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ERROR ANALYSES OF TYPICAL APOLLO SPACECRAFT MANEUVERS USING THE PGNCS AND SCS TO CONTROL THE RCS

Guidance and Performance Branch

MISSION PLANNING AND ANALYSIS DIVISION

MANNED SPACECRAFT CENTER

HOUSTON, TEXAS

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ERROR ANALYSES OF TYPICAL APOLLO SPACECRAFT MANEUVERS USING THE PGNCS AND SCS TO CONTROL THE RCS

By R. Leroy McHenry
Guidance and Performance Branch

October 8, 1968

MISSION PLANNING AND ANALYSIS DIVISION
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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ERROR ANALYSES OF TYPICAL APOLLO SPACECRAFT MANEUVERS USING THE PGNCS AND SCS TO CONTROL THE RCS

By R. Leroy McHenry

SUMMARY

Individual error analyses data from three initial platform orientations of a typical reaction control system (RCS) maneuver controlled by the primary guidance and navigation control system (PGNCS) are presented in this report. Also included are data for a RCS maneuver controlled by the stabilization and control system (SCS).

Results of the PGNCS controlled maneuver indicate that the preferred orientation is preferred over any other platform orientation.

INTRODUCTION

A guidance and navigation error analysis of typical Apollo command and service module (CSM) service propulsion system (SPS) maneuvers has been documented (ref. 1). The information presented in this document represents the results of simulating three initial platform orientations of an RCS maneuver of the same spacecraft using the PGNCS and an RCS maneuver using the SCS. The data in this report is intended to supplement the data and conclusions presented in reference 1.

The tables which appear in this report present some perturbed parameters which result from simulating the RCS maneuvers with some of the error sources and magnitudes specified in references 2, 3, and 4.

METHOD

As in the previous study for the SPS, both CSM control systems were simulated for the error analyses of the RCS maneuvers. Three

horizontal in-plane 200-second RCS maneuvers were simulated under control of the PGNCS. The three platform orientations considered were as follows:

(a) inner gimbal angle (IGA) = 0°, middle gimbal angle (MGA) = 0°

outer gimbal angle (OGA) = 0°, (preferred orientation)

(b) IGA = 0°, MGA = 45°, OGA = 0°

(c) IGA = 45°, MGA = 0°, OGA = 0°

To achieve the desired inertial platform orientation for cases (b) and (c), the stable member axes were rotated from the preferred orientation case (a), through the proper gimbal angles. Error analysis data for the PGNCS controlled RCS maneuvers are presented in tables I through III.

To obtain the data presented in this report related to SCS capabilities and limitations, a 200-second RCS maneuver was simulated under control of the SCS. Since the body mounted attitude gyros (BMAG's) are rigidly fixed to the CSM body axes, only one inertial orientation was studied. Error analysis data for the SCS controlled RCS maneuver are contained in table IV.

DISCUSSION OF RESULTS

In general, for in-plane horizontal spacecraft maneuvers deviations in parameters such as flight-path angle, altitude, vehicle pitch angle, inner gimbal angle, and radial velocity change can be associated with accelerometer measurement errors along the yaw and roll axes and gyro drifts about the pitch axis of the spacecraft; whereas, deviations in other parameters such as inclination, right ascension of the ascending node, vehicle yaw angle, middle gimbal angle, and the cross-axis velocity that is normal to the local vertical plane can be associated with accelerometer measurement errors along the pitch axis and gyro drifts about the yaw axis of the vehicle. A cursory look at all of the data presented in this report for the PGNCS-controlled RCS maneuvers (Tables I through III) reveals that, regardless of platform orientation, these parameters are subject to specific hardware associated errors, even though the effect of an individual error is influenced in some cases by a different platform orientation.

The hardware associated errors which affect the first set of parameters (primarily, in-plane) are X- and Z-accelerometer biases, Y-axis (pitch, in general) stable member misalignment, and Y-gyro

(pitch) bias drift. The most significant of these errors is the X-accelerometer bias drift. The second set of parameters (primarily, out-of-plane) are primarily affected by Y-accelerometer bias, Z-axis (yaw) stable member misalignment, and Z-gyro (yaw) bias drift. Similarly, the Y-accelerometer bias is the most significant hardware error upon these parameters.

The preceding discussion more specifically illustrates an observation made in reference 2 that much similarity exists between the error analyses of the three spacecraft maneuvers which differ only by initial platform orientation. However, as was earlier stated, the effect of specific errors on their associated parameters may depend upon the platform orientation.

For instance, if the platform is oriented such that the MGA is 45°, the revised effect of the Z-accelerometer bias [table II(a)] is to significantly increase the perturbations in the IGA and OGA. Moreover, the broad effect of a misaligned Y-axis of the stable member on all of the parameters is trimmed slightly [table II(c)].

It should be noted that while the effect of a bias in the Y accelerometer [table II(a)] on inclination, right ascension of the ascending node, vehicle yaw angle, middle gimbal angle, and out-of-plane velocity is slightly curtailed for this case; its influence on flight-path angle, altitude, and vehicle pitch angle is increased. Exactly the reverse circumstances occur from an X-accelerometer bias in the deviations in these parameters.

The explanation is quite simple if it is understood that for this case the Y accelerometer is oriented such that it measures more of the total horizontal velocity change. Furthermore, since they are orthogonal, the X and Y accelerometers share equally the horizontal ΔV measurement. Therefore, the effect of an equal bias in the X accelerometer should be approximately equal in magnitude to the effect of Y-accelerometer bias. Inspection of table II(a) reveals this to be true.

When the platform is oriented such that the IGA is 45° a Z-accelerometer bias is more disturbing on velocity, flight-path angle, altitude, downrange velocity change, spacecraft weight, and burn time and less effective on pitch angle, inner gimbal angle, and radial velocity than in the preferred alignment. Exactly the reverse statement can be said of the X-accelerometer bias. Of course, this is expected since the X and Z accelerometer are situated so that they share equally the measurement of the total in-plane velocity change.

No gimbal lock situations were encountered in the study of the PGNCS controlled RCS maneuvers. However, in all cases the MGA is

adversely affected by a Y-accelerometer bias and by an X-accelerometer bias when the initial platform orientation is such that the MGA is 45° [table II(a)].

The most significant error studied for the SCS controlled RCS maneuver was a bias in the EMS accelerometer which is mounted along the longitudinal axis of the spacecraft. The largest dispersions were noted in inertial velocity, flight-path angle, pitch angle, downrange velocity, weight, and burn duration. In fact, the effects of the EMS accelerometer bias are from ten to thirty times greater in several instances than are the effects of an X-accelerometer bias under PGNCS control.

CONCLUSIONS

As can be seen from the data presented in tables I through III, recommendations for using particular platform orientations are arbitrary.

For instance, if it is known that an X-accelerometer bias exists an initial IGA setting of 45° would curtail some of the dispersions. However, if other errors are present such as a Z-accelerometer bias, the most desirable choice of platform orientation is the preferred alignment.

TABLE I. 200-SECOND PGNCS CONTROLLED RCS MANEUVER RESULTS FOR PREFERRED ORIENTATION

(a) Accelerometer errors

	Initial conditions	Nominal end conditions	+3σ X accel bias end conditions	+10σ X accel bias end conditions	+3σ Y accel bias end conditions	+10σ Y accel bias end conditions	+3σ Z accel bias end conditions	+10σ Z accel bias end conditions
Inertial velocity, fps	25578.891	25657.558	25654.493	25648.195	25657.487	25657.334	25656.579	25654.236
Inertial flight-path angle, deg	.015646	.157349	.148383	.131266	.157348	.159018	.165805	.187514
Altitude, ft	735890.5	739995.8	739546.5	738738.8	739998.3	740106.5	740340.8	741272.8
Inclination, deg	31.60216	31.60746	31.60716	31.60658	31.60465	31.59800	31.60747	31.60755
Right ascension, deg	18.94586	18.91466	18.91592	18.91848	18.93049	18.96770	18.91465	18.91432
Eccentricity	.005978	.012784	.012487	.011890	.012778	.012780	.012757	.012713
CSM pitch angle, deg[a]	0.00000	13.55056	12.95425	11.75667	13.55490	13.71232	16.54602	23.70159
CSM yaw angle, deg[a]	0.00000	.01755	.01678	.01524	3.08385	10.25801	.01801	.02140
IGA, deg	0.00000	0.00004	0.00004	0.00004	-0.00062	-0.00168	2.99081	9.98800
MGA, deg	0.00000	0.00000	0.00000	0.00001	-2.98973	-9.98361	-0.00032	-0.00030
ØGA, deg	0.00000	0.00000	0.00000	0.00000	0.00025	0.00227	0.00086	0.00045
ΔV_X, fps[b]	-	85.9304	82.1447	74.5427	85.8651	85.8766	85.8648	85.8759
ΔV_Y, fps[b]	-	0.0000	0.0000	0.0000	-3.9343	-13.2683	0.0000	0.0000
ΔV_Z, fps[b]	-	0.0000	0.0000	0.0000	-0.0002	0.0000	-3.9342	-13.2682
CSM weight, lb	30000.0	29850.94	29857.495	29870.655	29850.889	29849.142	29850.890	29849.142
Burn time, sec	-	199.815	191.033	173.392	199.888	202.231	199.887	202.231

[a]Vehicle attitude with respect to instantaneous local vertical coordinates.

[b]Accumulated ΔV in local vertical coordinates defined at ignition.

TABLE I. 200-SECOND PGNCS CONTROLLED RCS MANEUVER RESULTS FOR PREFERRED ORIENTATION -Continued

(b) Gyro bias drifts

	Initial conditions	Nominal end conditions	+3σ X gyro bias drift end conditions	+10σ X gyro bias drift end conditions	+3σ Y gyro bias drift end conditions	+10σ Y gyro bias drift end conditions	+3σ Z gyro bias drift end conditions	+10σ Z gyro bias drift end conditions
Inertial velocity, fps	25578.891	25657.558	25657.558	25657.558	25657.509	25657.394	25657.558	25657.555
Inertial flight-path angle, deg	.015646	.157349	.157346	.157346	.157792	.158823	.157346	.157344
Altitude, ft	735890.5	739995.8	739995.8	739995.8	740015.8	740063.3	739995.8	739995.5
Inclination, deg	31.60216	31.60746	31.60746	31.60746	31.60746	31.60746	31.60760	31.60792
Right ascension, deg	18.94586	18.91466	18.91466	18.91466	18.91466	18.91467	18.91386	18.91198
Eccentricity	.005978	.012784	.013784	.012784	.01283	.012780	.012784	.012783
CSM pitch angle, deg[a]	0.00000	13.55056	13.55056	13.55056	13.69216	14.02253	13.55056	13.55055
CSM yaw angle, deg[a]	0.00000	.01755	.01755	.01755	.01755	.01756	-0.11475	-0.42344
IGA, deg	0.00000	0.00004	0.00004	0.00004	0.00130	0.00425	0.00004	0.00003
MGA, deg	0.00000	0.00000	0.00000	0.00000	0.00000	0.00001	-0.00126	-0.00422
ØGA, deg	0.00000	0.00000	-0.00502	-0.01670	-0.00001	0.00000	0.00000	0.00000
ΔV_X, fps[b]	-	85.9304	85.9304	85.9304	85.9301	85.9276	85.9301	85.9278
ΔV_Y, fps[b]	-	0.0000	0.0000	0.0000	0.0000	0.0000	0.1993	0.6642
ΔV_Z, fps[b]	-	0.0000	0.0000	0.0000	-0.2067	-0.6889	0.0000	0.0000
CSM weight, lb	30000.0	29850.943	29850.943	29850.943	29850.943	29850.943	29850.943	29850.943
Burn time, sec	-	199.815	199.815	199.815	199.815	199.815	199.815	199.815

[a]Vehicle attitude with respect to instantaneous local vertical coordinates.

[b]Accumulated ΔV in local vertical coordinates defined at ignition.

TABLE I.- 200-SECOND PGNCS CONTROLLED RCS MANEUVER FOR PREFERRED ORIENTATION -Concluded

(c) Stable member misalignments

	Initial conditions	Nominal end conditions	2 deg. Y_{SM} misalignment end conditions	2 deg. Z_{SM} misalignment end conditions
Inertial velocity, fps	25578.891	25657.558	25656.813	25657.508
Inertial flight-path angle, deg	.0156465	.157349	.163758	.157308
Altitude, ft	735890.5	739995.8	740288.5	739993.8
Inclination, deg	31.60216	31.60746	31.60746	31.60953
Right ascension, deg	18.94586	18.91466	18.91466	18.90255
Eccentricity	.005978	.012784	.012764	.012780
CSM pitch angle, deg[a]	0.00000	13.55056	15.55294	13.55129
CSM yaw angle, deg[a]	0.00000	.01755	.01768	-2.03632
IGA, deg	0.00000	0.00004	0.00273	0.00062
MGA, deg	0.00000	0.00000	0.00000	0.00375
ØGA, deg	0.00000	0.00000	0.00000	0.00022
ΔV_X, fps[b]	-	85.9304	85.8779	85.8779
ΔV_Y, fps[b]	-	0.0000	0.0000	2.9979
ΔV_Z, fps[b]	-	0.0000	-2.9979	0.0000
CSM weight, lb	30000.	29850.943	29850.943	29850.943
Burn time, sec	-	199.815	199.815	199.815

[a]Vehicle attitude with respect to instantaneous local vertical coordinates.

[b]Accumulated ΔV in local vertical coordinates defined at ignition.

TABLE II. 200-SECOND PGNCS CONTROLLED RCS MANEUVER RESULTS FOR IGA = 0°, MGA = 45°, ØGA = 0°

(a) Accelerometer errors

	Initial conditions	Nominal end conditions	+3σ X accel bias end conditions	+10σ X accel bias end conditions	+3σ Y accel bias end conditions	+10σ Y accel bias end conditions	+3σ Z accel bias end conditions	+10σ Z accel bias end conditions
Inertial velocity, fps	25578.891	25657.559	25655.369	25650.601	25655.367	25650.597	25656.580	25654.237
Inertial flight-path angle, deg	.015646	.157348	.151050	.138630	.151048	.138622	.165810	.187518
Altitude, ft	735890.5	739995.8	739677.0	739081.8	739677.5	739085.0	740340.8	741272.8
Inclination, deg	31.60216	31.60747	31.60917	31.61272	31.60534	31.60097	31.60747	31.60755
Right ascension, deg	18.94586	18.91466	18.90468	18.88330	18.92640	18.95113	18.91465	18.91432
Eccentricity	.005978	.012784	.012572	.012123	.012572	.012122	.012757	.012713
CSM pitch angle, deg [a]	0.00000	13.55071	13.13245	12.30069	13.13261	12.30111	16.534001	23.69856
CSM yaw angle, deg [a]	0.00000	0.01742	-2.17166	-7.47259	2.20503	7.50412	.01800	0.02120
IGA, deg	0.00000	0.00005	-0.00037	0.00007	-0.00031	0.00005	4.19423	13.98076
MGA, deg	45.00000	45.00009	47.13739	52.33700	42.86316	37.66318	44.74074	44.13580
ØGA, deg	0.00000	-0.00004	0.00020	0.00000	0.00029	-0.00007	-2.94963	-9.83209
ΔV_X, fps [b]	-	85.9314	83.2312	77.5031	83.2313	77.5031	85.8648	85.8759
ΔV_Y, fps [b]	-	0.0002	2.6957	8.4163	-2.6954	-8.4160	0.0000	0.0004
ΔV_Z, fps [b]	-	0.0000	0.0000	0.0000	0.0000	0.0000	-3.9342	-13.2682
CSM weight, lb	30000.0	29850.942	29855.533	29864.670	29855.533	29864.670	29850.890	29849.815
Burn time, sec	-	199.817	193.663	181.415	193.663	181.415	199.878	202.223

[a] Vehicle attitude with respect to instantaneous local vertical coordinates.

[b] Accumulated ΔV in local vertical coordinates defined at ignition.

TABLE II. - 200-SECOND PGNCS CONTROLLED RCS MANEUVER RESULTS FOR IGA = 0°, MGA = 45°, OGA = 0° -Continued

(b) Gyro bias drifts

	Initial conditions	Nominal end conditions	+3σ X gyro bias drift end conditions	+10σ X gyro bias drift end conditions	+3σ Y gyro bias drift end conditions	+10σ Y gyro bias drift end conditions	+3σ Z gyro bias drift end conditions	+10σ Z gyro bias drift end conditions
Inertial velocity, fps	25578.891	25657.559	25657.592	25657.669	25657.525	25657.443	25657.558	25657.555
Inertial flight-path angle, deg	.015646	.157348	.157033	.156300	.157662	.158395	.157349	.157345
Altitude, ft	735890.5	739995.8	739982.0	739948.5	740010.3	740043.3	739996.0	739995.5
Inclination, deg	31.60216	31.60747	31.60746	31.60746	31.60747	31.60747	31.60760	31.60792
Right ascension, deg	18.94586	18.91466	18.91466	18.91467	18.91466	18.91466	18.91386	18.91198
Eccentricity	.005978	.012784	.012784	.012786	.012783	.012781	.012784	.012783
CSM pitch angle, deg[a]	0.00000	13.55071	13.45053	13.21699	13.65082	13.88443	13.55070	13.55064
CSM yaw angle, deg[a]	0.00000	0.01742	0.14043	0.46779	0.01733	0.01642	-0.11488	-0.42356
IGA, deg	0.00000	0.00005	-0.00121	-0.00415	0.00131	0.00426	0.00005	0.00005
MGA, deg	45.00000	45.00009	45.00009	45.00009	45.00010	45.00010	44.99882	44.99586
ØGA, deg	0.00000	-0.00004	-0.00269	-0.00886	-0.00448	-0.01483	-0.00004	-0.00003
ΔV_X, fps[b]	-	85.9314	85.9312	85.9300	85.9312	85.9300	85.9311	85.9283
ΔV_Y, fps[b]	-	0.0002	0.0000	-0.0012	0.0003	0.0016	0.1994	0.6644
ΔV_Z, fps[b]	-	0.0000	0.1462	0.4871	-0.1462	-0.4872	0.0000	0.0000
CSM weight, lb	30000.0	29850.942	29850.942	29850.942	29850.942	29850.942	29850.942	29850.943
Burn time, sec	-	199.817	199.817	199.817	199.817	199.817	199.817	199.816

[a]Vehicle attitude with respect to instantaneous local vertical coordinates.

[b]Accumulated ΔV in local vertical coordinates defined at ignition.

TABLE II.- 200-SECOND PGNCS CONTROLLED RCS MANEUVER RESULTS FOR IGA = 0°, MGA = 45°, OGA = 0° -Concluded

(c) Stable member misalignments

	Initial conditions	Nominal end conditions	$+2^\circ$ Y_{SM} misalignment end conditions	$+2^\circ$ Z_{SM} misalignment end conditions
Inertial velocity, fps	25578.891	25657.559	25657.041	25657.509
Inertial flight-path angle, deg	.015646	.157348	.161888	.157311
Altitude, ft	735890.5	739995.8	740203.5	739993.8
Inclination, deg	31.60216	31.60747	31.60748	31.60953
Right ascenstion, deg	18.94586	18.91466	18.91456	18.90254
Eccentricity	.005978	.012784	.012771	.012780
CSM pitch angle, deg[a]	0.00000	13.55071	14.96627	13.55092
CSM yaw angle[a], deg	0.00000	0.01742	-0.00024	-2.03484
IGA, deg	0.00000	0.00005	0.00263	0.00024
MGA, deg	45.00000	45.00009	44.99977	45.00228
ØGA, deg	0.00000	-0.00004	-0.00182	-0.00010
ΔV_X, fps[b]	-	85.9314	85.9047	85.8787
ΔV_Y, fps[b]	-	0.0002	0.0263	2.9986
ΔV_Z, fps[b]	-	0.0000	-2.1203	0.0000
CSM weight, lb	30000.0	29850.942	29850.941	29850.940
Burn time, sec	-	199.817	199.818	199.820

[a]Vehicle attitude with respect to instantaneous local vertical coordinates.

[b]Accumulated ΔV in local vertical coordinates defined at ignition.

TABLE III. 200-SECOND PGNCS CONTROLLED RCS MANEUVER RESULTS FOR IGA = 45°, MGA = 0°, OGA = 0°

(a) Accelerometer errors

	Initial conditions	Nominal end conditions	+3σ X accel bias end conditions	+10σ X accel bias end conditions	+3σ Y accel bias end conditions	+10σ Y accel bias end conditions	+3σ Z accel bias end conditions	+10σ Z accel bias end conditions
Inertial velocity, fps	25578.891	25657.559	25654.764	25648.828	25657.487	25657.334	25659.121	25662.954
Inertial flight-path angle, deg	.015646	.157347	.156854	.156849	.157347	.159017	.170395	.206398
Altitude, ft	735890.5	739995.8	739903.5	739733.5	739998.3	740106.8	740618.8	742528.3
Inclination, deg	31.60216	31.60747	31.60725	31.60684	31.60464	31.59799	31.60770	31.60871
Right ascension, deg	18.94586	18.91466	18.91554	18.91731	18.93049	18.96770	18.91372	18.91107
Eccentricity	.005978	.012784	.012557	.012084	.012778	.012780	.012988	.013537
CSM pitch angle, deg[a]	0.00000	13.55069	15.26996	19.63769	13.55443	13.71464	16.09619	22.11388
CSM yaw angle, deg[a]	0.00000	0.01755	0.01677	0.01618	3.08052	10.26223	0.018409	0.02885
IGA, deg	45.00000	45.00013	47.13738	52.33707	44.99899	45.00056	47.09258	51.82515
MGA, deg	0.00000	0.00000	0.00032	0.00000	-2.98649	-9.98763	-0.00018	-0.00807
ØGA, deg	0.00000	-0.00001	-0.00001	-0.00002	0.00041	-0.00077	0.00005	0.00863
ΔV_X, fps[b]	-	85.9306	83.2307	77.5020	85.8647	85.8762	88.7583	96.3727
ΔV_Y, fps[b]	-	0.0000	0.0000	0.0000	-3.9343	-13.2682	0.0000	-0.0000
ΔV_Z, fps[b]	-	-0.0002	-2.6957	-8.4162	-0.0003	-0.0002	-2.8742	-10.4587
CSM weight, lb	30000.0	29850.943	29855.534	29864.672	29850.890	29849.141	29845.964	29831.840
Burn time, sec	-	199.815	193.662	181.412	199.887	202.232	206.490	225.424

[a]Vehicle attitude with respect to instantaneous local vertical coordinates.

[b]Accumulated ΔV in local vertical coordinates defined at ignition.

TABLE III. 200-SECOND PGNCS CONTROLLED RCS MANEUVER RESULTS FOR IGA = 45°, MGA = 0°, OGA = 0°-Continued

(b) Gyro drift errors

	Initial conditions	Nominal end conditions	+3σ X gyro bias drift end conditions	+10σ X gyro bias drift end conditions	+3σ Y gyro bias drift end conditions	+10σ Y gyro bias drift End Conditions	+3σ Z gyro bias drift end conditions	+10σ Z gyro bias drift end conditions
Inertial velocity, fps	25578.891	25657.559	25657.558	25657.557	25657.509	25657.394	25657.558	25657.556
Inertial flight-path angle, deg	.015646	.157347	.157348	.157341	.157792	.158822	.157347	.157346
Altitude, ft	735890.5	739995.8	739996.0	739995.5	740015.8	740064.3	739996.0	739996.0
Inclination, deg	31.60216	31.60747	31.60757	31.60780	31.60747	31.60746	31.60756	31.60779
Right ascension, deg	18.94586	18.91466	18.91407	18.91270	18.91467	18.91466	18.91410	18.91277
Eccentricity	.005978	.012784	.012784	.012784	.012783	.012780	.012784	.012784
CSM pitch angle, deg[a]	0.00000	13.55069	13.55060	13.54970	13.69226	14.02258	13.55076	13.55146
CSM yaw angle, deg[a]	0.00000	0.01755	-0.08518	-0.32465	0.01755	0.01757	-0.07600	-0.29427
IGA, deg	45.00000	45.00013	45.00013	45.00013	45.00140	45.00435	45.00012	45.00010
MGA, deg	0.00000	0.00000	0.00090	0.00298	0.00000	0.00000	-0.00089	-0.00299
ØGA, deg	0.00000	-0.00001	-0.00354	-0.01180	-0.00001	0.00000	-0.00354	-0.01179
ΔV_X, fps	-	85.9306	85.9305	85.9292	85.9301	85.9273	85.9305	85.9293
ΔV_Y, fps[b]	-	0.0000	0.1463	0.4871	0.0000	0.0000	0.1409	0.4697
ΔV_Z, fps[b]	-	-0.0002	0.0000	0.0012	-0.2068	-0.6891	-0.0003	-0.0015
CSM weight, lb	30000.0	29850.943	29850.943	29850.943	29850.943	29850.944	29850.943	29850.943
Burn time, sec	-	199.815	199.815	199.815	199.815	199.814	199.815	199.815

[a]Vehicle attitude with respect to instantaneous local vertical coordinates.

[b]Accumulated ΔV in local vertical coordinates defined at ignition.

TABLE III. 200-SECOND PGNCS CONTROLLED RCS MANEUVER RESULTS FOR IGA = 45°, MGA = 0°, OGA = 0°-Concluded

(c) Stable member misalignments

	Initial conditions	Nominal end conditions	$+2^\circ$ Y_{SM} misalignment end conditions	$+2^\circ$ Z_{SM} misalignment end conditions
Inertial velocity, fps	25578.891	25657.559	25656.813	25657.526
Inertial flight-path angle, deg	.015646	.157347	.163758	.157386
Altitude, ft	735890.5	739995.8	740288.8	739997.8
Inclination, deg	31.60216	31.60747	31.60746	31.60893
Right ascenstion, deg	18.94586	18.91466	18.91466	18.90610
Eccentricity	.005978	.012784	.012764	.012781
CSM pitch angle, deg[a]	0.00000	13.55069	15.55364	13.56756
CSM yaw angle, deg[a]	0.00000	0.01755	0.01904	-1.43549
IGA, deg	45.00000	45.00013	45.00347	44.99945
MGA, deg	0.00000	0.00000	-0.00136	0.00339
ØGA, deg	0.00000	-0.00001	0.00047	-0.00012
ΔV_X, fps[b]	-	85.9306	85.8782	85.9042
ΔV_Y, fps[b]	-	0.0000	0.0000	2.1202
ΔV_Z, fps[b]	-	-0.0002	-2.9986	-0.0264
CSM weight, lb	30000.0	29850.943	29850.941	29850.943
Burn time, sec	-	199.815	199.818	199.817

[a]Vehicle attitude with respect to instantaneous local vertical coordinates.

[b]Accumulated ΔV in local vertical coordinates defined at ignition.

TABLE IV. 200-SECOND SCS CONTROLLED RCS MANEUVER RESULTS

(a) Accelerometer bias

	Initial conditions	Nominal end conditions	$+3\sigma$ EMS accel. bias end conditions	$+10\sigma$ EMS accel bias end conditions
Inertial velocity, fps	25369.570	25417.921	25410.520	25399.464
Inertial flight-path angle, deg	.251652	.271536	.2610297	.2507619
Altitude, ft	909407.25	936170.88	931702.53	925467.11
Inclination, deg	31.62239	31.61312	31.61453	31.61664
Right ascension, deg	18.84096	18.82041	18.82422	18.82939
Eccentricity	.004845	.005499	.004988	.004472
CSM pitch angle, deg[a]	2.96200	15.80354	13.66919	10.57988
CSM yaw angle, deg[a]	-.62079	-.47970	-.46494	-.45029
IGA, deg	0.00000	-.46755	-.46286	-.47554
MGA, deg	0.00000	.14428	.15651	.16904
OGA, deg	0.00000	-.18987	-.12415	.00776
ΔV_X, fps[b]	-	78.3887	65.7256	47.5454
ΔV_Y, fps[b]	-	0.4230	0.3570	0.2579
ΔV_Z, fps[b]	-	2.3644	1.9907	1.4415
CSM weight, lb	30000.0	29599.167	29654.39	29750.264
Burn time, sec	-	199.758	167.665	121.496

[a]Vehicle attitude with respect to instantaneous local vertical coordinates.

[b]Accumulated ΔV in local vertical coordinates defined at ignition.

TABLE IV. 200-SECOND SPS CONTROLLED RCS MANEUVERS RESULTS -Concluded

(b) Gyro bias drifts

	Initial conditions	Nominal end conditions	+3σ yaw gyro bias drift end conditions	+10σ yaw gyro bias drift end conditions	+3σ Pitch gyro bias drift end conditions	+10σ Pitch gyro bias drift end conditions
Inertial velocity, fps	25369.570	25417.921	25417.920	25417.919	25417.945	25417.992
Inertial flight-path angle, deg	.251652	.271536	.271532	.271531	.271365	.270948
Altitude, ft	909407.25	936170.88	936170.88	936170.57	936165.27	936150.92
Inclination, deg	31.62239	31.61312	31.61300	31.61271	31.61311	31.61311
Right ascenstion, deg.	18.84096	18.82041	18.82013	18.81946	18.82039	18.82040
CSM pitch angle, deg[a]	2.96200	.005499	.005499	.005499	15.68953	15.43410
CSM yaw angle, deg[a]	-0.62079	-0.47970	-0.59991	-0.869307	-.48759	-.47827
IGA, deg.	0.00000	-0.46755	-0.47069	-0.464658	-.581542	-.837004
MGA, deg.	0.00000	0.14428	0.02846	-0.231159	.136441	.144810
OGA, deg.	0.00000	-0.18987	-0.15388	-0.151915	-.153459	-.150325
ΔV_X, fps[b]	-	78.3887	78.3670	78.3660	78.3668	78.3468
ΔV_Y, fps[b]	-	0.4230	0.5091	0.7065	0.4238	0.4234
ΔV_Z, fps[b]	-	2.3644	2.3644	2.3646	2.2802	2.0819
CSM weight, lb	30000.0	29599.167	29599.021	29599.021	29599.021	29599.021
Burn time, sec	-	199.758	199.758	199.758	199.758	199.758

[a]Vehicle attitude with respect to instantaneous local vertical coordinates.

[b]Accumulated ΔV in local vertical coordinates defined at ignition.

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