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SKYLAB MISSION PLANNING SUPPORT THROUGH THE USE OF A HYBRID SIMULATION

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16. ABSTRACT

This report describes the manner in which a hybrid simulation was used in support of Skylab operations in the area of dynamics and control. Simulation results were used in the development of acceptable vehicle maneuvers and in the verification of acceptability when the maneuvers were integrated into daily flight plans. The criterion of acceptability was based on vehicle controllability and the minimization of thruster system propellant usage. This report includes a simulation of a representative daily flight plan containing three experimental maneuvers. Also included are thruster attitude control system propellant usage tables which show predicted and actual usage for each mission. The inherent characteristics of quick turnaround and flexibility afforded by the hybrid computer proved invaluable in the operations support required throughout the Skylab mission.

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DEFINITIONS OF SYMBOLS

Symbol	Definition
H_x	X-axis control moment gyro momentum
H_y	Y-axis control moment gyro momentum
H_z	Z-axis control moment gyro momentum
H_t	total control moment gyro momentum
ω_x	X-axis angular velocity
ω_y	Y-axis angular velocity
ω_z	Z-axis angular velocity
δ_{1i}	inner gimbal angle for CMG number i (1, 2, or 3)
δ_{3i}	outer gimbal angle for CMG number i (1, 2, or 3)
η_t	orbital position
ν_z	Skylab X-axis displacement from orbital plane
η_x	solar elevation from orbital plane
Z-LV	Skylab negative Z-axis pointed to center of earth

TECHNICAL MEMORANDUM X-64889

SKYLAB MISSION PLANNING SUPPORT THROUGH THE USE OF A HYBRID SIMULATION

INTRODUCTION

The support of the Skylab mission in the area of dynamics and control presented Marshall Space Flight Center engineers with a mode of operation that was significantly different from the Saturn program. Marshall Center's operational support for the Saturn program was limited to a booster flight time that did not exceed 30 min, whereas operational support requirements of the Skylab mission extended for a period of time in excess of 8 months. Premission planning included the use of a control system simulation that was programmed on an EAI 8900 hybrid computer system capable of running 100 times real time. Original plans called for the use of this computer for 24 to 36 hours a week with an on-call emergency capability of being operational within 4 hours. Due to significant hardware failures which occurred throughout the mission, this hybrid simulation was in operation 24 hours a day, 7 days a week for most of the 8-month mission period.

The first malfunction which significantly impacted the operation of the Skylab control system was the loss of the Workshop meteoroid shield and solar panel during the launch phase of the mission. This failure resulted in the vehicle being placed in an attitude to reduce Workshop temperatures. However, this "thermal attitude" imposed requirements on the control system which were outside design criteria. Another system problem which occurred during SL-2 was rate gyro drift and noise, a condition which required drift rate monitoring and adjustments. A third major malfunction was the bearing failure in one of the three control moment gyros (CMGs) during SL-4. The last system component failure was the loss of the outer gimbal optic encoder of the star tracker. The effect of each of these malfunctions on the vehicle controllability was analyzed extensively, not only to find a workable mode of operation but also to help define a satisfactory "fix" to the problem.

Although the use of the hybrid control system simulation, as described in this report, is basically one of day-to-day operations, many studies were conducted on specific maneuvers and operational modes days before they were to be performed. The daily operations have been divided into real-time and near-real-time activities. In real time, a comparison of predicted vehicle control system parameters to those obtained from telemetry were tracked. If significant differences were detected, the subsequent activities were simulated after updating the hybrid with real time flight data. Near-real-time support normally began with the acquisition of a proposed flight plan for the following day. This flight plan and basic information concerning vehicle maneuvers, trim burns, etc., were generally available 18 to 24 hours prior to execution. The simulator was then used to develop flight plans which did not exceed control system constraints. Results of these analyses were combined with inputs from other disciplines to generate a final flight plan. With the availability of this flight plan, a simulation was run to define predicted control system behavior.

A representative flight plan with associated maneuver descriptions and the analog strip chart outputs for a 24-hour activity period are included in this report. Real-time comments and flight data have been superimposed on the simulation strip charts. An examination of these charts indicates good correlation between predicted and actual control system parameters. Also included here are thruster attitude control system (TACS) impulse usage tables for the total Skylab mission.

HYBRID SIMULATION

The EAI 8900 hybrid computing system was selected to model the Skylab vehicle operation since it offered good turnaround time at a reasonable cost and could be dedicated for the full 9-month mission. In addition, the analog computer offers several features desirable in modeling a time domain, dynamical problem. The digital computer with 32K memory was programmed to match closely the onboard control computer, determine the environmental data, and handle the sequence of operation between computers. To prevent loss of support due to computer malfunctions, a backup system was available with minimal switchover time.

The analog computer involved two boards which were coupled with five strip chart recorders. The CMG gimbal angles, direction cosines, and vehicle body dynamics were modeled in the analog system. The digital system included the driver program and subroutines describing maneuvers, attitude, momentum management, steering and control laws, the thruster attitude control system logic, and a variety of external torques.

Time scaling options were available for operating the simulation at real time, 10 times as fast, 50 times as fast, and 100 times as fast. The trade between quick turnaround and accurate response of the thruster attitude control system resulted in the selection of 50 times real time for the usual operating mode. Thus an entire day for crew operations could be simulated in about 30 min. The time required to initialize the computer was approximately 30 min; this included loading initial conditions, maneuver commands, and special control logic and setting CMG gimbal angle potentiometers.

The hybrid system also proved invaluable for "man-in-the-loop" control studies, such as controllability during rate gyro switchover to the "six pack" module. It was shown that, during this switchover period in which there was no rate feedback for control, manual control of the Skylab using the TACS was possible.

Another positive feature of this simulation was the relative simplicity of logic changes to permit a variety of maneuver sequences. For example, the conditions imposed by two-CMG operation necessitated revisions to the earth resource experiment maneuver (EREP). This revision allowed the vehicle to operate in an offset attitude before and after the experiment data were taken. A detailed description of the hybrid simulation may be found in footnote 1 and Reference 1.

OPERATIONAL PROCEDURES

The Skylab's onboard computer system and sensors relayed to the ground tracking stations significant parameters regarding the control and stability conditions of the orbiting vehicle. During high activity periods of the mission, close observance was given to certain key vehicle parameters, i.e., vehicle rates, CMG gimbal angles, CMG momentum, and TACS counters. A comparison of vehicle data to simulated flight data was made by plotting the flight data points on the hybrid strip charts. The proposed flight plan simulation had been generated the previous day and showed the effects of vent torques, maneuvers, and momentum management. As the day's activities progressed, the Support Team, Attitude Control (STAC) evaluated the control state of the Skylab.

Some differences in estimated versus predicted data were attributed to uncertainties in the Skylab environment, sensor dynamics, and system nonlinearities and noise. Some common causes of large differences were torques due to unpredicted venting, time sequencing problems associated with onboard experiments, and sensor anomalies. When these large differences in the data

1. Buchanan, Harry; Nixon, Douglas; and Joyce, Ron: A Computer Simulation of Skylab Dynamics and Attitude Control for Performance Verification and Operational Support. NASA Technical Memorandum to be published.

occurred, it was necessary to alert the support team and to simulate the remainder of the flight plan with updated initial conditions. This provided STAC with the capability of assessing the impact on the remainder of the flight plan schedule. The resultant action ranged from simply alerting the crew to monitor selected control parameters to canceling an upcoming experiment maneuver.

The flight plan of a crew work day consisted of a detailed time schedule of many experiments, maneuvers, and other crew activities. This schedule was subject to many operational constraints from several groups, such as the thermal, power, control, and experiments groups. Thus the flight plan evolved from a first cut collection of experiments to a final, approved flight plan, incorporating many trade-offs involving all subsystems. The simulation of the proposed flight plan was consequently preceded by the study and evaluation of the two or three individual maneuvers which could be included in one day's schedule.

The basic attitude of the Skylab was solar inertial (SI). Maneuvers to other attitudes were primarily for astronomical investigations and earth pointing experiments. The performance of these experiments involved two types of control requirements — maneuvering capability and vehicle stabilization. In studying a maneuver, the attitude pointing and control system performance analyst strived to ensure that the CMG system did not reach the gimbal stop condition, yet stay within the estimated TACS fuel budget allowed. The control constraints included maneuver rate limits, pointing requirements, momentum margin for anomalies, and CMG singularity avoidance.

The analysis of a maneuver included a parameterization of maneuver times to find the best gimbal trace condition. For some maneuvers, the in-orbit position at which the maneuver was initiated and/or terminated was analyzed. There were several other control options, such as momentum biasing, TACS-only maneuvers with CMG control inhibited, CMG manual resets, etc. At various times, combinations of all these were studied for the more difficult maneuvers.

In the last manned mission, the loss of CMG number 1 resulted in a control system with a reduced capability to perform maneuvers. Since CMG momentum saturation and gimbal stop margin were significantly reduced, all maneuvers were run under nominal conditions and under 20 percent off-nominal conditions in each of H_x, H_y, and H_z, individually. When these perturbations led to loss of attitude control, the maneuver was either canceled, given further analysis, or postponed until a more favorable orbital geometry was obtained.

One of the major control factors for two-CMG operation was momentum bias. The loss of CMG number 1 caused an unacceptable distribution of momentum about the control axes. Given a momentum bias, the CMG's gimbal pattern was shifted so that both gimbal stops and momentum saturation during normal solar inertial operation were avoided. Since the momentum accumulation was dependent on η_x, the sun's position relative to the orbit plane, which varied about 5 deg per day, a bias update was required every few days. Special biases were required to maximize controllability during some maneuvers. The hybrid simulation was the primary program used for defining and checking the bias changes.

An additional biasing problem occurred when the CMG's were gimballed into the anti-parallel condition. Under the two CMG operations, this condition occurred when the total CMG momentum was zero. The antiparallel condition could cause unpredictable gimbal behavior and excessive actuator loads.

A control option available for maneuvers to earth-pointing (Z-LV) attitudes for EREP passes under two-CMG operation was the use of an offset Z-LV attitude that was entered at the orbit noon prior to the experiment. A typical attitude command chosen for the Z-LV offset was (0, -4.2, -1.0 deg) from Z-LV attitude. Offset Z-LV attitudes were selected to prevent momentum accumulation. A maneuver of only 5 deg was required to align with true Z-LV near the desired viewing target. On completion of the experiment, the vehicle was commanded to return to solar inertial attitude. Sometimes it was necessary to realign to the offset Z-LV attitude prior to the return to solar inertial attitude at the following orbit noon. These long EREP maneuvers severely lessened solar power storage and were rarely used more than once per day.

Because of the large maneuvers required, it was costly to achieve some of the attitudes required for astronomical observations. For many of these experiments, it was mandatory that there be no TACS firings during the observation periods. As a result, there were few options available to minimize fuel costs. Most of the comet Kohoutek observations were basically roll maneuvers and were easily achieved. Large torques were not required to rotate the vehicle about the roll axis because of the magnitude of the moment of inertia about this axis. In addition, the observation times were usually less than 20 min.

The extravehicular activities (EVA) of the Skylab crew were for erecting the sun shield, rate-gyro package switchover, film retrieval, maintenance, and photographs. It was difficult to make the simulations of the proposed EVAs because of uncertainties in suit-vent torques, which were dependent on astronaut position, attitude, and lengths of time at work stations. Therefore, it was necessary to parameterize these torques and evaluate different control schemes. The control schemes analyzed were momentum biasing, periodic caging of the CMGs to the nominal profile or to a specified momentum level, and the use of manual CMG resets.

COMPARISON OF RESULTS

A prediction of vehicle control system behavior for mission day 58 of SL-4 is presented on Figures 1 and 2. Superimposed on these strip charts are control system parameter data obtained by realtime monitoring. Figure 1 presents time traces of CMG momentum (H_x, H_y, H_z, H_t), vehicle angular rates (ω_x, ω_y, ω_z), and TACS firing data. Figure 2 presents traces of CMG gimbal angles (δ_{11}, δ_{12}, δ_{13}, δ_{31}, δ_{32}, δ_{33}), vehicle orbital position (η_t), and vehicle Z-axis rotation (ν_z). The hybrid simulation was initialized in solar inertial attitude two orbits prior to the initiation of the first experiment. The Greenwich mean time (G. m. t.) corresponding to each orbital midnight is identified on the charts. Each subdivision on the time scale represents a period of 250 sec. Ground station coverage was marked on the charts to identify when real-time data were available. Other significant events identified in the figures are momentum management maneuvers, momentum bias changes, and experiments which affected the control system.

An overview of MD-58 activity is contained in the flight plan (Fig. 3). This plan identifies crew activities, venting, vehicle maneuvers, and momentum management dump inhibits. Vent models for the trash airlock (TAL) and the M092 experiments were in the hybrid simulation. The other vents listed in the flight plan were found to be of insignificant magnitude and, therefore, were not modeled. The day's experiment activity required four CMG momentum dump inhibits for the S-233, EREP number 27, S-063K, and S-201K experiments.

The Kohoutek Comet S-233 photography experiment, which did not require a vehicle maneuver, was performed near the time of orbital midnight, 12:53. The CMG traces show the effect of this dump inhibit, a gradual increase in momentum resulting in a TACS desaturation minimum impulse bit (MIB) firing at 13:34. Desaturation was programmed to occur when the total system momentum reached a value equal to 96 percent of the total momentum capability of the CMGs. Since CMG number 1 had failed prior to MD-58, the TACS firing level was set at 5980 Nms. The predicted MIB at 13:34 did not occur on board because of the lower peak momentum that was attributed to Z-axis alignment problems which, in turn, resulted from the failure of the star tracker on MD-42 of SL-4.

At 10:11, ground controllers instructed the crew to change the current values of the CMG bias from (-11.0, +11.0, 0.) percent to (-17.0, +7.0, 0.) percent of 3 H. These values were loaded in the onboard computer to increase the control margin of the CMGs for the execution of the EREP. The near-real-time studies on the hybrid simulator had resulted in the selection of (-17.0, +7.0, 0.) percent biases for the EREP pass. As noted in Figure 1, the bias was changed back following the completion of the earth resources pass at 17:52.

The maneuver from solar inertial to Z-LV for EREP number 27 was initiated at 16:31. A description of the geometry describing this earth resources pass is in Figure 4. As may be observed from the hybrid strip chart or the maneuver pad, the vehicle maneuvers from SI to Z-LV attitude at orbital noon. Subsequent to the data take, the vehicle maneuvers to an offset Z-LV attitude until the following noon, at which time it returns to SI. This noon-to-noon technique to perform EREPs was a result of near-real-time studies to improve controllability and reduce TACS impulse usage under two-CMG control. As shown on Figure 1, real-time momentum data followed the predicted traces until the vehicle was maneuvered from Z-LV to Z-LV offset. The Z-LV offset maneuver placed the X principal vehicle axis in the orbital plane, with the vehicle maneuvering about the pitch axis at orbital rate such that the total CMG momentum would remain constant. As is evident from flight data, there was sufficient Y-axis momentum accumulation during this attitude phase to require four additional MIB firings to reduce the momentum to a nominal level. This inability to predict the precise offset maneuvers relates to the star tracker failure. Figures 5 and 6 contain maneuver geometries for the photography experiments S-063K and S-201K, respectively. The figures contain pertinent information such as maneuver rates, CMG biases, maneuver angles, sun angle (η_X), Z-axis rotation (ν_Z), data take period, and execution times associated with each maneuver. These two similar Kohoutek maneuvers were expected to require one desaturation firing 22 N-s (5 lb-s of impulse). Flight data showed that no TACS impulse was required for either maneuver. These maneuvers were designed to maintain sufficient control margin such that the CMGs' outer gimbals would not hit gimbal stops. The real-time CMG gimbal angle data (Fig. 2) verified that the predicted gimbal angle traces were followed closely.

A report was submitted to STAC about 10 hours prior to the start of MD-58 crew activities predicting no CMG gimbal stop problems and TACS impulse usage of 220 N-s (50 lb-s). Flight data verified that the outer gimbals did not hit the stops and that TACS impulse usage was 355 N-s (80 lb-s). For the nominal, two-CMG control mode, occassional gimbal patterns were observed where the telemetry data of the gimbal angles were significantly different from those predicted.

The CMG gimbal history for satisfying the torque requirements demonstrated the nonunique solution characteristics in the steering law of the control system. The gimbal patterns for the outer gimbals might be expected to repeat in a cyclical manner for successive momentum dumps for nonventing conditions; however, it was noted on several occasions the CMG traces would switch polarities and the outer gimbals would almost ride the gimbal stops. This was predominant in the large sun angle, η_x, periods. A quick-look study was conducted to determine if simple patches could be made to the onboard computer to prevent this; but no simple, reliable control law change was found. As a result, any small anomaly in the environmental torques or sensors could result in an unexpected gimbal stop problem.

The CMG traces for successive momentum dumps driving the gimbal angles into opposite operating regions are shown in Figures 7 and 8. In this case, the outer gimbals did not hit the stops, but this is an example of the switchover condition for a nominal gravity gradient torque requirement under solar inertial conditions. The inner gimbals also show the switchover in polarity and, in the first dump cycle, the inner gimbal of number 2 hit its positive stop twice. This caused no problem since the outer gimbals were not on their stops.

A comparison of predicted to actual TACS usage for the Skylab mission is presented in Tables 1 through 5. Table 1 contains TACS usage from orbital insertion to true solar inertial acquisition. No predictions are listed in this table because of the nature of the operational support that was required during this phase of the mission. The hybrid computer was used to analyze fuel consumption on an orbit-to-orbit basis rather than the day-to-day type procedure followed during the remainder of the mission. Preflight studies for a nominal mission had estimated TACS impulse usage for this phase of flight of 26 525 N-s (5960 lb-s). The usage shown in the table reflects requirements from previously mentioned major problems. Tables 2, 3, and 4 contain detailed prediction and TACS usage for SL-2, SL-3, and SL-4 missions, respectively. An examination of footnotes to the tables reveals that most prediction inaccuracy resulted from events involving man-in-the-loop activities and control system hardware failures.

TACS impulse required to perform an EVA was difficult to predict because of uncertainties in the suit vent torques. The suit vent torques were a function of astronaut location, direction, and duration of EVA activity; and for certain activities a vent deflector was employed to prevent contamination to film or lens. In addition, a schedule of EVA activities was only a guideline for the sequence of events and was not expected to be followed exactly. Rendezvous and docking TACS requirements were also difficult to predict. The propellant used was primarily dependent on the position of the vehicle in orbit, length of the rendezvous and docking phase, and the number of docking attempts before a hard dock was achieved. A summary of TACS impulse usage for each flight and the total mission is shown in Table 5.

For the three manned missions, more than 160 maneuvers were performed for earth viewing or astronomical observations. The conditions under which these were made included sensor and controller malfunctions, and external torques due to unplanned vents. Excluding eight maneuvers from the sample which were performed differently than planned, the results of the TACS prediction effort shows, from Figure 9:

1. Nearly half of the maneuver TACS predictions were exact.

2. Three-fourths of the predictions were correct within 66 N-s (15 lb-s) or 3 MIBs,

3. Ninety-five percent of the predictions were correct within 176 N-s (40 lb-s) or eight MIBs.

A more comprehensive evaluation of the Skylab control system can be found in Reference 2.

CONCLUSIONS AND RECOMMENDATIONS

The hybrid computer simulation provided STAC with invaluable support in daily evaluation of spacecraft control and performance. Without the good turnaround capability of the hybrid runs, the initial emergency maneuvers required for balancing thermal and power problems could have expended considerably more TACS fuel leaving the spacecraft without a backup control system. Also, the total number of experiment maneuvers for earth and astronomy studies would have been severely reduced because of insufficient time to analyze the many different maneuvers.

Mission planning must include defining support requirements for emergency situations. Many problems resulted from not being prepared to simulate a complete day's mission that included as many as six maneuvers. Additionally, the computer setup for initializing at any specified time could have been simplified by extracting onboard data and having a digital computer system furnish punched cards for initial conditions.

Toward the end of the mission the timing of the proposed flight plan and subsequent modifications had been worked out such that adequate time was allowed for evaluating the different maneuvers. However, this was a routine that was established during the mission, not beforehand.

TABLE 1. TACS IMPULSE USAGE FROM SL-1 LAUNCH TO ACQUISITION OF SI ATTITUDE

Event	Predicted Impulse Usage[a]		Impulse Usage	
	N-s	lb-s	N-s	lb-s
Insertion and TACS-Only Control	-	-	78 700	17 685
Rendezvous and Docking	-	-	48 505	10 900
CMG Desaturation and Resets	-	-	46 615	10 475
Maneuver to SI Attitude	-	-	17 155	3 855
Total	-	-	190 975	42 915

a. Prediction procedure explained in text.

TABLE 2. TACS IMPULSE USAGE FOR SL-2 MISSION

Event	Predicted Impulse Usage		Impulse Usage	
	N-s	lb-s	N-s	lb-s
11 EREPs	825	185	2 515	565[a]
2 Trim Burns	2180	490	2 580	580
Thermal Attitude	1335	300	3 850	865[b]
Rate Gyro Calibration	-	-	265	60[c]
CMG Desaturation	-	-	290	65
2 EVAs	0	0	1 090	245[d]
Thermal Attitude and Undocking	3115	700	3 070	690
Total	7455	1675	13 660	3070

a. Excess usage due to performance of unplanned maneuver. Predicted usage for EREP number 7, 18 lb-s; actual usage 348 lb-s.
b. Excess usage due to rate gyro failure.
c. Unplanned maneuver.
d. Prediction difficulties for docking and EVAs explained in text.

TABLE 3. TACS IMPULSE USAGE FOR SL-3 MISSION

Event	Predicted Impulse Usage		Impulse Usage	
	N-s	lb-s	N-s	lb-s
Docking	2625	590	3 650	820
39 EREPs	535	120	1 200	270[a]
Rate Gyro Failure	0	0	11 460	2575
Rate Gyro Calibration	90	20	90	20
CMG Desaturation	-	-	645	145
3 EVAs	3650	820	5 205	1170
JOP 13 Experiment	980	220	1 110	250
Undocking	0	0	3 915	880[b]
Total	7880	1770	27 275	6130

a. Excess usage due to performance of unplanned maneuver. Predicted usage for EREP number 12, 0 lb-s; actual usage 140 lb-s.
b. Unscheduled CSM vent and TACS-only control.

TABLE 4. TACS IMPULSE USAGE FOR SL-4 MISSION

	Event	Predicted Impulse Usage		Impulse Usage	
		N-s	lb-s	N-s	lb-s
3-CMG Operation	Docking	2 535	570	4 605	1 035
	EVA	1 555	350	2 360	530
2-CMG Operation	CMG Desaturation	-	-	1 425	320[a]
	50 EREPs	17 895	4 022	29 145	6 550[b]
	Experimental Maneuvers	10 275	2 309	14 460	3 250[c]
	3 EVAs	18 345	4 123	37 535	8 435
	EREP Calibrations	2 570	577	2 870	645
	Undocking and Storage	-	-	18 870	4 240[a]
Total		53 175	11 951	111 270	25 005

a. No official prediction was made for these occurrences.

b. EREP number 6 CMGs switched polarity; predicted 270 lb-s, used 949 lb-s. EREP number 14 performance of unplanned maneuver; predicted 137 lb-s, used 625 lb-s. EREP number 22 performance of unplanned maneuver; predicted 40 lb-s, used 877 lb-s.

c. S232-Doy 331 CMGs switched polarity; predicted 200 lb-s, used 725 lb-s. JOP 18D-Doy 364 Error due to star tracker failure; predicted 29 lb-s, used 352 lb-s.

TABLE 5. TACS IMPULSE USAGE SUMMARY

Event	TACS Impulse Used	
	N-s	lb-s
SL-1 Launch to Acquisition of SI	190 975	42 915
SL-2	13 660	3 070
SL-3	27 275	6 130
SL-4	111 270	25 005
Total	343 180	77 120

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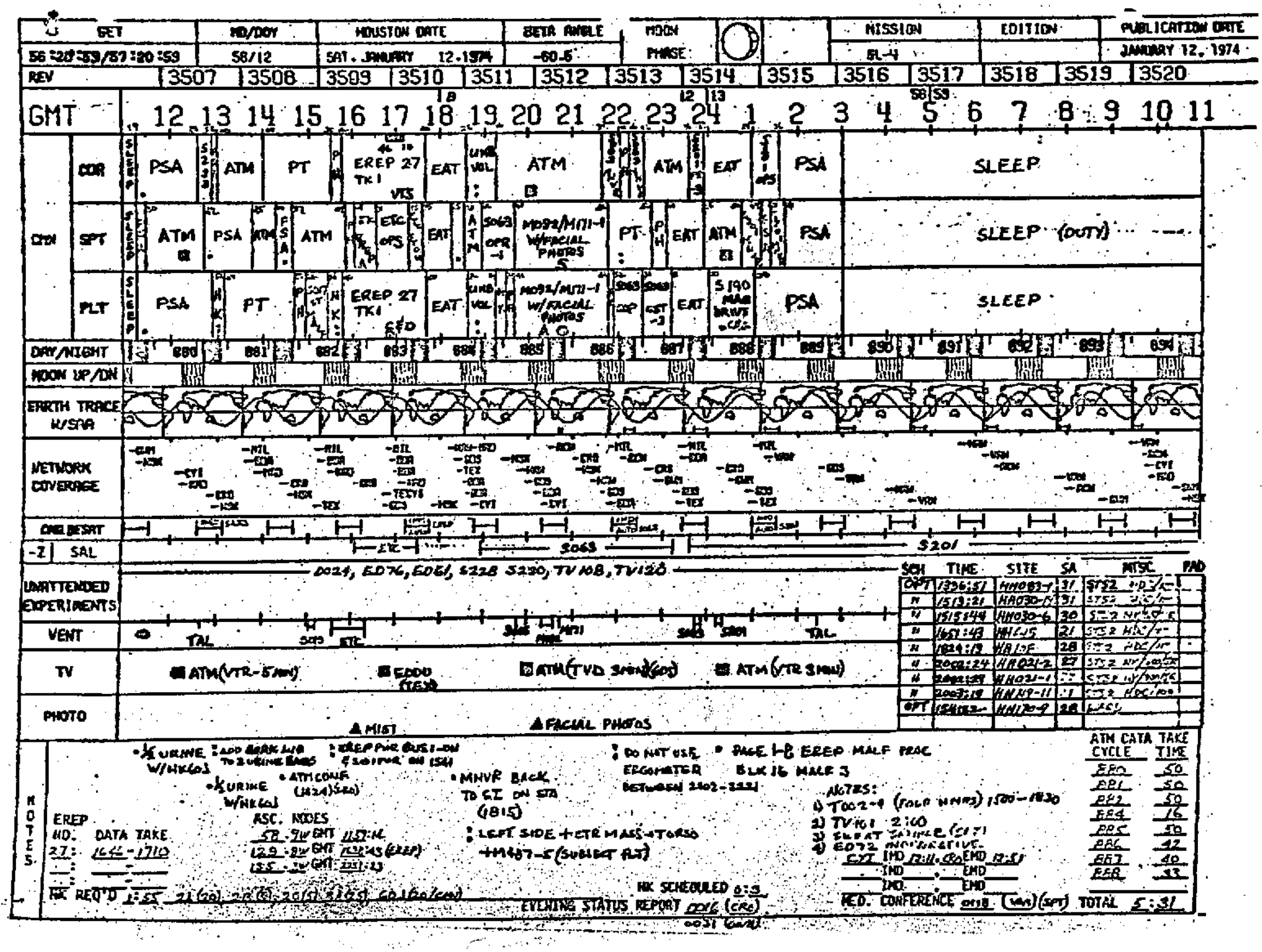


Figure 3. Summary flight plan for mission day 58 of SL-4.

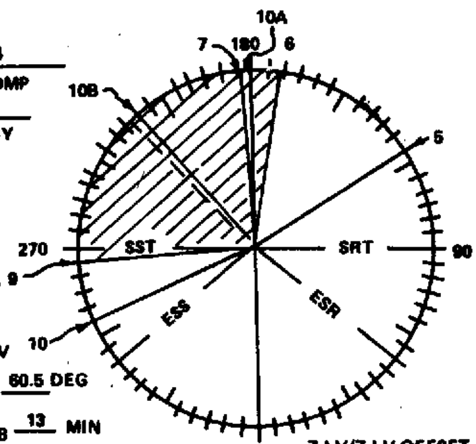
FINAL

H-BAR MANEUVER PAD

GMT 011:06:44
TIME OF COMP

SHEA
PREPARED BY

REVISED BY ROTHER
011:18:30:00



REV A

EREP # 27 TK1

#1 #2

η_x 60.11 DEG 63.8

ν_z 6.87 DEG 8.18

Ω_0 NOM DEG/SEC

SI→Z-LV

MNVR ∢θ 60.5 DEG

TAU ☐☐ 8 13 MIN

MNVR RT 0.080 DEG/SEC

EIGN

OFFSET Z-LV → SI

MNVR ∢θ 61.1 DEG

TAU ☐☐ 8 10 MIN

MNVR RT 0.105 DEG/SEC

EIGN

Z-LV/Z-LV OFFSET
TAU 5 MIN

CMG BIAS X-17 Y 7 Z 0

RATE SI TO Z-LV

X = -.080

Y = -.006

Z = -.001

RATE Z-LV TO Z-LV OFFSET

X = -.002

Y = .078

Z = -.004

RATE Z-LV OFFSET TO SI

+X = .102

+Y = -.015

+Z = .017

NO	EVENT	ORB POS	TIME
1	ORB MID	0	012:15:58:43
2	ESR	50	16:12:41
3	ORB NOON	180	16:46:20
4	ESS	310	17:19:58
5	MVR START (SI→Z-LV)	121	16:31:00
6	MVR END (SI→Z-LV)	171	16:44:00
7	DATA START	179	16:46:00
8	DATA END	276	17:11:00
9	MVR ST Z-LV/Z-LV OFFSET	276	17:11:00
10	MVR END Z-LV/Z-LV OFFSET	296	17:16:00
10A	MVR ST Z-LV OFFSET/SI	182	18:20:00
10B	MVR END Z-LV OFFSET/SI	220	18:30:00
11	END PREV DMP	54	16:13:43
12	NEXT DMP BEGIN (AUTOIMD)	288	17:14:23
13	Z-LV CENTER	223	16:57:30
14	TOTAL Z-LV DURATION	(104)	(27 MIN)

Z-LV OFFSET

+X = 0

+Y = 4.2

+Z = -1.0

USE H P G-20, G21

*FROM EREP

EST TACS REQ'D 30 LB-SEC

6 MIBS

Figure 4. Earth resource experiment pass maneuver geometry.

S063K **REV-A**

H-BAR MANEUVER PAD

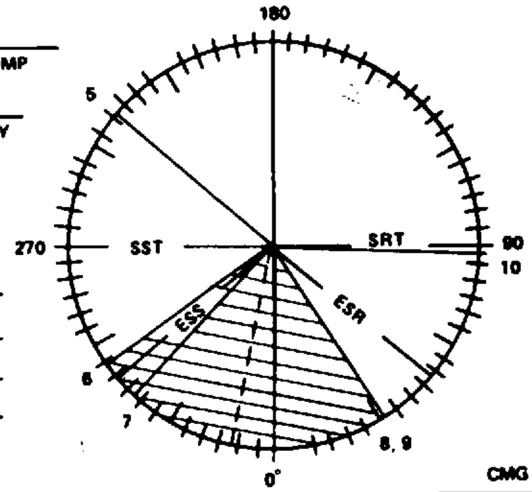
DOY 012

GMT 011:10:41
TIME OF COMP

SHEA
PREPARED BY

REVISED BY ROTHER
011:18:30:

η_x 61.13 ν_z 7.20



MNVR NO	X	Y	Z
1	-75.1	-4.9	-1.3
2	—	—	
3			

MNVR NO	EIG ANG	TAU MIN	EIG RT
1	75.3	20	.083
2	75.3	15	.084
3			

CMG BIAS
(-11, 11, 0)

RATE IN (5)

$\dot{\phi}_x$ = -.063

$\dot{\phi}_y$ = -.003

$\dot{\phi}_z$ = -.003

RATE OUT (9)

$\dot{\phi}_x$ = .084

$\dot{\phi}_y$ = .003

$\dot{\phi}_z$ = .005

AUTO IMD

NO	EVENT	ORB POS	TIME
1	ORB MID	0	012:22:12:56
2	ESR	49	22:25:31
3	ORB NOON	180	22:59:33
4	ESS	-49	22:00:11
5	MNVR START (SI → AH)	-131	21:39:00
6	MNVR END (SI - AH)	-54	21:59:00
7	DATA START	-42	22:02:00
8	DATA END	31	22:21:00
9	MNVR START (AH -SI)	31	22:21:00
10	MNVR END (AH - SI)	88	22:36:00
11	END PREV DUMP	-306	20:53:35
12	NEXT DUMP BEGIN	-72	21:54:16
13	AH CENTER	-11	22:10:00
14	TOTAL AH DURATION	(85)	(22 MIN)

EST TACS REQ'D 0 LB-SEC

Figure 5. Comet observation maneuver (S063K).

S201K

H-BAR MANEUVER PAD

REV - A

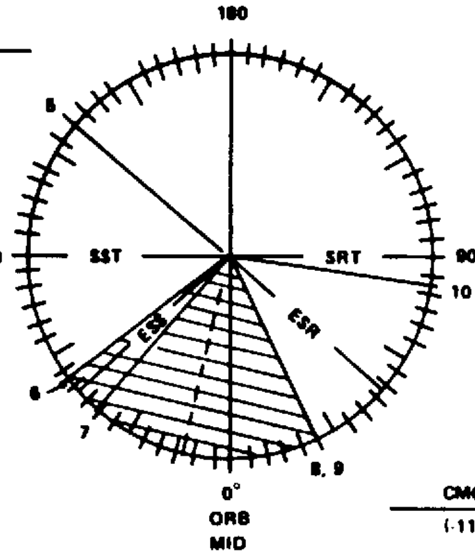
DOY 012

GMT 011:10:41
TIME OF COMP

PREPARED BY

REVISED BY ROTHER
011:18:30

η_x 61.64 $\quad \nu_z$ 7.37



MNVR NO	X	Y	Z
1	-75.1	-4.9	-1.3
2	—	—	
3			

MNVR NO	EIG ANG	TAU MIN	EIG RT
1	75.3	20	.08
2	75.3	15	.08
3			

CMG BIAS
(-11, 11, 0)

RATE IN (5)

$\dot{\phi}_x$ = -.083

$\dot{\phi}_y$ = -.003

$\dot{\phi}_z$ = -.003

RATE OUT (8)

$\dot{\phi}_x$ = .084

$\dot{\phi}_y$ = .003

$\dot{\phi}_z$ = .005

AUTO IMD

NO	EVENT	ORB POS	TIME
1	ORB MID	0	013:01:19:34
2	ESR	48	01:31:56
3	ORB NOON	180	02:06:11
4	ESS	-48	01:07:01
5	MNVR START (SI - AH)	-130	00:46:00
6	MNVR END (SI - AH)	-52	01:06:00
7	DATA START	-41	01:09:00
8	DATA END	25	01:26:00
9	MNVR START (AH - SI)	25	01:26:00
10	MNVR END (AH - SI)	83	01:41:00
11	END PREV DUMP	-307	00:00:10
12	NEXT DUMP BEGIN	-72	01:00:51
13	AH CENTER	-14	01:16:00
14	TOTAL AH DURATION	(77)	(20 MIN)

EST TACS REQ'D $\frac{5}{1\ \text{MIB}}$ LB-SEC

Figure 6. Comet observation maneuver (S201K).

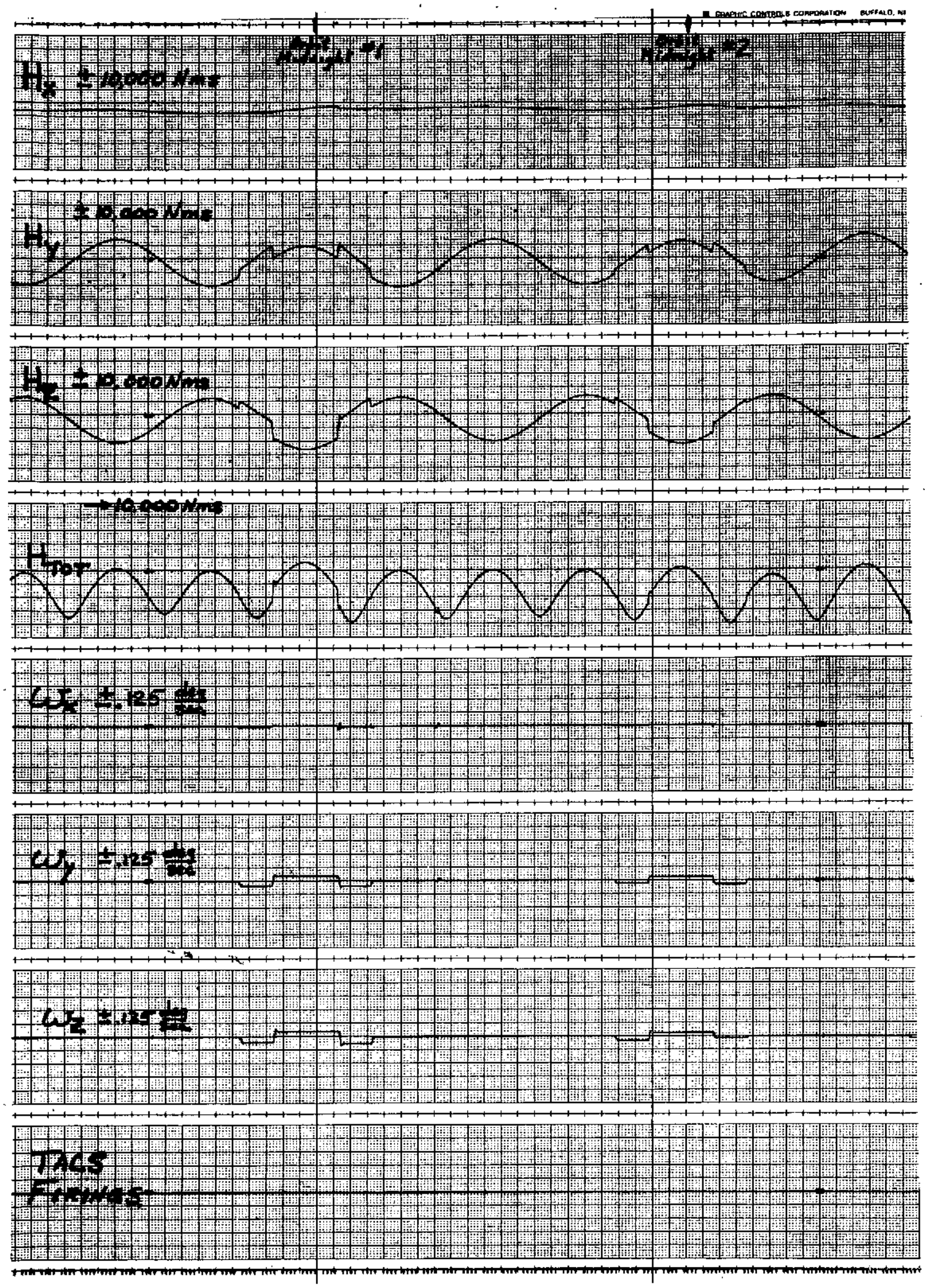


Figure 7. CMG momentum and vehicle rates for special case of CMG switchover.

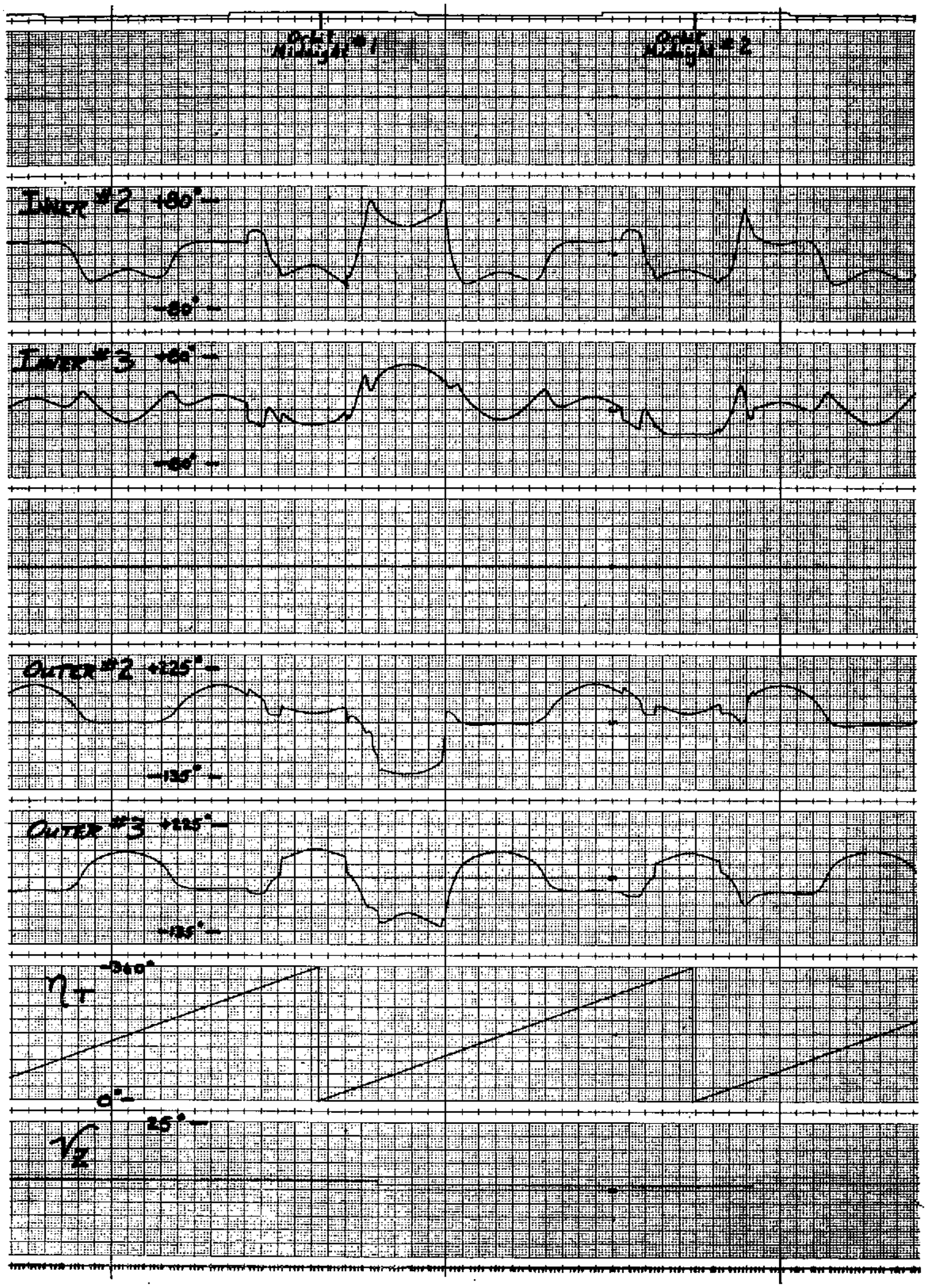


Figure 8. CMG gimbal angles for a special case of CMG switchover.

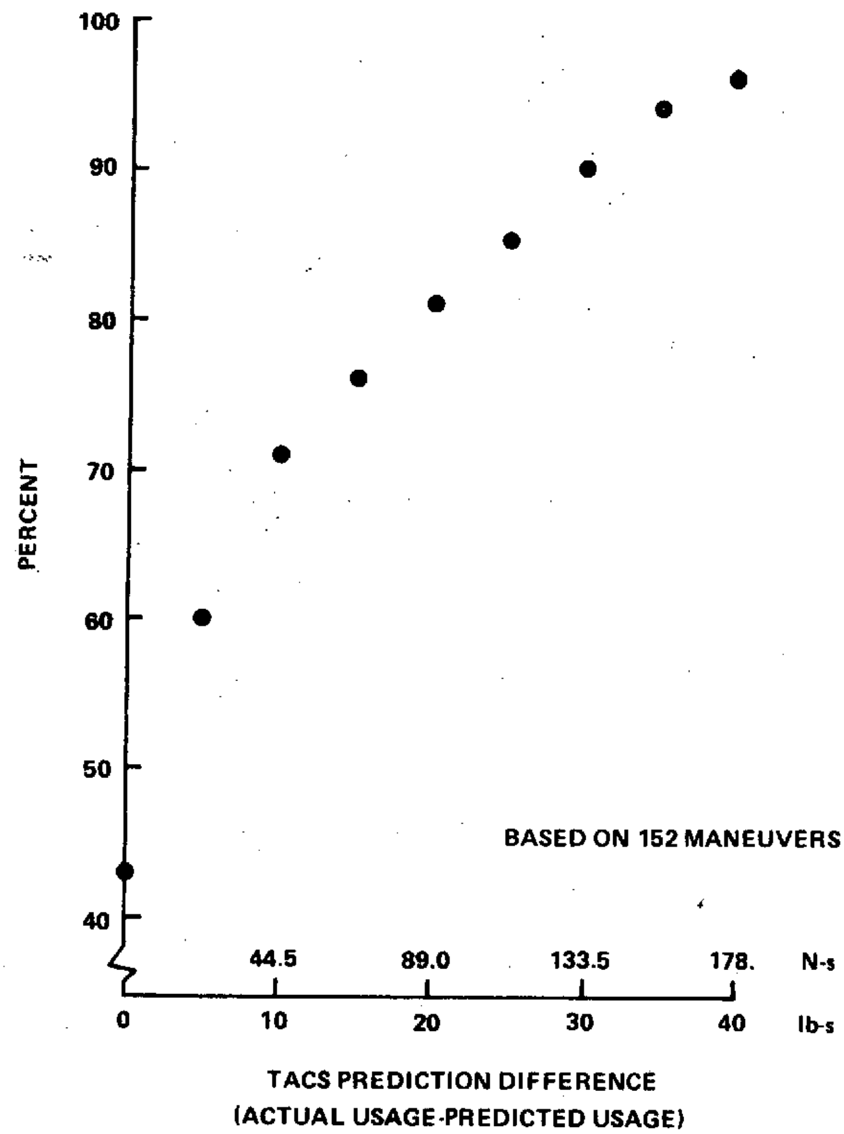


Figure 9. TACS prediction accuracy.

REFERENCES

1. Computer Science Corporation: Skylab TACS Impulse Budget Hybrid Simulation. Simulation Dept. Publication 74-7421-1, 1974.

2. Martin Marietta Aerospace: Skylab Postflight Mission Evaluation Report 80M19007, June 1974.

APPROVAL

SKYLAB MISSION PLANNING SUPPORT THROUGH THE USE OF A HYBRID SIMULATION

By M. W. Hammer and D. O. McNiel

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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