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APOLLO 10 (MISSION F) (AS-505/CSM-106/LM-4) SPACECRAFT DISPERSION ANALYSIS ADDENDUM TO VOLUME 1 NAVIGATION ERROR ANALYSIS

(NASA-TM-X-69637) APOLLO 10 (MISSION F) (AS-505/CSM-106/LM-4) SPACECRAFT DISPERSION ANALYSIS. ADDENDUM TO VOLUME 1: NAVIGATION ERROR ANALYSIS (NASA) 37 p

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HOUSTON, TEXAS

MSC INTERNAL NOTE NO. 69-FM-138

PROJECT APOLLO

APOLLO 10 (MISSION F)(AS-505/CSM-106/LM-4) SPACECRAFT DISPERSION ANALYSIS ADDENDUM TO VOLUME I - NAVIGATION ERROR ANALYSIS

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May 14, 1969

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APOLLO 10 (MISSION F)(AS-505/CSM-106/LM-4)

SPACECRAFT DISPERSION ANALYSIS

ADDENDUM TO VOLUME I - NAVIGATION ERROR ANALYSIS

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1. SUMMARY

This document describes the navigation accuracy analysis of the lunar orbit phase of the F mission. The analysis of the rendezvous navigation was performed by MSC/TRW Task A-194 and was not included in the "Apollo Mission F Navigation Error Analysis" (MSC IN 69-FM-83). Analysis of the MSFN updates was performed by MSC. For this analysis, covariance matrices for the MSFN updates were constructed so that the errors produced by incorrectly modeling the lunar potential in the RTCC were simulated.

The error model used to generate these matrices was derived from postflight analysis results of Langley Lunar Orbiter III and Apollo 8 navigation data and includes observed effects which cannot be modeled analytically because of the current lack of knowledge of the true lunar gravitational potential.

This document presents an analysis of the MSFN update accuracies at LOI-2, SEP, INS and TEI, and an analysis of the onboard navigation accuracy during the rendezvous. Results are presented in the form of MSFN update uncertainties at LOI-2, SEP, INS and TEI, and LM and CSM onboard inertial and relative state vector uncertainties at maneuver points during the rendezvous.

A summary of velocity uncertainties is presented in the tables below:

CSM MSFN update uncertainties (3σ RST velocity)

LOI-2	55.8 ft/sec
SEP	24.3 ft/sec
INS	28.6 ft/sec
TEI	33.8 ft/sec

3σ RST relative velocity uncertainties for LGC estimates at rendezvous maneuver times.

INS	53.9 ft/sec
CSI	7.4 ft/sec
PC	6.1 ft/sec
CDH	7.6 ft/sec
TPI	5.6 ft/sec
MC-1	2.1 ft/sec
MC-2	1.4 ft/sec

The acceptability of the MSFN and LGC rendezvous navigation will be determined by dispersion analyses. However, based on previous experience the accuracy of the LGC rendezvous navigation after INS appears to be acceptable. The LGC relative state uncertainty at INS based on rendezvous radar tracking between FCT and INS appears large. However, this uncertainty will not affect the mission outcome since INS targeting is not based on the LGC estimate.

2. SYMBOLS

CDH	coelliptic delta height
CSI	coelliptic sequence initiation
CSM	command service module
DOI	descent orbit insertion
FCT	phasing
IMU	inertial measurement unit
INS	insertion
LGC	LM guidance computer
LM	lunar module
LOI-1	first lunar orbit insertion
LOI-2	second lunar orbit insertion
MC-1	first midcourse correction
MC-2	second midcourse correction
MSFN	Manned Space Flight Network
PC	plane change
RANGEVAR	square of range data weight in percent of range
RATEVAR	square of range rate data weight in percent of range
RR	rendezvous radar
RST	root semitrace (square root of the sum of variances)
RVARMIN	square of the minimum value of the range data weight
SEP	separation
SHAFTVAR	square of the radar shaft angle data weight
TEI	transearth injection
TPI	terminal phase initiation

TPF	terminal phase finalization
TRUNVAR	square of the radar trunnion angle data weight
VVARMIN	square of the minimum value of the range rate data weight
σ_u	standard deviation of the radial position error
σ_v	standard deviation of the downrange position error
σ_w	standard deviation of the out-of-plane position error
$\sigma_{\dot{u}}$	standard deviation of the radial velocity error
$\sigma_{\dot{v}}$	standard deviation of the downrange velocity error
$\sigma_{\dot{w}}$	standard deviation of the out-of-plane velocity error
σ_{tr}	standard deviation of the rendezvous radar trunnion angle bias error
σ_{shaft}	standard deviation of the rendezvous radar shaft angle bias error

3. INTRODUCTION

This document describes the navigation accuracy analysis of the lunar orbit phase of the F mission. The lunar orbit phase includes the time between LOI-1 and TEI (76.08:17 g.e.t. to 129:51:35 g.e.t.). An event schedule for this phase of the mission is presented in Figure 1. The navigation considered in this analysis consists of the following:

1. MSFN update prior to LOI-2
2. MSFN update prior to SEP
3. MSFN update after INS
4. LM rendezvous radar tracking during the rendezvous
5. MSFN update at TEI

4. ACCURACY OF MSFN UPDATES

MSFN updates of the CSM state occur prior to LOI-2, SEP, and TEI and immediately after INS. Covariance matrices describing the accuracy of these updates were generated using a technique similar to that described in Reference 1. For example, initial errors in radius and downtrack velocity were incorporated into the covariance matrices at the SEP update. These errors included the expected increase in those quantities caused by incorrect potential modeling during propagation from SEP to INS.

When these covariance matrices are propagated, the downtrack position and radial velocity errors exhibit a secular growth which is consistent with the Apollo 8 data.

The technique employed to generate these matrices is considered to be preliminary, and the evolution of improved techniques can be expected.

4.1 MSFN Update Error Models

The error models used to generate the MSFN update covariance matrices are given in Table I. The error models for the SEP, INS, and TEI updates are based on the assumption that the MSFN data will be processed using a Boeing R-2 lunar potential model and that the data arc consists of more than one complete frontside pass. The error model for the LOI-2 update also assumes processing with the R-2 potential model, but the data arc is assumed to consist of only one frontside pass.

4.2 MSFN Update Covariance Matrices

The covariance matrices describing the accuracy of the MSFN update used for support of the LOI-2 maneuver and the TEI maneuver are presented in Table II. The covariance matrix is symmetric and, therefore, only the lower triangular portion is presented. The numbers in the upper triangular portion of the matrix (i.e., above the diagonal) are correlation coefficients. Each matrix is associated with the time of ignition for a particular maneuver and is expressed in the spacecraft's local U, V, W coordinate system at that time. (U is radial, positive outward, W is in the direction of the angular momentum vector, and V completes the right-handed system.) The LOI-2 and TEI matrices are valid only at the maneuver time for which they are intended and will not afford valid results if propagated forward. These matrices were taken from References 2 and 3.

The covariance matrix describing the accuracy of the MSFN update of the LM and CSM state vector just prior to the separation maneuver (SEP) is presented in Table III. This matrix is applicable only for

the region between SEP and INS. Propagated past INS, this matrix does not accurately reflect the MSFN navigation accuracy. Also, the matrix does not reflect the LM accuracy after INS if onboard measurements are not used to update the estimate of the LM state. Table III also shows the covariance matrix describing the accuracy of the MSFN update of the CSM state immediately after the insertion maneuver (INS). This matrix is considered applicable only for the region between INS and TPF. The SEP and INS matrices are from Reference 4.

5. NAVIGATION ACCURACY ANALYSIS OF THE LM ACTIVE RENDEZVOUS PHASE

The purpose of this analysis was to determine the accuracy with which the F mission lunar rendezvous maneuver state vectors can be determined from the MSFN and onboard tracking data. This information is used to support a dispersion analysis which determines the trajectory variations and fuel requirements.

This analysis was accomplished using linear error analysis techniques and utilized TRW TAPP-IV, FASTAP, and SNAP (References 5, 6, and 7) computer programs. This analysis was conducted for the reference trajectory described in Reference 8.

5.1 Error Model

The error sources used in this analysis and their standard deviations are shown in Table IV. These error magnitudes are consistent with those given in Reference 9. After each burn the LM real-world covariance matrix was degraded by adding a value of 0.01 to the variances of each of the velocity components. This addition corresponds to an accuracy degradation of 0.1 foot per second in each component of velocity.

5.2 Navigation Plan

The tracking schedule used in this analysis is presented in Figure 2 and is consistent with that given in Reference 10.

This tracking schedule was set by the F Mission Rendezvous Navigation Analysis Panel and is consistent with all present mission constraints and limitations.* Rendezvous radar tracking consists of range, range rate, and shaft and trunnion angle observations taken at a rate of one mark per minute. Tracking data are processed by the LGC to obtain differential corrections to the six components of position and velocity and the shaft and trunnion angle biases.

*Since this analysis was performed, the tracking schedule has changed slightly (Reference 11).

The fit world covariance matrix (W matrix) was reinitialized according to the following schedule.

Reinitialization Epoch	Reinitialization Values
1st observation after phasing	2,000 ft; 2 ft/sec; 5 mr*
21st observation after phasing	2,000 ft; 2 ft/sec; 5 mr*
1st observation after INS	10,000 ft; 10 ft/sec; 15 mr
5th observation after CSI	2,000 ft; 2 ft/sec; 5 mr
5th observation after PC	2,000 ft; 2 ft/sec; 5 mr
5th observation after CDH	2,000 ft; 2 ft/sec; 5 mr
1st observation after TPI	2,000 ft; 2 ft/sec; 5 mr
1st observation after MC-1	2,000 ft; 2 ft/sec; 5 mr

The following values were used for the P20 erasable memory data weight constants.

RANGEVAR	$0.1111E^{-4}$
RATEVAR	$0.1877\ E^{-4}$
RVARMIN	$67\ (m)^2$
VVARMIN	$0.178\ E^{-5}\ (m/csec)^2$
SHAFTVAR	$0.000001\ (rad)^2$
TRUNVAR	$0.000001\ (rad)^2$

5.3 Results of Rendezvous Navigation Accuracy Analysis

One sigma uncertainties in components of the relative, LM, and CSM state vector estimation errors are shown in Table V. Relative uncertainties are given in LM orbit plane coordinates. CSM and LM uncertainties are given in CSM and LM orbit plane coordinates, respectively. Values are presented for each maneuver between SEP and TPF. Uncertainties in the shaft and trunnion angle biases and root semitraces (RST's) of position and velocity errors are also presented. Covariance matrices for the LM, CSM, and relative state vector errors at each maneuver are presented in the Appendix.

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*At the time of publication the most recent tracking schedule called for pre-INS reinitialization values of 10,000 ft/10 ft/sec and 5 mr. The effect of this change on the uncertainties at INS should be small. The INS uncertainties are not of great importance since the INS estimate is not used for targeting.

Table I. Error Models for MSFN Updates

Error Model for LOI-2 Update*

	Local 1σ Uncertainty	Growth Rate (per revolution)
U	1,000 ft	500 ft
V	3,000 ft	11,000 ft
θ	0.1 deg	0.005 deg
γ	0.01 deg	0.005 deg

Error Model for SEP, INS, and TEI Updates**

	Local 1σ Uncertainty	Growth Rate (per revolution)
U	1,000 ft	500 ft
V	3,000 ft	3,000 ft
θ	0.1 deg	0.005 deg
γ	0.01 deg	0.005 deg

U is the radial position component

V is the downrange position component

θ is the wedge angle between the actual and estimated angular momentum vector

γ is the flight-path angle

*Data arc of one revolution

**Data arc of two revolutions

Table II. MSFN Update Covariance Matrices for LOI-2 and TEI

CSM Update at LOI-2

.7529395+007	-.7882608+000	.3059150-004	.8064008+000	.9902570+000	.5188135-004
-.4035317+008	.3480438+009	-.1573003-004	-.9970991+000	.7196895+000	-.4918176-004
.9502509+002	-.3322033+003	.1281488+007	.1391115-004	-.4297499-004	.9999999+000
.3536538+005	-.2973053+006	.2516912+000	.2554434+003	-.7364335+000	.4676869-004
-.5464232+004	.2699997+005	-.9783052-001	-.2366912+002	.4043918+001	-.6124939-004
.1327366+001	-.8555013+001	.1055496+005	.6969508-002	-.1148425-002	.8693590+002

σ_u = 2,744 ft $\sigma_{\dot{u}}$ = 15.98 ft/sec

σ_v = 18,656 ft $\sigma_{\dot{v}}$ = 2.01 ft/sec

σ_w = 1,132 ft $\sigma_{\dot{w}}$ = 9.32 ft/sec

CSM Update at TEI

.2311513+007	-.1892977+000	.6895577-004	.2147857+000	-.9986572+000	.9079733-004
-.2455780+007	.7281011+008	-.6447233-004	-.9902028+000	.1754369+000	-.1044405-003
.1543917+003	-.8101667+003	.2168754+007	.6834743-004	-.6806806-004	.7300540+000
.2173607+004	-.5624029+005	.6699692+000	.4430523+002	-.1993541+000	.1091915-003
-.2021016+004	.1992609+004	-.1334399+000	-.1766274+001	.1771782+001	-.8948131-004
.1234498+001	-.7969551+001	.9614556+004	.6499584-002	-.1065139-002	.7997203+002

σ_u = 1,520 ft $\sigma_{\dot{u}}$ = 6.66 ft/sec

σ_v = 8,533 ft $\sigma_{\dot{v}}$ = 1.33 ft/sec

σ_w = 1,473 ft $\sigma_{\dot{w}}$ = 8.94 ft/sec

Table III. MSFN Update Covariance Matrices for SEP and INS

CSM Update at SEP

.21119580+07	.33153042-00	-.33499634-05	-.35670555-00	-.99852777-00	.36085875-05
.23979100+07	.24770439+08	-.10256381-03	-.95571532-00	-.34828544-00	.10183778-03
-.33031420+02	-.34634230+04	.46035100+08	.10490698-03	.51836597-05	-.98063364-00
-.22368979+04	-.20525280+05	.30714440+01	.18620329+02	.37310096-00	-.10420177-03
-.18594769+04	-.22212130+04	.45068079-01	.20630419+01	.16420110+01	-.51224695-05
.35518239-01	.34327910+01	-.45063289+05	-.30453719-02	-.44456879-04	.45871519+02

σ_u = 1453 ft $\sigma_{\dot{u}}$ = 4.32 ft/sec

σ_v = 4977 ft $\sigma_{\dot{v}}$ = 1.28 ft/sec

σ_w = 6785 ft $\sigma_{\dot{w}}$ = 6.77 ft/sec

CSM Update at INS

.20289569+07	.18611633-00	-.24551618-05	-.19352103-00	-.99847540-00	.26559315-05
.12419429+07	.21946310+08	-.10636221-03	-.95103859-00	-.20372593-00	.10764140-03
-.12724480+02	-.18129740+04	.13238750+08	.10429063-03	.80233262-06	-.95622545-00
-.11689200+04	-.18892920+05	.16091220+01	.17982099+02	.21034895-00	-.10554182-03
-.17871760+04	-.11992799+04	.36683559-02	.11208670+01	.15790180+01	-.64986628-06
.31978049-01	.42624450+01	-.29409150+05	-.37830620-02	-.69026559-05	.71449199+02

σ_u = 1424 ft $\sigma_{\dot{u}}$ = 4.24 ft/sec

σ_v = 4685 ft $\sigma_{\dot{v}}$ = 1.26 ft/sec

σ_w = 3639 ft $\sigma_{\dot{w}}$ = 8.45 ft/sec

Table IV. Error Model for Rendezvous Analysis

Error Source	1σ Uncertainty
Lunar gravitational potential μ_{moon}*	7.10×10^9 ft^3/sec^2
IMU misalignment	0.33 mr per axis
IMU drift	0.139×10^{-6} rad/sec per axis
RR range bias	170 ft/27 ft for range (greater than 50 n mi/less than 50 n mi)
RR range rate bias	0.3 ft/sec
Noise:	
angle data	1.0 mr
range	25.2 ft or 0.333% of range (whichever is greater)
range rate	0.433 ft/sec or 0.433% of range rate (whichever is greater)

*Assumptions concerning the LGC dynamics capability are as follows:

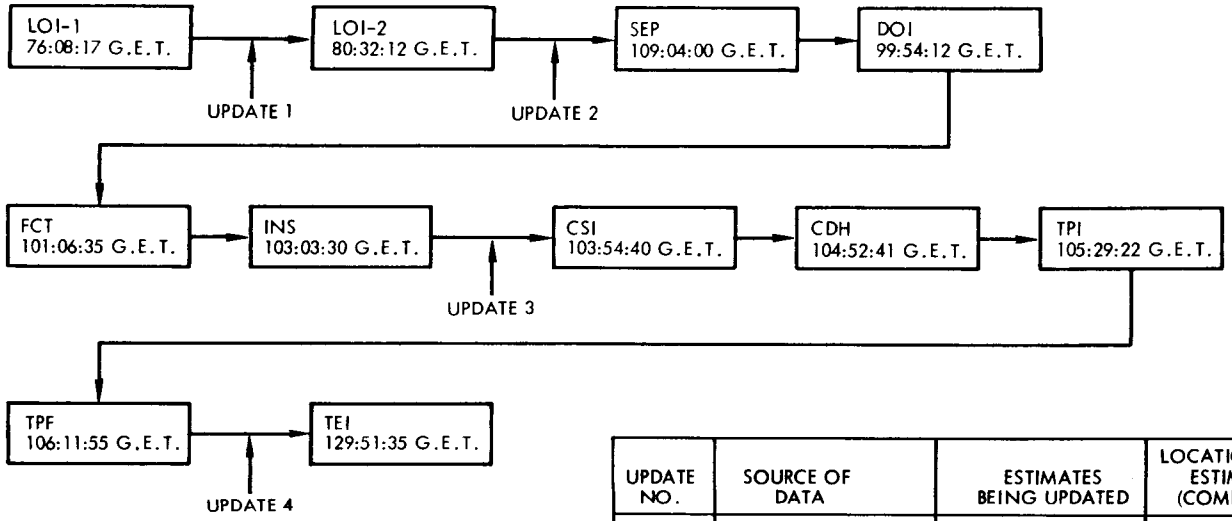
a) Propagation of the error in the CSM state is always treated as representative of an onboard R2 potential model.

b) Errors in LM state also exhibit growth as if propagated with R2, until relative tracking data are incorporated after INS. From then on the LM propagation errors are representative of an LGC and real-world with a spherical lunar potential.

c) The correlations built up between LM state error and CSM state error caused by incorporation of relative tracking data are calculated assuming an LGC with a spherical lunar potential. It is assumed that these correlations are not significantly different for LGC with R2 capability.

Table V. One-Sigma LGC Estimation Uncertainties During Rendezvous

		RST Position (ft)	RST Velocity (ft/sec)	σ_u (ft)	σ_v (ft)	σ_w (ft)	$\sigma_{\dot{u}}$ (ft/sec)	$\sigma_{\dot{v}}$ (ft/sec)	$\sigma_{\dot{w}}$ (ft/sec)	σ_{tr} (mr)	σ_{shaft} (mr)
DOI	Relative	30	0	6	20	14	0	0	0		
	LM	10,160	8.8	1,560	7,200	6,990	5.6	1.4	6.6	15	15
	CSM	10,140	8.8	1,560	7,190	6,980	5.6	1.4	6.6		
Phasing	Relative	2,430	1.8	1,000	1,420	1,720	1.3	1.0	0.9		
	LM	7,000	10.8	1,420	6,100	3,130	5.9	1.3	8.9	15	15
	CSM	7,950	9.8	1,430	6,190	4,780	5.5	1.3	8.0		
INS	Relative	22,110	18.0	12,220	18,240	2,580	17.9	1.7	1.3		
	LM	11,400	13.0	1,430	10,500	4,210	9.7	1.3	8.5		
	CSM	19,960	18.6	8,080	18,090	2,410	15.5	5.2	9.0	2.1	2.8
CSI	Relative	1,810	2.5	1,060	780	1,252	1.0	0.9	2.1		
	LM	9,890	8.5	1,680	7,030	6,750	5.7	1.4	6.2	2.4	1.1
	CSM	10,350	8.6	1,550	7,180	7,300	5.6	1.4	6.3		
PC	Relative	1,780	2.0	1,330	810	860	1.7	0.7	0.9		
	LM	10,470	9.3	1,970	7,740	6,760	6.4	1.4	6.6	0.8	1.6
	CSM	10,260	9.3	1,520	7,760	6,530	6.0	1.3	7.0		
CDH	Relative	2,200	2.5	1,660	1,100	920	2.3	0.6	0.9		
	LM	10,280	8.8	2,270	6,500	7,640	6.0	1.4	6.3	1.2	1.8
	CSM	10,240	8.2	1,470	6,440	7,830	5.5	1.3	5.9		
TPI	Relative	1,510	1.9	1,170	850	460	1.7	0.4	0.7		
	LM	11,370	7.7	1,980	6,800	8,900	6.4	1.4	4.1	1.7	2.1
	CSM	11,340	7.5	1,500	6,770	8,970	6.0	1.3	4.4		
MC-1	Relative	360	0.7	220	220	190	0.4	0.4	0.4		
	LM	12,620	7.5	1,580	7,870	9,730	6.7	1.5	3.0	1.8	2.8
	CSM	12,660	7.3	1,550	7,940	9,740	6.7	1.4	2.8		
MC-2	Relative	360	0.5	260	170	180	0.3	0.3	0.2		
	LM	10,310	11.0	1,540	9,000	4,780	7.3	1.4	8.1	1.9	3.2
	CSM	10,320	10.9	1,530	9,030	4,760	7.3	1.4	8.1		



UPDATE NO.	SOURCE OF DATA	ESTIMATES BEING UPDATED	LOCATIONS OF ESTIMATE (COMPUTER)	TIME TAG	UPDATE TIME
1	MSFN REVOLUTION 1	CSM AND LM	LGC AND CMC	LOI-2 - 10 MIN	REVOLUTION 2
2	MSFN REVOLUTIONS 10, 11	LM	LGC AND CMC	DOI - 10 MIN	REVOLUTION 12
	MSFN REVOLUTIONS 10, 11 + CONFIRMED ΔV FOR SEP BURN	CSM	LGC AND CMC	FCT + 5 MIN	REVOLUTION 12
3	MSFN REVOLUTIONS 12, 13	CSM	LGC AND CMC	INS + 20 MIN	BEFORE INS
	LGC	LM	CMC	INS + 20 MIN	AFTER INS
4	MSFN REVOLUTION 26, 27	CSM	CMC	TEI - 10 MIN	REVOLUTION 28

Figure 1. F Mission Lunar Orbit Phase Event Schedule

In the figure below the numbers above the line refer to minutes of time during which there is no tracking; those below the line refer to the number of marks. The letter R refers to reinitialization of the fit-world covariance matrix. The data rate was one mark per minute.

Post-INS tracking was used to update the LM state. Pre-INS tracking was used to update the CSM state.

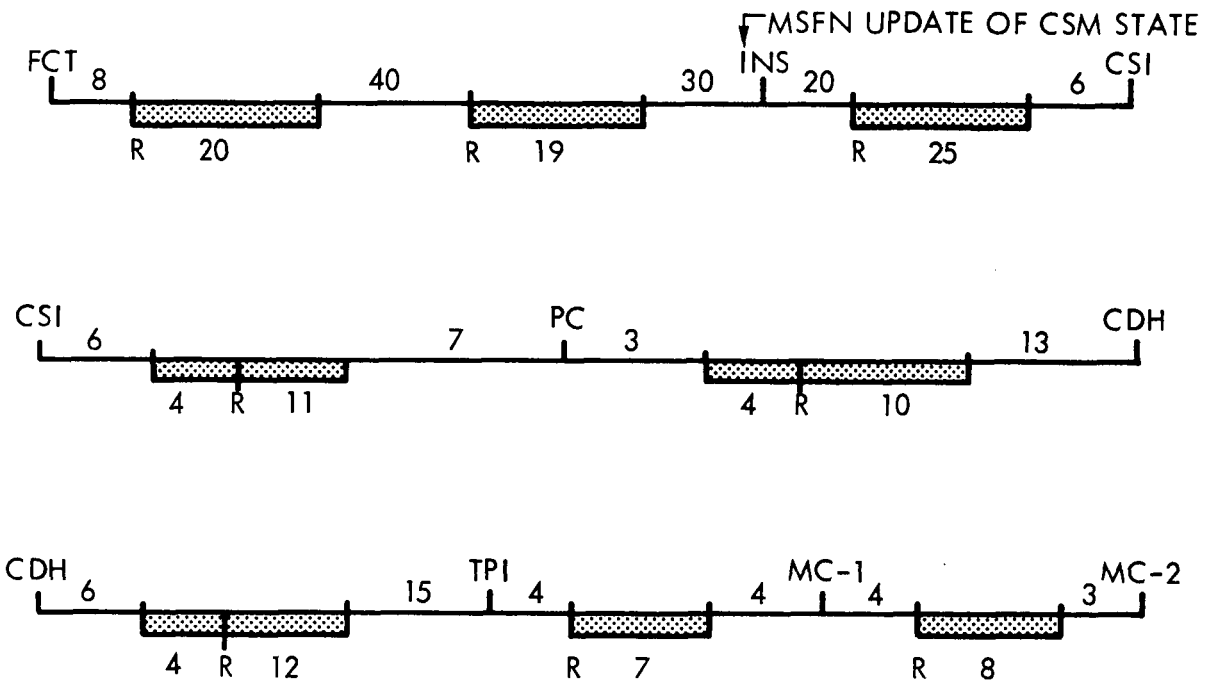


Figure 2. Rendezvous Radar Tracking Schedule

APPENDIX

This appendix contains covariance matrices for the relative state, LM state, and CSM state uncertainties at each maneuver time during the F mission rendezvous. The matrices are symmetric and, thus, only the lower triangular portion is shown. The numbers in the upper triangular portion are correlation coefficients. Correlation coefficients relating to the CSM state uncertainties and the LM state uncertainties are also presented.

Relative State Covariance Matrix

.36094774+02	.14744757-00	.65479120-03	-.10746650+00	.57386573-00	.70059514-03
.18072722+02	.41622446+03	.12894728-03	-.98804110-00	.88857496-00	.23094724-03
.55859198-01	.37354738-01	.20162269+03	-.46040757-03	.63352741-03	.98246679-00
-.11249545-01	-.35121940-00	-.11390738-03	.30358437-03	-.84801272-00	-.54670463-03
.56400009-01	.26500620-00	.13150228-03	-.21599327-03	.21369597-03	.74052351-03
.25144533-04	.28146920-04	.83337770-01	-.56904518-07	.64668280-07	.35686880-04

LM State Covariance Matrix

.24397686+07	-.38904501-00	.33940899-04	.43097562-00	-.99880229-00	-.35068882-04
-.43776460+07	.51895888+08	.62307566-04	-.98486792-00	.38051319-00	-.62149494-04
.37078261+03	.31392721+04	.48915152+08	-.69812854-04	-.35514187-04	-.98081724-00
.37600908+04	-.39629243+05	-.27272717+01	.31199140+02	-.42042010-00	.69302868-04
-.21372007+04	.37551531+04	-.34026325-00	-.32169644+01	.18766485+01	.36362238-04
-.36160877-00	-.29556077+01	-.45284806+05	.25554374-02	.32884012-03	.43579821+02

CSM State Covariance Matrix

.24273560+07	-.38459760-00	.34562461-04	.42624778-00	-.99882758-00	-.35700832-04
-.43079605+07	.51688842+08	.62151625-04	-.98484528-00	.37849576-00	-.61993773-04
.37586077+03	.31189361+04	.48720438+08	-.69673637-04	-.35962749-04	-.98077434-00
.36993776+04	-.39442661+05	-.27090927+01	.31031274+02	-.41820735-00	.69160983-04
-.21293769+04	.37235287+04	-.34348183-00	-.31877683+01	.18723653+01	.36821485-04
-.36751372-00	-.29449297+01	-.45232767+05	.25455957-02	.33290863-03	.43657307+02

FCT

Relative State Covariance Matrix

.99065528+06	-.26620282-00	.26829710-03	.53641933-00	.73855107-00	.40282443-03
-.37524129+06	.20057343+07	-.13337244-03	-.93420419-00	.36481439-00	-.38627090-04
.45450582+03	-.32148817+03	.28968393+07	-.40589105-03	-.37848719-03	.98968594-00
.67428075+03	-.16709120+04	-.87246244-00	.15949612+01	-.70322946-01	-.47145832-03
.69788298+03	.49051180+03	-.61158130-00	-.84316567-01	.90132538-00	-.17171369-03
.37485304-00	-.51146116-01	.15748658+04	-.55667578-03	-.15241569-03	.87411370-00

LM State Covariance Matrix

.20115931+07	.15624450-00	.15683105-05	-.17411920-00	-.99631418-00	.51957628-04
.13518692+07	.37215145+08	-.78685692-04	-.97067796-00	-.14203704-00	.34203633-04
.69558002+01	-.15010688+04	.97788989+07	.11098897-03	.45214432-04	-.94608922-00
-.14463423+04	-.34680824+05	.20327276+01	.34301157+02	.15567678-00	-.73381853-04
-.18568537+04	-.11386042+04	.18579473-00	.11980903+01	.17267230+01	-.88168589-04
.65675718-00	.18595914+01	-.26367109+05	-.38302621-02	-.10325490-02	.79427499+02

CSM State Covariance Matrix

.20476875+07	.17829812-00	-.20004632-05	-.18952226-00	-.99839642-00	.23716195-05
.15792906+07	.38314832+08	-.55306789-04	-.97113051-00	-.20726611-00	.53349087-04
-.13673325+02	-.16352103+04	.22815154+08	.56424856-04	.36444192-05	-.97181454-00
-.14895003+04	-.33014868+05	.14802350+01	.30164561+02	.21813950-00	-.54490560-04
-.18036404+04	-.16196711+04	.21976327-01	.15125089+01	.15937867+01	-.35707331-05
.27124508-01	.26393408+01	-.37100529+05	-.23919648-02	-.36029439-04	.63880752+02

Relative State Covariance Matrix

.14925327+09	-.81388881-00	.16635203-03	.90693939-00	-.46951684-00	.14519268-02
-.18137682+09	.33274352+09	-.17829628-03	-.97817159-00	.47274110-00	-.10143345-02
.52432735+04	-.83909198+04	.66561788+07	.16495182-03	.43461209-03	.35431294-00
.19789529+06	-.31868756+06	.76008974+01	.31899989+03	-.53701660-00	.12351428-02
-.98442990+04	.14799596+05	.19243585+01	-.16460941+02	.29453940+01	-.20832604-02
.22541280+02	-.23512994+02	.11616396+04	.28033954-01	-.45434651-02	.16148934+01

LM State Covariance Matrix

.20383039+07	.17270637-00	-.37794276-04	-.18668553-00	-.99323378-00	.81601039-04
.25887148+07	.11023333+09	-.19767859-03	-.98964643-00	-.23434144-00	.14812649-03
-.22720902+03	-.87393910+04	.17730874+08	.21305986-03	.86632743-04	-.96762886-00
-.25972353+04	-.10125179+06	.87424441+01	.94958167+02	.24557212-00	-.16581906-03
-.18933613+04	-.32851341+04	.48707370-00	.31951611+01	.17827691+01	-.12005172-03
.99020350-00	.13218541+02	-.34631250+05	-.13733932-01	-.13624175-02	.72241805+02

CSM State Covariance Matrix

.65204038+08	-.90247760-00	.47384653-03	.93285020-00	-.99724751-00	.43040857-03
-.13183371+09	.32726958+09	-.13433976-03	-.97438001-00	.88996068-00	-.62359419-03
.92170551+04	-.58542956+04	.58027581+07	.35696212-03	-.41927148-03	-.73134199-00
.11642201+06	-.27243765+06	.13290010+02	.23887566+03	-.91431125-00	.51246672-03
-.42091905+05	.84155408+05	-.52792342+01	-.73864947+02	.27322269+02	-.48616757-03
.31102399+02	-.10095565+03	-.15765708+05	.70880593-01	-.22741552-01	.81085053+02

CSI

Relative State Covariance Matrix

.11174641+07	-.24259754-00	-.17264663-02	.39652140-00	.76611016-00	.32584181-02
-.19901902+06	.60225835+06	-.23666100-02	-.81851421-00	.33950543-01	.23750740-02
-.22845283+04	-.22996[illegible]43+04	.15669074+07	-.14461662-02	-.11650309-02	-.75360717-00
.41007005+03	-.62143007+03	-.17709835+01	.95708226-00	-.99688716-01	.35582840-02
.79734715+03	.23012444+02	-.12737486+01	-.85181490-01	.76286765-00	.44881082-03
.72166463+01	.38617163+01	-.19764166+04	.72933499-02	.82129606-03	.43895867+01

LM State Covariance Matrix

.28370272+07	-.39732160-00	-.16194751-02	.47562400-00	-.96798536-00	.20240464-02
-.47031860+07	.49389709+08	.12652767-03	-.98020697-00	.39869321-00	-.93594339-04
-.18401009+05	.59984548+04	.45506271+08	-.47986660-03	.12320681-02	-.95190568-00
.45303359+04	-.38955691+05	-.18305898+02	.31979361+02	-.45545074-00	.63179469-03
-.22649639+04	.38924032+04	.11545988+02	-.35779730+01	.19298409+01	-.12768731-02
.21102718+02	-.40714958+01	-.39748040+05	.22115514-01	-.10979806-01	.38315311+02

CSM State Covariance Matrix

.23969545+07	-.37213269-00	.37279960-04	.41819254-00	-.99882107-00	-.37906034-04
-.41342034+07	.51490636+08	.55934021-04	-.98478067-00	.36805053-00	-.55767591-04
.42103525+03	.29278801+04	.53214040+08	-.64632291-04	-.37092711-04	-.98090246-00
.36[illegible]40504+04	-.39335830+05	-.26245046+01	.30986274+02	-.41219604-00	.64158176-04
-.21748401+04	.35947864+04	-.36830126-00	-.31231297+01	.18526912+01	.37649728-04
-.37226[illegible]67-00	-.25383[illegible]+01	-.45388711+05	.22654036-02	.32506654-03	.41236281+02

Relative State Covariance Matrix

.17795584+07	-.48028665-00	-.14801939-02	.73137969-00	.48639020-00	.17124627-02
-.51888760+06	.65539346+06	-.85372720-03	-.73227600-00	.13966838-01	-.19933872-02
-.17013749+04	-.59574590+03	.74242160+06	-.21778302-02	.20014305-03	.37951267-00
.16278204+04	-.98946154+03	-.31308106+01	.27836520+01	-.98339795-01	.21769387-02
.46722730+03	.81452047+01	.12418041+00	-.11814736+00	.51853078-00	-.20210477-02
.20669651+01	-.14183091+01	.28728580+03	.31909224-02	-.12785756-02	.77183624-00

LM State Covariance Matrix

.38811760+07	.12140871-02	-.19975993-02	.11019986+00	-.77293232-00	-.15892885-02
.18515945+05	.59927861+08	-.72426695-04	-.97258455-00	-.10859180+00	-.14678574-03
-.26603455+05	-.37901905+04	.45697372+08	-.47871289-03	.20865014-02	.97345013-00
.13822594+04	-.47936750+05	-.20603924+02	.40537194+02	.10918608+00	-.34076982-03
-.20641858+04	-.11395597+04	.19120196+02	.94236635-00	.18376015+01	.18637882-02
-.20700799+02	-.75127852+01	.43507527+05	-.14344673-01	.16704171-01	.43712475+02

CSM State Covariance Matrix

.23049442+07	.12600516-00	-.37063185-05	-.14138625-00	-.99879698-00	-.29705127-05
.14850790+07	.60264573+08	-.37585713-04	-.98830949-00	-.13649000-00	-.41456947-04
-.36766142+02	-.19064655+04	.42692368+08	.48033357-04	-.90007079-05	.98026963-00
-.12810145+04	-.45786843+05	.18729870+01	.35615037+02	.15350392-00	.52094917-04
-.20118748+04	-.14058061+04	-.78027076-01	.12154293+01	.17603016+01	-.96756893-05
-.31426733-01	-.22426730+01	.44633227+05	.21664549-02	-.89456742-04	.48559615+02

CDH

Relative State Covariance Matrix

.27529830+07	-.79408257-00	-.19403977-02	.93592431-00	-.47211158-00	-.39389879-03
-.14520821+07	.12146397+07	.26372831-02	-.88854697-00	.58579811-00	-.66374800-03
-.29761247+04	.26868232+04	.85451012+06	-.20443806-02	.45827724-02	.37043674-00
.35736088+04	-.22535574+04	-.43489546+01	.52957691+01	-.65715807-00	-.93684396-04
-.47486940+03	.39138076+03	.25681161+01	-.91677365-00	.36749846-00	.41516291-03
-.55717667-00	-.62363929-00	.29193030+03	-.18379694-03	.21456200-03	.72679680-00

LM State Covariance Matrix

.51597402+07	.50236490-01	.19458318-02	.10347013+00	-.85592118-00	-.24009892-02
.74190161+06	.42269412+08	-.45914681-04	-.95519586-00	-.20913904-00	-.12312042-03
.33747174+05	-.22792023+04	.58295683+08	.81338619-03	-.14926786-02	-.96485759-00
.14152069+04	-.37393538+05	.37394352+02	.36256181+02	.14503972-00	-.75838096-03
-.27408256+04	-.19168226+04	-.16066387+02	.12311521+01	.19873183+01	.17467899-02
-.28703339+02	-.50549514+01	-.46521658+05	-.28837142-01	.15550636-01	.39879302+02

CSM State Covariance Matrix

.21531851+07	.28074442-00	-.20683338-05	-.30301420-00	-.99852133-00	.19862102-05
.26512260+07	.41418072+08	-.51993786-04	-.97397113-00	-.30620404-00	.50353688-04
-.23751096+02	-.26185974+04	.61241342+08	.52453081-04	.22713372-05	-.98046827-00
-.24555168+04	-.34616269+05	.22669011+01	.30498500+02	.32828154-00	-.50804853-04
-.18933745+04	-.25465040+04	.22969021-01	.23427407+01	.16698484+01	-.21307795-05
.17042433-01	.18949246+01	-.44866440+05	-.16406282-02	-.16100626-04	.34192546+02

Relative State Covariance Matrix

.13655302+07	-.82213374-00	.24671996-02	.97396545-00	-.81243445-00	-.42671654-02
-.81324386+06	.71656457+06	-.17775505-02	-.88394165-00	.78206170-00	-.15355488-02
.13154382+04	-.68653885+03	.20817617+06	.27044191-02	-.15870115-02	.24750247-00
.19183778+04	-.12612210+04	.20798376+01	.28410567+01	-.84862990-00	-.24715962-02
-.40253584+03	.28069472+03	-.30701610-00	-.60649028-00	.17977577-00	.35933309-02
-.33831445+01	-.88190582-00	.76617146+02	-.28264961-02	.24720544-02	.46032213-00

LM State Covariance Matrix

.39141189+07	-.44360516-00	.10365504-02	.52731480-00	-.92034505-00	.61266975-03
-.59644035+07	.46185628+08	-.20610809-03	-.97000938-00	.44931406-00	-.13011869-03
.18253562+05	-.12467767+05	.79228314+08	.89729453-04	-.23874775-02	.95841493-00
.66219774+04	-.41843702+05	.50696264+01	.40290390+02	-.48835829-00	.44612870-04
-.25908705+04	.43449168+04	-.30238310+02	-.44107996+01	.20246784+01	-.20080859-02
.49090989+01	-.35813887+01	.34550323+05	.11468833-02	-.11572273-01	.16402750+02

CSM State Covariance Matrix

.22454455+07	-.43936227-00	.13948881-04	.45531622-00	-.99863824-00	.13224089-04
-.44552539+07	.45792765+08	.47813796-04	-.97686300-00	.41833339-00	.50700402-04
.18746479+03	.29018886+04	.80437424+08	-.42046094-04	-.25761016-05	.97313904-00
.40851306+04	-.39579806+05	-.22578563+01	.35849503+02	-.43357675-00	-.45181866-04
-.19753381+04	.37368266+04	-.30498189-01	-.34268062+01	.17424647+01	-.20744737-05
.86375524-01	.14954900+01	.38043254+05	-.11791781-02	-.11936132-04	.18999727+02

Relative State Covariance Matrix

.47183101+05	-.47104395-01	-.22454260-03	.86701195-00	-.82854351-01	.10813183-01
-.22070905+04	.46529774+05	.54065157-02	.14495927-01	.29622546-01	-.50943150-03
-.91743022+01	.21936332+03	.35380352+05	-.25681218-02	-.66664389-02	.13860460-00
.76702503+02	.12735109+01	-.19673784-00	.16587557-00	-.81103133-01	.84362349-02
-.68439525+01	.24298881+01	-.47684079-00	-.12561089-01	.14460951-00	-.34626379-03
.10229564+01	-.47858777-01	.11354527+02	.14964087-02	-.57347678-04	.18967962-00

LM State Covariance Matrix

.24817632+07	-.49973561-00	-.23003334-02	.53694654-00	-.95788277-00	.23914350-02
-.61970522+07	.61962564+08	-.16304309-03	-.98211769-00	.48641970-00	.18661952-03
-.35266773+05	-.12489983+05	.94708621+08	-.69525471-03	.12255718-02	-.94269703-00
.57045858+04	-.52136409+05	-.45630117+02	.45480559+02	-.51914305-00	.71870810-03
-.21811888+04	.55344769+04	.17239880+02	-.50605843+01	.20893031+01	-.12804146-02
.11363117+02	.44307829+01	-.27671047+05	.14619218-01	-.55822599-02	.90974029+01

CSM State Covariance Matrix

.24128217+07	-.50190990-00	.33546007-04	.53156839-00	-.99883047-00	-.32000600-04
-.61888471+07	.63014826+08	.35258099-04	-.98410419-00	.48893820-00	-.32120278-04
.50750200+03	.27259292+04	.94856835+08	-.33467659-04	-.31056623-04	-.94320261-00
.54936926+04	-.51976261+05	-.21687138+01	.44267519+02	-.51701504-00	.30018780-04
-.21224882+04	.53096544+04	-.41378950-00	-.47058348+01	.18714655+01	.29668882-04
-.13826288-00	-.70922743-00	-.25551957+05	.55554660-03	.11289559-03	.77369490+01

Relative State Covariance Matrix

.69264760+05	.99011639-01	-.69684056-02	.82875112-00	-.43959523-00	.88740799-02
.43317648+04	.27634175+05	.39403022-02	-.16418256-00	.65992092-00	-.35584851-01
-.32945093+03	.11766658+03	.32270247+05	.20332459-02	-.11374470-01	.24684712-00
.66815127+02	-.83607260+01	.11188853+00	.93840221-01	-.56607515-00	.20775410-01
-.34884226+02	.33077625+02	-.61610150-00	-.52286379-01	.90915918-01	-.32438298-01
.41257055-00	-.10449761+01	.78333575+01	.11242499-02	-.17278130-02	.31205953-01

LM State Covariance Matrix

.23749074+07	-.35246965-00	-.10433085-02	.38815100-00	-.97953559-00	.10315720-02
-.48901517+07	.81050290+08	.33088145-03	-.98811120-00	.38630705-00	-.51965600-03
-.76826994+04	.14234017+05	.22832610+08	-.14774135-04	.57857573-03	-.97099411-00
.43609085+04	-.64853889+05	-.51467463-00	.53150315+02	-.41577005-00	.20885596-03
-.21014412+04	.48415412+04	.38486791+01	-.42196830+01	.19379717+01	-.87369481-03
.12811946+02	-.37703829+02	-.37392681+05	.12271341-01	-.98022484-02	.64950797+02

CSM State Covariance Matrix

.23497189+07	-.37048929-00	.32542814-04	.39986792-00	-.99885911-00	-.34371377-04
-.51290046+07	.81564079+08	.21713982-04	-.98928930-00	.36236422-00	-.21092289-04
.23737835+03	.93318342+03	.22644155+08	-.27193584-04	-.31424213-04	-.97168224-00
.44656204+04	-.65092365+05	-.94276137-00	.53078001+02	-.38992351-00	.26385807-04
-.21625644+04	.44084927+04	-.20143633-00	-.38267672+01	.18146409+01	.33072311-04
-.42171714-00	-.15247181+01	-.37009967+05	.15386648-02	.35659584-03	.64066759+02

Matrices of Correlation Coefficients Relating CSM State Uncertainties and LM State Uncertainties Expressed in Their Local UVW Coordinate Systems

DOI

.99881660-00	-.22119068-00	.47084385-04	.24813479-00	-.99609169-00	-.37719451-04
-.24416617-00	.99996918-00	.76452849-04	-.98806692-00	.19161133-00	-.90016499-04
-.17333122-03	.52449072-04	.99972183-00	-.40807012-04	.11896700-03	-.90656277-00
.26852205-00	-.98870872-00	-.86643959-04	.99976190-00	-.21434350-00	.10261594-03
-.99747648-00	.21540999-00	-.46837388-04	-.24045497-00	.99748810-00	.36758648-04
.15772839-03	-.54856884-04	-.90737169-00	.33813398-04	-.12029958-03	.99995192-00

Phasing

.94847358-00	.13692283-00	.10217617-04	-.18333598-00	-.96242046-00	-.12202204-06
.25466410-00	.97223005-00	-.68394993-04	-.95213789-00	-.22717786-00	.80531428-04
-.26818112-04	-.47345581-04	.99409761-00	.75889383-04	.72164084-04	-.97558420-00
-.23373498-00	-.94104066-00	.76629947-04	.97817770-00	.20259792-00	-.87616918-04
-.94913416-00	-.16536673-00	-.79923845-05	.21149336-00	.96440759-00	-.18922796-05
.57425023-04	.50736526-05	-.94073857-00	-.38752191-04	-.94555090-04	.99980118-00

INS

.16007218-00	.77537578-01	.22050951-04	-.73440865-01	-.16655972-00	-.31713405-04
-.47314547-01	.41075959-01	.26134783-03	.86298466-02	.39438803-01	-.26013225-03
-.82195297-04	-.47229205-03	.83194499-00	.54166703-03	.12667669-03	-.73498210-00
-.52328780-02	-.16571064-00	-.11253533-03	.13955542-00	.17468259-01	.11370908-03
-.21709579-00	-.10637171+00	.36641380-04	.10218980+00	.22687396-00	-.25927023-04
.65905511-04	.16185228-03	-.96888958-00	-.15194528-03	-.11666109-03	.99071258-00

Matrices of Correlation Coefficients Relating CSM State Uncertainties and LM State Uncertainties Expressed in Their Local UVW Coordinate Systems

CSI

.94231594-00	-.34789190-00	.42294975-04	.41245344-00	-.98878020-00	-.12090184-04
-.40620973-00	.99363493-00	.13242470-03	-.97226119-00	.41657604-00	-.14029805-03
-.14210102-02	.79349125-04	.98714122-00	-.30850621-03	.13032853-02	-.92610449-00
.43808860-00	-.97680370-00	-.14769086-03	.98539355-00	-.44866401-00	.16338390-03
-.94169530-00	.34388749-00	-.42872404-04	-.40677567-00	.99034290-00	.13166377-04
.14027257-02	-.83703684-04	-.96617207-00	.30056553-03	-.13139513-02	.94440087-00

PC

.80387682-00	.13966502-00	-.15011013-03	-.12504665-00	-.97274458-00	.46247884-04
.21559846-01	.99443831-00	-.25549696-03	-.95816220-00	-.98991059-01	-.30746497-03
-.17833128-02	.15869173-03	.99217437-00	-.64341982-03	.20092049-02	.97172458-00
-.44641409-01	-.98234729-00	.27557129-03	.96572307-00	.12087491+00	.30606584-03
-.80272606-00	-.14999901-00	.14029857-03	.13654146-00	.97393458-00	-.56283118-04
-.17823760-02	.14772789-03	.97385781-00	-.63864478-03	.19960166-02	.99300624-00

CDH

.70103963-00	.28426083-00	-.15830901-03	-.29418506-00	-.84540579-00	.61954296-04
.13715234-00	.96429414-00	-.40936243-03	-.92096031-00	-.20822095-00	-.76064653-04
.14117228-02	.44276650-03	.99563320-00	.22840666-03	-.63176696-03	-.97607432-00
-.18634069-00	-.92865089-00	.33585273-03	.92837842-00	.25367507-00	-.11052282-03
-.69847465-00	-.30864609-00	.16693883-03	.31790160-00	.84538156-00	-.58830274-04
-.14849300-02	-.41643944-03	-.97448640-00	-.26098915-03	.69817148-03	.99284548-00

Matrices of Correlation Coefficients Relating CSM State Uncertainties and LM State Uncertainties Expressed in Their Local UVW Coordinate Systems

TPI

.80713108-00	-.44144694-00	-.74[illegible]107-04	.45888430-00	-.958874[illegible]6-00	-.99023423-05
-.38206771-00	.99224417-00	.32152290-03	-.95316175-00	.41774137-00	.38908516-03
.10382973-02	-.46740716-03	.99872478-00	.32026775-03	-.24431410-02	.95774557-00
.37115033-00	-.96397284-00	-.31705557-03	.96421568-00	-.41938060-00	-.23216222-03
-.80598040-00	.42078964-00	.79040053-04	-.43816315-00	.96[illegible]5279-00	.15949347-04
.10376365-02	-.44516046-03	.97241898-00	.31632628-03	-.23881699-02	.98966379-00

MC-1

.99049332-00	-.50242695-00	-.11694508-03	.53368489-00	-.96420107-00	.16346845-03
-.49896542-00	.99966382-00	.32177979-03	-.98284827-00	.48552615-00	-.27046667-03
-.21500307-02	-.45239915-03	.99981365-00	-.40865496-03	.11140750-02	-.94322015-00
.52775421-00	-.98328286-00	-.31722867-03	.99824505-00	-.51607818-00	.33298334-03
-.98933891-00	.48949777-00	.11577493-03	-.51921407-00	.96482293-00	-.15951963-03
.20326431-02	.42675863-03	-.94299250-00	.37544873-03	-.11170154-02	.99197716-00

MC-2

.98644593-00	-.37235584-00	-.34891421-05	.40011983-00	-.97548561-00	.39722128-04
-.35072621-00	.99983537-00	.19917013-03	-.98814831-00	.38197728-00	-.37425625-03
-.96824934-03	.15125377-03	.99929897-00	.14450512-03	.63[illegible]35008-03	-.97170708-01
.38194938-00	-.98912232-00	-.19116950-03	.99912029-00	-.41[illegible]38497-00	.38130212-03
-.98528519-00	.36424356-00	.43567405-05	-.39016542-00	.97612051-00	-.37196035-04
.92637391-03	-.15360655-03	-.97119683-00	-.16315529-03	-.64214914-03	.99978156-00

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