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# APOLLO MISSION D (AS-503/CSM-103/LM-3) NAVIGATION ERROR ANALYSIS

Mathematical Physics Branch

MISSION PLANNING AND ANALYSIS DIVISION

MANNED SPACECRAFT CENTER

HOUSTON, TEXAS

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# PROJECT APOLLO

# APOLLO MISSION D (AS-503/CSM-103/LM-3) NAVIGATION ERROR ANALYSIS

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September 20, 1968

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## SYMBOLS

| | |
|---|---|
| ACN, ACS | Ascension Island |
| APS | ascent propulsion system |
| ANG, ANT | Antigua Island |
| BDA | Bermuda Island |
| CAL | Pt. Arguello, California |
| CDH | coelliptical maneuver |
| CNB | Canberra, Australia |
| CRO | Carnarvon, Australia |
| CSI | concentric sequence initiation |
| CSM | command service module |
| CYI | Canary Island |
| DPS | descent propulsion system |
| GBI, GBM | Grand Bahama Island |
| GDS | Goldstone, California |
| GWM | Guam Island |
| GYM | Guaymas, Mexico |
| HAW | Kauai, Hawaii |
| IMU | inertial measurement unit |
| LGC | Lunar Module Guidance Computer |
| LM | lunar module |
| MAD | Madrid, Spain |
| MCC | midcourse correction |
| MIL, MLA | Merritt Island |
| MSFN | Manned Space Flight Network |
| PAT | Patrick Air Force Base, Florida |

| | |
|---|---|
| PRE | Pretoria, South Africa |
| S-IVB | Saturn IVB launch vehicle |
| SPS | service propulsion system |
| TAN | Tananarive, Malagasy Republic |
| TEX | Corpus Christi, Texas |
| TPF | terminal phase finalization |
| TPI | terminal phase initiation |
| USB | unified S-band |
| WHS | White Sands, New Mexico |

# APOLLO MISSION D (AS-503/CSM-103/LM-3)

# NAVIGATION ERROR ANALYSIS

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## 1. SUMMARY

An error analysis of simulated observations by Manned Space Flight Network (MSFN) stations and the rendezvous radar has been performed in order to determine the expected accuracy of both the ground and the onboard orbit determination programs at specific times during the D mission. Relative uncertainties in the CSM/LM position and velocity vectors are presented in the interval from phasing to the end of the CSM/LM rendezvous. During the other phases of the mission, the MSFN is tracking either a docked configuration (CSM/LM or CSM/LM/S-IVB), the LM, or the CSM. Estimated errors are presented at burn initiation times during all phases of the D mission.

During the rendezvous sequence, the maximum three-sigma uncertainties (as defined in this study) in the estimated relative position and velocity magnitude occur at the nominal time of terminal phase finalization (TPF) and are 1.3 nautical miles and 8.6 feet per second, respectively. At initiation of the first service propulsion system (SPS) burn, the three-sigma uncertainties in the position and velocity vectors of the CSM are 16.88 nautical miles and 118.1 feet per second, respectively. These large uncertainties are due primarily to the venting of the Saturn IVB launch vehicle. The three-sigma uncertainties at initiation of the remaining SPS burns are considerably less than those uncertainties quoted for the first SPS burn. The three-sigma uncertainties of the spacecraft position and velocity at nominal time of reentry are 0.46 nautical mile and 5.19 feet per second, respectively. In addition, the three-sigma uncertainties in flight-path angle and speed are 0.09 degree and 1.8 feet per second.

## 2. INTRODUCTION

The navigation analysis was conducted for the reference trajectory described in Reference 1. The purpose of this analysis was to compute an estimate of the accuracy with which the D mission trajectories could be determined from the MSFN and onboard tracking data. This information is used to support a dispersion analysis for the D mission which computes an estimate of the fuel required and the expected trajectory variations. The analysis simulates the results which would be achieved using the data incorporation and filtering techniques which may be employed either onboard or on the ground.

The computer programs used for conducting the analysis are described below:

a) The TAPP IV program is the tracking program used to perform the following required steps of the analysis:

- Generate an integrated trajectory which matches the reference trajectory described in Reference 1

- Perform a complete tracking simulation of the mission including the generation of vehicle rise-set times and the generation of tracking information matrices when given the tracking stations, their associated data types and rates, and the trajectory

- Generate coordinate transformation and state transition matrices

b) FASTAP 1 processes the several TAPP IV tapes and forms a tape containing all information, state transition, and coordinate transformation matrices for the mission

c) MOFIT uses the information from the FASTAP 1 tape to compute the accuracies using a linear error analysis technique

For the analysis, it was assumed that the ground orbit determination scheme solved for three components of position and three components of velocity for the vehicle being updated. The LM onboard orbit determination program also solved for three components of position and three components of velocity and, in addition, the two rendezvous radar angle biases.

### 2.1 Error Model

The error sources considered in the generation of the ground tracking information matrices are the noise and bias on each data type, and the uncertainties in the drag parameter, the vent acceleration, the gravitational constant of the earth, and the station locations. The error sources for

onboard measurements include the noise and bias on each data type, platform misalignment, platform drift, and the uncertainties in the drag parameter, the gravitational constant of the earth, and the position and velocity of the CSM. Optimum data weighting was used in both the ground and onboard orbit determination schemes. The onboard weighting matrix was initialized at 3 days 22 hours 35 minutes, g. e. t. , which is the time of the first observation following the first ground state update. This weighting matrix was reinitialized at 4 days 1 hour 40 minutes, g. e. t. , the time of the first observation following the second ground state update. These times are also indicated in Figure 3. After each maneuver during the rendezvous sequence, the real-world covariance matrix for the Lunar Module Guidance Computer (LGC) estimate of the LM state is degraded to represent errors of execution. The inertial measurement unit (IMU) is aligned twice during the rendezvous sequence. The first alignment is at 3 days 22 hours 18 minutes, g. e. t. ; the second alignment is at 4 days 1 hour 14 minutes, g. e. t. Tables I and II list the one-sigma values of the systematic errors and the noise values for ground and onboard data, respectively.

## 2. 2 Tracking Data Descriptions

For this analysis, the selection of the stations used to simulate the tracking was limited by the criterion that two or more unified S-band (USB) stations cannot track the vehicle simultaneously. Therefore, at times when the vehicle was visible to several stations, the station which would view the vehicle for the longest time was designated to track. A minimum elevation angle of 5 degrees was assumed for all ground based stations.

The USB stations were used to track the CSM and docked configurations and received two-way doppler and angle (X/Y) measurements at the rate of one set of measurements per 6 seconds. The C-band stations were used to track the LM and received range, azimuth angle, and elevation angle at the rate of one set of measurements per 6 seconds. When available, three revolutions of tracking data were used to form a ground update solution. During the periods when onboard tracking was simulated, the LM rendezvous radar was used to provide range, range rate, shaft angle, and trunnion angle measurements at the rate of one set of measurements per minute.

## 2. 3 Mission Description and Tracking Schedule

The description of the mission is discussed in three phases:

Phase I: Insertion to the docked DPS burn

Phase II: Rendezvous sequence

Phase III: APS-1 burn to reentry

2.3.1 Phase I. - The simulated lift-off date for this analysis is 1 September 1968, 15 hours, Greenwich mean time. The docked configuration is inserted into orbit and coasts until 2 hours 43 minutes 12 seconds, g.e.t., at which time, the CSM and S-IVB/LM are separated; at 3 hours 33 minutes, g.e.t., LM withdrawal occurs. A ground update is assumed sent from Antigua (ANG) at 3 hours 32 minutes, g.e.t., to determine an estimate for the first SPS burn. The update for the second SPS burn is assumed sent from Canberra (CNB) at 21 hours 37 minutes, g.e.t.; for the third SPS burn from Guam (GWM) at 23 hours 10 minutes, g.e.t.; for the fourth SPS burn from Bermuda (BDA) at 1 day 2 hours 56 minutes, g.e.t.; for the docked DPS burn from CNB at 2 days 28 minutes, g.e.t. Figure 2 is a bar graph of the tracking schedule during Phase I.

2.3.2 Phase II. - The rendezvous sequence begins with a phasing maneuver at 3 days 22 hours 39 minutes 46 seconds, g.e.t. A ground update for the phasing maneuver is assumed sent from Carnarvon (CRO) at 3 days 22 hours 10 minutes, g.e.t., for both the CSM and LM. The LGC updates this estimate with rendezvous radar data between maneuvers of the rendezvous sequence. This estimate is replaced by a second ground update which is assumed sent from Hawaii (HAW) at 4 days 1 hour 40 minutes, g.e.t., for both the CSM and LM. For the analysis, no MSFN or rendezvous radar tracking was assumed between the midcourse correction (MCC) and TPF maneuvers.

The data from the rendezvous radar consists of range, range rate, shaft angle, and trunnion angle measurements which were taken at a rate of one set of measurements per minute. Table III presents the one-sigma values for the noise and bias on these data. Figure 3 is a bar graph of the tracking schedule during Phase II.

2.3.3 Phase III. - The remainder of the mission consists of an ascent propulsion system (APS) burn to depletion and three SPS burns ending with reentry. C-band tracking for the APS burn began approximately two revolutions prior to the maneuver time. The estimate for the LM was based on the LGC estimate following the rendezvous sequence. No update was assumed for the APS burn since the LM is unmanned and cannot accept an update. Tracking began three revolutions prior to the ground update for the fifth SPS burn. The update is assumed sent from CNB at 4 days 23 hours 48 minutes, g.e.t. There was no update assumed for the sixth SPS burn due to insufficient tracking prior to the maneuver. The ground update for the SPS deorbit burn is assumed sent from Canary Island (CYI) at 9 days 19 hours 41 minutes, g.e.t. There is no time for a tracking update following the deorbit maneuver prior to reentry; however, the ground stations continue to track the spacecraft. The uncertainties calculated prior to the SPS deorbit burn are propagated to the nominal time of reentry and are the reentry target conditions. The uncertainties presented as the reentry ground estimate are calculated from tracking information obtained after the SPS deorbit burn to the nominal time of reentry. Figure 4 is a bar graph of the tracking schedule during Phase III.

## 3. RESULTS

The values presented in Table IV for the uncertainties in the magnitudes of the estimated relative position and velocity vectors are defined as three-sigma uncertainties. These values were calculated by taking the square root of the sum of the variances of the three position components and the three velocity components, respectively, and multiplying the resulting values by three.

The three-sigma uncertainties in the three-position and the three-velocity components are presented in Table V. These values are associated with a Gaussian distribution with a zero mean. However, for the rendezvous phase a non-zero mean was assumed in order to account for the fact that the onboard orbit determination program does not use drag in trajectory computations.

The covariance matrices in Table VI are presented at burn initiation times. These matrices for the maneuvers during Phases I and III are referenced to a u, v, w (orbit plane) coordinate system relative to the CSM. During the rendezvous sequence, Phase II, the LM and CSM covariance matrices and means are referenced to their respective u, v, w (orbit plane) coordinate systems. The relative covariance matrices and relative means are expressed with respect to the CSM u, v, w frame. The LGC estimate of the LM is eight dimensional; the first two parameters are the shaft angle and trunnion angle biases, and the next six are the position and velocity components of the LM state.

## 4. CONCLUSIONS

As a result of the error analysis, the following conclusions were reached:

a) The largest relative uncertainties are in the in-plane components during the rendezvous sequence.

b) MSFN tracking reduces out-of-plane errors much faster than the rendezvous radar.

Therefore, the a priori weights must be large enough so that incorporating rendezvous radar data after a ground update does not corrupt the out-of-plane component, and at the same time, these weights should not be so large that they hinder the ability to correct relative errors in the line-of-sight direction.

c) The relatively large uncertainties for the first SPS burn result from the dynamic systematic error associated with the vent profile documented in Reference 4. A vent uncertainty factor of 0.1 (representing a 10 percent uncertainty in the nominal vent profile) was used in the analysis.

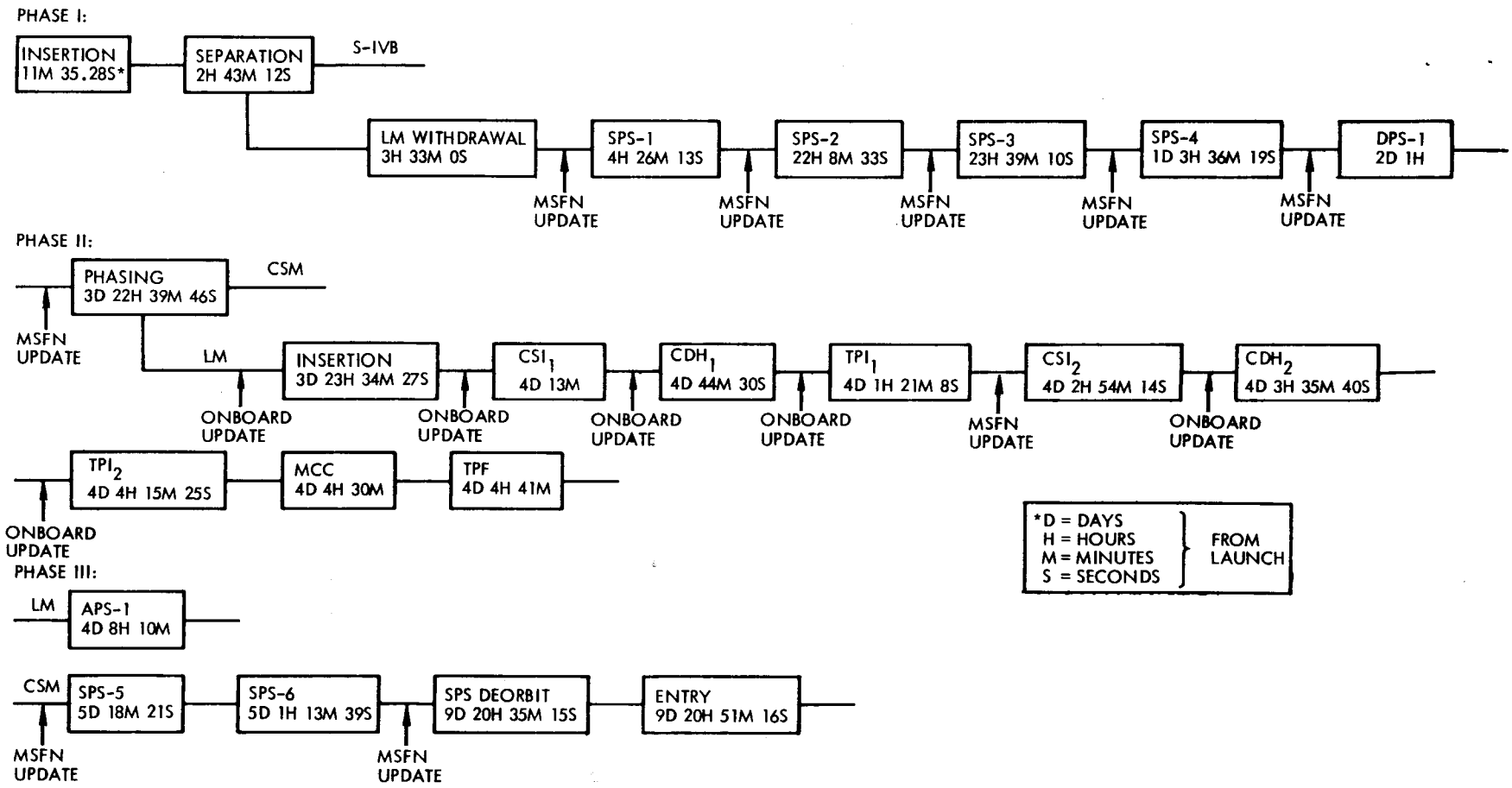



Figure 1. Event Schedule

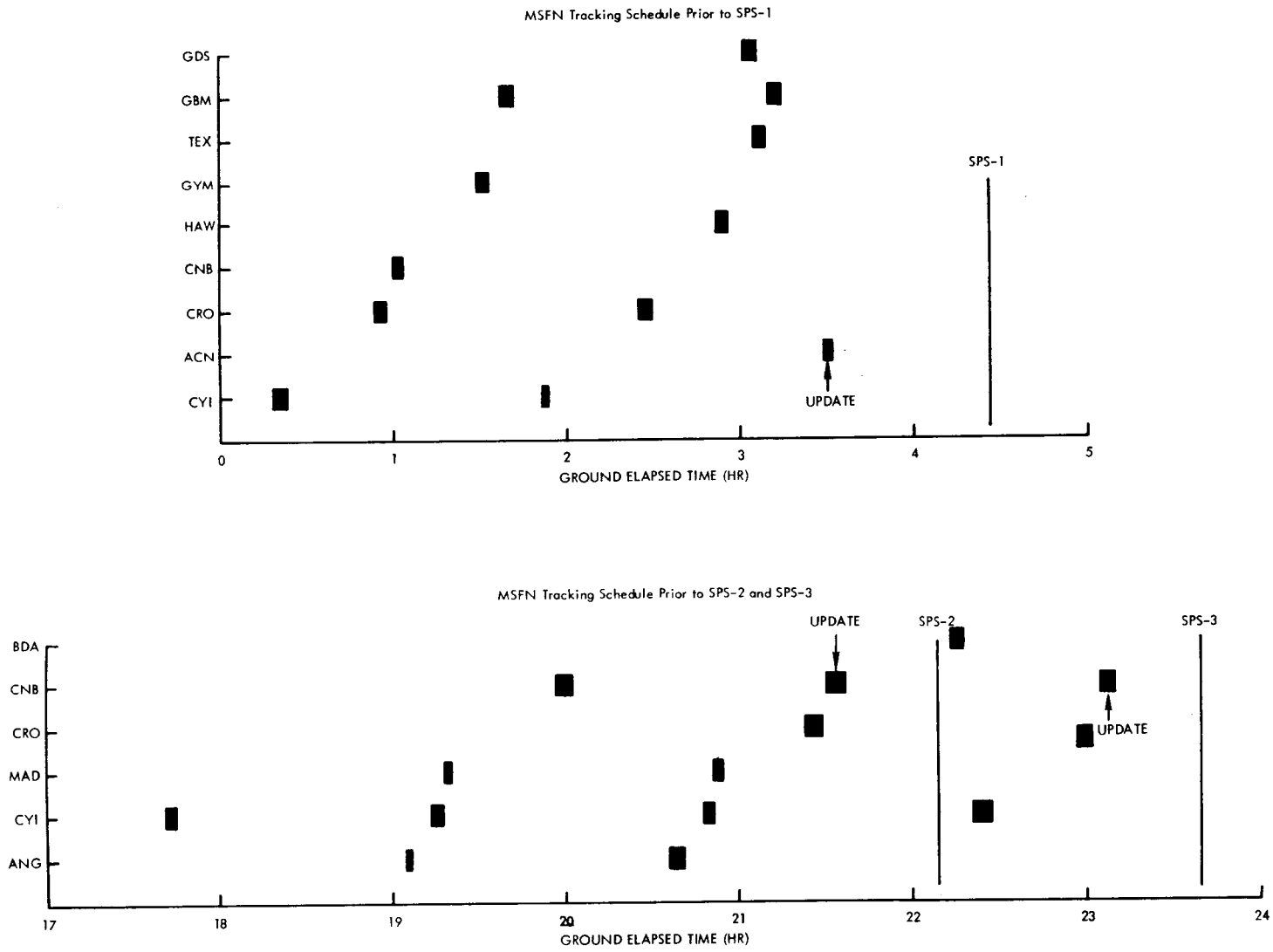
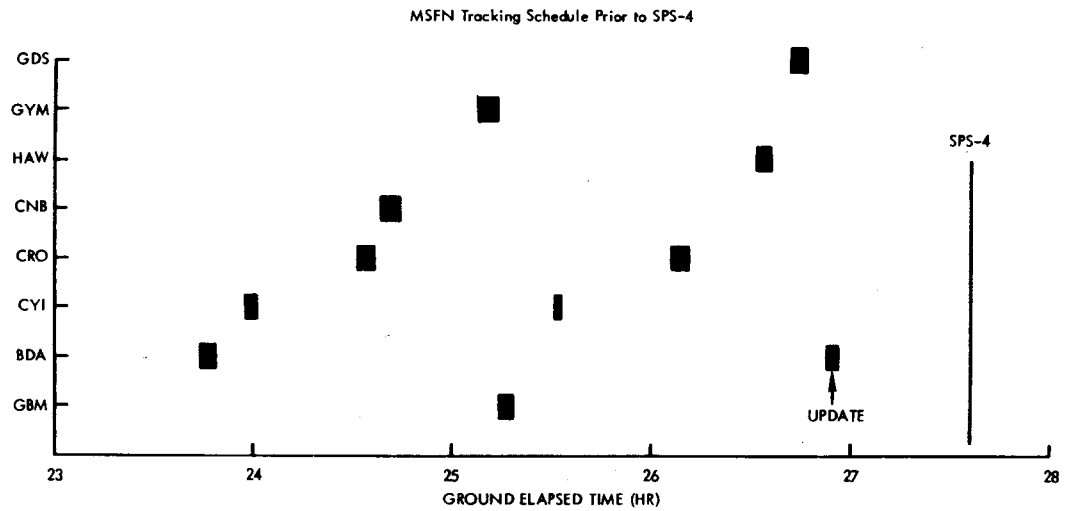



Figure 2. MSFN Tracking Schedule During Phase I



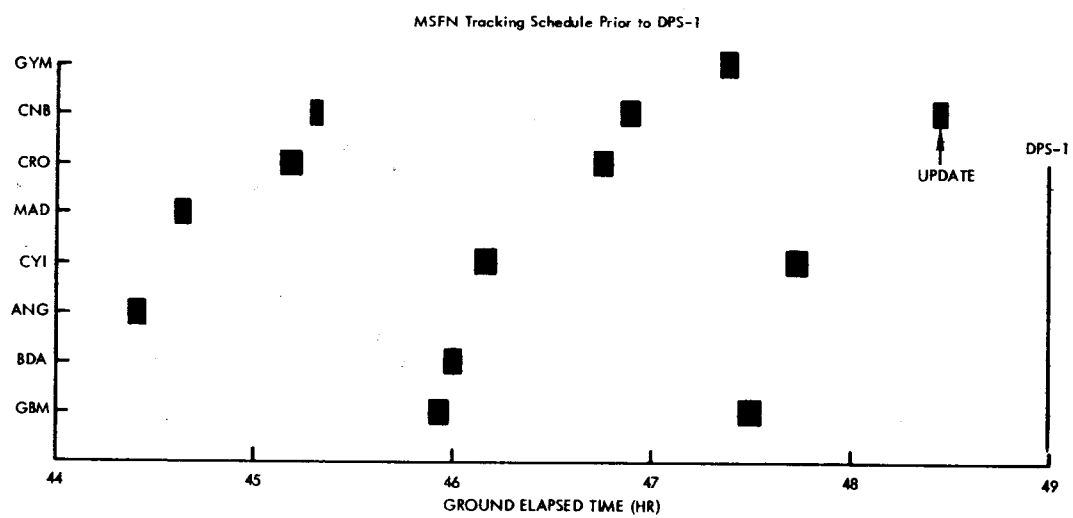
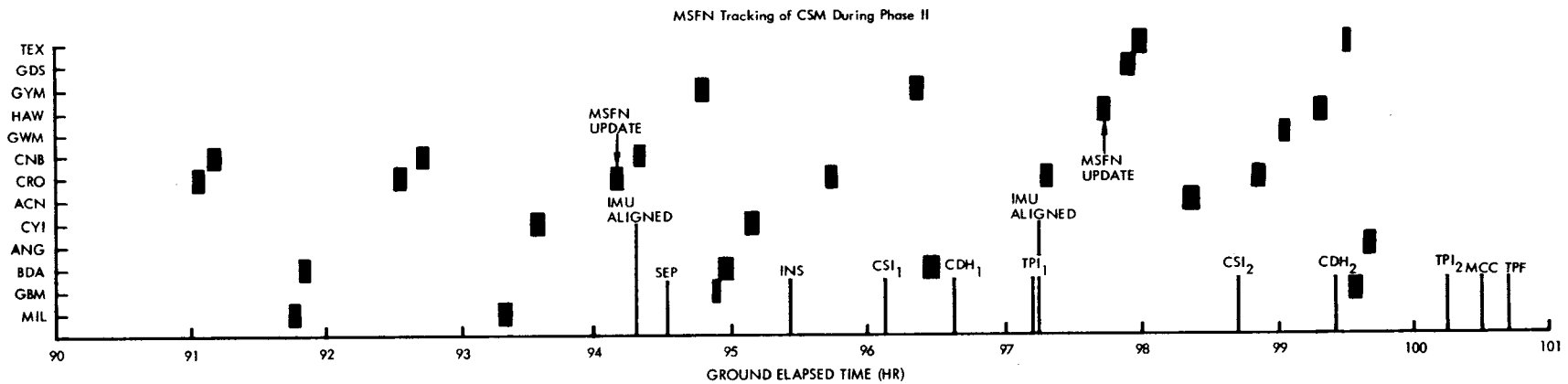




Figure 2. MSFN Tracking Schedule During Phase I (Continued)



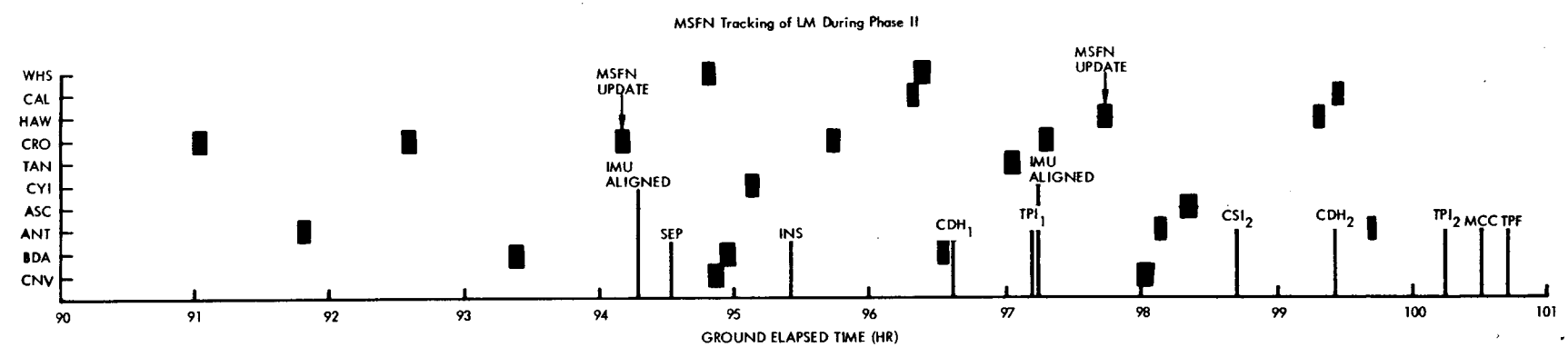
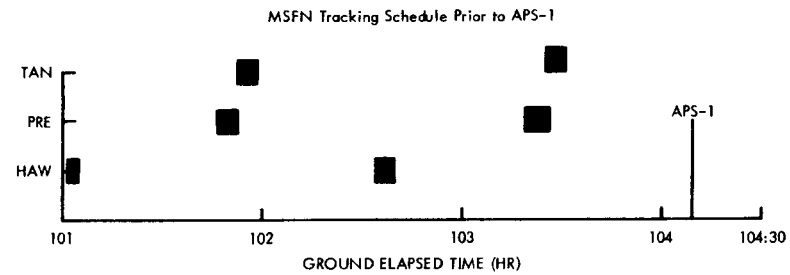




Figure 3. MSFN Tracking Schedule During Phase II



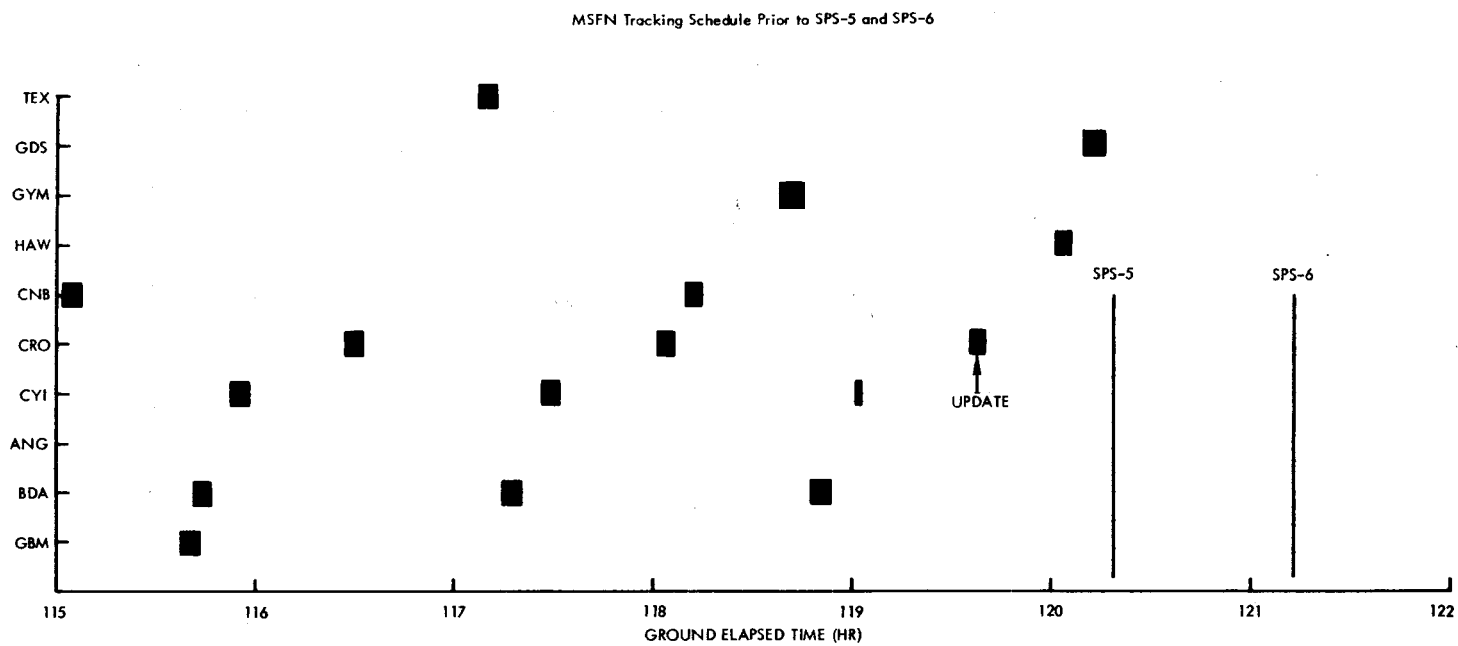




Figure 4. MSFN Tracking Schedule During Phase III

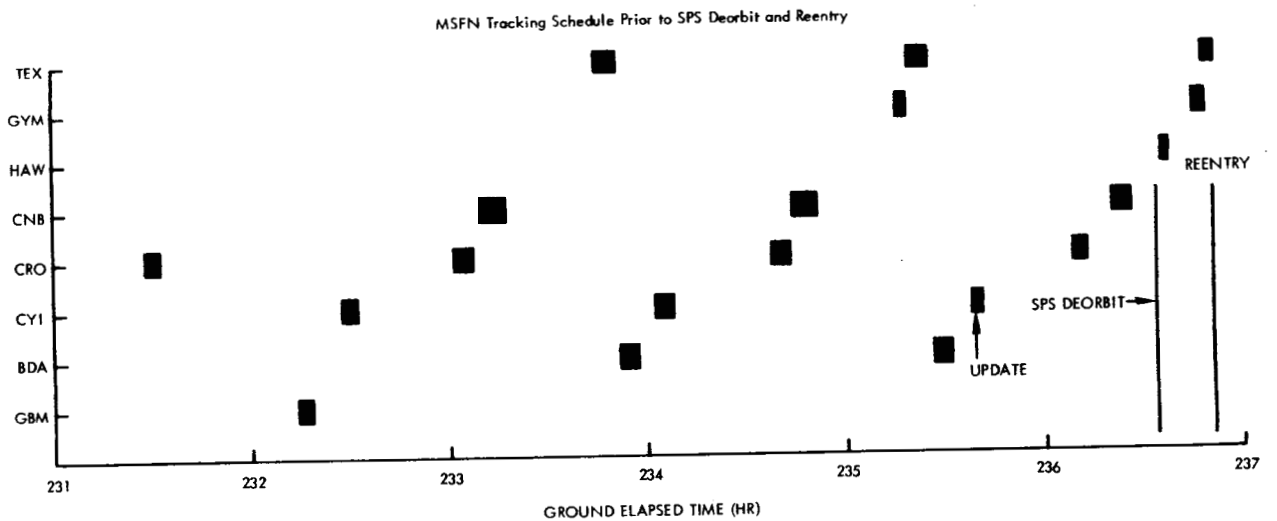



Figure 4. MSFN Tracking Schedule During Phase III (Continued)

Table I. One-Sigma Values of MSFN Error Sources

USBS Tracking Accuracy

| | Noise | Bias |
|---|---|---|
| X-Y Mount: | 0.8 mrad | 1.6 mrad |
| Two-way Doppler: | 0.02 fps | 0.03 fps |

C-band Tracking Accuracy

| Station | Type of C-band Radar | Azimuth Noise (mrad) | Azimuth Bias (mrad) | Elevation Noise (mrad) | Elevation Bias (mrad) | Range Noise (ft) | Range Bias (ft) |
|---|---|---|---|---|---|---|---|
| MLA | TPQ-18 | 0.15 | 0.3 | 0.15 | 0.3 | 20 | 40 |
| GBI | TPQ-18 | 0.15 | 0.3 | 0.15 | 0.3 | 20 | 40 |
| ANT | FPS-6 | 0.15 | 0.3 | 0.15 | 0.3 | 20 | 40 |
| BDA | FPQ-6 | 0.15 | 0.3 | 0.15 | 0.3 | 20 | 40 |
| CYI | MPS-26 | 1.0 | 2.0 | 1.0 | 2.0 | 60 | 120 |
| ASC | TPQ-18 | 0.15 | 0.3 | 0.15 | 0.3 | 20 | 40 |
| CRO | FPQ-6 | 0.15 | 0.3 | 0.15 | 0.3 | 20 | 40 |
| PAT | FPQ-6 | 0.15 | 0.3 | 0.15 | 0.3 | 20 | 40 |
| CAL | FPS-16 | 0.2 | 0.4 | 0.2 | 0.4 | 30 | 60 |
| PRE | MPS-25 | 0.2 | 0.4 | 0.2 | 0.4 | 30 | 60 |
| TAN | FPS-16 | 0.2 | 0.4 | 0.2 | 0.4 | 30 | 60 |
| WHS | FPS-16 | 0.2 | 0.4 | 0.2 | 0.4 | 30 | 60 |

Table I. One-Sigma Values of MSFN Error Sources (Continued)

| Station | Station Location Uncertainties | | |
|---|---|---|---|
| | Latitude (rad) | Longitude (rad) | Altitude (ft) |
| MLA,MIL* | $0.484813 \times 10^{-5}$ | $0.581776 \times 10^{-5}$ | 131.2 |
| GBI, GBM | $0.484813 \times 10^{-5}$ | $0.581776 \times 10^{-5}$ | 134.5 |
| ANT, ANG | $0.533295 \times 10^{-5}$ | $0.581776 \times 10^{-5}$ | 137.8 |
| BDA, BDA | $0.581776 \times 10^{-5}$ | $0.678739 \times 10^{-5}$ | 141.1 |
| CYI, CYI | $0.2230142 \times 10^{-4}$ | $0.2472549 \times 10^{-4}$ | 105.0 |
| ASC, ACN | $0.1648366 \times 10^{-4}$ | $0.16968479 \times 10^{-4}$ | 105.0 |
| CRO, CRO | $0.921145 \times 10^{-5}$ | $0.106659 \times 10^{-4}$ | 216.5 |
| PAT | $0.48481369 \times 10^{-5}$ | $0.58177643 \times 10^{-5}$ | 131.2 |
| PRE | $0.678739 \times 10^{-5}$ | $0.72722 \times 10^{-5}$ | 141.0 |
| TAN | $0.16483666 \times 10^{-4}$ | $0.16968479 \times 10^{-4}$ | 216.5 |
| WHS | $0.484813 \times 10^{-5}$ | $0.581776 \times 10^{-5}$ | 131.2 |
| GWM | $0.3102807 \times 10^{-4}$ | $0.319977 \times 10^{-4}$ | 105.0 |
| HAW | $0.678739 \times 10^{-5}$ | $0.775701 \times 10^{-5}$ | 141.1 |
| GYM | $0.48481369 \times 10^{-5}$ | $0.58177643 \times 10^{-5}$ | 134.5 |

Table I. One-Sigma Values of MSFN Error Sources (Continued)

| Station | Station Location Uncertainties | | |
|---|---|---|---|
| | Latitude (rad) | Longitude (rad) | Altitude (ft) |
| TEX | $0.484813 \times 10^{-5}$ | $0.533295 \times 10^{-5}$ | 131.2 |
| MAD | $0.48481369 \times 10^{-5}$ | $0.38785094 \times 10^{-5}$ | 141.0 |
| CNB | $0.921145 \times 10^{-5}$ | $0.106659 \times 10^{-4}$ | 216.5 |
| GDS | $0.53329506 \times 10^{-5}$ | $0.58177643 \times 10^{-5}$ | 131.2 |

*These C-band and USB stations are considered as co-located stations for purposes of this study.

K-factor or drag factor uncertainty: 0.10 (represents 10% of nominal drag)

K-factor or vent factor uncertainty: 2 pounds (Approximately 10% of nominal vent)

Uncertainty in gravitational constant of the earth: $1.06 \times 10^{11}$ (int ft)$^3$/sec$^2$

Table II. One-Sigma Values of Onboard Error Sources

| | |
|---|---|
| K-factor or drag factor uncertainty: | 0.25 (represents 25% of nominal drag) |
| Uncertainty in gravitational constant of the earth: | $1.06 \times 10^{11}$ (int ft)$^3$/sec$^2$ |
| IMU - misalignment<br>IMU - drift | These values are classified, but may be obtained from Reference 4. |
| Velocity Execution Errors | 0.2 ft/sec for each axis |

Table III. One-Sigma Values for Rendezvous Radar

| | Noise | Bias |
|---|---|---|
| Range | $\mathrm{Max}\left\{\frac{80}{3}, \frac{\rho}{300}\right\}$ft | 27 ft for $\rho \leq 50$ n mi<br>170 ft for $\rho > 50$ n mi |
| Range rate | $\mathrm{Max}\left\{\frac{1.3}{3}, \frac{1.3\dot{\rho}}{300}\right\}$fps | 0.3 fps |
| Trunnion angle | 1.0 mrad | * |
| Shaft angle | 1.0 mrad | * |

*These parameters were solved for in the differential correction.

Table IV. Three-Sigma Values for Uncertainties in Position and Velocity

| Event | Time of Event (hr:min:sec, g. e. t.) | Inertial CSM $3\sigma_p$ (n mi) | Inertial CSM $3\sigma_v$ (fps) | Inertial LM $3\sigma_p$ (n mi) | Inertial LM $3\sigma_v$ (fps) | Relative $3\sigma_p$ (n mi) | Relative $3\sigma_v$ (fps) |
|---|---|---|---|---|---|---|---|
| Separation | 02:43:12 | 4.51 | 29.86 | | | | |
| SPS-1 | 04:26:13 | 16.88 | 118.20 | | | | |
| SPS-2 | 22:08:33 | 0.16 | 2.45 | | | | |
| SPS-3 | 23:39:10 | 0.29 | 2.19 | | | | |
| SPS-4 | 27:36:19 | 0.24 | 2.20 | | | | |
| DPS-1 | 48:59:51 | 0.18 | 1.67 | | | | |
| Phasing | 94:39:46 | 0.30 | 1.06 | | | | |
| Insertion | 95:34:27 | 0.29 | 2.02 | 0.49 | 3.18 | 0.39 | 2.46 |
| $CSI_1$ | 96:13:00 | 0.33 | 1.44 | 0.65 | 4.30 | 0.56 | 4.06 |
| $CDH_1$ | 96:44:30 | 0.39 | 3.81 | 1.20 | 8.20 | 1.13 | 7.71 |
| $TPI_1$ | 97:21:08 | | | | | | |
| $CSI_2$ | 98:52:14 | 0.21 | 1.64 | 1.15 | 9.56 | 1.12 | 9.58 |
| $CDH_2$ | 99:35:40 | 0.31 | 2.30 | 0.58 | 4.00 | 0.49 | 3.47 |
| $TPI_2$ | 100:15:25 | 0.41 | 3.07 | 0.52 | 3.75 | 0.31 | 2.27 |
| MCC | 100:30:00 | 0.49 | 3.13 | 0.59 | 4.18 | 0.33 | 2.52 |
| TPF | 100:41:00 | 0.48 | 3.24 | 1.38 | 9.33 | 1.30 | 8.64 |
| APS-1 | 104:10:00 | 0.28 | 2.22 | | | | |

Table IV. Three-Sigma Values for Uncertainties in Position and Velocity (Continued)

| Event | Time of Event (hr:min:sec, g. e. t.) | Inertial CSM | | Inertial LM | | Relative | |
|---|---|---|---|---|---|---|---|
| | | $3\sigma_p$ (n mi) | $3\sigma_v$ (fps) | $3\sigma_p$ (n mi) | $3\sigma_v$ (fps) | $3\sigma_p$ (n mi) | $3\sigma_v$ (fps) |
| SPS-5 | 120:18:06 | 0.25 | 2.06 | | | | |
| SPS-6 | | 0.69 | 4.61 | | | | |
| Deorbit | 236:35:15 | 0.37 | 2.01 | | | | |
| Reentry-target Conditions | 236:51:16 | 0.52 | 4.68 | | | | |
| Reentry-ground Estimate | 236:51:16 | 0.46 | 5.19 | | | | |

Table V. Three-Sigma Values for Uncertainties in the Three Components of Position and Three Components of Velocity

| Event Vehicle | Separation CSM/LM | SPS-1 | SPS-2 | SPS-3 | SPS-4 | DPS-1 |
|---|---|---|---|---|---|---|
| u*(n mi) | 1.19 | 0.42 | 0.06 | 0.11 | 0.12 | 0.07 |
| v (n mi) | 4.34 | 16.86 | 0.13 | 0.26 | 0.16 | 0.16 |
| w (n mi) | 0.14 | 0.97 | 0.07 | 0.08 | 0.13 | 0.06 |
| $\dot{u}$ (fps) | 28.75 | 118.10 | 0.84 | 1.71 | 1.05 | 1.04 |
| $\dot{v}$ (fps) | 5.12 | 2.43 | 0.46 | 0.54 | 0.79 | 0.47 |
| $\dot{w}$ (fps) | 6.21 | 4.26 | 2.26 | 1.25 | 1.76 | 1.22 |

| Event Vehicle | Phasing CSM/LM | Insertion | | | $CSI_1$ | | |
|---|---|---|---|---|---|---|---|
| | | CSM | LM | Relative | CSM | LM | Relative |
| u (n mi) | 0.05 | 0.07 | 0.15 | 0.14 | 0.08 | 0.33 | 0.32 |
| v (n mi) | 0.14 | 0.22 | 0.38 | 0.32 | 0.19 | 0.45 | 0.41 |
| w (n mi) | 0.26 | 0.18 | 0.26 | 0.19 | 0.25 | 0.32 | 0.19 |
| $\dot{u}$ (fps) | 0.82 | 1.34 | 2.59 | 2.22 | 1.13 | 3.72 | 3.53 |
| $\dot{v}$ (fps) | 0.33 | 0.49 | 0.92 | 0.79 | 0.40 | 1.81 | 1.76 |
| $\dot{w}$ (fps) | 0.58 | 1.43 | 1.60 | 0.71 | 0.79 | 1.19 | 0.98 |

| Event Vehicle | $CDH_1$ | | | $CSI_2$ | | |
|---|---|---|---|---|---|---|
| | CSM | LM | Relative | CSM | LM | Relative |
| u (n mi) | 0.06 | 0.33 | 0.32 | 0.06 | 0.88 | 0.85 |
| v (n mi) | 0.30 | 1.10 | 1.06 | 0.19 | 0.73 | 0.71 |
| w (n mi) | 0.24 | 0.33 | 0.24 | 0.08 | 0.12 | 0.11 |

*The coordinate system is described on the format page of Table 6.

Table V. Three-Sigma Values for Uncertainties in the Three Components of Position and Three Components of Velocity (Continued)

| Event Vehicle | $CDH_1$ CSM | $CDH_1$ LM | $CDH_1$ Relative | $CSI_2$ CSM | $CSI_2$ LM | $CSI_2$ Relative |
|---|---|---|---|---|---|---|
| $\dot{u}$ (fps) | 2.26 | 7.55 | 7.17 | 1.30 | 8.91 | 8.9 |
| $\dot{v}$ (fps) | 0.29 | 2.01 | 1.67 | 0.38 | 3.32 | 3.44 |
| $\dot{w}$ (fps) | 0.98 | 2.49 | 2.28 | 0.92 | 0.90 | 1.04 |

| Event Vehicle | $CDH_2$ CSM | $CDH_2$ LM | $CDH_2$ Relative | $TPI_2$ CSM | $TPI_2$ LM | $TPI_2$ Relative | MCC CSM | MCC LM | MCC Relative |
|---|---|---|---|---|---|---|---|---|---|
| u (n mi) | 0.06 | 0.14 | 0.12 | 0.06 | 0.09 | 0.04 | 0.05 | 0.18 | 0.17 |
| v (n mi) | 0.29 | 0.55 | 0.47 | 0.39 | 0.49 | 0.29 | 0.46 | 0.54 | 0.22 |
| w (n mi) | 0.07 | 0.11 | 0.10 | 0.05 | 0.11 | 0.10 | 0.14 | 0.17 | 0.17 |
| $\dot{u}$ (fps) | 2.04 | 3.81 | 3.24 | 2.87 | 3.58 | 1.99 | 3.09 | 4.02 | 2.27 |
| $\dot{v}$ (fps) | 0.40 | 0.70 | 0.65 | 0.37 | 0.43 | 0.28 | 0.33 | 0.84 | 0.78 |
| $\dot{w}$ (fps) | 0.97 | 0.99 | 1.06 | 1.02 | 1.02 | 1.06 | 0.35 | 0.78 | 0.77 |

| Event Vehicle | TPF CSM | TPF LM | TPF Relative | APS-1 CSM | SPS-5 CSM | SPS-6 CSM | Deorbit CSM | Reentry Target Conditions CSM | Reentry Ground Estimate CSM |
|---|---|---|---|---|---|---|---|---|---|
| u (n mi) | 0.05 | 0.41 | 0.41 | 0.14 | 0.07 | 0.16 | 0.07 | 0.23 | 0.41 |
| v (n mi) | 0.47 | 1.31 | 1.22 | 0.20 | 0.22 | 0.65 | 0.29 | 0.40 | 0.09 |
| w (n mi) | 0.11 | 0.15 | 0.21 | 0.14 | 0.09 | 0.27 | 0.21 | 0.17 | 0.19 |
| $\dot{u}$ (fps) | 3.13 | 9.01 | 8.29 | 1.07 | 1.58 | 4.50 | 1.80 | 3.77 | 4.70 |

Table V. Three-Sigma Values for Uncertainties in the Three Components of Position and Three Components of Velocity (Continued)

| Event | TPF | | | APS-1 | SPS-5 | SPS-6 | Deorbit | Reentry Target Conditions | Reentry Ground Estimate |
|---|---|---|---|---|---|---|---|---|---|
| Vehicle | CSM | LM | Relative | CSM | CSM | CSM | CSM | CSM | CSM |
| $\dot{v}$ (fps) | 0.33 | 2.15 | 2.14 | 0.94 | 0.52 | 0.51 | 0.42 | 0.50 | 1.75 |
| $\dot{w}$ (fps) | 0.79 | 1.12 | 1.13 | 1.70 | 1.21 | 0.69 | 0.79 | 1.62 | 1.45 |

Table VI. Covariance Matrices (One-Sigma)

Format for Covariance Matrices

$$
\begin{array}{cccccc}
\sigma_{uu} & \sigma_{uv} & \sigma_{uw} & \sigma_{u\dot{u}} & \sigma_{u\dot{v}} & \sigma_{u\dot{w}} \\
 & \sigma_{vv} & \sigma_{vw} & \sigma_{v\dot{w}} & \sigma_{v\dot{v}} & \sigma_{v\dot{w}} \\
 & & \sigma_{ww} & \sigma_{w\dot{u}} & \sigma_{w\dot{v}} & \sigma_{w\dot{w}} \\
 & & & \sigma_{\dot{u}\dot{u}} & \sigma_{\dot{u}\dot{v}} & \sigma_{\dot{u}\dot{w}} \\
\text{symmetrical} & & & & \sigma_{\dot{v}\dot{v}} & \sigma_{\dot{v}\dot{w}} \\
 & & & & & \sigma_{\dot{w}\dot{w}}
\end{array}
$$

The coordinate system for the covariance matrices is described below:

u - in the direction of the geocentric radius vector of the vehicle at the time of the event

v - orthogonal to u, pointing downrange in the orbit plane

w - mutually orthogonal to u and v, completing the right-handed system.

The units for position and velocity are feet and feet per second, respectively. The relative covariances are in the coordinates of the CSM. The means presented for the CSM and LM-CSM are given in the coordinates centered at the CSM while the LM means are given in coordinates centered at the LM. The CSM and LM-CSM means are six-dimensional representing components of position and velocity given in units of feet and feet per second. The LM means are eight dimensional; the first two components refer to the angles and are in units of radians, and the remaining components refer to position and velocity and are in units of feet and feet per second.

The following pages (pages 27 to 50) present the covariance matrices and means.

Inertial Covariance of CSM/LM/S-IVB
Separation

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 5.8256143+06 | -2.1205154+07 | -4.7502979+04 | 2.3115326+04 | -4.1449109+03 | -4.9727114+03 |
| 2 | -2.1205154+07 | 7.7316824+07 | 1.6726036+05 | -8.4259660+04 | 1.5103991+04 | 1.8136601+04 |
| 3 | -4.7502979+04 | 1.6726036+05 | 7.4830342+04 | -1.8180077+02 | 3.5855170+01 | 5.8125384+01 |
| 4 | 2.3115326+04 | -8.4259660+04 | -1.8180077+02 | 9.1846413+01 | -1.6465022+01 | -1.9759491+01 |
| 5 | -4.1449109+03 | 1.5103991+04 | 3.5855170+01 | -1.6465022+01 | 2.9597155+00 | 3.5456193+00 |
| 6 | -4.9727114+03 | 1.8136601+04 | 5.8125384+01 | -1.9759491+01 | 3.5456193+00 | 4.2813195+00 |

Inertial Covariance of CSM/LM
SPS-1

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 7.1509615+05 | -2.8379973+07 | -1.6122562+06 | 3.2738142+04 | 6.5805635+02 | -1.1686124+03 |
| 2 | -2.8379973+07 | 1.1643848+09 | 6.6652958+07 | -1.3433160+06 | -2.7435783+04 | 4.7894973+04 |
| 3 | -1.6122562+06 | 6.6652958+07 | 3.8721518+06 | -7.6898950+04 | -1.5720253+03 | 2.7055319+03 |
| 4 | 3.2738142+04 | -1.3433160+06 | -7.6898950+04 | 1.5497493+03 | 3.1650865+01 | -5.5255572+01 |
| 5 | 6.5805635+02 | -2.7435783+04 | -1.5720253+03 | 3.1650865+01 | 6.5747704-01 | -1.1276242+00 |
| 6 | -1.1686124+03 | 4.7894973+04 | 2.7055319+03 | -5.5255572+01 | -1.1276242+00 | 2.0165361+00 |

Inertial Covariance of CSM/LM
SPS-2

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 1.3982098+04 | 1.5541866+04 | 1.7763788+03 | -1.5743143+01 | -1.1207398+01 | -4.8050188+01 |
| 2 | 1.5541866+04 | 7.1281304+04 | -7.0627692+03 | -7.3381586+01 | -2.2766490+01 | -1.2645185+02 |
| 3 | 1.7763788+03 | -7.0627692+03 | 2.2058753+04 | 7.7969288+00 | -3.3172436+00 | -7.8778822+00 |
| 4 | -1.5743143+01 | -7.3381586+01 | 7.7969288+00 | 7.8154583-02 | 2.3122585-02 | 1.2835341-01 |
| 5 | -1.1207398+01 | -2.2766490+01 | -3.3172436+00 | 2.3122585-02 | 2.3699299-02 | 6.4439156-02 |
| 6 | -4.8050188+01 | -1.2645185+02 | -7.8778822+00 | 1.2835341-01 | 6.4439156-02 | 5.6769059-01 |

Inertial Covariance of CSM/LM
SPS-3

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 5.3424931+04 | -7.5267875+04 | -4.2018490+03 | 9.1684965+01 | -3.4008475+01 | 4.6029070+01 |
| 2 | -7.5267875+04 | 2.6990118+05 | -8.0110800+03 | -2.9309545+02 | 2.6643445+01 | -1.0183570+02 |
| 3 | -4.2018490+03 | -8.0110800+03 | 2.7542687+04 | 7.8070693+00 | 1.3186782+01 | -4.3405727+01 |
| 4 | 9.1684965+01 | -2.9309545+02 | 7.8070693+00 | 3.2596651-01 | -3.7202461-02 | 1.0785554-01 |
| 5 | -3.4008475+01 | 2.6643445+01 | 1.3186782+01 | -3.7202461-02 | 3.1855273-02 | -4.6784332-02 |
| 6 | 4.6029070+01 | -1.0183570+02 | -4.3405727+01 | 1.0785554-01 | -4.6784332-02 | 1.7480662-01 |

Inertial Covariance of CSM/LM
SPS-4

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 5.4303095+04 | -2.6087867+04 | 4.1135675+04 | 2.1294262+01 | -5.4392294+01 | -2.7741425+01 |
| 2 | -2.6087867+04 | 1.0548140+05 | -2.2538951+04 | -1.1210323+02 | 2.6523632+01 | 4.8893294+00 |
| 3 | 4.1135675+04 | -2.2538951+04 | 7.1407011+04 | 1.7221051+01 | -4.9530355+01 | 2.9013046+01 |
| 4 | 2.1294262+01 | -1.1210323+02 | 1.7221051+01 | 1.2365038-01 | -2.1040764-02 | -6.8975232-03 |
| 5 | -5.4392294+01 | 2.6523632+01 | -4.9530355+01 | -2.1040764-02 | 6.9495364-02 | 3.7801401-02 |
| 6 | -2.7741425+01 | 4.8893294+00 | 2.9013046+01 | -6.8975232-03 | 3.7801401-02 | 3.4310383-01 |

Inertial Covariance of CSM/LM
DPS-1

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 1.8600733+04 | -2.4632027+04 | -2.6969409+03 | 2.5483549+01 | -1.4479724+01 | -5.0019011+00 |
| 2 | -2.4632027+04 | 1.0268358+05 | 4.2765961+03 | -1.0974014+02 | 2.6762509+01 | -2.4712119+00 |
| 3 | -2.6969409+03 | 4.2765961+03 | 1.3204484+04 | -4.3908576+00 | 4.3963749+00 | 2.6839799+01 |
| 4 | 2.5483549+01 | -1.0974014+02 | -4.3908576+00 | 1.1952302-01 | -2.7580735-02 | 2.0874559-03 |
| 5 | -1.4479724+01 | 2.6762509+01 | 4.3963749+00 | -2.7580735-02 | 2.4808235-02 | 6.0078955-03 |
| 6 | -5.0019011+00 | -2.4712119+00 | 2.6839799+01 | 2.0874559-03 | 6.0078955-03 | 1.6597420-01 |

Inertial Covariance of CSM/LM
Initial Phasing

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 1.0402534+04 | 7.0072482+03 | 2.6488077+04 | 2.7195916+00 | -4.3180494+00 | -1.5672522-01 |
| 2 | 7.0072482+03 | 8.3529103+04 | 4.3385110+04 | -6.8286699+01 | -5.0559741+00 | -1.8796173+00 |
| 3 | 2.6488077+04 | 4.3385110+04 | 2.7754715+05 | 7.8878102-01 | -2.3735754+01 | -4.9462958+01 |
| 4 | 2.7195916+00 | -6.8286699+01 | 7.8878102-01 | 7.4680278-02 | -5.1249595-03 | 5.1628691-03 |
| 5 | -4.3180494+00 | -5.0559741+00 | -2.3735754+01 | -5.1249595-03 | 1.2385282-02 | -9.3979185-04 |
| 6 | -1.5672522-01 | -1.8796173+00 | -4.9462958+01 | 5.1628691-03 | -9.3979185-04 | 3.7308828-02 |

Inertial Covariance of CSM
Prior to Insertion

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 1.8025080+04 | 4.0311547+04 | 2.8284638+04 | -3.7314205+01 | -1.4502676+01 | -2.2781656+01 |
| 2 | 4.0311547+04 | 1.9515213+05 | 9.8447736+04 | -1.9369101+02 | -5.3184997+01 | -8.0845511+01 |
| 3 | 2.8284638+04 | 9.8447738+04 | 1.3958353+05 | -9.4715320+01 | -3.8668635+01 | -1.5482461+02 |
| 4 | -3.7314205+01 | -1.9369101+02 | -9.4715317+01 | 1.9825524-01 | 5.0262399-02 | 7.8165126-02 |
| 5 | -1.4502673+01 | -5.3184997+01 | -3.8668635+01 | 5.0262399-02 | 2.6174945-02 | 3.3526520-02 |
| 6 | -2.2781655+01 | -8.0845512+01 | -1.5482462+02 | 7.8165127-02 | 3.3526520-02 | 2.2823296-01 |

## Inertial Covariance of LM Insertion

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 9.9964231-05 | 1.4292600-12 | -1.9812594-03 | 1.9578291-03 | 2.9645249-01 | -3.7383194-06 |
| 2 | 1.4292600-12 | 9.9978530-05 | -5.0206461-03 | 8.1079112-03 | 1.5523798-04 | -1.0142363-05 |
| 3 | -1.9812594-03 | -5.0206461-03 | 9.5207830+04 | -1.2983901+05 | 2.7534015+04 | 1.6271167+02 |
| 4 | 1.9578291-03 | 8.1079112-03 | -1.2983901+05 | 6.0369800+05 | 9.9517318+04 | -6.6510949+02 |
| 5 | 2.9645249-01 | 1.5523798-04 | 2.7534015+04 | 9.9517318+04 | 2.8303608+05 | -9.6500551+01 |
| 6 | -3.7383194-06 | -1.0142363-05 | 1.6271166+02 | -6.6510949+02 | -9.6500549+01 | 7.4486095-01 |
| 7 | 1.4742296-06 | 5.3202025-06 | -8.7204682+01 | 1.0551348+02 | -3.8301223+01 | -1.3646219-01 |
| 8 | 2.8123339-05 | 2.5467738-07 | -2.2413061+01 | -8.1282502+01 | -1.8528394+02 | 7.8740561-02 |

| | 7 | 8 |
|---|---|---|
| 1 | 1.4742296-06 | 2.8123339-05 |
| 2 | 5.3202025-06 | 2.5467738-07 |
| 3 | -8.7204681+01 | -2.2413062+01 |
| 4 | 1.0551349+02 | -8.1282500+01 |
| 5 | -3.8301223+01 | -1.8528394+02 |
| 6 | -1.3646219-01 | 7.8740558-02 |
| 7 | 9.5022221-02 | 3.3277105-02 |
| 8 | 3.3277105-02 | 2.8446519-01 |

## Covariance of Relative State Insertion

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 7.7251595+04 | -1.7096785+05 | -1.0291567+03 | 2.0107327+02 | -7.2599939+01 | 5.1668787-01 |
| 2 | -1.7096785+05 | 4.1000487+05 | 1.1139922+03 | -4.7359513+02 | 1.5951104+02 | -8.8512611-01 |
| 3 | -1.0291567+03 | 1.1139922+03 | 1.4265603+05 | -1.9902725+00 | 7.7863121-01 | -3.0064636+01 |
| 4 | 2.0107327+02 | -4.7359513+02 | -1.9902706+00 | 5.4977339-01 | -1.8766443-01 | 1.1669807-03 |
| 5 | -7.2599940+01 | 1.5951104+02 | 7.7863216-01 | -1.8766443-01 | 6.8591146-02 | -4.5316666-04 |
| 6 | 5.1668835-01 | -8.8512802-01 | -3.0064639+01 | 1.1669826-03 | -4.5316666-04 | 5.6662429-02 |

Means Associated with CSM State, LM State, and LM/CSM Relative State Estimates
Insertion

CSM

| | 1 |
|---|---|
| 1 | 1.5954158+02 |
| 2 | -2.6566371+02 |
| 3 | -5.3830545-01 |
| 4 | 3.8561196-01 |
| 5 | -1.0863945-01 |
| 6 | -1.4105407-03 |

LM

| | 1 |
|---|---|
| 1 | 7.9266568-11 |
| 2 | -6.7613726-09 |
| 3 | 1.4469818+02 |
| 4 | -2.5084226+02 |
| 5 | -5.3833874-01 |
| 6 | 3.5773638-01 |
| 7 | -9.6995913-02 |
| 8 | -1.2645817-03 |

LM-CSM

| | 1 |
|---|---|
| 1 | 1.6325431+01 |
| 2 | -1.3925793+01 |
| 3 | -1.5745237-03 |
| 4 | 2.8476633-02 |
| 5 | -9.4870534-03 |
| 6 | -1.4735565-04 |

Inertial Covariance of CSM
$CSI_1$

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 2.6656282+04 | -4.0986578+04 | -2.6330842+04 | 4.0523987+01 | -1.3955889+01 | 9.5864379-01 |
| 2 | -4.0986586+04 | 1.5400951+05 | 8.5228868+04 | -1.4727062+02 | 2.4041307+01 | -8.4717772+00 |
| 3 | -2.6330843+04 | 8.5228869+04 | 2.5407092+05 | -7.6726462+01 | 1.5959482+01 | -9.9142220+01 |
| 4 | 4.0523987+01 | -1.4727060+02 | -7.6726459+01 | 1.4266804-01 | -2.3924395-02 | 6.0259821-03 |
| 5 | -1.3955889+01 | 2.4041301+01 | 1.5959481+01 | -2.3924403-02 | 1.7910114-02 | -9.9564512-04 |
| 6 | 9.5864375-01 | -8.4717774+00 | -9.9142219+01 | 6.0259824-03 | -9.9564512-04 | 6.9635771-02 |

Inertial Covariance of LM
$CSI_1$

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 9.9933040-05 | -1.8964747-12 | -2.0798173-03 | 3.1925874-03 | -2.3334610-01 | -4.7047455-06 |
| 2 | -1.8964747-12 | 9.9961204-05 | 1.1946333-03 | -9.9433321-04 | 4.7315904-04 | 1.8852316-06 |
| 3 | -2.0798173-03 | 1.1946333-03 | 4.4102725+05 | -5.4150472+05 | -9.5992894+04 | 7.8434746+02 |
| 4 | 3.1925874-03 | -9.9433321-04 | -5.4150473+05 | 8.4595205+05 | 1.8330516+05 | -1.1111022+03 |
| 5 | -2.3334610-01 | 4.7315904-04 | -9.5992895+04 | 1.8330516+05 | 4.2539917+05 | -2.0887240+02 |
| 6 | -4.7047455-06 | 1.8852316-06 | 7.8434746+02 | -1.1111021+03 | -2.0887239+02 | 1.5366519+00 |
| 7 | 1.5193135-06 | -1.1457328-06 | -3.9028089+02 | 4.8315208+02 | 8.2411120+01 | -6.9771998-01 |
| 8 | -1.3532054-04 | -2.9305062-07 | -4.0219055+01 | 5.4546236+01 | -4.2503739+01 | -7.4876171-02 |

| | 7 | 8 |
|---|---|---|
| 1 | 1.5193135-06 | -1.3532054-04 |
| 2 | -1.1457328-06 | -2.9305062-07 |
| 3 | -3.9028090+02 | -4.0219055+01 |
| 4 | 4.8315209+02 | 5.4546236+01 |
| 5 | 8.2411120+01 | -4.2503737+01 |
| 6 | -6.9771998-01 | -7.4876173-02 |
| 7 | 3.6225756-01 | 3.7209636-02 |
| 8 | 3.7209636-02 | 1.5773544-01 |

Covariance of Relative State
$CSI_1$

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 4.1608687+05 | -4.9939492+05 | -7.1224897+04 | 7.4304379+02 | -3.7727451+02 | -3.8763823+01 |
| 2 | -4.9939493+05 | 6.9087404+05 | 9.6678998+04 | -9.5865165+02 | 4.6001329+02 | 5.5654507+01 |
| 3 | -7.1224897+04 | 9.6679003+04 | 1.6243257+05 | -1.3155524+02 | 6.7514921+01 | 3.6943334+01 |
| 4 | 7.4304379+02 | -9.5865162+02 | -1.3155524+02 | 1.3842355+00 | -6.7519216-01 | -7.4182054-02 |
| 5 | -3.7727451+02 | 4.6001329+02 | 6.7514921+01 | -6.7519215-01 | 3.4476196-01 | 3.6612874-02 |
| 6 | -3.8763823+01 | 5.5654507+01 | 3.6943331+01 | -7.4182053-02 | 3.6612874-02 | 1.0596785-01 |

Means Associated with CSM State, LM State, LM/CSM Realtive State Estimates
$CSI_1$

CSM

| | 1 |
|---|---|
| 1 | 2.0078701+01 |
| 2 | -6.8093827+02 |
| 3 | 3.6924256-01 |
| 4 | 7.7379511-01 |
| 5 | 4.3809395-02 |
| 6 | 9.3900478-04 |

LM

| | 1 |
|---|---|
| 1 | -1.7477514-08 |
| 2 | -2.7521633-08 |
| 3 | 6.3084597+01 |
| 4 | -6.6262458+02 |
| 5 | 5.6247841+00 |
| 6 | 8.5030780-01 |
| 7 | 5.2729686-02 |
| 8 | 4.1643039-03 |

LM-CSM

| | 1 |
|---|---|
| 1 | -5.5101628+01 |
| 2 | -1.8562897+01 |
| 3 | -5.2585364+00 |
| 4 | -7.5856693-02 |
| 5 | -2.2668791-02 |
| 6 | -3.2405881-03 |

Inertial Covariance of CSM
$CDH_1$

| | | | | | | |
|---|---|---|---|---|---|---|
| 1 | 1.3058828+04 | -4.5831691+04 | 1.3180600+04 | 5.7368600+01 | -2.3533478+00 | 1.5075189+01 |
| 2 | -4.5831754+04 | 3.8107579+05 | -8.8742068+04 | -4.6049486+02 | 8.6283474+00 | -1.0353284+02 |
| 3 | 1.3180600+04 | -8.8742073+04 | 2.2786219+05 | 1.1912083+02 | -6.1135932+00 | 1.2741918+02 |
| 4 | 5.7368654+01 | -4.6049483+02 | 1.1912083+02 | 5.6539017-01 | -1.1332272-02 | 1.3516331-01 |
| 5 | -2.3533535+00 | 8.6282902+00 | -6.1135934+00 | -1.1332225-02 | 9.4193425-03 | -5.3774070-03 |
| 6 | 1.5075190+01 | -1.0353285+02 | 1.2741918+02 | 1.3516331-01 | -5.3774075-03 | 1.0596021-01 |

Inertial Covariance of LM
$CDH_1$

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 9.9916322-05 | 2.7823479-12 | -1.4256214-03 | 5.1817197-03 | 8.5804076-02 | -6.7047142-06 |
| 2 | 2.7823479-12 | 9.9951650-05 | 1.1303772-04 | -1.8916056-03 | -1.8011990-04 | 1.7540531-06 |
| 3 | -1.4256214-03 | 1.1303772-04 | 4.4885214+05 | -9.3041010+05 | 7.6007608+04 | 1.2074453+03 |
| 4 | 5.1817197-03 | -1.8916056-03 | -9.3041011+05 | 4.9967777+06 | -7.5838460+05 | -5.5585176+03 |
| 5 | 8.5804076-02 | -1.8011990-04 | 7.6007604+04 | -7.5838460+05 | 4.5172058+05 | 8.1352462+02 |
| 6 | -6.7047142-06 | 1.7540531-06 | 1.2074453+03 | -5.5585176+03 | 8.1352463+02 | 6.3325150+00 |
| 7 | 6.0956142-07 | -9.3274835-08 | -3.6704539+02 | 6.7093511+02 | -4.4252142+01 | -8.8791490-01 |
| 8 | 3.0397728-04 | 2.2632530-07 | 1.1762727+02 | -1.2479059+03 | 3.8201012+02 | 1.3268494+00 |

| | 7 | 8 |
|---|---|---|
| 1 | 6.0956142-07 | 3.0397728-04 |
| 2 | -9.3274835-08 | 2.2632530-07 |
| 3 | -3.6704538+02 | 1.1762727+02 |
| 4 | 6.7093511+02 | -1.2479059+03 |
| 5 | -4.4252140+01 | 3.8201012+02 |
| 6 | -8.8791489-01 | 1.3268494+00 |
| 7 | 4.4783791-01 | -1.4286273-01 |
| 8 | -1.4286273-01 | 6.9258390-01 |

Covariance of Relative State
$CDH_1$

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 4.3269210+05 | -8.7417293+05 | 6.3344929+04 | 1.1342100+03 | -3.6210553+02 | 1.0166943+02 |
| 2 | -8.7417293+05 | 4.5920657+06 | -6.7523970+05 | -5.0618076+03 | 6.5399231+02 | -1.1425572+03 |
| 3 | 6.3344926+04 | -6.7523970+05 | 2.3286033+05 | 7.0018298+02 | -3.8520220+01 | 2.4926487+02 |
| 4 | 1.1342100+03 | -5.0618076+03 | 7.0018299+02 | 5.7135980+00 | -8.6361499-01 | 1.1873863+00 |
| 5 | -3.6210553+02 | 6.5399231+02 | -3.8520222+01 | -8.6361500-01 | 3.0989552-01 | -5.8013892-02 |
| 6 | 1.0166943+02 | -1.1425572+03 | 2.4926487+02 | 1.1873863+00 | -5.8013891-02 | 5.7689430-01 |

Means Associated with CSM State, LM State, LM/CSM Relative State Estimates
$CDH_1$

CSM

| | 1 |
|---|---|
| 1 | 2.1644958+02 |
| 2 | -8.8514152+02 |
| 3 | 9.4772950-03 |
| 4 | 1.2096845+00 |
| 5 | -1.3988984-01 |
| 6 | -7.2846405-05 |

LM

| | 1 |
|---|---|
| 1 | 1.6058133-07 |
| 2 | -1.2516566-07 |
| 3 | 4.5266384+02 |
| 4 | -1.3469130+03 |
| 5 | 3.1756139+01 |
| 6 | 1.7760946+00 |
| 7 | -3.5281397-01 |
| 8 | 4.5322422-02 |

LM-CSM

| | 1 |
|---|---|
| 1 | -2.5026838+02 |
| 2 | 4.5845252+02 |
| 3 | -3.1766460+01 |
| 4 | -5.6877886-01 |
| 5 | 1.9377168-01 |
| 6 | -4.5375882-02 |

Inertial Covariance of CSM
$CSI_2$

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 1.5903871+04 | -1.1753393+04 | 8.6810791+03 | 1.5988117+01 | -9.0323486+00 | 1.9996534+01 |
| 2 | -1.1753387+04 | 1.4435567+05 | -2.0040569+03 | -1.6281326+02 | 6.5370102+00 | -1.1260982+01 |
| 3 | 8.6810792+03 | -2.0040572+03 | 2.6942895+04 | 4.6075039+00 | -7.4323129+00 | 3.8203267+01 |
| 4 | 1.5988117+01 | -1.6281328+02 | 4.6075034+00 | 1.8837637-01 | -9.9095851-03 | 1.7229397-02 |
| 5 | -9.0323468+00 | 6.5370140+00 | -7.4323128+00 | -9.9095777-03 | 1.6361660-02 | -2.2323645-02 |
| 6 | 1.9996534+01 | -1.1260982+01 | 3.8203267+01 | 1.7229397-02 | -2.2323645-02 | 9.4876879-02 |

Inertial Covariance of LM
$CSI_2$

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 9.9975719-05 | -2.4676717-14 | 1.5687574-05 | 3.6481708-05 | 1.5660209-02 | 2.7350076-08 |
| 2 | -2.4676717-14 | 9.9986262-05 | 3.7010860-03 | -3.4193861-03 | 8.1696040-06 | 6.8268394-06 |
| 3 | 1.5687574-05 | 3.7010860-03 | 3.1974421+06 | -2.3398738+06 | 2.7717657+05 | 5.1968639+03 |
| 4 | 3.6481708-05 | -3.4193861-03 | -2.3398738+06 | 2.1764889+06 | -1.7580401+05 | -4.1983764+03 |
| 5 | 1.5660209-02 | 8.1696040-06 | 2.7717657+05 | -1.7580400+05 | 6.1972066+04 | 4.2796512+02 |
| 6 | 2.7350076-08 | 6.8268394-06 | 5.1968639+03 | -4.1983765+03 | 4.2796513+02 | 8.8216332+00 |
| 7 | 5.2196907-08 | -2.4624874-06 | -1.9573232+03 | 1.4878074+03 | -1.6145010+02 | -3.2101554+00 |
| 8 | 3.0931622-05 | -4.4184774-08 | 5.9987755+01 | -3.4744076+01 | 2.7886576+01 | 9.0178779-02 |

| | 7 | 8 |
|---|---|---|
| 1 | 5.2196907-08 | 3.0931622-05 |
| 2 | -2.4624874-06 | -4.4184774-08 |
| 3 | -1.9573232+03 | 5.9987754+01 |
| 4 | 1.4878074+03 | -3.4744073+01 |
| 5 | -1.6145009+02 | 2.7886575+01 |
| 6 | -3.2101553+00 | 9.0178777-02 |
| 7 | 1.2222914+00 | -3.4808509-02 |
| 8 | -3.4808509-02 | 1.0250423-01 |

## Covariance of Relative State
## $CSI_2$

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 2.9949110+06 | -2.2922801+06 | 2.4351680+05 | 5.0657804+03 | -1.9754923+03 | 6.4138918+01 |
| 2 | -2.2922801+06 | 2.0684265+06 | -1.6498899+05 | -4.1049647+03 | 1.5573456+03 | -4.2758589+01 |
| 3 | 2.4351680+05 | -1.6498899+05 | 4.9579065+04 | 3.9566176+02 | -1.5600891+02 | 1.6822797+01 |
| 4 | 5.0657804+03 | -4.1049648+03 | 3.9566176+02 | 8.7537394+00 | -3.3646702+00 | 1.0377049-01 |
| 5 | -1.9754923+03 | 1.5573456+03 | -1.5600891+02 | -3.3646703+00 | 1.3178597+00 | -4.0523466-02 |
| 6 | 6.4138920+01 | -4.2758591+01 | 1.6822798+01 | 1.0377049-01 | -4.0523466-02 | 1.2119426-01 |

## Means Associated with CSM State, LM State, LM/CSM State Estimate
## $CSI_2$

**CSM**

| | 1 |
|---|---|
| 1 | 7.5174522+01 |
| 2 | -5.4049926+01 |
| 3 | -8.1095362-01 |
| 4 | 1.3816094-01 |
| 5 | -3.5341393-02 |
| 6 | 1.7856631-04 |

**LM**

| | 1 |
|---|---|
| 1 | -2.2998246-11 |
| 2 | -4.5435643-11 |
| 3 | 5.9115005+01 |
| 4 | -4.4461098+01 |
| 5 | -5.5531982-01 |
| 6 | 1.0750468-01 |
| 7 | -3.0371458-02 |
| 8 | 1.1139998-04 |

**LM-CSM**

| | 1 |
|---|---|
| 1 | 1.7258231+01 |
| 2 | -7.3813128+00 |
| 3 | -2.5786958-01 |
| 4 | 3.1417464-02 |
| 5 | -1.8480511-03 |
| 6 | 6.5336514-05 |

Inertial Covariance of CSM
$CDH_2$

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 1.3786962+04 | -2.4987558+04 | 2.6976649+03 | 3.0607719+01 | -8.2864523+00 | 1.4849780+01 |
| 2 | -2.4987558+04 | 3.4978817+05 | 1.3424722+04 | -4.0086984+02 | 1.1443203+01 | 4.2646842+01 |
| 3 | 2.6976648+03 | 1.3424722+04 | 2.0400874+04 | -1.3415606+01 | -5.8868033+00 | 3.2023222+01 |
| 4 | 3.0607719+01 | -4.0086984+02 | -1.3415606+01 | 4.6404764-01 | -1.5082300-02 | -4.3790273-02 |
| 5 | -8.2864533+00 | 1.1443203+01 | -5.8868034+00 | -1.5082307-02 | 1.8188939-02 | -1.8930794-02 |
| 6 | 1.4849780+01 | 4.2646842+01 | 3.2023222+01 | -4.3790273-02 | -1.8930794-02 | 1.0395581-01 |

Inertial Covariance of LM
$CDH_2$

| | | | | | | |
|---|---|---|---|---|---|---|
| 1 | 9.9949288-05 | -2.6397758-14 | 6.5575791-05 | -8.4620159-05 | -4.0743223-03 | 1.3440146-07 |
| 2 | -2.6397758-14 | 9.9971333-05 | 2.0842305-04 | -5.7415961-04 | 3.3139904-05 | 6.8291049-07 |
| 3 | 6.5575791-05 | 2.0842305-04 | 8.3559407+04 | -2.1320944+05 | -2.0476522+04 | 2.4333604+02 |
| 4 | -8.4620159-05 | -5.7415961-04 | -2.1320944+05 | 1.2409727+06 | -1.5065234+03 | -1.4128532+03 |
| 5 | -4.0743223-03 | 3.3139904-05 | -2.0476523+04 | -1.5065196+03 | 5.1881590+04 | -1.2639451+00 |
| 6 | 1.3440146-07 | 6.8291049-07 | 2.4333604+02 | -1.4128532+03 | -1.2639446+00 | 1.6144115+00 |
| 7 | -3.9172470-08 | -1.6557996-07 | -5.8096465+01 | 1.5567184+02 | 1.8502092-01 | -1.7523091-01 |
| 8 | -1.4472554-05 | 9.7505006-08 | -6.3710523+00 | 3.6365763+00 | 2.3245963+01 | -3.8854457-03 |

| | 7 | 8 |
|---|---|---|
| 1 | -3.9172470-08 | -1.4472554-05 |
| 2 | -1.6557996-07 | 9.7505006-08 |
| 3 | -5.8096465+01 | -6.3710523+00 |
| 4 | 1.5567184+02 | 3.6365766+00 |
| 5 | 1.8502098-01 | 2.3245963+01 |
| 6 | -1.7523091-01 | -3.8854461-03 |
| 7 | 5.4447882-02 | -2.1123094-04 |
| 8 | -2.1123087-04 | 1.1033523-01 |

Covariance of Relative State
$CDH_2$

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 6.3361933+04 | -1.9385219+05 | -1.2408341+04 | 2.1824153+02 | -5.3629341+01 | -4.2817914+00 |
| 2 | -1.9385219+05 | 9.0283346+05 | 7.5803125+03 | -1.0244577+03 | 1.5174150+02 | 4.7211838-01 |
| 3 | -1.2408342+04 | 7.5803163+03 | 4.2567973+04 | -1.0900591+01 | 8.8628564+00 | 9.3216820+00 |
| 4 | 2.1824152+02 | -1.0244577+03 | -1.0900591+01 | 1.1635258+00 | -1.6996668-01 | -1.0613436-03 |
| 5 | -5.3629341+01 | 1.5174150+02 | 8.8628563+00 | -1.6996668-01 | 4.7154051-02 | 1.4575275-03 |
| 6 | -4.2817915+00 | 4.7211790-01 | 9.3216825+00 | -1.0613431-03 | 1.4575277-03 | 1.2526803-01 |

Means Associated with CSM State, LM State, LM/CSM State Estimates
$CDH_2$

CSM

| | 1 |
|---|---|
| 1 | 2.1063040+02 |
| 2 | -8.0598336+02 |
| 3 | 8.5992103-01 |
| 4 | 9.5834500-01 |
| 5 | -1.3292821-01 |
| 6 | 1.5251475-05 |

LM

| | 1 |
|---|---|
| 1 | 2.1945266-10 |
| 2 | -1.6454475-11 |
| 3 | 1.8585025+02 |
| 4 | -7.5779530+02 |
| 5 | -1.4879123-01 |
| 6 | 9.0695024-01 |
| 7 | -1.0007757-01 |
| 8 | -1.3291901-03 |

LM-CSM

| | 1 |
|---|---|
| 1 | 4.2628353+01 |
| 2 | -4.3311310+01 |
| 3 | 1.0291882+00 |
| 4 | 5.4110587-02 |
| 5 | -1.1533875-02 |
| 6 | 1.3575463-03 |

Inertial Covariance of CSM
$TPI_2$

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 1.7063664+04 | -4.7875571+04 | 2.9942339+03 | 6.0627056+01 | -8.5432377+00 | 1.9554438+01 |
| 2 | -4.7875571+04 | 6.4960673+05 | -4.7542760+03 | -7.6854781+02 | 2.5586006+01 | -2.7630696+01 |
| 3 | 2.9942339+03 | -4.7542761+03 | 1.2130342+04 | 7.2715138+00 | -1.0517184+00 | 1.7415836+01 |
| 4 | 6.0627056+01 | -7.6854784+02 | 7.2715137+00 | 9.1541527-01 | -3.4036368-02 | 4.3121077-02 |
| 5 | -8.5432377+00 | 2.5586013+01 | -1.0517183+00 | -3.4036368-02 | 1.4981132-02 | -2.1113387-02 |
| 6 | 1.9554438+01 | -2.7630697+01 | 1.7415836+01 | 4.3121077-02 | -2.1113387-02 | 1.1532041-01 |

Inertial Covariance of LM
$TPI_2$

| | | | | | | |
|---|---|---|---|---|---|---|
| 1 | 9.9925028-05 | -1.4593872-13 | 3.2581303-04 | -8.5788389-04 | 1.3627354-02 | 1.0051735-06 |
| 2 | -1.4593872-13 | 9.9957605-05 | 6.2534084-05 | -6.6723667-04 | -2.9828776-05 | 7.5444336-07 |
| 3 | 3.2581303-04 | 6.2534084-05 | 3.3040906+04 | -9.8595559+04 | 1.3750155+04 | 1.2139830+02 |
| 4 | -8.5788389-04 | -6.6723667-04 | -9.8595567+04 | 1.0144074+06 | -1.8805409+04 | -1.1987621+03 |
| 5 | 1.3627354-02 | -2.9828776-05 | 1.3750156+04 | -1.8805410+04 | 4.5667429+04 | 1.9726414+01 |
| 6 | 1.0051735-06 | 7.5444336-07 | 1.2139830+02 | -1.1987622+03 | 1.9726413+01 | 1.4260825+00 |
| 7 | -2.2887171-07 | -2.4902603-08 | -1.7088611+01 | 4.0455902+01 | 4.4313888+00 | -5.3081382-02 |
| 8 | 4.4074320-05 | -1.9222629-07 | 6.6896042+00 | -1.7184414+01 | 1.1490299+01 | 1.9572652-02 |

| | 7 | 8 |
|---|---|---|
| 1 | -2.2887171-07 | 4.4074320-05 |
| 2 | -2.4902603-08 | -1.9222629-07 |
| 3 | -1.7088611+01 | 6.6896041+00 |
| 4 | 4.0455902+01 | -1.7184414+01 |
| 5 | 4.4313884+00 | 1.1490299+01 |
| 6 | -5.3081386-02 | 1.9572651-02 |
| 7 | 2.0981591-02 | -9.1096281-04 |
| 8 | -9.1096285-04 | 1.1652752-01 |

Covariance of Relative State
$TPI_2$

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 8.0752920+03 | -2.6631575+04 | 5.4471091+03 | 3.1095976+01 | -7.6355398+00 | 5.0011937+00 |
| 2 | -2.6631583+04 | 3.3900506+05 | -2.4822881+04 | -3.8510190+02 | 1.1321673+01 | -1.7068770+01 |
| 3 | 5.4471093+03 | -2.4822882+04 | 4.1146182+04 | 2.7616388+01 | -3.2278841+00 | -5.9239113+00 |
| 4 | 3.1095972+01 | -3.8510191+02 | 2.7616387+01 | 4.3961884-01 | -1.3853646-02 | 1.8170089-02 |
| 5 | -7.6355398+00 | 1.1321673+01 | -3.2278837+00 | -1.3853642-02 | 8.4481856-03 | -3.7659858-03 |
| 6 | 5.0011937+00 | -1.7068770+01 | -5.9239116+00 | 1.8170091-02 | -3.7659858-03 | 1.2432916-01 |

Means Associated with CSM State, LM State, LM/CSM State Estimates
$TPI_2$

CSM

| | 1 |
|---|---|
| 1 | 2.4884655+02 |
| 2 | -1.7385585+03 |
| 3 | 6.8143630-01 |
| 4 | 2.1023859+00 |
| 5 | -1.2953987-01 |
| 6 | -4.1150730-04 |

LM

| | 1 |
|---|---|
| 1 | 2.1250886-09 |
| 2 | 8.5345902-10 |
| 3 | 3.5446018+02 |
| 4 | -1.8615326+03 |
| 5 | 1.3188905-01 |
| 6 | 2.3238709+00 |
| 7 | -2.0177865-01 |
| 8 | 5.2598134-03 |

LM-CSM

| | 1 |
|---|---|
| 1 | -9.3655612+01 |
| 2 | 1.2472780+02 |
| 3 | 5.7566690-01 |
| 4 | -2.2064334-01 |
| 5 | 8.6709427-02 |
| 6 | -5.6903251-03 |

Inertial Covariance of CSM
MCC

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 1.1397801+04 | -2.4731195+04 | 8.9748167+03 | 2.5957717+01 | -4.4957841+00 | -2.0491162+00 |
| 2 | -2.4731193+04 | 8.7216768+05 | -6.9798158+04 | -9.5961481+02 | 2.3610842+01 | 5.7180972+00 |
| 3 | 8.9748171+03 | -6.9798158+04 | 8.5873868+04 | 6.4159639+01 | -1.0168310+01 | -8.5200032+00 |
| 4 | 2.5957715+01 | -9.5961481+02 | 6.4159639+01 | 1.0638688+00 | -2.5242441-02 | -6.6285037-03 |
| 5 | -4.4957838+00 | 2.3610845+01 | -1.0168310+01 | -2.5242441-02 | 1.2019344-02 | -1.4125544-04 |
| 6 | -2.0491162+00 | 5.7180973+00 | -8.5200031+00 | -6.6285037-03 | -1.4125539-04 | 1.3620988-02 |

Inertial Covariance of LM
MCC

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 9.9914452-05 | 2.7011745-14 | 7.0978326-05 | -3.2234119-04 | 1.0526706-02 | 3.8391324-07 |
| 2 | 2.7011745-14 | 9.9951629-05 | 6.1191994-05 | -7.0696355-04 | -1.0097153-04 | 7.3526284-07 |
| 3 | 7.0978326-05 | 6.1191994-05 | 1.3878553+05 | -1.7517036+05 | 2.5163406+04 | 3.1502170+02 |
| 4 | -3.2234119-04 | -7.0696355-04 | -1.7517037+05 | 1.1835694+06 | -8.8964789+03 | -1.3960847+03 |
| 5 | 1.0526706-02 | -1.0097153-04 | 2.5163406+04 | -8.8964790+03 | 1.1921965+05 | 3.9313702+01 |
| 6 | 3.8391324-07 | 7.3526284-07 | 3.1502170+02 | -1.3960847+03 | 3.9313702+01 | 1.7971452+00 |
| 7 | -1.7123229-08 | -4.8267470-08 | -8.8976208+01 | 1.4221675+02 | -1.2101508+01 | -2.2420886-01 |
| 8 | 3.1049906-05 | 9.7325341-08 | -2.1683364+01 | 7.9319407+00 | -4.7764025+00 | -2.3272900-02 |

| | 7 | 8 |
|---|---|---|
| 1 | -1.7123229-08 | 3.1049906-05 |
| 2 | -4.8267470-08 | 9.7325341-08 |
| 3 | -8.8976208+01 | -2.1683364+01 |
| 4 | 1.4221674+02 | 7.9319406+00 |
| 5 | -1.2101508+01 | -4.7764026+00 |
| 6 | -2.2420885-01 | -2.3272899-02 |
| 7 | 7.8404055-02 | -2.9956423-03 |
| 8 | -2.9956421-03 | 6.7189930-02 |

Covariance of Relative State
MCC

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 1.2236708+05 | -1.1830573+05 | 2.3432603+04 | 2.5180721+02 | -8.3582963+01 | -1.3596648+01 |
| 2 | -1.1830574+05 | 2.0239545+05 | -1.2079082+04 | -3.0441809+02 | 1.0092958+02 | 1.7341359+01 |
| 3 | 2.3432603+04 | -1.2079082+04 | 1.2130571+05 | 4.2228154+01 | -1.2114780+01 | 1.3259174+01 |
| 4 | 2.5180721+02 | -3.0441806+02 | 4.2228154+01 | 5.7404402-01 | -1.7890598-01 | -3.4534032-02 |
| 5 | -8.3582963+01 | 1.0092958+02 | -1.2114780+01 | -1.7890598-01 | 6.6842645-02 | 7.0193336-03 |
| 6 | -1.3596648+01 | 1.7341359+01 | 1.3259174+01 | -3.4534033-02 | 7.0193338-03 | 6.5356227-02 |

Means Associated with CSM State, LM State, LM/CSM State Estimates
MCC

CSM

| | 1 |
|---|---|
| 1 | 1.8119332+02 |
| 2 | -2.2529901+03 |
| 3 | 1.6241586+00 |
| 4 | 2.5731163+00 |
| 5 | -1.1737997-01 |
| 6 | -2.4048974-03 |

LM

| | 1 |
|---|---|
| 1 | -1.4619757-09 |
| 2 | 3.5296239-08 |
| 3 | 3.2601946+02 |
| 4 | -2.5687189+03 |
| 5 | -3.2299802+01 |
| 6 | 2.9763254+00 |
| 7 | -2.3107079-01 |
| 8 | 1.2098164-02 |

LM-CSM

| | 1 |
|---|---|
| 1 | 1.8126638+02 |
| 2 | -2.2527197+03 |
| 3 | 1.5131350+00 |
| 4 | 2.5838434+00 |
| 5 | -1.1717416-01 |
| 6 | -2.5898305-03 |

Inertial Covariance of CSM
TPF

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 1.0386713+04 | 7.8034864+03 | -3.4390598+03 | -7.5500538+00 | -4.0193034+00 | 1.1211337+00 |
| 2 | 7.8034908+03 | 8.8757563+05 | -5.1611955+04 | -9.7900895+02 | -1.8327297+01 | 6.2189665+01 |
| 3 | -3.4390594+03 | -5.1611956+04 | 4.5853455+04 | 4.5761757+01 | 2.8604253+00 | -4.5412249+01 |
| 4 | -7.5500610+00 | -9.7900896+02 | 4.5761756+01 | 1.0885320+00 | 1.8298589-02 | -5.6985152-02 |
| 5 | -4.0193006+00 | -1.8327293+01 | 2.8604256+00 | 1.8298585-02 | 1.2417695-02 | -3.5028093-03 |
| 6 | 1.1211333+00 | 6.2189666+01 | -4.5412249+01 | -5.6985153-02 | -3.5028090-03 | 6.8889150-02 |

Inertial Covariance of LM
TPF

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 9.9914447-05 | 2.7011747-14 | 2.2487774-04 | -7.1682411-04 | 1.5280784-02 | 9.2901438-07 |
| 2 | 2.7011747-14 | 9.9951618-05 | -5.0985165-05 | -5.8945606-04 | 1.2586060-04 | 7.2473314-07 |
| 3 | 2.2487774-04 | -5.0985165-05 | 7.0424911+05 | -1.6847203+06 | -5.1835339+04 | 2.0433725+03 |
| 4 | -7.1682411-04 | -5.8945606-04 | -1.6847203+06 | 7.0257745+06 | 1.6372656+05 | -7.8830675+03 |
| 5 | 1.5280784-02 | 1.2586060-04 | -5.1835338+04 | 1.6372656+05 | 9.5532434+04 | -1.7931458+02 |
| 6 | 9.2901438-07 | 7.2473314-07 | 2.0433725+03 | -7.8830676+03 | -1.7931458+02 | 9.0125611+00 |
| 7 | -1.6898685-07 | 8.1884655-08 | -5.9089194+02 | 1.3858733+03 | 3.1628668+01 | -1.6717944+00 |
| 8 | -2.8082319-05 | 3.9498769-08 | -2.5911816+01 | 1.1115868+02 | 2.5518424+01 | -1.1921064-01 |

| | 7 | 8 |
|---|---|---|
| 1 | -1.6898685-07 | -2.8082319-05 |
| 2 | 8.1884655-08 | 3.9498769-08 |
| 3 | -5.9089194+02 | -2.5911816+01 |
| 4 | 1.3858732+03 | 1.1115868+02 |
| 5 | 3.1628667+01 | 2.5518424+01 |
| 6 | -1.6717944+00 | -1.1921064-01 |
| 7 | 5.1536406-01 | 3.0254287-02 |
| 8 | 3.0254287-02 | 1.4044002-01 |

## Covariance of Relative State
## TPF

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 6.9527832+05 | -1.6765410+06 | -3.4395772+04 | 2.0305552+03 | -5.9309305+02 | -3.9463477+01 |
| 2 | -1.6765410+06 | 6.0973999+06 | 1.3865054+05 | -6.7482272+03 | 1.4276979+03 | 1.3105148+02 |
| 3 | -3.4395771+04 | 1.3865054+05 | 1.7347239+05 | -1.6661714+02 | 2.6200652+01 | -3.5804806+01 |
| 4 | 2.0305551+03 | -6.7482273+03 | -1.6661714+02 | 7.6445012+00 | -1.7169623+00 | -1.2582356-01 |
| 5 | -5.9309305+02 | 1.4276979+03 | 2.6200654+01 | -1.7169623+00 | 5.1091910-01 | 3.7421384-02 |
| 6 | -3.9463478+01 | 1.3105148+02 | -3.5804806+01 | -1.2582356-01 | 3.7421384-02 | 1.4096847-01 |

## Means Associated with the CSM State and LM State Estimates

**CSM**

| | 1 |
|---|---|
| 1 | 1.3758360+02 |
| 2 | -2.4190127+03 |
| 3 | -6.0947004-01 |
| 4 | 2.7845658+00 |
| 5 | -5.4136386-02 |
| 6 | -2.4766967-03 |

**LM**

| | 1 |
|---|---|
| 1 | -1.4619549-09 |
| 2 | 3.5296214-08 |
| 3 | 2.5129090+02 |
| 4 | -3.4040515+03 |
| 5 | 2.7226080+01 |
| 6 | 4.0650462+00 |
| 7 | -8.9548297-02 |

Inertial Covariance of LM
APS-1

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 8.2840672+04 | -1.0389673+05 | -3.4056240+04 | 9.2250971+01 | -8.3557465+01 | -5.9457044+01 |
| 2 | -1.0389673+05 | 1.6279835+05 | 3.5731653+04 | -1.4291489+02 | 1.1353081+02 | 7.1402987+01 |
| 3 | -3.4056240+04 | 3.5731653+04 | 7.6538268+04 | -3.8765516+01 | 3.7564458+01 | 1.3636257+02 |
| 4 | 9.2250971+01 | -1.4291489+02 | -3.8765516+01 | 1.2806465-01 | -1.0060857-01 | -8.0993465-02 |
| 5 | -8.3557465+01 | 1.1353081+02 | 3.7564458+01 | -1.0060857-01 | 9.8551878-02 | 7.3038600-02 |
| 6 | -5.9457044+01 | 7.1402987+01 | 1.3636257+02 | -8.0993465-02 | 7.3038600-02 | 3.2067860-01 |

Inertial Covariance of CSM
SPS-5

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 2.0568898+04 | 1.3060004+02 | 8.5188030+03 | -5.0620985+00 | -1.7824407+01 | -7.2878867+00 |
| 2 | 1.3060004+02 | 2.0558829+05 | 6.3193213+03 | -2.3644766+02 | -9.2949314+00 | 7.6077427+00 |
| 3 | 8.5188030+03 | 6.3193213+03 | 3.5937097+04 | -8.7037181+00 | -7.2754265+00 | 4.9825440+01 |
| 4 | -5.0620985+00 | -2.3644766+02 | -8.7037181+00 | 2.7643014-01 | 1.6832373-02 | -4.7839104-04 |
| 5 | -1.7824407+01 | -9.2949314+00 | -7.2754265+00 | 1.6832373-02 | 3.0421486-02 | 9.2508740-03 |
| 6 | -7.2878867+00 | 7.6077427+00 | 4.9825440+01 | -4.7839104-04 | 9.2508740-03 | 1.6278036-01 |

Inertial Covariance of CSM
SPS-6

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 1.0622958+05 | -4.0784762+05 | 1.1669868+04 | 4.5748658+02 | -4.3026607+01 | -3.1931210+00 |
| 2 | -4.0784762+05 | 1.7681902+06 | -2.1080114+04 | -2.0041987+03 | 1.2644671+02 | -3.3620215+01 |
| 3 | 1.1669868+04 | -2.1080114+04 | 5.5147462+04 | 1.5764675+01 | -1.6108207+01 | 1.6017201+01 |
| 4 | 4.5748658+02 | -2.0041987+03 | 1.5764675+01 | 2.2798247+00 | -1.3477394-01 | 4.6954701-02 |
| 5 | -4.3026607+01 | 1.2644671+02 | -1.6108207+01 | -1.3477394-01 | 2.9169139-02 | 1.1537012-02 |
| 6 | -3.1931210+00 | -3.3620215+01 | 1.6017201+01 | 4.6954701-02 | 1.1537012-02 | 5.4381993-02 |

Inertial Covariance of CSM
SPS Deorbit

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 2.0283185+04 | -4.0420948+04 | 2.1430124+04 | 4.8008510+01 | -1.2459035+01 | 1.9834078+00 |
| 2 | -4.0420948+04 | 3.4305019+05 | 4.4245932+04 | -3.4817706+02 | 2.2800849+01 | -7.3633403+00 |
| 3 | 2.1430124+04 | 4.4245932+04 | 1.8781028+05 | -2.7628899+01 | -2.3310413+01 | -6.1945526+01 |
| 4 | 4.8008510+01 | -3.4817706+02 | -2.7628899+01 | 3.6071625-01 | -3.1276761-02 | 1.0597850-02 |
| 5 | -1.2459035+01 | 2.2800849+01 | -2.3310413+01 | -3.1276761-02 | 1.9514415-02 | -2.8053826-03 |
| 6 | 1.9834078+00 | -7.3633403+00 | -6.1945526+01 | 1.0597850-02 | -2.8053826-03 | 6.9496931-02 |

Inertial Covariance of CSM
Reentry Based on Data to SPS Deorbit Update

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 2.5876969+05 | -4.4998715+05 | 4.0047985+04 | 7.1188498+02 | -5.7764801+01 | 2.9967134+01 |
| 2 | -4.4998715+05 | 8.0897656+05 | -7.8166001+04 | -1.2999810+03 | 9.9630839+01 | -3.5215712+01 |
| 3 | 4.0047985+04 | -7.8166001+04 | 4.5259226+04 | 1.1520477+02 | -2.0624358+01 | -2.8985663+01 |
| 4 | 7.1188498+02 | -1.2999810+03 | 1.1520477+02 | 2.1347490+00 | -1.4313655-01 | 1.0827958-01 |
| 5 | -5.7764801+01 | 9.9630839+01 | -2.0624358+01 | -1.4313655-01 | 2.6713373-02 | 2.7270336-02 |
| 6 | 2.9967134+01 | -3.5215712+01 | -2.8985663+01 | 1.0827958-01 | 2.7270336-02 | 2.7720000-01 |

Inertial Covariance of CSM
Reentry Based on Data to SPS Deorbit

| | | | | | | |
|---|---|---|---|---|---|---|
| 1 | 2.1907803+05 | -3.7201805+05 | 2.8349038+04 | 5.6246521+02 | -5.6891392+01 | 3.4953520+01 |
| 2 | -3.7201805+05 | 6.5605095+05 | -5.5982149+04 | -1.0082029+03 | 9.6969011+01 | -4.7141089+01 |
| 3 | 2.8349038+04 | -5.5982149+04 | 4.6554719+04 | 7.7270151+01 | -2.0188005+01 | -4.5656821+01 |
| 4 | 5.6246521+02 | -1.0082029+03 | 7.7270151+01 | 1.5830097+00 | -1.3590152-01 | 1.2333207-01 |
| 5 | -5.6891392+01 | 9.6969011+01 | -2.0188005+01 | -1.3590152-01 | 2.8546350-02 | 2.8414556-02 |
| 6 | 3.4953520+01 | -4.7141089+01 | -4.5656821+01 | 1.2333207-01 | 2.8414556-02 | 2.9431564-01 |

Inertial Covariance of CSM
Reentry Based on Data Prior to and After SPS Deorbit

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 5.6622139+04 | -7.0174186+04 | 8.2206926+03 | 7.2603124+01 | -2.2731831+01 | 4.1506893+00 |
| 2 | -7.0174186+04 | 1.0156713+05 | -1.7045775+04 | -1.1829328+02 | 2.9336073+01 | 4.7427758+00 |
| 3 | 8.2206926+03 | -1.7045775+04 | 2.1220607+04 | 2.2306744+01 | -9.3685669+00 | -8.9570963+00 |
| 4 | 7.2603124+01 | -1.1829328+02 | 2.2306744+01 | 1.6537947-01 | -2.3795076-02 | 2.4453521-02 |
| 5 | -2.2731831+01 | 2.9336073+01 | -9.3685669+00 | -2.3795076-02 | 2.2441620-02 | 2.4497014-02 |
| 6 | 4.1506893+00 | 4.7427758+00 | -8.9570963+00 | 2.4453521-02 | 2.4497014-02 | 2.0080351-01 |

Inertial Covariance of CSM
Reentry Based on Data After SPS Deorbit

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 6.9219336+05 | -1.0811844+05 | -3.0153870+05 | 1.2857788+03 | -1.5545233+02 | 1.2114185+02 |
| 2 | -1.0811844+05 | 3.2844087+04 | 5.2070558+04 | -2.2433253+02 | 8.1620541+01 | -5.1308651+01 |
| 3 | -3.0153870+05 | 5.2070558+04 | 1.4441344+05 | -5.6666560+02 | 9.2053905+01 | -5.3663557+01 |
| 4 | 1.2857788+03 | -2.2433253+02 | -5.6666560+02 | 2.4576177+00 | -4.0239771-01 | 3.0727119-01 |
| 5 | -1.5545233+02 | 8.1620541+01 | 9.2053905+01 | -4.0239771-01 | 3.4084196-01 | -2.1172199-01 |
| 6 | 1.2114185+02 | -5.1308651+01 | -5.3663557+01 | 3.0727119-01 | -2.1172199-01 | 1.9913127-01 |

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