used in these studies will also be used in future AGC studies and because of its importance as an engineering tool will be described in some detail. It is called the Apollo Guidance Computer Functional Simulator (AGCFS).

APOLLO GUIDANCE COMPUTER FUNCTIONAL SIMULATOR

Prior to the development of the AGCFS, the only high fidelity Apollo digital control system simulation available was the AGC bit-by-bit simulator. This simulator duplicates the actual flight computer characteristics on a general purpose digital computer (CDC 3800) in a bit-by-bit fashion. Coupled with a Fortran environments package, it is used for flight program software validation. Although the bit-by-bit simulator is a very accurate representation of the AGC, it is not a practical engineering tool because: (1) It requires a large amount of computer time to run (at best, 7 to 1 computer to real time), (2) the run initialization process is extremely difficult, and (3) individual parameters used in the AGC program are not very accessible for design modification studies. The AGCFS, programmed by LEC/CAD, was designed to overcome these drawbacks and still model the guidance and control portions of the flight software as closely as possible. This was done by coupling essentially the same environments programs used by the bit-by-bit simulator, through MTT defined interfaces, with a series of

Fortran programs that functionally duplicate the logic of the actual flight listing. These Fortran programs, called user segments, are derived directly from the flight listing and are easily altered for design modification studies. Included among them are the RCS DAP, the TVC DAP, the Entry DAP, the LM DAP, cross product steering, and their many supporting routines. A more detailed description of the AGCFS, authored by its programmers, is given in reference 3.

At the time of this writing, most of these user segments were in production status for SUNDISK and SUNDANCE, the first hard wired Apollo flight programs for the CSM and LM, respectively. Some are in the checkout stage for subsequent flight programs, COLOSSUS and LUMINARY. Revisions to all flight programs are reflected in the user segments as soon as practical.

The RCS DAP, coupled with its related steering routines (KALCMANU, VECPOINT, et cetera) was used to generate the data in this note. In making the runs for the MMDB verification study, only the SUNDISK version of the RCS DAP was used as the COLOSSUS version had not yet reached the production stage. However, although there were significant programming changes in COLOSSUS, the basic design remained functionally the same, and the COLOSSUS version should yield substantially the same results.

MMDB DATA VERIFICATION

This section presents a comparison between the PGNCS RCS propellant data in the MMDB and the corresponding data generated by the AGCFS. The MMDB data was derived theoretically and it is used for calculating RCS propellant budgets.

Comparison data was generated for single and 3-axis simultaneous automatic maneuvers and two and four jet +X translations. Y and Z translation data, not covered in the MMDB, was also generated in the study.

Three vehicle configurations were used, and the associated mass properties are given in Table I.

Single-axis automatic maneuvers.- A series of single-axis automatic maneuver runs were generated to compare AGCFS and MMDB propellant usage data. The results are shown in Table II.

TABLE I. - MASS PROPERTIES

Vehicle Configuration	X cg(in)	Y cg(in)	Z cg(in)	I XX(sl-ft ²)	I AV(sl-ft ²)
(1) CSM 23,145#	985.1	-2.82	8.52	12,948	40,747
(2) CSM 34,345#	951.0	1.353	6.18	19,137	60,730
(3) CSM-LM 92,000#	1042	2.78	4.96	53,574	523,588

TABLE II. - SINGLE-AXIS AUTOMATIC MANEUVERS

Vehicle Configuration	Maneuver (deg) (ϕ, θ, ψ)	Maneuver (deg/sec) rate	Prop. in Pounds	
			AGCFS	MMDB
CSM 23,145#	20, 0, 0	.2	.11	.1
	20, 0, 0	.5	.234	.4*
	0, 20, 0	.2	.264	.25
	0, 20, 0	.5	.513	.4
CSM 34,345#	0, 20, 0	.2	.311	.3
	0, 20, 0	.5	.753	.6
CSM-LM 92,000#	20, 0, 0	.2	.266	.26
	0, 20, 0	.2	2.2	2.07
	0, 20, 0	.5	6.27	5.4

Except for one probable bad data point (denoted by *), the AGCFS predicts a somewhat higher propellant consumption. The end of the maneuver as defined in the AGCFS runs was the time when the S/C had approximately achieved a minimum impulse limit cycle; this may have included additional jet firings not considered in the MMDB data.

Three-axis Automatic Maneuvers. - The results of the 3-axis automatic maneuver study is shown in Table III.

TABLE III. - 3-AXIS AUTOMATIC MANEUVERS

Vehicle Configuration	Maneuver (deg) (ϕ, θ, ψ)	Maneuver (deg/sec) rate	Prop. in Pounds	
			AGCES	MMDB
CSM 23,145#	(50,50,50)	.2	.458	-
	(50,50,50)	.5	.863	-
	(20,20,20)	.2	.41	.5
	(20,20,20)	.5	.751	.9
CSM-LM 92,000#	(50,50,50)	.2	4.14	-
	(50,50,50)	.5	9.35	-
	(20,20,20)	.2	3.19	3.16
	(20,20,20)	.5	8.49	7.85

The MMDB data indicates a slightly higher propellant consumption for the near empty CSM and predicts approximately the same propellant usage for the heavy (full) CSM-LM.

X-Translations.- X-translations were performed for three vehicle configurations with all three possible quad choices. Propellant consumption data from these runs agreed well with the MMDB data as is illustrated in the Table below.

TABLE IV. - X-TRANSLATION PROPELLANT CONSUMPTION

10 FT/SEC ΔV

Vehicle Configuration	Data Source	Prop. in Pounds		
		AC	BD	AC & BD
CSM 23,145#	FS	28.6	30.62	28.42
	MMDB	27.8	*	27.5
CSM 34,345#	FS	39.78	43.35	39.49
	MMDB	40.8	*	40.7
CSM-LM 92,000#	FS	110.59	114.07	105.86
	MMDB	Not given		110.

*MMDB data did not differentiate between AC and BD quads.

Y and Z Translations.- Y and Z translation data can be obtained approximately from the MMDB by adding to the MMDB X-translation data the theoretical propellant required to null the disturbing torque introduced by the RCS thruster plane offset.

The formula for deriving this data is,

$$Y \text{ or } Z\text{-translation poundage} = X\text{-translation } X \left(1 + \left| \frac{X}{cg} \frac{-959.}{84.} \right| \right)$$

where the term in the absolute value brackets is the ratio of disturbing torque to restoring torque.

A comparison of the data generated in this manner with the data derived from the AGCFS is given in Table V.

TABLE V. - Y AND Z TRANSLATIONS

10 FT/SEC ΔV

Vehicle Configuration	Data Source	Prop. in Pounds	
		Y	Z
CSM	AGCFS	41.56	38.83
23,145#	MMDB Derived	36.44	36.44
CSM	AGCFS	48.82	45.85
34,345#	MMDB Derived	44.69	44.69

The AGCFS indicates that this MMDB derived data is approximately correct, but can be low by 15 percent.

EFFECT OF COMPUTER INERTIA VALUES

The RCS DAP uses inertia values in its angular rate estimating scheme and its calculation of jet-on times. In COLOSSUS, these inertia values are tracked automatically under PGNC operation. However, SUNDISK does not have this provision, and inertia values must be updated either by the crew or the ground. The question arose as to how much inertia variation (caused by depletion of SPS propellant) could be tolerated by the RCS DAP before inertia updates became desirable, and finally, mandatory. A study was made to give insight to the question.

The RCS DAP estimates the vehicles angular rate by digitally filtering the change in CDU angles in a continuous fashion and accounting

for jet firings by adding in the expected value of integrated torque for a DAP cycle (.1 second). This term is inversely proportional to the DAP's estimate of inertia. Jet-on times are calculated in direct proportion to the DAP's estimates of inertia. Should these estimates of inertia be low, an inversely proportional error will be generated in the rate estimator; moreover, the jet-on times will be too small. Due to buildup and decay transients, small jet firings are inefficient, hence propellant will be wasted.

On the other hand, if the DAP's estimate of inertia is too high, the rate estimator will again be distorted by an inversely proportional error and the jet firings will be too long causing the DAP to overshoot its aimpoint and possibly causing corrective jet firings in the opposite direction.

Hence non-exact DAP inertia values reduce efficiency whether they be high or low. However, MIT felt there were more drawbacks in having a high value of inertia due to a potential instability problem. Therefore, in the calculation of jet-on times, the inertia value is premultiplied by a .8 factor. In essence, this indicates the most efficient values of inertia to load in the DAP are those approximately 1.25 times the actual S/C inertias. This was confirmed in the study.

A series of runs were made with a lightly loaded CSM (vehicle 2) executing an automatic maneuver of (20,20,20) at .5°/sec with various computer loaded inertia values. The results are tabulated in Table VI.

TABLE VI. - OFF-NOMINAL INERTIAS

Computer Loaded Inertia Values	RCS Propellant(lbs)
50% High	1.14
25% High	.955
15% High	.986
Nominal	1.09
15% Low	1.22
25% Low	1.31
50% Low	1.55

From this data, it was felt that an inertia update was desirable when a discrepancy of about +15 percent was suspected and mandatory for a +25 percent discrepancy.

CONCLUSIONS

The AGCFS is a sophisticated simulator which can be used as an acceptable program to study digital autopilot performance.

RCS propellant usage data employed in compilation of RCS propellant budgets has been upgraded for Apollo CSM DAP.

Sensitivity of the Apollo CSM DAP performance, as regards RCS propellant usage, to variations in the error between actual vehicle inertia and the onboard computer estimate of vehicle inertia, has been demonstrated.

REFERENCES

1. MSC Apollo Data Request Number MSC-R-87: Verification and supplement of the SM-RCS propellant prediction as presented in the CSM MMDB Performance Data Supplement. April 9, 1968.
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3. Lockheed Electronics Company (LEC) IC LEC/GC/32: Apollo Guidance Computer Functional Simulator Programmer User's Guide - Revision 0. December 19, 1967.