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ANALYSIS OF LEM MISSION
INERTIAL UNCERTAINTIES
by
John M. Dahlen
Malcolm W. Johnston
December 1963

[redacted]

INSTRUMENTATION LABORATORY

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E-1473

ANALYSIS OF LEM MISSION INERTIAL UNCERTAINTIES

ABSTRACT

The major sources contributing to LEM position and velocity uncertainties at perilune, hover, and burn-out are individually investigated. The format utilized to trace each component uncertainty through these phases also serves as a common basis upon which the following alternate inertial schemes are compared:

1. Gimballed vs gimballess inertial measurement unit,
2. Crude vs precision gyros,
3. Inertial realignment between injection and perilune vs no realignment.

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TABLE OF CONTENTS

		Page
I	LIST OF SYMBOLS	7
II	INTRODUCTION	9
III	DISCUSSION	13
	Orbital Navigation Uncertainties	13
	LEM Inertial Uncertainties	13
	Illustrative Example	13
IV	CONCLUSIONS	17
V	REFERENCES	19
VI	APPENDICES	27
	A. Analysis I GIMU - Precision Gyros - Realignment	27
	B. Analysis II IMU - Precision Gyros - Realignment	41
	C. Analysis III GIMU - Precision Gyros - No Realignment	43
	D. Analysis IV IMU - Precision Gyros - No Realignment	53
	E. Analysis V GIMU - Crude Gyros - Realignment	55
	F. Analysis VI GIMU - Crude Gyros - No Realignment	61
	G. Description of Descent and Ascent Trajectory Parameters	67

I LIST OF SYMBOLS

IMU	Gimballed inertial measurement unit
GIMU	Gimballess inertial measurement unit
(U)R, (U)T, (U)H	Range, track, altitude uncertainty
$(U)\dot{R}$, $(U)\dot{T}$, $(U)\dot{H}$	Range rate, track rate, altitude rate uncertainty
BDX, BDY, BDZ	Bias drift about x, y, z axes
ACBX, ACBY, ACBZ	Accelerometer bias along the x, y, z axes
SFEX, SFEY, SFEZ	Accelerometer scale factor uncertainty along the x, y, z axes
MLM	Misalignment
Inj	Injection
Per	Perilune
Hov	Hover

ANALYSIS OF LEM MISSION INERTIAL UNCERTAINTIES

II INTRODUCTION

The major sources contributing to position and velocity uncertainties during a LEM mission are investigated.

A format is presented (in the appendix) that traces the effects of each uncertainty source from injection of the LEM into its descent orbit through perilune and hover to burn-out. The format serves three purposes:

1. It reveals the important sources of inertial uncertainties and when they occur,
2. It indicates the effects of "initial condition" or orbital navigation uncertainties,
3. It serves as a common basis for the analysis and comparison of several alternate inertial guidance schemes.

Three comparisons were made:

1. Gimballed vs gimballess inertial measurement unit,
2. "Crude" vs "precision" gyros,
3. Realignment of IMU and GIMU between injection and perilune vs no realignment.

Table I summarizes the results obtained when one assumes that each component uncertainty, though unknown, is constant over the entire mission profile. Table II shows the results if one assumes that each component uncertainty changes in random fashion from one phase to the next within the mission profile. A detailed analysis of each component contribution

for both tables is included in Appendices A-F. Table III indicates qualitatively the effects of guidance uncertainties on fuel requirements. Table IV summarizes the resultant cut-off uncertainties for a normal ascent from the lunar surface.

Figure 1 illustrates the phases of the LEM mission as well as indicating the coordinate systems utilized.

The body of this report will be restricted to a brief discussion of the selected uncertainty sources followed by an illustrative example of the analysis, tracing the effects of a single uncertainty source through all mission phases.

The analyses involve LEM inertial uncertainties and initial condition uncertainties only. No scheme employing external sensing during landing is considered. (External terminal guidance has the principal effect of nulling terminal velocity and altitude errors).

For Tables I and II, an abort from hover was used instead of a normal launch because the abort case appeared to be most critical with respect to subsequent rendezvous maneuver fuel requirements.

The position and velocity uncertainties listed in Tables I and II are "Root-Sum-Square" values. For example, the RSS range uncertainty is the square root of the sum of the variances* in range uncertainty due to each uncertainty source. If the

---

* The variance of a random variable, X, is the average value of the square of the difference between X and its average value, $\overline{X}$. That is:

$$\text{Variance } (X) = \overline{(X - \overline{X})^2}$$

The standard deviation or "one sigma variation" of X is the square root of the variance. That is:

$$\sqrt{\text{Variance}}\ (X) = \text{STD. DEV. } (X) = \sigma(X)$$

sources are independent (a valid assumption) the RSS range uncertainty is also the square root of the variance of the total range uncertainty. The results in Tables I and II may therefore safely be called RMS or 1 σ uncertainties.

Certain qualifications regarding the analysis should be pointed out. First, regarding accuracy of the GIMUs, two bias drift rates were assumed to correspond to "crude" and "precision" gyros. For "precision" gyros, 10 meru drift was used to see the result that would occur if gyro performance were not degraded in the "strap-down" environment. For "crude" gyros, 66.7 meru (1.0 degree/hour) drift was used to gain feel for the trajectory errors that would result from gyro performance degradation. While the best engineering judgment of the Apollo Staff anticipates a serious performance degradation in the early application of the gyro in the "strap-down" environment, there is no sound technical basis for assuming that such degradation can be treated as a factor of seven increase in bias drift. This treatment is simply the most appropriate method in view of the lack of information and time needed for a more valid performance comparison.

Secondly, as will be seen, gross trajectory errors associated with 1.0 degree/hour gyro drift can be greatly decreased by re-alignment fifteen minutes before perilune. It should be understood that such a re-alignment, while possible, would rather seriously interfere with an otherwise orderly and comfortable sequence of astronaut activities in preparation for the start of the powered descent. The re-alignment would require re-orientation of the vehicle and about five minutes of time.

III DISCUSSION

This study concerns the uncertainties in position and velocity existing at various phases of the LEM mission as a result of orbital navigation schemes and LEM inertial instrumentation. Reference to a summary sheet of one of the schemes analyzed (Appendices A-F) will clarify the following discussion.

Orbital Navigation Uncertainties

This category consists of those position and velocity uncertainties that exist prior to LEM injection. They represent the sum of all CM system uncertainties up to this point in the mission. The particular numbers used correspond to an M.I.T. orbital navigation scheme - Model I - Std (Reference 1). Their appearance on the summary sheet is desirable in order that LEM inertial uncertainties be kept in perspective. Larger orbital navigation uncertainties would tend to overwhelm the LEM inertial uncertainties thus diminishing the importance of the latter.

LEM - Inertial Uncertainties

The first uncertainty source listed under this category, alignment, means the misalignment of the accelerometer package which results from star tracking uncertainties, angle read-out uncertainties, etc. Gyro bias drift, accelerometer bias, and accelerometer scale factor uncertainty constitute the most important inertial uncertainties for the LEM mission though many more exist. (Reference 2)

Illustrative Example

The example chosen to illustrate the use of appendices utilizes a GIMU with "precision" gyros and a realignment

between injection and perilune. In particular, the effect of the constant drift of 10 meru (0.15 degrees/hour) of the y gyro will be traced to burn-out. (Appendix A, analysis I, BDY, page 34)

The left hand column of this analysis sheet divides the mission into separate phases of instrument utilization. In this case four phases are delineated. We consider each phase separately, or independently, so that we can calculate the final uncertainties when the component uncertainty is assumed to vary from one phase to the next.

Within each phase individual uncertainty sources are listed. (It should be remembered that these are, in turn, a result of the single uncertainty source represented by the particular analysis sheet, BDY in this case). The following example may clarify the shorthand notation utilized throughout the analyses: y Per mlm reads, "the misalignment about the y axis at perilune." To the right of each listed source is seen its effects at perilune, hover, and burn-out. Each of these phases is described in more detail below.

1. Drift Between Alignment and Injection

Fifteen minutes of drift occuring between initial alignment and injection causes a misalignment about the y axis at injection of 0.0375^{o} (See Fig. 1). Application of 373 feet/second (essentially radial injection velocity) results in a range rate uncertainty of 0.24 feet/second at injection because of this thrust vector misalignment.

The perilune effects of this injection velocity uncertainty were obtained through free fall error propagation equations. (Reference 3)

The perilune position and velocity uncertainties just obtained are propagated to hover and burn-out by means of a

"GIMU guidance error sub-routine" into which is fed knowledge of the descent and ascent trajectory parameters. The results of this routine (developed by F. Grant - M.I.T. Instrumentation Laboratory) are used to determine all effects occurring during, or being propagated through, any powered phase. (Description of the descent and ascent trajectories used in the error sub-routine are included as Appendix G).

2. Drift Between Realignment and Perilune

The misalignment at injection has been wiped out by the realignment performed 15 minutes before perilune.

Fifteen minutes of drift occurring between realignment and perilune causes a misalignment about the y axis at perilune of 0.0375^{o}. The GIMU error sub-routine determines the effects of this misalignment on position and velocity at hover and propagates these uncertainties at hover to burn-out.

In addition, the misalignment at perilune transforms to a like misalignment at hover, the effects of which are propagated to burn-out. (In this case the body and target axes coincide. A more complicated transformation is required if they don't. An x or z misalignment at perilune results in both an x and a z misalignment at hover.

3. Drift During Descent

During the six minutes of powered descent the continuous gyro drift rate causes position and velocity uncertainties at hover which are, in turn, propagated to burn-out.

In addition, a misalignment at hover, due to the integrated effect of gyro drift during descent, must also be propagated to burn-out. (Again, a more complicated computation of integrated drift effects is necessary for the x and z gyros).

4. Drift During Ascent

Finally, the continuous bias drift acting during the ascent

will result in uncertainties at burn-out. Again, these are obtained from the error sub-routine.

There are two different ways of handling the columns of uncertainty figures corresponding to perilune, hover, and burn-out appearing on each analysis sheet. Remember that the entire sheet concerns a single instrument uncertainty. It could be argued that the value of the instrument uncertainty is not the same during all phases of instrument utilization, i.e., the drift during the injection is not the same as the drift during powered ascent, etc. Within each phase, however, it has been assumed that each component uncertainty can be assumed constant. If one assumes that the instrument uncertainty shifts randomly from one phase to the next, it is necessary to RSS the position and velocity uncertainties found for each phase.

An alternate approach would be to consider that the uncertainty, though unknown, is constant throughout the mission, in which case we arithmetically add the position and velocity uncertainties found for each phase.

Both procedures are followed on the analysis sheets, the latter technique is represented on Table I, the former on Table II. The actual uncertainties will, most likely, lie somewhere between these two extremes.

IV CONCLUSION

The following remarks primarily concern information appearing in summary form on Table I and II.

Comparisons of analyses I and II or III and IV indicate the effects of a gimballed vs a gimballess inertial measurement unit. Both systems yield essentially the same results at perilune and hover while the gimballess system gives better results at burn-out. This is a result of the fact that the body-mounted gyros and accelerometers are flipped (as the vehicle is reoriented) at hover so that the sense of their uncertainties during ascent tends to cancel the uncertainties built up during descent. This cancellation is much less pronounced if the uncertainties are assumed to be variable (Table II).

The effects of crude (1.0^{o}/hr or 66.7 meru) vs precision (0.15^{o}/hr or 10 meru) gyros are found by comparing analysis I and V or III and VI. Though the gyro bias drifts differ by more than a factor of six, all other effects contributing to the total uncertainty figures remain the same. Therefore, the effects of gyro degradation are somewhat subdued. Nonetheless, reference to Table I indicates how significant such degradation is to hover and burn-out conditions, especially in terms of CEP and burn-out velocity uncertainties.

The effects of realignment vs no realignment between injection and perilune can be seen by comparing analyses I and III, or II and IV, or V and VI. In the first two comparisons, where precision gyros are used, it is seen that the effects primarily involve larger hover uncertainties. If crude gyros are employed and the system is not realigned prior to perilune,

a poor scheme (V) becomes even worse (VI) in position and velocity uncertainties at both hover and burn-out.

The principal differences between Tables I and II concern altitude and altitude rate uncertainties. These are nicely cancelled to a large extent because of the sequence of axes rotations if one can assume constant uncertainties (Table I). The terms are significant because they effect landing altimeter acquisition altitude and abort trajectory lofting. It is, therefore, important to find a realistic method of analysis with respect to these terms. It is also important to point out that increased inertial guidance uncertainties involve increased fuel consumption. Table III attempts to point out the principal accuracy/fuel relationship without attempting to assign numerical values. The results shown on Table IV suggest that a minimum time between alignment and launch is most critical, especially in a system utilizing crude gyros.

Further discussion of the many ramifications of these results will not be attempted here.

V REFERENCES

1. Monthly Technical Progress Report; Project Apollo Guidance and Navigation Program, M. I. T. Instrumentation Laboratory Report, E - 1306, Period from January 11, 1963 to February 11, 1963.

2. IMU Error Data For Apollo Trajectories, Frederic D. Grant, M. I. T. Instrumentation Laboratory Report, E - 1212, September, 1962.

3. Summary of Error Propagation in an Inertial System, Janusz Sciegienny, M. I. T. Instrumentation Laboratory Report, E - 1388, August, 1963

TABLE I

LEM INERTIAL UNCERTAINTIES

(Instrument uncertainties constant throughout mission)

	Uncertainties* at Perilune						Uncertainties at Hover						Uncertainties at Burn-out					
ANALYSIS	(U)R	(U)T	(U)H	$(U)\dot{R}$	$(U)\dot{T}$	$(U)\dot{H}$	(U)R	(U)T	(U)H	$(U)\dot{R}$	$(U)\dot{T}$	$(U)\dot{H}$	(U)R	(U)T	(U)H	$(U)\dot{R}$	$(U)\dot{T}$	$(U)\dot{H}$
I.) GIMU Precision Gyro; Realignment	1485	703	928	0.61	0.53	1.62	1670	1432	687	2.43	5.62	4.51	1789	2719	1172	2.03	4.40	2.82
II.) IMU Precision Gyro; Realignment	Same						1593	1399	732	2.52	5.74	4.86	2070	2671	1734	5.28	5.56	5.38
III.) GIMU Precision Gyro; No Realignment	Same						1762	2395	1332	2.71	12.29	11.38	1840	4788	3519	3.44	5.35	2.22
IV.) IMU Precision Gyro; No Realignment	Same						1592	2379	1407	3.06	12.43	12.31	2203	4708	4005	7.24	7.85	4.98
V.) GIMU Crude Gyro; Realignment	1958	1847	3545	1.69	0.53	4.65	3927	6716	687	4.64	29.22	23.63	4861	11901	3457	10.02	10.02	11.86
VI.) GIMU Crude Gyro; No Realignment	Same						5416	14456	7673	9.25	78.54	73.51	5647	28859	22385	21.04	22.59	2.33

*All 1σ uncertainties

TABLE II.

LEM INERTIAL UNCERTAINTIES

(Instrument uncertainties vary randomly from one phase to the next)

	Uncertainties* at Perilune						Uncertainties at Hover						Uncertainties at Burn-out					
ANALYSIS	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$
I.) GIMU Precision Gyro; Realignment	1485	703	928	0.61	0.53	1.62	1722	1088	1538	2.47	5.25	5.62	2215	2108	2938	3.45	3.41	4.89
III.) GIMU** Precision Gyro; No Realignment	1485	703	928	0.61	0.53	1.62	1769	2021	2116	2.72	11.72	11.83	2231	4225	4812	4.22	4.40	5.39
V.) GIMU Crude Gyro; Realignment	1958	1847	3545	1.69	0.53	4.65	3215	4469	6483	3.98	25.54	26.68	4769	8950	12367	7.04	9.72	14.23
VI.) GIMU Crude Gyro; No Realignment	1958	1847	3545	1.69	0.53	4.65	3926	11913	12599	8.07	74.50	75.55	4916	25786	29634	17.17	20.91	22.54

*All 1σ uncertainties

**No IMU data available for analyses II. and IV.

TABLE III

Effects of Guidance Uncertainties

on Fuel Requirements

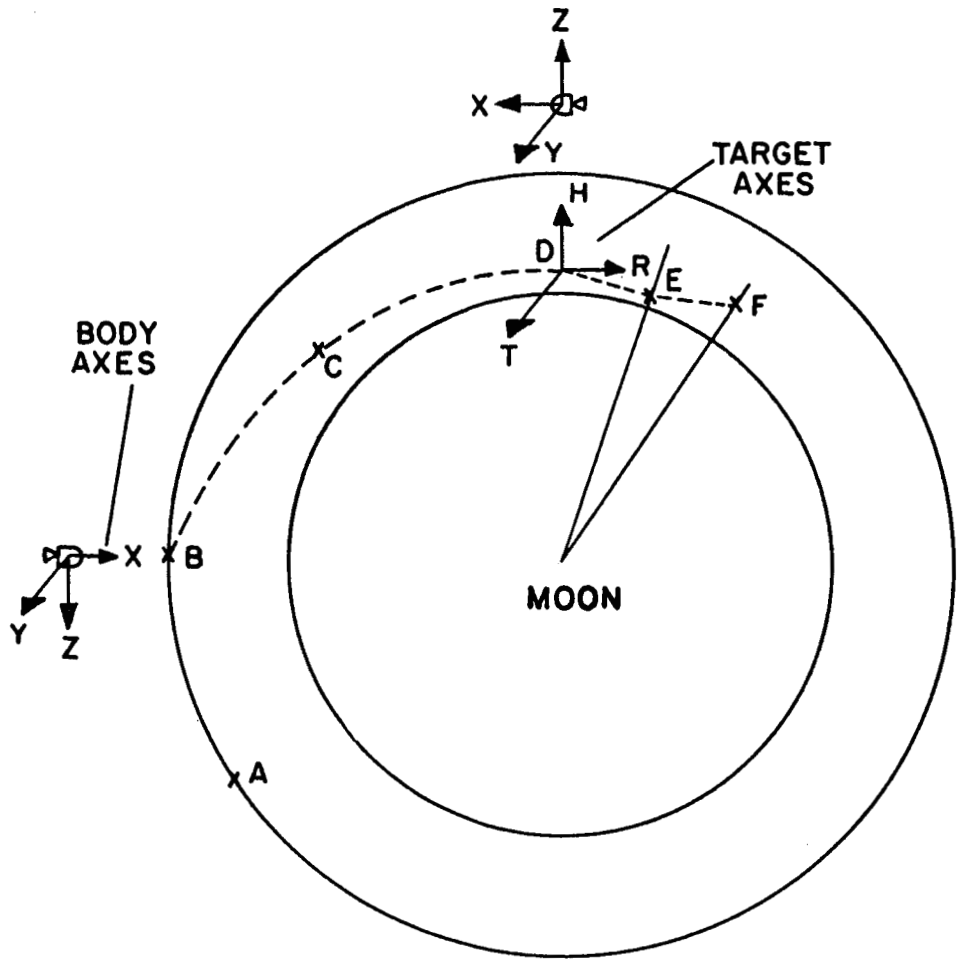
Guidance Error	Effect on Fuel
1. Perilune Altitude	Causes upward bias on nominal perilune altitude, thereby increasing landing fuel.
2. Altitude late in powered descent	Defines time and altitude when altimeter data is required for safe guidance. Increased altitude error causes increased altimeter range requirement and earlier acquisition which may in turn require earlier vehicle pitch-up with resultant landing fuel penalty.
3. Range and track late in powered descent	Defines amount of terminal maneuvering required to land on pre-determined target.
4. Velocity at cut-off (Burn-out)	Defines amount of midcourse maneuvering required to place LEM on collision course with CSM.

TABLE IV

"NORMAL ASCENT"

Uncertainty Sources	Uncertainties at Burn-Out					
	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$
Align X (1/2 MR)	0	-288	0	0	-1.51	0
Align Y (1/2 MR)	-86	0	430	-0.84	0	2.68
Align Z (1/2 MR)	0	-335	0	0	-2.36	0
BDX (1°/Hour)	0	-2500	0	0	-13.20	0
Prelaunch (.25°)	0	-47	0	0	-0.27	0
Ascent						
BDY (1 °/ Hour)	-750	0	3760	-7.33	0	23.30
Prelaunch (.25°)	-20	0	440	-0.53	0	4.07
Ascent						
BDZ (1 °/ Hour)	0	-2930	0	0	-20.70	0
Prelaunch (.25°)	0	446	0	0	4.13	0
Ascent						
ACBX (0.00656 ft/sec^2)	-378	0	-78	-2.16	0	-0.71
ACBY (0.00656 ft/sec^2)	0	-382	0	0	-2.21	0
ACBZ (0.00656 ft/sec^2)	-79	0	368	-0.73	0	2.04
SFEX (0.01%)	-89	0	-17	-0.57	0	-0.17
SFEY (0.01%)	0	0	0	0	0	0
SFEZ (0.01%)	0	0	0	0	0	0
RSS (Inertial)	853	3921	3829	7.76	25.15	23.90
RSS (Inertial) *	432	1062	1037	2.94	7.31	7.07

* Note: If total RSS prelaunch misalignment was held to 1 MR these inertial uncertainties would apply.



A. ALIGNMENT PRIOR TO INJECTION (80 N.M. CIRCULAR ORBIT)

B. INJECTION MANEUVER (373 FEET/SECOND ESSENTIALLY RADIALLY INWARD)

C. REALIGNMENT BETWEEN INJECTION AND PERILUNE

D. PERILUNE (50 K FEET)

E. HOVER (LESS THAN 1000 FEET)

F. BURN-OUT (50 K FEET)

Figure 1

VI APPENDICES

A. Analysis I GIMU - Precision Gyros - Realignment

The following represents a detailed outline of an uncertainty analysis of a LEM abort from hover. The system utilized has the following characteristics:

1. Gimballess inertial measurement unit (GIMU),
2. Precision gyros,
3. Realignment between injection and perilune.

The first two pages summarize the subsequent analysis. The first summary represents the case where it has been assumed that the instrument uncertainties are constant throughout the LEM mission. The second summary represents a case where instrument uncertainties are assumed to vary randomly throughout the LEM mission.

ANALYSIS I - SUMMARY A INSTRUMENT UNCERTAINTIES CONSTANT THROUGHOUT MISSION

UNCERTAINTY SOURCES	UNCERTAINTIES AT PERILUNE						UNCERTAINTIES AT HOVER						UNCERTAINTIES AT BURNOUT					
	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$
Orbital																		
Navigation	1440	589	481	0.45	0.53	1.23	1473	576	611	0.50	0.55	1.34	1457	557	989	0.68	0.56	1.90
(MOD I - STD)																		
Inertial																		
Align x	0	0	0	0	0	0	0	-111	0	0	-1.05	0	0	-471	0	0	-0.65	0
Align y	-142	0	396	-0.19	0	0.51	-393	0	137	-0.51	0	-2.06	-540	0	-231	-0.90	0	0.57
Align z	0	198	0	0	0	0	0	620	0	0	2.53	0	0	1017	0	0	-0.53	0
BDX	0	0	0	0	0	0	0	-144	0	0	-1.34	0	0	-688	0	0	-1.14	0
BDY	-187	0	518	-0.24	0	0.66	-539	0	3	-0.60	0	-3.52	-685	0	-495	-1.49	0	1.75
BDZ	0	259	0	0	0	0	0	985	0	0	4.14	0	0	1618	0	0	-0.75	0
ACBX	-404	0	202	-0.19	0	0.33	-121	0	186	2.14	0	0.25	183	0	304	-0.15	0	-0.63
ACBY	0	-202	0	0	0	0	0	-576	0	0	-2.14	0	0	-1653	0	0	-4.06	0
ACBZ	-146	0	404	-0.19	0	0.52	-382	0	211	-0.38	0	-1.38	-525	0	40	-0.77	0	0.71
SFEX	-78	0	39	-0.04	0	0.07	-7	0	30	0.56	0	0.02	83	0	46	-0.07	0	-0.24
SFEY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SFEZ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RSS (Inertial)	496	384	794	0.41	0	1.06	778	1311	314	2.38	5.59	4.31	1038	2661	628	1.91	4.36	2.08
RSS (Total)	1485	703	928	0.61	0.53	1.62	1670	1432	687	2.43	5.62	4.51	1789	2719	1172	2.03	4.40	2.82

ANALYSIS I - SUMMARY B INSTRUMENT UNCERTAINTIES VARY RANDOMLY FROM ONE PHASE TO THE NEXT

UNCERTAINTY SOURCES	UNCERTAINTIES AT PERILUNE						UNCERTAINTIES AT HOVER						UNCERTAINTIES AT BURNOUT					
	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$
Orbital Navigation																		
	1440	589	481	0.45	0.53	1.23	1478	576	611	0.50	0.55	1.34	1457	557	989	0.68	0.56	1.90
(MOD I - STD)																		
Inertial																		
Align x	0	0	0	0	0	0	0	111	0	0	1.05	0	0	471	0	0	0.65	0
Align y	142	0	396	0.19	0	0.51	316	0	720	0.36	0	2.93	495	0	1371	0.68	0	1.47
Align z	0	198	0	0	0	0	0	472	0	0	2.64	0	0	875	0	0	0.43	0
BDX	0	0	0	0	0	0	0	145	0	0	1.37	0	0	618	0	0	0.87	0
BDY	187	0	518	0.24	0	0.66	409	0	955	0.47	0	3.96	640	0	1822	0.93	0	2.03
BDZ	0	259	0	0	0	0	0	641	0	0	3.53	0	0	1167	0	0	1.07	0
ACBX	404	0	202	0.19	0	0.38	629	0	278	2.26	0	0.53	1328	0	392	2.97	0	1.20
ACBY	0	202	0	0	0	0	0	430	0	0	2.20	0	0	1184	0	0	2.96	0
ACBZ	146	0	404	0.19	0	0.52	318	0	693	0.27	0	2.30	507	0	1516	0.81	0	3.54
SFEX	78	0	39	0.04	0	0.07	131	0	54	0.59	0	0.13	322	0	72	0.77	0	0.29
SFEY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SFEZ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RSS (Inertial)	496	384	794	0.41	0	1.06	884	923	1411	2.42	5.22	5.46	1667	2033	2767	3.38	3.36	4.51
RSS (Total)	1485	703	928	0.61	0.53	1.62	1722	1088	1538	2.47	5.25	5.62	2215	2108	2938	3.45	3.41	4.89

Align-x at 1/2 mr (0.0286°)

UNCERTAINTY SOURCES		UNCERTAINTIES AT PERILUNE						UNCERTAINTIES AT HOVER						UNCERTAINTIES AT BURNOUT					
		(U)R	(U)T	(U)H	(U)Ṙ	(U)Ṫ	(U)Ḣ	(U)R	(U)T	(U)H	(U)Ṙ	(U)Ṫ	(U)Ḣ	(U)R	(U)T	(U)H	(U)Ṙ	(U)Ṫ	(U)Ḣ
I. Alignment Prior To Injection	R																		
	T																		
	H																		
	Ṙ																		
	Ṫ																		
0.0286° x inj mlm	Ḣ																		
Arithmetic Sum I		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
II. Realignment Prior To Perilune	R													0	0	0	0	0	0
	T													0	-104	0	0	0.03	0
	H													0	0	0	0	0	0
	Ṙ													0	0	0	0	0	0
	Ṫ													0	-356	0	0	-1.00	0
	Ḣ													0	0	0	0	0	0
0.0286° x per mlm								0	-111	0	0	-1.05	0						
0.0222° x Hov mlm														0	-223	0	0	-1.17	0
-0.0181° z Hov mlm														0	212	0	0	1.49	0
Arithmetic Sum II		0	0	0	0	0	0	0	-111	0	0	-1.05	0	0	-471	0	0	-0.65	0
RSS (Total)		0	0	0	0	0	0	0	111	0	0	1.05	0	0	471	0	0	0.65	0
Arithmetic Sum (Total)		0	0	0	0	0	0	0	-111	0	0	-1.05	0	0	-471	0	0	-0.65	0

Align-y at 1/2 mr (0.0286°)

UNCERTAINTY SOURCES		UNCERTAINTIES AT PERILUNE						UNCERTAINTIES AT HOVER						UNCERTAINTIES AT BURNOUT					
		(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$
I. Alignment Prior To Injection	R							-132	0	-27	0.04	0	-0.01	-284	0	-43	0.09	0	0
	T							0	0	0	0	0	0	0	0	0	0	0	0
	H							-75	0	432	0	0	0.26	-92	0	630	-0.03	0	0.37
0.0286° y inj mlm	$\dot{R}$							-63	0	-12	-0.18	0	-0.04	-77	0	-12	-0.22	0	0.03
	$\dot{T}$							0	0	0	0	0	0	0	0	0	0	0	0
	$\dot{H}$							-33	0	180	-0.09	0	0.56	-40	0	272	-0.12	0	0.85
Arithmetic Sum I		-142	0	396	-0.19	0	0.51	-303	0	573	-0.23	0	0.77	-493	0	847	-0.28	0	1.25
II. Realignment Prior To Perilune	R													-84	0	-13	0.03	0	0
	T													0	0	0	0	0	0
	H													70	0	-480	0.02	0	-0.28
	$\dot{R}$													-94	0	-15	-0.26	0	0.04
	$\dot{T}$													0	0	0	0	0	0
	$\dot{H}$													147	0	-1000	0.43	0	-3.12
0.0286° y Per mlm								-90	0	-436	-0.28	0	-2.83						
0.0286° y Hov mlm														-86	0	430	-0.84	0	2.68
Arithmetic Sum II		0	0	0	0	0	0	-90	0	-436	-0.28	0	-2.83	-47	0	-1078	-0.62	0	-0.68
RSS (Total)		142	0	396	0.19	0	0.51	316	0	720	0.36	0	2.93	495	0	1371	0.68	0	1.47
Arithmetic Sum (Total)		-142	0	396	-0.19	0	0.51	-393	0	137	-0.51	0	-2.06	-540	0	-231	-0.90	0	0.57

Align-z at 1/2 mr (0.0286°)

UNCERTAINTY SOURCES		UNCERTAINTIES AT PERILUNE (U)R	(U)T	(U)H	(U)Ṙ	(U)Ṫ	(U)Ḣ	UNCERTAINTIES AT HOVER (U)R	(U)T	(U)H	(U)Ṙ	(U)Ṫ	(U)Ḣ	UNCERTAINTIES AT BURNOUT (U)R	(U)T	(U)H	(U)Ṙ	(U)Ṫ	(U)Ḣ
I. Alignment Prior To Injection	R							0	0	0	0	0	0	0	0	0	0	0	0
	T							0	187	0	0	-0.06	0	0	177	0	0	-0.06	0
	H							0	0	0	0	0	0	0	0	0	0	0	0
	Ṙ							0	0	0	0	0	0	0	0	0	0	0	0
0.0286° z inj mlm	Ṫ							0	0	0	0	0	0	0	-21	0	0	-0.06	0
	Ḣ							0	0	0	0	0	0	0	0	0	0	0	0
Arithmetic Sum I		0	198	0	0	0	0	0	187	0	0	-0.06	0	0	156	0	0	-0.12	0
II. Realignment Prior To Perilune	R													0	0	0	0	0	0
	T													0	408	0	0	-0.14	0
	H													0	0	0	0	0	0
	Ṙ													0	0	0	0	0	0
	Ṫ													0	895	0	0	250	0
	Ḣ													0	0	0	0	0	0
0.0286° z Per mlm								0	433	0	0	2.64	0	0	-182	0	0	-0.95	0
0.0181° x Hov mlm														0	-260	0	0	-1.82	0
0.0222° z Hov mlm														0	861	0	0	-0.41	0
Arithmetic Sum II		0	0	0	0	0	0	0	433	0	0	2.64	0						
														0	875	0	0	0.43	0
RSS (Total)		0	198	0	0	0	0	0	472	0	0	2.64	0	0	1017	0	0	-0.53	0
Arithmetic Sum (Total)		0	198	0	0	0	0	0	620	0	0	2.58	0						

BDX at 0.15°/hour

UNCERTAINTY SOURCES		UNCERTAINTIES AT PERILUNE						UNCERTAINTIES AT HOVER						UNCERTAINTIES AT BURNOUT					
		(U)R	(U)T	(U)H	(U)Ṙ	(U)Ṫ	(U)Ḣ	(U)R	(U)T	(U)H	(U)Ṙ	(U)Ṫ	(U)Ḣ	(U)R	(U)T	(U)H	(U)Ṙ	(U)Ṫ	(U)Ḣ
I. Drift Between Alignment and Injection	R																		
	T																		
	H																		
	Ṙ																		
0.0375° x Inj mlm	Ṫ																		
	Ḣ																		
Arithmetic Sum I		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
II. Drift Between Realignment and Perilune	R													0	0	0	0	0	0
	T													0	-137	0	0	0.05	0
	H													0	0	0	0	0	0
	Ṙ													0	0	0	0	0	0
	Ṫ													0	-464	0	0	-1.30	0
	Ḣ													0	0	0	0	0	0
0.0375° x Per mlm								0	-145	0	0	-1.37	0						
0.0291° x Hov mlm														0	-292	0	0	-1.53	0
-0.0238° z Hov mlm														0	279	0	0	1.96	0
Arithmetic Sum II		0	0	0	0	0	0	0	-145	0	0	-1.37	0	0	-614	0	0	-0.82	0
III. Drift During Powered Descent	R													0	0	0	0	0	0
	T													0	1	0	0	0	0
	H													0	0	0	0	0	0
	Ṙ													0	0	0	0	0	0
	Ṫ													0	10	0	0	0.03	0
	Ḣ													0	0	0	0	0	0
Increasing x mlm								0	1	0	0	0.03	0						
0.0133° x Hov mlm														0	-133	0	0	-0.70	0
-0.0047° z Hov mlm														0	55	0	0	0.39	0
Arithmetic Sum III		0	0	0	0	0	0	0	1	0	0	0.03	0	0	-67	0	0	-0.28	0
IV. Drift During Powered Ascent														0	-7	0	0	-0.04	0
Increasing x mlm																			
Arithmetic Sum IV		0	0	0	0	0	0	0	0	0	0	0	0	0	-7	0	0	-0.04	0
RSS - Total		0	0	0	0	0	0	0	145	0	0	1.37	0	0	618	0	0	0.87	0
Arithmetic Sum - Total		0	0	0	0	0	0	0	-144	0	0	-1.34	0	0	-688	0	0	-1.14	0

SECRET

SECRET

BDY at 0.15°/hour

UNCERTAINTY SOURCES		UNCERTAINTIES AT PERILUNE (U)R	(U)T	(U)H	(U)Ṙ	(U)Ṫ	(U)Ḣ	UNCERTAINTIES AT HOVER (U)R	(U)T	(U)H	(U)Ṙ	(U)Ṫ	(U)Ḣ	UNCERTAINTIES AT BURNOUT (U)R	(U)T	(U)H	(U)Ṙ	(U)Ṫ	(U)Ḣ
I. Drift Between Alignment and Injection	R							-172	0	-35	0.06	0	-0.01	-368	0	-57	0.12	0	0
	T							0	0	0	0	0	0	0	0	0	0	0	0
	H							-98	0	563	0	0	0.33	-120	0	820	-0.04	0	0.49
	Ṙ							-81	0	-16	-0.23	0	-0.05	-96	0	-14	-0.27	0	0.04
	Ṫ							0	0	0	0	0	0	0	0	0	0	0	0
0.0375° y inj mlm	Ḣ							-42	0	233	-0.12	0	0.72	-53	0	354	-0.15	0	1.11
Arithmetic Sum I.		-187	0	518	-0.24	0	0.66	-393	0	745	-0.29	0	1.00	-637	0	1103	-0.34	0	1.64
II. Drift Between Realignment and Perilune	R													-111	0	-17	0.03	0	0
	T													0	0	0	0	0	0
	H													91	0	-629	0.03	0	-0.37
	Ṙ													-125	0	-19	-0.35	0	0.06
	Ṫ													0	0	0	0	0	0
	Ḣ													196	0	-1330	0.56	0	-4.13
0.0375° y per mlm								-119	0	-572	-0.37	0	-3.75						
0.0375° y hov mlm														-113	0	565	-1.10	0	3.51
Arithmetic Sum II		0	0	0	0	0	0	-119	0	-572	-0.37	0	-3.75	-62	0	-1430	-0.83	0	-0.93
III. Drift During Powered Descent	R													-25	0	-4	0.01	0	0
	T													0	0	0	0	0	0
	H													27	0	-187	0.01	0	-0.11
	Ṙ													20	0	3	0.06	0	-0.01
	Ṫ													0	0	0	0	0	0
	Ḣ													40	0	-272	0.12	0	-0.85
Increasing y mlm								-27	0	-170	0.06	0	-0.77						
0.015° y hov mlm														-45	0	226	-0.44	0	1.40
Arithmetic Sum III.		0	0	0	0	0	0	-27	0	-170	0.06	0	-0.77	17	0	-234	-0.24	0	0.43
IV. Drift During Powered Ascent																			
Increasing y mlm														-3	0	66	-0.08	0	0.61
Arithmetic Sum IV.		0	0	0	0	0	0	0	0	0	0	0	0	-3	0	66	-0.08	0	0.61
RSS (Total)		187	0	518	0.24	0	0.66	409	0	955	0.47	0	3.96	640	0	1822	0.93	0	2.03
Arithmetic Sum (Total)		-187	0	518	-0.24	0	0.66	-539	0	3	-0.60	0	-3.52	-685	0	-495	-1.49	0	1.75

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BDZ at 0.15° hour

UNCERTAINTY SOURCES		UNCERTAINTIES AT PERILUNE						UNCERTAINTIES AT HOVER						UNCERTAINTIES AT BURNOUT					
		(U)R	(U)T	(U)H	(U)Ṙ	(U)Ṫ	(U)Ḣ	(U)R	(U)T	(U)H	(U)Ṙ	(U)Ṫ	(U)Ḣ	(U)R	(U)T	(U)H	(U)Ṙ	(U)Ṫ	(U)Ḣ
I. Drift Between	R							0	0	0	0	0	0	0	0	0	0	0	0
Alignment and Injection	T							0	245	0	0	-0.08	0	0	232	0	0	-0.08	0
	H							0	0	0	0	0	0	0	0	0	0	0	0
	Ṙ							0	0	0	0	0	0	0	0	0	0	0	0
0.0375° z inj mlm	Ṫ							0	0	0	0	0	0	0	-27	0	0	-0.08	0
	Ḣ							0	0	0	0	0	0	0	0	0	0	0	0
Arithmetic Sum I		0	259	0	0	0	0	0	245	0	0	-0.08	0	0	205	0	0	-0.16	0
	R													0	0	0	0	0	0
II. Drift Between	T													0	535	0	0	-0.18	0
Realignment and	H													0	0	0	0	0	0
Perilune	Ṙ													0	0	0	0	0	0
	Ṫ													0	1170	0	0	3.28	0
	Ḣ													0	0	0	0	0	0
0.0375° z per mlm								0	567	0	0	3.45	0						
0.0238° x hov mlm														0	-239	0	0	-1.25	0
0.0291° z hov mlm														0	-341	0	0	-2.39	0
Arithmetic Sum II		0	0	0	0	0	0	0	567	0	0	3.45	0	0	1125	0	0	-0.54	0
	R													0	0	0	0	0	0
III. Drift During	T													0	164	0	0	-0.05	0
Powered Descent	H													0	0	0	0	0	0
	Ṙ													0	0	0	0	0	0
	Ṫ													0	260	0	0	0.73	0
	Ḣ													0	0	0	0	0	0
Increasing z mlm								0	173	0	0	0.77	0						
0.0047° x hov mlm														0	-47	0	0	-0.25	0
0.0133° z hov mlm														0	-156	0	0	-1.10	0
Arithmetic Sum III		0	0	0	0	0	0	0	173	0	0	0.77	0	0	221	0	0	-0.67	0
IV. Drift During																			
Powered Ascent														0	67	0	0	0.62	0
Increasing z mlm																			
Arithmetic Sum IV		0	0	0	0	0	0	0	0	0	0	0	0	0	67	0	0	0.62	0
RSS (Total)		0	259	0	0	0	0	0	641	0	0	3.53	0	0	1167	0	0	1.07	0
Arithmetic Sum (Total)		0	259	0	0	0	0	0	985	0	0	4.14	0	0	1618	0	0	-0.75	0

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ACBX at 0.00656 feet/second^2

UNCERTAINTY SOURCES		UNCERTAINTIES AT PERILUNE						UNCERTAINTIES AT HOVER						UNCERTAINTIES AT BURNOUT					
		(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$
I. Accelerometer Bias	R							-376	0	-77	0.13	0	-0.02	-468	0	-72	0.16	0	0
Bias During Injection	T							0	0	0	0	0	0	0	0	0	0	0	0
	H							-38	0	221	0	0	0.13	-42	0	292	-0.01	0	0.17
	$\dot{R}$							-63	0	-12	-0.18	0	-0.04	-40	0	-6	-0.11	0	0.02
ΔH at inj = 0.19 ft/sec	$\dot{T}$							0	0	0	0	0	0	0	0	0	0	0	0
	$\dot{H}$							-24	0	134	-0.07	0	0.41	-25	0	170	-0.07	0	0.53
Arithmetic Sum I		-404	0	202	-0.19	0	0.38	-501	0	266	-0.12	0	0.48	-575	0	384	-0.03	0	0.72
II. Accelerometer Bias	R													356	0	54	-0.12	0	0
During Powered Descent	T													0	0	0	0	0	0
	H													13	0	-88	0	0	-0.05
	$\dot{R}$													755	0	113	2.13	0	-0.34
Constant bias	$\dot{T}$													0	0	0	0	0	0
	$\dot{H}$													12	0	-81	0.03	0	-0.25
Arithmetic Sum II		0	0	0	0	0	0	308	0	-80	2.26	0	-0.23	1136	0	-2	2.04	0	-0.64
III. Accelerometer Bias																			
During Powered Ascent														-378	0	-78	-2.16	0	-0.71
Constant bias																			
Arithmetic Sum III		0	0	0	0	0	0	0	0	0	0	0	0	-378	0	-78	-2.16	0	-0.71
RSS (Total)		404	0	202	0.19	0	0.38	629	0	278	2.26	0	0.53	1328	0	392	2.97	0	1.20
Arithmetic Sum (Total)		-404	0	202	-0.19	0	0.38	-121	0	186	2.14	0	0.25	183	0	304	-0.15	0	-0.63

ACBY at 0.00656 feet/second^2

UNCERTAINTY SOURCES		UNCERTAINTIES AT PERILUNE						UNCERTAINTIES AT HOVER						UNCERTAINTIES AT BURNOUT					
		(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$
I. Accelerometer Bias	R							0	0	0	0	0	0	0	0	0	0	0	0
During Injection	T							0	-192	0	0	0.06	0	0	-182	0	0	0.06	0
	H							0	0	0	0	0	0	0	0	0	0	0	0
	$\dot{R}$							0	0	0	0	0	0	0	0	0	0	0	0
ΔT at inj - 0.19 ft/sec	$\dot{T}$							0	0	0	0	0	0	0	20	0	0	0.06	0
	$\dot{H}$							0	0	0	0	0	0	0	0	0	0	0	0
Arithmetic Sum I		0	-202	0	0	0	0	0	-192	0	0	0.06	0	0	-162	0	0	0.12	0
	R													0	0	0	0	0	0
II. Accelerometer Bias	T													0	-363	0	0	0.12	0
During Powered	H													0	0	0	0	0	0
Descent	$\dot{R}$													0	0	0	0	0	0
Constant bias	$\dot{T}$													0	-746	0	0	-2.09	0
	$\dot{H}$													0	0	0	0	0	0
Arithmetic Sum II		0	0	0	0	0	0	0	-384	0	0	-2.20	0	0	-1109	0	0	-1.97	0
III. Accelerometer Bias																			
During Powered														0	-382	0	0	-2.21	0
Ascent																			
Constant bias																			
Arithmetic Sum III		0	0	0	0	0	0	0	0	0	0	0	0	0	-382	0	0	-2.21	0
RSS (Total)		0	202	0	0	0	0	0	430	0	0	2.20	0	0	1184	0	0	2.96	0
Arithmetic Sum (Total)		0	-202	0	0	0	0	0	-576	0	0	-2.14	0	0	-1653	0	0	-4.06	0

ACBZ at 0.00656 feet/second

UNCERTAINTY SOURCES		UNCERTAINTIES AT PERILUNE						UNCERTAINTIES AT HOVER						UNCERTAINTIES AT BURNOUT					
		(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$
I. Accelerometer Bias During Injection	R							-136	0	-28	0.05	0	-0.01	-289	0	-44	0.10	0	0
	T							0	0	0	0	0	0	0	0	0	0	0	0
	H							-77	0	441	0	0	0.26	-94	0	643	-0.03	0	0.38
	$\dot{R}$							-63	0	-12	-0.18	0	-0.04	-74	0	-11	-0.21	0	0.03
ΔR at inj = 0.19 ft/sec	$\dot{T}$							0	0	0	0	0	0	0	0	0	0	0	0
	$\dot{H}$							-33	0	183	-0.09	0	0.57	-41	0	275	-0.12	0	0.86
Arithmetic Sum I		-146	0	404	-0.19	0	0.52	-309	0	584	-0.22	0	0.78	-498	0	863	-0.26	0	1.27
II. Accelerometer Bias During Powered Descent	R													-68	0	-10	0.02	0	0
	T													0	0	0	0	0	0
	H													60	0	-411	0.02	0	-0.24
	$\dot{R}$													-54	0	-8	-0.15	0	0.02
Constant bias	$\dot{T}$													0	0	0	0	0	0
	$\dot{H}$													114	0	-762	0.33	0	-2.38
Arithmetic Sum II		0	0	0	0	0	0	-73	0	-373	-0.16	0	-2.16	52	0	-1191	0.22	0	-2.60
III. Accelerometer Bias During Powered Ascent																			
														-79	0	368	-0.73	0	2.04
Constant bias																			
Arithmetic Sum III		0	0	0	0	0	0	0	0	0	0	0	0	-79	0	368	-0.73	0	2.04
RSS (Total)		146	0	404	0.19	0	0.52	318	0	693	0.27	0	2.30	507	0	1516	0.81	0	3.54
Arithmetic Sum (Total)		-146	0	404	-0.19	0	0.52	-382	0	211	-0.38	0	-1.38	-525	0	40	-0.77	0	0.71

SFEX AT 0.01%

UNCERTAINTY SOURCES		UNCERTAINTIES AT PERILUNE						UNCERTAINTIES AT HOVER						UNCERTAINTIES AT BURNOUT					
		(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$
I. Accelerometer S.F. During Injection	R							-72	0	-15	0.02	0	0	-89	0	-18	0.03	0	-0.01
	T							0	0	0	0	0	0	0	0	0	0	0	0
	H							-7	0	43	0	0	0.03	-10	0	55	0	0	0.04
ΔH at inj 0.04 ft/sec	$\dot{R}$							-13	0	-3	-0.04	0	-0.01	-10	0	-2	-0.03	0	-0.01
	$\dot{T}$							0	0	0	0	0	0	0	0	0	0	0	0
	$\dot{H}$							-4	0	25	-0.01	0	0.08	-6	0	35	-0.02	0	0.11
Arithmetic Sum I		-78	0	39	-0.04	0	0.07	-96	0	50	-0.03	0	0.10	-115	0	70	-0.02	0	0.13
II. Accelerometer S.F. During Powered Descent	R													83	0	13	-0.03	0	0
	T													0	0	0	0	0	0
	H													3	0	-22	0	0	-0.01
	$\dot{R}$													197	0	30	0.54	0	-0.19
Constant S. F.	$\dot{T}$													0	0	0	0	0	0
	$\dot{H}$													4	0	-28	0.01	0	-0.09
Arithmetic Sum II		0	0	0	0	0	0	89	0	-20	0.59	0	-0.08	287	0	-7	0.52	0	-0.28
III. Accelerometer S.F. During Powered Ascent																			
														-89	0	-17	-0.57	0	-0.17
Constant S. F.																			
Arithmetic Sum III		0	0	0	0	0	0	0	0	0	0	0	0	-89	0	-17	-0.57	0	-0.17
RSS (Total)		78	0	39	0.04	0	0.07	131	0	54	0.59	0	0.13	322	0	72	0.77	0	0.29
Arithmetic Sum (Total)		-78	0	39	-0.04	0	0.07	-7	0	30	0.56	0	0.02	83	0	46	-0.07	0	-0.24
Note:		The effects of SFEY and SFEZ can be nulled to zero.																	

B. Analysis II IMU - Precision Gyros - Realignment

The system analyzed is identical to that utilized in Analysis I except that a gimballed inertial measurement unit (IMU) replaces the GIMU. The IMU analysis did not lend itself to the detailed breakdown of Analysis I. Therefore, only a single summary is included, representing the case where instrument uncertainties are assumed to be constant throughout the LEM mission. Comparison of this data with that of Analysis I, Summary A, indicates the effects of a gimballed vs a gimballess system.

ANALYSIS II SUMMARY A INSTRUMENT UNCERTAINTIES CONSTANT THROUGHOUT MISSION

UNCERTAINTY SOURCES	UNCERTAINTIES AT PERILUNE						UNCERTAINTIES AT HOVER						UNCERTAINTIES AT BURNOUT					
	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$
Orbital Navigation	1440	589	481	0.45	0.53	1.23	1478	576	611	0.50	0.55	1.34	1457	557	989	0.68	0.56	1.90
(Mod I - STD)																		
Inertial																		
Align x	0	0	0	0	0	0	0	-84	0	0	-0.90	0	0	-464	0	0	-1.05	0
Align y	-142	0	396	-0.19	0	0.51	-302	0	101	-0.62	0	-2.19	-595	0	-340	-1.38	0	0.52
Align z	0	198	0	0	0	0	0	639	0	0	2.64	0	0	1039	0	0	-0.79	0
BDX	0	0	0	0	0	0	0	-136	0	0	-1.53	0	0	-794	0	0	-1.83	0
BDY	-187	0	518	-0.24	0	0.66	-400	0	37	-1.00	0	-3.70	-944	0	-542	-2.80	0	2.05
BDZ	0	259	0	0	0	0	0	921	0	0	4.20	0	0	1353	0	0	-2.84	0
ACBX	-409	0	202	-0.19	0	0.38	-111	0	341	2.09	0	0.92	911	0	970	3.99	0	2.46
ACBY	0	-202	0	0	0	0	0	-589	0	0	-2.19	0	0	-1751	0	0	-4.18	0
ACBZ	-146	0	404	-0.19	0	0.52	-235	0	183	0.20	0	-1.56	76	0	-818	1.33	0	-3.84
SFEX	-78	0	39	-0.04	0	0.07	-185	0	33	-0.56	0	0	-280	0	2	0.11	0	0.13
SFEY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SFEZ	0	0	0	0	0	0	3	0	-17	0.03	0	-0.18	33	0	-96	0.08	0	-0.25
RSS (Inertial)	496	384	794	0.41	0	1.06	594	1275	403	2.47	5.71	4.67	1470	2612	1424	5.24	5.53	5.03
RSS (Total)	1485	703	928	0.61	0.53	1.62	1593	1399	732	2.52	5.74	4.86	2070	2671	1734	5.28	5.56	5.38

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C. Analysis III GIMU - Precision Gyros - No Realignment

The system is identical to that utilized in Analysis I except that there is no realignment between injection and perilune. In addition, analyses for the following uncertainty sources are identical to Analysis I. They will not be repeated.

ACBX
ACBY
ACBZ
SFEX
SFEY
SFEZ

ANALYSIS III - SUMMARY A INSTRUMENT UNCERTAINTIES CONSTANT THROUGHOUT MISSION

UNCERTAINTY SOURCES	UNCERTAINTIES AT PERILUNE (U)R	(U)T	(U)H	(U)Ṙ	(U)Ṫ	(U)Ḣ	UNCERTAINTIES AT HOVER (U)R	(U)T	(U)H	(U)Ṙ	(U)Ṫ	(U)Ḣ	UNCERTAINTIES AT BURNOUT (U)R	(U)T	(U)H	(U)Ṙ	(U)Ṫ	(U)Ḣ
ORBITAL																		
NAVIGATION	1440	589	481	0.45	0;53	1;23	1478	576	611	0.50	0.55	1.34	1457	557	989	0.68	0.56	1.90
(MOD I - STD)																		
Inertial																		
Align x	0	0	0	0	0	0	0	-111	0	0	-1.05	0	0	-471	0	0	-0.65	0
Align y	-142	0	396	-0.19	0	0.51	-393	0	137	-0.51	0	-2.06	-540	0	-231	-0.90	0	0.57
Align z	0	198	0	0	0	0	0	620	0	0	2.58	0	0	1017	0	0	-0.53	0
BDX	0	0	0	0	0	0	0	-434	0	0	-4.08	0	0	-1916	0	0	-2.78	0
BDY	-187	0	518	-0.24	0	0.66	-777	0	-1141	-1.34	0	-11.02	-809	0	-3355	-3.15	0	-0.11
BDZ	0	259	0	0	0	0	0	2119	0	0	11.04	0	0	3868	0	0	-1.83	0
ACBX	-404	0	202	-0.19	0	0.38	-121	0	186	2.14	0	0.25	183	0	304	-0.15	0	-0.6
ACBY	0	-202	0	0	0	0	0	-576	0	0	-2.14	0	0	-1653	0	0	-4.06	0
ACBZ	-146	0	404	-0.19	0	0.52	-382	0	211	-0.38	0	-1.38	-525	0	40	-0.77	0	0.71
SFEX	-78	0	39	-0.04	0	0.07	-7	0	30	0.56	0	0.02	83	0	46	-0.07	0	-0.24
SFEY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SFEZ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RSS (Inertial)	496	384	794	0.41	0	1.06	959	2325	1184	2.66	12.28	11.30	1123	4756	3377	3.37	5.32	1.14
RSS (Total)	1485	703	928	0.61	0.53	1.62	1762	2395	1332	2.71	12.29	11.38	1840	4788	3519	3.44	5.35	2.22

ANALYSIS III - SUMMARY B INSTRUMENT UNCERTAINTIES VARY RANDOMLY FROM ONE PHASE TO THE NEXT

UNCERTAINTY SOURCES	UNCERTAINTIES AT PERILUNE						UNCERTAINTIES AT HOVER						UNCERTAINTIES AT BURNOUT					
	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$
Orbital																		
Navigation																		
	1440	589	481	0.45	0.53	1.23	1478	576	611	0.50	0.55	1.34	1457	557	989	0.68	0.56	1.90
(MOD I - STD)																		
Inertial																		
Align x	0	0	0	0	0	0	0	111	0	0	1.05	0	0	471	0	0	0.65	0
Align y	142	0	396	0.19	0	0.51	393	0	137	0.51	0	2.06	540	0	231	0.90	0	0.57
Align z	0	198	0	0	0	0	0	620	0	0	2.58	0	0	1017	0	0	0.53	0
BDX	0	0	0	0	0	0	0	435	0	0	4.11	0	0	1843	0	0	2.48	0
BDY	187	0	518	0.24	0	0.66	532	0	1878	1.15	0	11.32	664	0	4436	2.53	0	3.32
BDZ	0	259	0	0	0	0	0	1727	0	0	10.38	0	0	3389	0	0	1.87	0
ACBX	404	0	202	0.19	0	0.38	629	0	278	2.26	0	0.53	1328	0	392	2.97	0	1.20
ACBY	0	202	0	0	0	0	0	430	0	0	2.20	0	0	1134	0	0	2.96	0
ACBZ	146	0	404	0.19	0	0.52	318	0	693	0.27	0	2.30	507	0	1516	0.81	0	3.54
SFEX	78	0	39	0.04	0	0.07	131	0	54	0.59	0	0.13	322	0	72	0.77	0	0.29
SFEY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SFEZ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RSS (Inertial)	496	384	794	0.41	0	1.06	972	1937	2026	2.67	11.71	11.75	1690	4188	4710	4.16	4.36	5.04
RSS (Total)	1485	703	928	0.61	0.53	1.62	1769	2021	2116	2.72	11.72	11.83	2231	4225	4812	4.22	4.40	5.39

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Align-x at 1/2 mr (0.0286^{o})

UNCERTAINTY SOURCES		UNCERTAINTIES AT PERILUNE (U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$	UNCERTAINTIES AT HOVER (U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$	UNCERTAINTIES AT BURNOUT (U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$
I. Alignment Prior to Injection	R																		
	T																		
	H																		
	$\dot{R}$																		
	$\dot{T}$																		
	$\dot{H}$																		
0.0286^{o} x inj mlm		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	R													0	0	0	0	0	0
	T													0	-104	0	0	0.03	0
	H													0	0	0	0	0	0
	$\dot{R}$													0	0	0	0	0	0
	$\dot{T}$													0	-356	0	0	-1.00	0
	$\dot{H}$													0	0	0	0	0	0
0.0286^{o} x per mlm								0	-111	0	0	-1.05	0						
0.0222^{o} x Hov mlm														0	-223	0	0	-1.17	0
-0.0181^{o} z Hov mlm														0	212	0	0	1.49	0
Arithmetic Sum I		0	0	0	0	0	0	0	-111	0	0	-1.05	0	0	-471	0	0	-0.65	0
RSS (Total)		0	0	0	0	0	0	0	111	0	0	1.05	0	0	471	0	0	0.65	0
Arithmetic Sum (Total)		0	0	0	0	0	0	0	-111	0	0	-1.05	0	0	-471	0	0	-0.65	0

Align-y at 1/2 mr (0.0286°)

UNCERTAINTY SOURCES		UNCERTAINTIES AT PERILUNE						UNCERTAINTIES AT HOVER						UNCERTAINTIES AT BURNOUT					
		(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$
I. Alignment Prior	R							-132	0	-27	0.04	0	-0.01	-284	0	-43	0.09	0	0
To Injection	T							0	0	0	0	0	0	0	0	0	0	0	0
	H							-75	0	432	0	0	0.26	-92	0	630	-0.03	0	0.37
0.0286° y inj mlm	$\dot{R}$							-63	0	-12	-0.18	0	-0.04	-77	0	-12	-0.22	0	0.03
	$\dot{T}$							0	0	0	0	0	0	0	0	0	0	0	0
	$\dot{H}$							-33	0	180	-0.09	0	0.56	-40	0	272	-0.12	0	0.85
		-142	0	396	-0.19	0	0.51												
	R													-84	0	-13	0.03	0	0
	T													0	0	0	0	0	0
	H													70	0	-480	0.02	0	-0.28
	$\dot{R}$													-94	0	-15	-0.26	0	0.04
	$\dot{T}$													0	0	0	0	0	0
	$\dot{H}$													147	0	-1000	0.43	0	-3.12
0.0286° y Per mlm								-90	0	-436	-0.28	0	-2.83						
0.0286° y Hov mlm														-86	0	430	-0.84	0	2.68
Arithmetic Sum I		-142	0	396	-0.19	0	0.51	-393	0	137	-0.51	0	-2.06	-540	0	-231	-0.90	0	0.57
RSS (Total)		142	0	396	0.19	0	0.51	393	0	137	0.51	0	2.06	540	0	231	0.90	0	0.57
Arithmetic Sum (Total)		-142	0	396	-0.19	0	0.51	-393	0	137	-0.51	0	-2.06	-540	0	-231	-0.90	0	0.57

Align-z at 1/2 mr (0.0286°)

UNCERTAINTY SOURCES		UNCERTAINTIES AT PERILUNE (U)R	(U)T	(U)H	(U)Ṙ	(U)Ṫ	(U)Ḣ	UNCERTAINTIES AT HOVER (U)R	(U)T	(U)H	(U)Ṙ	(U)Ṫ	(U)Ḣ	UNCERTAINTIES AT BURNOUT (U)R	(U)T	(U)H	(U)Ṙ	(U)Ṫ	(U)Ḣ
I. Alignment Prior To Injection	R							0	0	0	0	0	0	0	0	0	0	0	0
	T							0	187	0	0	-0.06	0	0	177	0	0	-0.06	0
	H							0	0	0	0	0	0	0	0	0	0	0	0
0.0286° z inj mlm	Ṙ							0	0	0	0	0	0	0	0	0	0	0	0
	Ṫ							0	0	0	0	0	0	0	-21	0	0	-0.06	0
	Ḣ							0	0	0	0	0	0	0	0	0	0	0	0
		0	198	0	0	0	0							0	0	0	0	0	0
	R													0	408	0	0	-0.14	0
	T													0	0	0	0	0	0
	H													0	0	0	0	0	0
	Ṙ													0	895	0	0	2.50	0
	Ṫ													0	0	0	0	0	0
	Ḣ																		
0.0286° z Per mlm								0	433	0	0	2.64	0						
0.0181° x Hov mlm														0	-182	0	0	-0.95	0
0.0222° z Hov mlm														0	-260	0	0	-1.82	0
Arithmetic Sum I		0	198	0	0	0	0	0	620	0	0	2.58	0	0	1017	0	0	-0.53	0
RSS (Total)		0	198	0	0	0	0	0	620	0	0	2.58	0	0	1017	0	0	0.53	0
Arithmetic Sum (Total)		0	198	0	0	0	0	0	620	0	0	2.58	0	0	1017	0	0	-0.53	0

BDX at 0.15 hour

UNCERTAINTY SOURCES		UNCERTAINTIES AT PERILUNE						UNCERTAINTIES AT HOVER						UNCERTAINTIES AT BURNOUT					
		(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$
I. Drift Between Alignment and Injection	R																		
	T																		
	H																		
	$\dot{R}$																		
0.0375° x Inj mlm	$\dot{T}$																		
	$\dot{H}$																		
Arithmetic Sum I		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
II. Drift Between Alignment and Perilune	R													0	0	0	0	0	0
	T													0	-411	0	0	0.15	0
	H													0	0	0	0	0	0
	$\dot{R}$													0	0	0	0	0	0
	$\dot{T}$													0	-1392	0	0	-3.90	0
	$\dot{H}$													0	0	0	0	0	0
0.1125° x Per mlm								0	-435	0	0	-4.11	0						
0.0873° x Hov mlm														0	-876	0	0	-4.59	0
0.0714° z Hov mlm														0	837	0	0	5.88	0
Arithmetic Sum II		0	0	0	0	0	0	0	-435	0	0	-4.11	0	0	-1842	0	0	-2.46	0
III. Drift During Powered Descent	R													0	0	0	0	0	0
	T													0	1	0	0	0	0
	H													0	0	0	0	0	0
	$\dot{R}$													0	0	0	0	0	0
	$\dot{T}$													0	10	0	0	0.03	0
	$\dot{H}$													0	0	0	0	0	0
Increasing x mlm								0	1	0	0	0.03	0						
0.0133° x Hov mlm														0	-133	0	0	-0.70	0
-0.0047° z Hov mlm														0	55	0	0	0.39	0
Arithmetic Sum III		0	0	0	0	0	0	0	1	0	0	0.03	0	0	-67	0	0	-0.28	0
IV. Drift During Powered Ascent														0	-7	0	0	-0.04	0
Increasing x mlm																			
Arithmetic Sum IV		0	0	0	0	0	0	0	0	0	0	0	0	0	-7	0	0	-0.04	0
RSS Total		0	0	0	0	0	0	0	435	0	0	4.11	0	0	1843	0	0	2.48	0
Arithmetic Sum Total		0	0	0	0	0	0	0	-434	0	0	-4.08	0	0	-1916	0	0	-2.78	0

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BDY at 0.15°/hour

UNCERTAINTY SOURCES		UNCERTAINTIES AT PERILUNE (U)R	(U)T	(U)H	(U)Ṙ	(U)Ṫ	(U)Ḣ	UNCERTAINTIES AT HOVER (U)R	(U)T	(U)H	(U)Ṙ	(U)Ṫ	(U)Ḣ	UNCERTAINTIES AT BURNOUT (U)R	(U)T	(U)H	(U)Ṙ	(U)Ṫ	(U)Ḣ
I. Drift Between Alignment and Injection	R							-172	0	-35	0.06	0	-0.01	-368	0	-57	0.12	0	0
	T							0	0	0	0	0	0	0	0	0	0	0	0
	H							-98	0	563	0	0	0.33	-120	0	820	-0.04	0	0.49
	Ṙ							-31	0	-16	-0.23	0	-0.05	-96	0	-14	-0.27	0	0.04
0.0375° y inj mlm	Ṫ							0	0	0	0	0	0	0	0	0	0	0	0
	Ḣ							-42	0	233	-0.12	0	0.72	-53	0	354	-0.15	0	1.11
Arithmetic Sum I		-187	0	518	-0.24	0	0.66	-393	0	745	-0.29	0	1.00	-637	0	1103	-0.34	0	1.64
II. Drift Between Alignment and Perilune	R													-333	0	-51	0.09	0	0
	T													0	0	0	0	0	0
	H													273	0	-1887	0.09	0	-1.11
	Ṙ													-375	0	-57	-1.05	0	0.18
	Ṫ													0	0	0	0	0	0
	Ḣ													588	0	-3990	1.68	0	-12.39
0.1125° y per mlm								-357	0	-1716	-1.11	0	-11.25						
0.1125° y hov mlm														-339	0	1695	-3.30	0	10.53
Arithmetic Sum II		0	0	0	0	0	0	-357	0	-1716	-1.11	0	-11.25	-186	0	-4290	-2.49	0	-2.79
III. Drift During Powered Descent	R													-25	0	-4	0.01	0	0
	T													0	0	0	0	0	0
	H													27	0	-187	0.01	0	-0.11
	Ṙ													20	0	3	0.06	0	-0.01
	Ṫ													0	0	0	0	0	0
	Ḣ													40	0	-272	0.12	0	-0.85
Increasing y mlm								-27	0	-170	0.06	0	-0.77						
0.015° y hov mlm														-45	0	226	-0.44	0	1.40
Arithmetic Sum III		0	0	0	0	0	0	-27	0	-170	0.06	0	-0.77	17	0	-234	-0.24	0	0.43
IV. Drift During Powered Ascent														-3	0	66	-0.08	0	0.61
Increasing y mlm																			
Arithmetic Sum IV		0	0	0	0	0	0	0	0	0	0	0	0	-3	0	66	-0.08	0	0.61
RSS (Total)		187	0	518	0.24	0	0.66	532	0	1873	1.15	0	11.32	664	0	4436	2.53	0	3.32
Arithmetic Sum (Total)		-187	0	518	-0.24	0	0.66	-777	0	-1141	-1.34	0	-11.02	-809	0	-3355	-3.15	0	-0.11

BDZ at 0.15°/hour

UNCERTAINTY SOURCES		UNCERTAINTIES AT PERILUNE						UNCERTAINTIES AT HOVER						UNCERTAINTIES AT BURNOUT					
		(U)R	(U)T	(U)H	(U)Ṙ	(U)Ṫ	(U)Ḣ	(U)R	(U)T	(U)H	(U)Ṙ	(U)Ṫ	(U)Ḣ	(U)R	(U)T	(U)H	(U)Ṙ	(U)Ṫ	(U)Ḣ
I. Drift Between Alignment and Injection	R							0	0	0	0	0	0	0	0	0	0	0	0
	T							0	245	0	0	-0.08	0	0	232	0	0	-0.08	0
	H							0	0	0	0	0	0	0	0	0	0	0	0
	Ṙ							0	0	0	0	0	0	0	0	0	0	0	0
0.0375° z inj mlm	Ṫ							0	0	0	0	0	0	0	-27	0	0	-0.08	0
	Ḣ							0	0	0	0	0	0	0	0	0	0	0	0
Arithmetic Sum I		0	259	0	0	0	0	0	245	0	0	-0.08	0	0	205	0	0	-0.16	0
II. Drift Between Alignment and Perilune	R													0	0	0	0	0	0
	T													0	1605	0	0	-0.54	0
	H													0	0	0	0	0	0
	Ṙ													0	0	0	0	0	0
	Ṫ													0	3510	0	0	9.84	0
	Ḣ													0	0	0	0	0	0
0.1125° z per mlm								0	1701	0	0	10.35	0						
0.0714° x hov mlm														0	-717	0	0	-3.75	0
0.0873° z hov mlm														0	-1023	0	0	-7.17	0
Arithmetic Sum II		0	0	0	0	0	0	0	1701	0	0	10.35	0	0	3375	0	0	-1.62	0
III. Drift During Powered Descent	R													0	0	0	0	0	0
	T													0	164	0	0	-0.05	0
	H													0	0	0	0	0	0
	Ṙ													0	0	0	0	0	0
	Ṫ													0	260	0	0	0.73	0
	Ḣ													0	0	0	0	0	0
Increasing z mlm								0	173	0	0	0.77	0						
0.0047° x hov mlm														0	-47	0	0	-0.25	0
0.0133° z hov mlm														0	-156	0	0	-1.10	0
Arithmetic Sum III		0	0	0	0	0	0	0	173	0	0	0.77	0	0	221	0	0	-0.67	0
IV Drift During Powered Ascent														0	67	0	0	0.62	0
Increasing z mlm																			
Arithmetic Sum IV		0	0	0	0	0	0	0	0	0	0	0	0	0	67	0	0	0.62	0
RSS (Total)		0	259	0	0	0	0	0	1727	0	0	10.38	0	0	3389	0	0	1.87	0
Arithmetic Sum (Total)		0	259	0	0	0	0	0	2119	0	0	11.01	0	0	3868	0	0	-1.83	0

D. Analysis IV IMU - Precision Gyros - No Realignment

The system analyzed is identical to that utilized in Analysis II except that there is no realignment between injection and perilune. Comparison of this data with that of Analysis III, Summary A, again indicates the effect of a gimballed vs a gimballess system.

ANALYSIS IV - SUMMARY A INSTRUMENT UNCERTAINTIES CONSTANT THROUGHOUT MISSION

UNCERTAINTY SOURCES	UNCERTAINTIES AT PERILUNE						UNCERTAINTIES AT HOVER						UNCERTAINTIES AT BURNOUT					
	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$
Orbital Navigation	1440	589	481	0.45	0.53	1.23	1478	576	611	0.50	0.55	1.34	1457	557	989	0.68	0.56	1.90
(MOD I - STD)																		
Inertial																		
Align x	0	0	0	0	0	0	0	-84	0	0	-0.90	0	0	-464	0	0	-1.05	0
Align y	-142	0	396	-0.19	0	0.51	-302	0	101	-0.62	0	-2.19	-595	0	-340	-1.38	0	0.52
Align z	0	198	0	0	0	0	0	639	0	0	2.64	0	0	1039	0	0	-0.79	0
BDX	0	0	0	0	0	0	0	-357	0	0	-3.89	0	0	-2004	0	0	-4.57	0
BDY	-187	0	518	-0.24	0	0.66	-397	0	-1202	-2.01	0	-11.90	-1210	0	-3651	-5.69	0	0.12
BDZ	0	259	0	0	0	0	0	2107	0	0	11.25	0	0	3671	0	0	-4.60	0
ACBX	-404	0	202	-0.19	0	0.38	-111	0	341	2.09	0	0.92	911	0	970	3.99	0	2.46
ACBY	0	-202	0	0	0	0	0	-589	0	0	-2.19	0	0	-1751	0	0	-4.18	0
ACBZ	-146	0	404	-0.19	0	0.52	-235	0	183	0.20	0	-1.56	76	0	-818	1.33	0	-3.84
SFEX	-78	0	39	-0.04	0	0.07	-185	0	33	-0.56	0	0	-280	0	2	0.11	0	0.13
SFEY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SFEZ	0	0	0	0	0	0	3	0	-17	0.03	0	-0.18	33	0	-96	0.08	0	-0.25
RSS (Inertial)	496	384	794	0.41	0	1.06	592	2308	1267	3.02	12.42	12.24	1653	4675	3881	7.21	7.83	4.60
RSS (Total)	1485	703	928	0.61	0.53	1.62	1592	2379	1407	3.06	12.43	12.31	2203	4708	4005	7.24	7.85	4.98

E. Analysis V GIMU - Crude Gyros - Realignment

The system analyzed is identical to that utilized in Analysis I except that crude gyros replace the precision gyros. In addition, analyses for the following uncertainty sources are identical to Analysis I. They will not be repeated.

Align X
Align Y
Align Z
ACBX
ACBY
ACBZ
SFEX
SFEY
SFEZ

ANALYSIS V - SUMMARY A
INSTRUMENT UNCERTAINTIES CONSTANT THROUGHOUT MISSION

UNCERTAINTY SOURCES	UNCERTAINTIES AT PERILUNE						UNCERTAINTIES AT HOVER						UNCERTAINTIES AT BURNOUT					
	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$
Orbital																		
Navigation	1440	589	481	0.45	0.53	1.23	1478	576	611	0.50	0.55	1.34	1457	557	989	0.68	0.56	1.90
(MOD I - STD)																		
Inertial																		
Align x	0	0	0	0	0	0	0	- 111	0	0	- 1.05	0	0	- 471	0	0	- 0.65	0
Align y	- 142	0	396	-0.19	0	0.51	- 393	0	137	-0.51	0	- 2.06	- 540	0	- 231	- 0.90	0	0.57
Align z	0	198	0	0	0	0	0	620	0	0	2.58	0	0	1017	0	0	- 0.53	0
BDX	0	0	0	0	0	0	0	- 960	0	0	- 8.93	0	0	- 4584	0	0	- 7.61	0
BDY	-1245	0	3460	-1.60	0	4.40	-3594	0	17	-4.00	0	-23.46	-4571	0	-3290	- 9.93	0	11.66
BDZ	0	1728	0	0	0	0	0	6567	0	0	27.60	0	0	10785	0	0	- 5.00	0
ACBX	- 404	0	202	-0.19	0	0.38	- 121	0	186	2.14	0	0.25	183	0	304	- 0.15	0	- 0.63
ACBY	0	-202	0	0	0	0	0	- 576	0	0	- 2.14	0	0	- 1653	0	0	- 4.06	0
ACBZ	- 146	0	404	-0.19	0	0.52	- 382	0	211	-0.38	0	- 1.38	- 525	0	40	- 0.77	0	0.71
SFEX	- 78	0	39	-0.04	0	0.07	- 7	0	30	0.56	0	0.02	83	0	46	- 0.07	0	- 0.24
SFEY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SFEZ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RSS (Inertial)	1327	1751	3512	1.63	0	4.48	3638	6691	315	4.61	29.22	23.59	4637	11888	3313	10.00	10.00	11.71
RSS (Total)	1958	1847	3545	1.69	0.53	4.65	3927	6716	687	4.64	29.22	23.63	4861	11901	3457	10.02	10.02	11.86

ANALYSIS V - SUMMARY B INSTRUMENT UNCERTAINTIES VARY RANDOMLY FROM ONE PHASE TO THE NEXT

UNCERTAINTY SOURCES	UNCERTAINTIES AT PERILUNE						UNCERTAINTIES AT HOVER						UNCERTAINTIES AT BURNOUT					
	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$
Orbital Navigation																		
(MOD I - STD)	1440	589	481	0.45	0.53	1.23	1478	576	611	0.50	0.55	1.34	1457	557	989	0.68	0.56	1.90
Inertial																		
Align x	0	0	0	0	0	0	0	111	0	0	1.05	0	0	471	0	0	0.65	0
Align y	142	0	396	0.19	0	0.51	316	0	720	0.36	0	2.93	495	0	1371	0.68	0	1.47
Align z	0	198	0	0	0	0	0	472	0	0	2.64	0	0	875	0	0	0.43	0
BDX	0	0	0	0	0	0	0	967	0	0	9.13	0	0	4115	0	0	5.79	0
BDY	1245	0	3460	1.60	0	4.40	2744	0	6370	3.16	0	26.38	4272	0	12150	6.21	0	13.51
BDZ	0	1728	0	0	0	0	0	4276	0	0	23.57	0	0	7777	0	0	7.15	0
ACBX	404	0	202	0.19	0	0.38	629	0	278	2.26	0	0.53	1328	0	392	2.97	0	1.20
ACBY	0	202	0	0	0	0	0	430	0	0	2.20	0	0	1184	0	0	2.96	0
ACBZ	146	0	404	0.19	0	0.52	318	0	693	0.27	0	2.30	507	0	1516	0.81	0	3.54
SFEX	78	0	39	0.04	0	0.07	131	0	54	0.59	0	0.13	322	0	72	0.77	0	0.29
SFEY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SFEZ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RSS (Inertial)	1327	1751	3512	1.63	0	4.48	2855	4432	6454	3.95	25.53	26.65	4541	8933	12327	7.01	9.70	14.10
RSS (Total)	1958	1847	3545	1.69	0.53	4.65	3215	4469	6483	3.98	25.54	26.68	4769	8950	12367	7.04	9.72	14.23

BDX at 1.00°/hour

UNCERTAINTY SOURCES		UNCERTAINTIES AT PERILUNE (U)R	(U)T	(U)H	(U)Ṙ	(U)Ṫ	(U)Ḣ	UNCERTAINTIES AT HOVER (U)R	(U)T	(U)H	(U)Ṙ	(U)Ṫ	(U)Ḣ	UNCERTAINTIES AT BURNOUT (U)R	(U)T	(U)H	(U)Ṙ	(U)Ṫ	(U)Ḣ
I Drift Between Alignment and Injection	R																		
	T																		
	H																		
0.2500° x Inj mlm	Ṙ																		
	Ṫ																		
	Ḣ																		
Arithmetic Sum I		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
II Drift Between Realignment and Perilune	R													0	0	0	0	0	0
	T													0	-913	0	0	0.33	0
	H													0	0	0	0	0	0
	Ṙ													0	0	0	0	0	0
	Ṫ													0	-3090	0	0	-8.70	0
	Ḣ													0	0	0	0	0	0
0.2500° x Per mlm								0	-967	0	0	-9.13	0						
0.1940° x Hov mlm														0	-1950	0	0	-10.20	0
-0.1590° z Hov mlm														0	1863	0	0	13.10	0
Arithmetic Sum II		0	0	0	0	0	0	0	-967	0	0	-9.13	0	0	-4090	0	0	-5.47	0
III Drift During Powered Descent	R													0	0	0	0	0	0
	T													0	7	0	0	0	0
	H													0	0	0	0	0	0
	Ṙ													0	0	0	0	0	0
	Ṫ													0	67	0	0	0.20	0
	Ḣ													0	0	0	0	0	0
Increasing x mlm								0	7	0	0	0.20	0						
0.0886° x Hov mlm														0	-888	0	0	-4.67	0
-0.0313° z Hov mlm														0	367	0	0	2.60	0
Arithmetic Sum III		0	0	0	0	0	0	0	7	0	0	0.20	0	0	-447	0	0	-1.87	0
IV Drift During Powered Ascent																			
														0	-47	0	0	-0.27	0
Increasing x mlm																			
Arithmetic Sum IV		0	0	0	0	0	0	0	0	0	0	0	0	0	-47	0	0	-0.27	0
RSS - Total		0	0	0	0	0	0	0	967	0	0	9.13	0	0	4115	0	0	5.79	0
Arithmetic Sum-Total		0	0	0	0	0	0	0	-960	0	0	-8.93	0	0	-4584	0	0	-7.61	0

BDY at 1.00°/hour

UNCERTAINTY SOURCES		UNCERTAINTIES AT PERILUNE						UNCERTAINTIES AT HOVER						UNCERTAINTIES AT BURNOUT					
		(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$
I. Drift Between	R							-1145	0	-233	0.40	0	-0.07	-2450	0	-380	0.80	0	0
Alignment and	T							0	0	0	0	0	0	0	0	0	0	0	0
Injection	H							-653	0	3755	0	0	2.20	-800	0	5465	-0.27	0	3.26
	$\dot{R}$							-540	0	-107	-1.53	0	-0.33	-640	0	-93	-1.80	0	0.27
0.2500° y inj mlm	$\dot{T}$							0	0	0	0	0	0	0	0	0	0	0	0
	$\dot{H}$							-282	0	1555	-0.80	0	4.87	-360	0	2368	-1.00	0	7.40
Arithmetic Sum I		-1245	0	3460	-1.60	0	4.40	-2620	0	4970	-1.93	0	6.67	-4250	0	7360	-2.27	0	10.93
II. Drift Between	R													-740	0	-113	0.20	0	0
Realignment and	T													0	0	0	0	0	0
Perilune	H													606	0	-4190	0.20	0	-2.46
	$\dot{R}$													-832	0	-127	-2.34	0	0.40
	$\dot{T}$													0	0	0	0	0	0
	$\dot{H}$													1308	0	-8860	3.74	0	-27.60
0.2500° y per mlm								-794	0	-3820	-2.47	0	-25.00						
0.2500° y hov mlm														-756	0	3760	-7.33	0	23.46
Arithmetic Sum II		0	0	0	0	0	0	-794	0	-3820	-2.47	0	-25.00	-414	0	-9530	-5.53	0	-6.20
III. Drift During	R													-167	0	-27	0.07	0	0
Powered Descent	T													0	0	0	0	0	0
	H													180	0	-1250	0.07	0	-0.73
	$\dot{R}$													133	0	20	0.40	0	-0.07
	$\dot{T}$													0	0	0	0	0	0
	$\dot{H}$													267	0	-1810	0.80	0	-5.68
Increasing y mlm								-180	0	-1133	0.40	0	-5.13						
0.100° y hov mlm														-300	0	1507	-2.94	0	9.34
Arithmetic Sum III		0	0	0	0	0	0	-180	0	-1133	0.40	0	-5.13	113	0	-1560	-1.60	0	2.86
IV. Drift During																			
Powered Ascent																			
														-20	0	440	-0.53	0	4.07
Increasing y mlm																			
Arithmetic Sum IV		0	0	0	0	0	0	0	0	0	0	0	0	-20	0	440	-0.53	0	4.07
RSS (Total)		1245	0	3460	1.60	0	4.40	2744	0	6370	3.16	0	26.38	4272	0	12150	6.21	0	13.51
Arithmetic Sum (Total)		-1245	0	3460	-1.60	0	4.40	-3594	0	17	-4.00	0	-23.46	-4571	0	-3290	-9.93	0	11.66

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BDZ at 1.00° /hour

UNCERTAINTY SOURCES		UNCERTAINTIES AT PERILUNE (U)R	(U)T	(U)H	(U)Ṙ	(U)Ṫ	(U)Ḣ	UNCERTAINTIES AT HOVER (U)R	(U)T	(U)H	(U)Ṙ	(U)Ṫ	(U)Ḣ	UNCERTAINTIES AT BURNOUT (U)R	(U)T	(U)H	(U)Ṙ	(U)Ṫ	(U)Ḣ
I. Drift Between Alignment and Injection	R							0	0	0	0	0	0	0	0	0	0	0	0
	T							0	1634	0	0	-0.53	0	0	1547	0	0	-0.53	0
	H							0	0	0	0	0	0	0	0	0	0	0	0
	Ṙ							0	0	0	0	0	0	0	0	0	0	0	0
	Ṫ							0	0	0	0	0	0	0	-180	0	0	-0.54	0
0.2500° z inj mlm	Ḣ							0	0	0	0	0	0	0	0	0	0	0	0
Arithmetic Sum I		0	1728	0	0	0	0	0	1634	0	0	-0.53	0	0	1367	0	0	-1.07	0
II. Drift Between Realignment and Perilune	R													0	0	0	0	0	0
	T													0	3567	0	0	-1.20	0
	H													0	0	0	0	0	0
	Ṙ													0	0	0	0	0	0
	Ṫ													0	7800	0	0	21.88	0
	Ḣ													0	0	0	0	0	0
0.2500° z per mlm								0	3780	0	0	23.00	0						
0.1590° x hov mlm														0	-1592	0	0	-8.33	0
0.1940° z hov mlm														0	-2275	0	0	-15.95	0
Arithmetic Sum II		0	0	0	0	0	0	0	3780	0	0	23.00	0	0	7500	0	0	-3.60	0
III. Drift During Powered Descent	R													0	0	0	0	0	0
	T													0	1090	0	0	-0.33	0
	H													0	0	0	0	0	0
	Ṙ													0	0	0	0	0	0
	Ṫ													0	1730	0	0	4.87	0
	Ḣ													0	0	0	0	0	0
Increasing z mln																			
0.0313° x hov mlm								0	1153	0	0	5.13	0						
0.0886° z hov mlm														0	-308	0	0	-1.67	0
														0	-1040	0	0	-7.33	0
Arithmetic Sum III		0	0	0	0	0	0	0	1153	0	0	5.13	0	0	1472	0	0	-4.46	0
IV Drift During Power Ascent Increasing z mlm																			
														0	446	0	0	4.13	0
Arithmetic Sum IV		0	0	0	0	0	0	0	0	0	0	0	0	0	446	0	0	4.13	0
RSS (Total)		0	1728	0	0	0	0	0	4276	0	0	23.57	0	0	7777	0	0	7.15	0
Arithmetic Sum (Total)		0	1728	0	0	0	0	0	6567	0	0	27.60	0		10785	0	0	-5.00	0

F. Analysis VI GIMU - Crude Gyros - No Realignment

The system analyzed is identical to that utilized in Analysis III except that crude gyros replace the precision gyros. In addition, analyses for the following uncertainty sources are identical to Analysis III. They will not be repeated.

Align X
Align Y
Align Z
ACBX
ACBY
ACBZ
SFEX
SFEY
SFEZ

ANALYSIS VI - SUMMARY A
INSTRUMENT UNCERTAINTIES CONSTANT THROUGHOUT MISSION

UNCERTAINTY SOURCES	UNCERTAINTIES AT PERILUNE						UNCERTAINTIES AT HOVER						UNCERTAINTIES AT BURNOUT					
	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$
Orbital Navigation	1440	589	481	0.45	0.53	1.23	1478	576	611	0.50	0.55	1.34	1457	557	989	0.68	0.56	1.90
(MOD I - STD)																		
Inertial																		
Align x	0	0	0	0	0	0	0	-111	0	0	-1.05	0	0	-471	0	0	-0.65	0
Align y	-142	0	396	-0.19	0	0.51	-393	0	137	-0.51	0	-2.06	-540	0	-231	-0.90	0	0.57
Align z	0	198	0	0	0	0	0	620	0	0	2.58	0	0	1017	0	0	-0.53	0
BDX	0	0	0	0	0	0	0	-2893	0	0	-27.20	0	0	-12794	0	0	-18.54	0
BDY	-1245	0	3460	-1.60	0	4.40	-5180	0	-7643	-8.95	0	-73.46	-5400	0	-22360	-21.00	0	-0.74
BDZ	0	1728	0	0	0	0	0	14127	0	0	73.60	0	0	25785	0	0	-12.20	0
ACBX	-404	0	202	-0.19	0	0.38	-121	0	186	2.14	0	0.25	183	0	304	-0.15	0	-0.63
ACBY	0	-202	0	0	0	0	0	-576	0	0	-2.14	0	0	-1653	0	0	-4.06	0
ACBZ	-146	0	404	-0.19	0	0.52	-382	0	211	-0.38	0	-1.38	-525	0	40	-0.77	0	0.71
SFEX	-78	0	39	-0.04	0	0.07	-7	0	30	0.56	0	0.02	83	0	46	-0.07	0	-0.24
SFEY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SFEZ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RSS (Inertial)	1327	1751	3512	1.63	0	4.48	5210	14445	7649	9.24	78.54	73.50	5456	28854	22363	21.03	22.58	1.35
RSS (Total)	1958	1847	3545	1.69	0.53	4.65	5416	14456	7673	9.25	78.54	73.51	5647	28859	22385	21.04	22.59	2.33

ANALYSIS VI - SUMMARY B — INSTRUMENT UNCERTAINTIES VARY RANDOMLY FROM ONE PHASE TO THE NEXT

UNCERTAINTY SOURCES	UNCERTAINTIES AT PERILUNE						UNCERTAINTIES AT HOVER						UNCERTAINTIES AT BURNOUT					
	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$
Orbital Navigation																		
	1440	589	481	0.45	0.53	1.23	1478	576	611	0.50	0.55	1.34	1457	557	989	0.68	0.56	1.90
(MOD I - STD)																		
Inertial																		
Align x	0	0	0	0	0	0	0	111	0	0	1.05	0	0	471	0	0	0.65	0
Align y	142	0	396	0.19	0	0.51	393	0	137	0.51	0	2.06	540	0	231	0.90	0	0.57
Align z	0	198	0	0	0	0	0	620	0	0	2.58	0	0	1017	0	0	0.53	0
BDX	0	0	0	0	0	0	0	2900	0	0	27.40	0	0	12308	0	0	16.51	0
BDY	1245	0	3460	1.60	0	4.40	3544	0	12561	7.68	0	75.47	4430	0	29576	16.84	0	22.14
BDZ	0	1728	0	0	0	0	0	11515	0	0	69.19	0	0	22594	0	0	12.44	0
ACBX	404	0	202	0.19	0	0.38	629	0	278	2.26	0	0.53	1328	0	392	2.97	0	1.20
ACBY	0	202	0	0	0	0	0	430	0	0	2.20	0	0	1184	0	0	2.96	0
ACBZ	146	0	404	0.19	0	0.52	318	0	693	0.27	0	2.30	507	0	1516	0.81	0	3.54
SFEX	78	0	39	0.04	0	0.07	131	0	54	0.59	0	0.13	322	0	72	0.77	0	0.29
SFEY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SFEZ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RSS (Inertial)	1327	1751	3512	1.63	0	4.48	3637	11899	12584	8.05	74.50	75.54	4695	25780	29618	17.16	20.90	22.46
RSS (Total)	1958	1847	3545	1.69	0.53	4.65	3926	11913	12599	8.07	74.50	75.55	4916	25786	29634	17.17	20.91	22.54

BDX at 1.00°/hour

UNCERTAINTY SOURCES		UNCERTAINTIES AT PERILUNE (U)R	(U)T	(U)H	(U)Ṙ	(U)Ṫ	(U)Ḣ	UNCERTAINTIES AT HOVER (U)R	(U)T	(U)H	(U)Ṙ	(U)Ṫ	(U)Ḣ	UNCERTAINTIES AT BURNOUT (U)R	(U)T	(U)H	(U)Ṙ	(U)Ṫ	(U)Ḣ
I. Drift Between Alignment and Injection	R																		
	T																		
	H																		
	Ṙ																		
0.2500° x Inj mlm	Ṫ																		
	Ḣ																		
Arithmetic Sum I		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
II. Drift Between Alignment and Perilune	R													0	0	0	0	0	0
	T													0	-2750	0	0	1.00	0
	H													0	0	0	0	0	0
	Ṙ													0	0	0	0	0	0
	Ṫ													0	-9290	0	0	-26.00	0
	Ḣ													0	0	0	0	0	0
0.7500° x Per mlm								0	-2900	0	0	-27.40	0						
0.5820° x Hov mlm														0	-5840	0	0	-30.6	0
-0.4760° z Hov mlm														0	5580	0	0	39.2	0
Arithmetic Sum II		0	0	0	0	0	0	0	-2900	0	0	-27.40	0	0	-12300	0	0	-16.40	0
III. Drift During Powered Descent	R													0	0	0	0	0	0
	T													0	7	0	0	0	0
	H													0	0	0	0	0	0
	Ṙ													0	0	0	0	0	0
	Ṫ													0	67	0	0	0.20	0
	Ḣ													0	0	0	0	0	0
Increasing x mlm								0	7	0	0	0.20	0						
0.0886° x Hov mlm														0	-888	0	0	-4.67	0
-0.0313° z Hov mlm														0	367	0	0	2.60	0
Arithmetic Sum III		0	0	0	0	0	0	0	7	0	0	0.20	0	0	-447	0	0	-1.87	0
IV. Drift During Powered Ascent																			
														0	-47	0	0	-0.27	
Increasing x mlm																			
Arithmetic Sum IV		0	0	0	0	0	0	0	0	0	0	0	0	0	-47	0	0	-0.27	
RSS - Total		0	0	0	0	0	0	0	2900	0	0	27.40	0	0	12308	0	0	16.51	0
Arithmetic Sum - Total		0	0	0	0	0	0	0	-2893	0	0	-27.20	0	0	-12794	0	0	-18.54	0

BDY at 1.00°/hour

UNCERTAINTY SOURCES		UNCERTAINTIES AT PERILUNE						UNCERTAINTIES AT HOVER						UNCERTAINTIES AT BURNOUT					
		(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$	(U)R	(U)T	(U)H	(U)$\dot{R}$	(U)$\dot{T}$	(U)$\dot{H}$
I. Drift Between Alignment and Injection	R							-1149	0	-233	0.40	0	-0.07	-2450	0	-380	0.80	0	0
	T							0	0	0	0	0	0	0	0	0	0	0	0
	H							-653	0	3760	0	0	2.17	-800	0	5472	-0.27	0	3.26
	$\dot{R}$							-540	0	-107	-1.53	0	-0.33	-640	0	-93	-1.80	0	0.27
0.2500° y inj mlm	$\dot{T}$							0	0	0	0	0	0	0	0	0	0	0	0
	$\dot{H}$							-280	0	1550	-0.80	0	4.90	-360	0	2360	-1.00	0	7.40
Arithmetic Sum I		-1245	0	3460	-1.60	0	4.40	-2620	0	4970	-1.93	0	6.67	-4250	0	7360	-2.27	0	10.93
II. Drift Between Alignment and Perilune	R													-2223	0	-340	0.60	0	0
	T													0	0	0	0	0	0
	H													1820	0	-12580	0.60	0	-7.4
	$\dot{R}$													-2500	0	-380	-7.00	0	1.2
	$\dot{T}$													0	0	0	0	0	0
	$\dot{H}$													3920	0	-26600	11.20	0	-82.90
0.7500° y per mlm								-2380	0	-11480	-7.42	0	-75.00						
0.7500° y hov mlm														-2260	0	11300	-22.00	0	70.50
Arithmetic Sum II		0	0	0	0	0	0	-2380	0	-11480	-7.42	0	-75.00	-1243	0	-28600	-16.60	0	-18.60
III. Drift During Powered Descent	R													-166	0	-27	0.07	0	0
	T													0	0	0	0	0	0
	H													180	0	-1248	0.07	0	-0.73
	$\dot{R}$													133	0	20	0.40	0	-0.07
	$\dot{T}$													0	0	0	0	0	0
	$\dot{H}$													266	0	-1810	0.80	0	-5.64
Increasing y mlm								-180	0	-1133	0.40	0	-5.13						
0.100° y hov mlm														-300	0	1505	-2.94	0	9.30
Arithmetic Sum III		0	0	0	0	0	0	-180	0	-1133	0.40	0	-5.13	113	0	-1560	-1.60	0	2.86
IV. Drift During Powered Ascent																			
														-20	0	440	-0.53	0	4.07
Increasing y mlm																			
Arithmetic Sum IV		0	0	0	0	0	0	0	0	0	0	0	0	-20	0	440	-0.53	0	4.07
RSS (Total)		1245	0	3460	1.60	0	4.40	3544	0	12561	7.68	0	75.47	4430	0	29576	16.84	0	22.14
Arithmetic Sum (Total)		-1245	0	3460	-1.60	0	4.40	-5180	0	-7093	-8.95	0	-73.46	-5400	0	-22360	-21.00	0	-0.74

BDZ at 1.00°/hour

UNCERTAINTY SOURCES		UNCERTAINTIES AT PERILUNE						UNCERTAINTIES AT HOVER						UNCERTAINTIES AT BURNOUT					
		(U)R	(U)T	(U)H	(U)Ṙ	(U)Ṫ	(U)Ḣ	(U)R	(U)T	(U)H	(U)Ṙ	(U)Ṫ	(U)Ḣ	(U)R	(U)T	(U)H	(U)Ṙ	(U)Ṫ	(U)Ḣ
I. Drift Between Alignment and Injection	R							0	0	0	0	0	0	0	0	0	0	0	0
	T							0	1634	0	0	-0.53	0	0	1547	0	0	-0.53	0
	H							0	0	0	0	0	0	0	0	0	0	0	0
	Ṙ							0	0	0	0	0	0	0	0	0	0	0	0
0.2500° z inj mlm	Ṫ							0	0	0	0	0	0	0	-180	0	0	-0.54	0
	Ḣ							0	0	0	0	0	0	0	0	0	0	0	0
Arithmetic Sum I		0	1728	0	0	0	0	0	1634	0	0	-0.53	0	0	1367	0	0	-1.07	0
II. Drift Between Alignment and Perilune	R													0	0	0	0	0	0
	T													0	10700	0	0	-3.60	0
	H													0	0	0	0	0	0
	Ṙ													0	0	0	0	0	0
	Ṫ													0	23400	0	0	65.60	0
	Ḣ													0	0	0	0	0	0
0.7500° z per mlm								0	11340	0	0	69.00	0						
0.4760° x hov mlm														0	-4780	0	0	-25.00	0
0.5820° z hov mlm														0	-6820	0	0	-47.80	0
Arithmetic Sum II		0	0	0	0	0	0	0	11340	0	0	69.00	0	0	22500	0	0	-10.80	0
III. Drift During Powered Descent	R													0	0	0	0	0	0
	T													0	1090	0	0	-0.33	0
	H													0	0	0	0	0	0
	Ṙ													0	0	0	0	0	0
	Ṫ													0	1736	0	0	4.87	0
	Ḣ													0	0	0	0	0	0
Increasing z mlm								0	1153	0	0	5.13	0						
0.0313° x hov mlm														0	-314	0	0	-1.67	0
0.0886° z hov mlm														0	-1040	0	0	-7.33	0
Arithmetic Sum III		0	0	0	0	0	0	0	1153	0	0	5.13	0	0	1472	0	0	-4.46	0
IV. Drift During Powered Ascent																			
														0	446	0	0	4.13	0
Increasing z mlm																			
Arithmetic Sum IV		0	0	0	0	0	0	0	0	0	0	0	0	0	446	0	0	4.13	0
RSS (Total)		0	1728	0	0	0	0	0	11515	0	0	69.19	0	0	22594	0	0	12.44	0
Arithmetic Sum (Total)		0	1728	0	0	0	0	0	14127	0	0	73.60	0	0	25785	0	0	-12.20	0

G. Description of Descent & Ascent Trajectory Parameters

The descent was initiated at a perilune altitude of 50,000 feet with the thrust vector oriented to 4° below the local horizontal. A constant pitch rate of 0.1138 degrees/second was maintained for 344 seconds at which point the hover condition was defined. The thrust level was maintained at 10,000 pounds and the Isp at 305 seconds. The initial thrust/mass ratio was 0.4.

The ascent was assumed to initiate at the hover point (except for the normal ascent case, Table IV, when it initiated from the lunar surface.) The initial thrust vector angle was 158.91^{o} CW from the inertial horizontal (approx. 32° CCW from the local horizontal). A constant pitch rate of 0.1241 degrees/-second was maintained for 343 seconds to cut-off. The thrust was maintained at 4000 pounds and the Isp was again assumed to be 305 seconds. The initial thrust/mass was again 0.4.

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