TRW NOTE NO. 69-FMT-764

PROJECT APOLLO
TASK MSC/TRW A-190

LOW SPEED REENTRY GUIDANCE DISPERSION EVALUATION

29 JULY 1969

Prepared by
Atmospheric Flight Mechanics Section

Prepared for
MISSION PLANNING AND ANALYSIS DIVISION
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS
NAS 9-8166

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TABLES

1. INTRODUCTION AND SUMMARY

The purpose of this report is to present a set of partial derivatives relating entry guidance errors to touchdown dispersions. Two sources of errors were studied, i.e., guidance system initialization errors at the entry interface and inertial measurement unit (IMU) hardware errors. These two error sources were taken independently of each other and no attempt was made to couple the error sources. This study, which was conducted under MSC/TRW Task A-190, Reference 1, is applicable to Apollo guided entries with entry velocities less than 27,000 feet per second and for realistic values of the error sources considered.

Three sets of partial derivatives are presented within this report. Of these three, only the Navigation-Actual (NAV-ACT) partials are constant with respect to error magnitude. The NAV-ACT partial is the most significant because it does not contain the effect of the perturbation on the random control errors. The other two sets of partials, both of which contain the perturbation's effect on the control error, are presented for information purposes only.

One sigma IMU hardware errors and realistic, but arbitrary, values of initialization errors were used to generate the touchdown dispersions. Most of the touchdown dispersions were less than 1.0 nautical mile and no dispersion was larger than 1.5 nautical miles. The partials were formed by dividing the dispersions by the magnitude of the error source.

This report parallels Reference 2 which presents a similar analysis for high-speed entries. The results presented in this report are similar to those presented in Reference 2.

2. METHOD OF APPROACH

This section discusses the methods used to develop the partials presented in this report. The following subsections describe the math model, the initial conditions, the comparisons used to determine the partials, and the method of presenting the partials.

2.1 MATH MODEL

The basic math model used in this analysis is the Apollo Reentry Simulation Program, version 4 (ARS04), Reference 3. This model is capable of simulating both the entry guidance system as programmed on the command module computer (CMC) and the actual trajectory. The two sets of equations may be initiated independently of one another, with subsequent position and velocity components being calculated independently. The only interfaces between the two sets of equations are the aerodynamic body forces. These are calculated by the trajectory equations and are used as inputs to the guidance routine.

Initialization errors were introduced by initiating the guidance equations with a state vector which was different from the trajectory equation initialization vector. IMU hardware errors were introduced by altering the accelerations calculated by the trajectory equations before they were used by the guidance routine.

The basic ARS04 IMU math model was modified to compensate for the Block II vehicle Z-platform axis gyroscope alignment. The basic ARS04 IMU model was programmed for a Block I vehicle. The modification resulted in a sign change for various terms affecting the drift rate about the Z-platform axis. The generalized equations used in the IMU error model are presented in Appendix A.

2.2 INITIAL CONDITION DATA

The entry vector from the Apollo 9 mission was assumed to be a nominal low speed entry vector and was used in this analysis. Splashdown dispersions were generated for four target ranges, i.e., relative ranges of 1250, 1500, 2000, and 2500 nautical miles. The distances between these target ranges necessitated adjusting the velocity vector's position within the entry corridor. Entry flight-path angles were chosen as described in Reference 4 to be compatible with the target range and entry velocity.

The state vectors and targets used in this analysis are presented in Table 1 along with the vehicle constants and environment.

2.3 DEFINITION OF COORDINATE SYSTEMS

This subsection defines the coordinate systems in which the partial derivatives are presented. Two sets of partials are presented for the initialization errors. One set describes the range differences at splash-down in the topocentric coordinate system due to a unit error in the orbit plane coordinate system. The other set describes the range differences in the topocentric coordinate system due to a unit error in the platform coordinate system. These coordinate systems are defined below and Appendix B contains the mathematical derivation of the topocentric and orbit plane coordinate systems.

2.3.1 Navigation Reference Frame (Platform Coordinate System)

Prior to lift-off, the guidance platform is released to hold a fixed attitude in inertial space. The Z-platform is aligned along the local vertical (down), the X-platform axis along the horizontal pointed downrange at an azimuth of 72.0 degrees east of true north, and the Y-axis completes the right-handed coordinate system. For reentry, the platform will nominally be aligned prior to the deorbit burn with the X-axis along the negative thrust vector ($-\vec{A}_T$), the Y-axis in the $-\vec{A}_T \times \vec{R}_G$ direction (R_G is the position of the space craft at retrofire), and the Z-axis completing the right-handed coordinate system.

2.3.2 Topocentric Coordinate System

The comparison vectors defined in Section 2.4 were calculated from the simulations in the platform coordinate system just defined: however, a more meaningful representation is used for presentation of the partials. The comparison vectors are rotated into a topocentric coordinate system with directions u', v', and w', where u' is downrange, v' is crossrange, and w' is altitude. Partials for both initialization and IMU errors are presented in the topocentric coordinate system.

2.3.3 Orbit Plane Coordinate System

The guidance position and velocity errors at entry may be expressed in an orbit plane coordinate system with directions u, v, and w: u is along the radius vector directed upward, v is directed downrange in the orbit plane, (formed by the position and velocity vectors at entry), and w is normal to the orbit plane.

2.4 DEFINITION OF COMPARISON VECTORS

Since the guidance equations calculate navigation (NAV) state vectors independently of the actual (ACT) trajectory equations of motion, the guidance and actual trajectory state vectors will differ at drogue chute deployment. Thus, when comparing a perturbed case to the nominal, there were four touchdown vectors to be compared. The most significant comparisons to be made between these four vectors were:

1) How well could the perturbed navigation trajectory simulate the resulting actual trajectory (NAV-ACT)

2) How well could the perturbed navigation trajectory simulate the nominal unperturbed actual trajectory (NAV-NOM)

3) How well did the actual trajectory resulting from a perturbed navigation trajectory approximate the nominal unperturbed actual trajectory (ACT-NOM)

No simulation will hit the precise target due to a condition which exists called "overcontrol" or "undercontrol." These control effects are due to such factors as the simplified trajectory equations in the guidance routine, the large computation cycle of the guidance routine (2 seconds), and the time lag between issuance of the roll command and acquisition of the proper bank angle. These control effects are non-linear functions of the guidance errors and the presence of these control errors in comparisons 2 and 3 above causes their non-linearity.

Comparison 1 above was determined to be the most informative since this comparison of partials does not contain the control effects. This fact is illustrated in the mathematical derivation of the comparison vectors presented in Appendix C.

3. RESULTS

The range partials with respect to initialization and IMU errors and the errors used to determine the partials are presented in this section.

3.1 RANGE PARTIALS DUE TO IMU ERRORS

Touchdown dispersions were generated for one sigma (1σ) values of IMU errors taken from Reference 5. These errors were treated independently of one another and no attempt was made to couple the effects. The IMU errors are defined in Table 2. Also presented in Table 2 are the 1σ values of the IMU errors.

The partials formed by dividing the 1σ touchdown dispersion by the IMU error magnitude are presented in Table 3. The transformation matrix formed by the partials correlates a covariance matrix of IMU errors with range dispersions at drogue chute deployment. The NAV-ACT dispersion is linear; thus, only the partials resulting from positive error source are presented. The NAV-NOM and ACT-NOM dispersions are nonlinear and are presented based on both the positive and negative error sources.

3.2 RANGE PARTIALS DUE TO INITIALIZATION ERRORS

Touchdown dispersions were generated for initialization errors of the same magnitude as those used in Reference 2. These errors expressed in platform coordinates are:

$$X_p = \pm 10{,}000.0 \text{ ft.} \qquad \dot{X}_p = \pm 10.0 \text{ ft/sec}$$

$$Y_p = \pm 10{,}000.0 \text{ ft.} \qquad \dot{Y}_p = \pm 10.0 \text{ ft/sec}$$

$$Z_p = \pm 10{,}000.0 \text{ ft.} \qquad \dot{Z}_p = \pm 10.0 \text{ ft/sec}$$

The errors were taken independently of one another and no attempt was made to couple the effects.

The partials are formed by dividing the dispersions by the appropriate error magnitude. The transformation matrix of these partials correlates a covariance matrix of initialization errors at the entry interface with range dispersions at drogue deployment.

These partials are presented in Table 4. Due to the linearity of the NAV-ACT dispersion, only the partial derived from the positive error source are presented. Partials based upon both positive and negative error sources are presented for the NAV-NOM and ACT-NOM partials, since the resulting dispersions are non-linear.

APPENDIX A

IMU ERROR MODEL

Two types of IMU errors were studied, i.e., gyroscope (gyro) errors and accelerometer errors. The gyros determine the inertial platform coordinate system; thus, a misalignment of the gyro causes a misalignment of the platform coordinate axes. The errors defined in Table 2 affect the misalignment angle in the following manner:

$$\theta(i) = THETAP(i) + W(i) \cdot t$$

and

$$W(i) = GCDR(i) + GSAU(i) \cdot A(1) + GIAU(i) \cdot A(2) + GANI(i) \cdot A(1) \cdot A(2)$$

where

$\theta(i)$ = i^{th} gyro misalignment about the input axis
$W(i)$ = i^{th} gyro drift rate about the input axis
$A(1)$ = Acceleration along the i^{th} gyro input axis
$A(2)$ = Acceleration along the i^{th} gyro spin axis
$THETAP(i)$ = i^{th} gyro initial misalignment angle
$GCDR(i)$ = i^{th} gyro uncompensated drift rate
$GSAU(i)$ = i^{th} gyro drift rate due to acceleration along its input axis
$GIAU(i)$ = i^{th} gyro drift rate due to acceleration along its spin axis
$GANI(i)$ = i^{th} gyro drift rate due to acceleration along its input and spin axes

The accelerometer errors defined in Table 2 affect the sensed acceleration received by the guidance routine in the following manner:

$$\underline{A}(i) = \sum_{j=1}^{3} EPS\,(i,j) \cdot A(j)$$

and

$$A(i) = B(i) + \{1.0 + SF(i)\} \cdot A(i) + QUAD(i) \cdot A^2(i)$$

where

A(i) = corrected acceleration along the i^{th} gyro input axis

A(j) = sensed acceleration along the j^{th} gyro input axis

EPS(i,j) = accelerometer misalignment

B(i) = accelerometer bias

SF(i) = accelerometer scale factor error

QUAD (i) = accelerometer non-linearity

APPENDIX B

MATHEMATICAL DERIVATION OF THE TOPOCENTRIC AND ORBIT PLANE COORDINATE SYSTEM

This appendix presents the mathematics used to relate the topocentric and orbit plane coordinate systems to the platform coordinate system.

Topocentric Coordinate System

The topocentric coordinate system (u', v', w') is a right-handed system centered at the nominal touchdown point (altitude = 23,500 feet), as seen in Figure B-1. The nominal touchdown is the zero perturbation touchdown point. The direction of the coordinates are calculated from the instantaneous vehicle positions at entry interface (R_{EI}) and touchdown (R_{TD}) expressed in navigation coordinates.

$$\hat{w}' = \begin{bmatrix} w'_x \\ w'_y \\ w'_z \end{bmatrix} = \vec{R}_{TD} / |\vec{R}_{TD}| \qquad \text{(B-1)}$$

$$\hat{v}' = \begin{bmatrix} v'_x \\ v'_y \\ v'_z \end{bmatrix} = \vec{R}_{EI} \times \vec{R}_{TD} / |\vec{R}_{EI} \times \vec{R}_{TD}| \qquad \text{(B-2)}$$

$$\hat{u}' = \begin{bmatrix} u'_x \\ u'_y \\ u'_z \end{bmatrix} = \hat{v}' \times \hat{w}' \qquad \text{(B-3)}$$

To convert a vector in the navigation coordinate system (x_N, y_N, z_N) to the topocentric coordinate system (u', v', w'), the following matrix multiplication is used:

$$\begin{bmatrix} u' \\ v' \\ w' \end{bmatrix} = \begin{bmatrix} u'_x & u'_y & u'_z \\ v'_x & v'_y & v'_z \\ w'_x & w'_y & w'_z \end{bmatrix} \cdot \begin{bmatrix} x_N \\ y_N \\ z_N \end{bmatrix} \qquad \text{(B-4)}$$

Orbit Plane Coordinate System

Since the covariance matrix at entry interface may be given in the orbit plane coordinate system (see Figure B-1) it was necessary to express the partial derivatives in the orbit plane coordinate system. The orbit plane coordinate system is a right-handed system centered at the entry interface. The directions of the coordinates are calculated from the position (R) and velocity (V) of the vehicle at the entry interface.

$$\hat{u} = \begin{bmatrix} u_x \\ u_y \\ u_z \end{bmatrix} = R/|R| \tag{B-5}$$

$$\hat{w} = \begin{bmatrix} w_x \\ w_y \\ w_z \end{bmatrix} = \vec{R} \times \vec{V}/|\vec{R} \times \vec{V}| \tag{B-6}$$

$$\hat{v} = \begin{bmatrix} v_x \\ v_y \\ v_z \end{bmatrix} = \hat{w} \times \hat{u} \tag{B-7}$$

To convert the partial derivatives ([D]) based on errors in the navigation coordinate system to errors expressed in the orbit plane coordinate system, it was necessary to perform the following matrix multiplication:

$$[D]_{\text{orbit plane}} = [D]_{NAV}\,[M] \tag{B-8}$$

where

$$[M] = \begin{bmatrix} u_x & v_x & w_x & & & \\ u_y & v_y & w_y & & 0 & \\ u_z & v_z & w_z & & & \\ & & & u_x & v_x & w_x \\ & 0 & & u_y & v_y & w_y \\ & & & u_z & v_z & w_z \end{bmatrix} \tag{B-9}$$

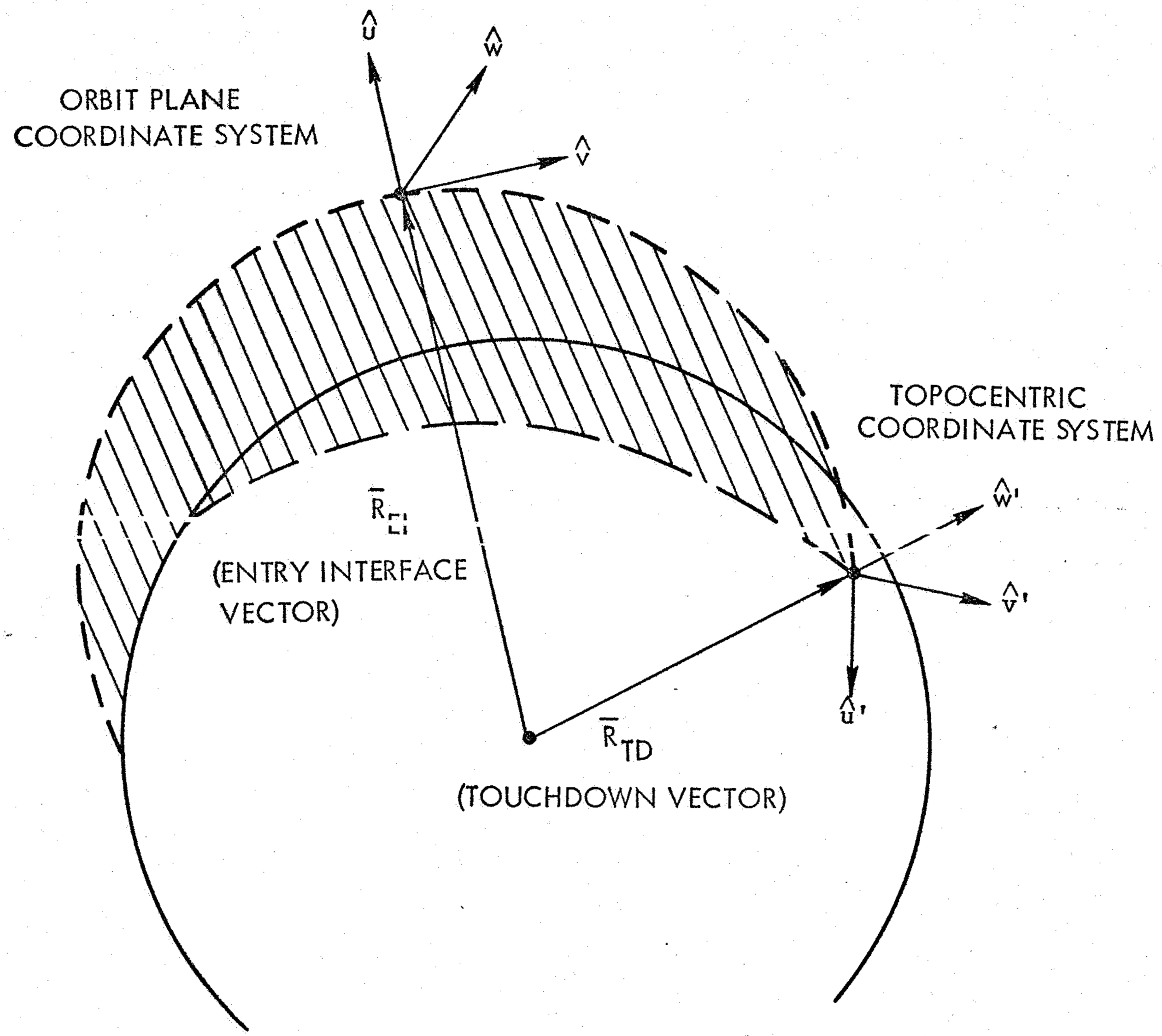

Figure B-1. Orbit Plane and Topocentric Coordinate Systems

APPENDIX C

RELATIONSHIP BETWEEN ENTRY AND TOUCHDOWN ERRORS

Introduction

The relationship between touchdown errors and entry errors is discussed in the following paragraphs along with the reasoning and assumptions that led to this relationship. For this analysis, refer to Figure C-1.

Approach Taken for the Analysis

Note that only the dispersions in the downrange and crossrange directions are to be considered.

Define: $\vec{P} = u' \hat{u}' + v' \hat{v}'$ (C-1)

where: $\vec{P}$ = the position vector in the topocentric coordinate system at touchdown (altitude = 23,500 feet), not including the altitude component. The coordinates (u', v') are in the downrange and crossrange directions, respectively.

The basic assumption to be taken in this analysis will be that of small perturbations of physical parameters. No perturbations will be introduced which will cause the guidance system to "lose control completely" and miss the target by a large distance. If no perturbation errors are introduced (nominal entry) into the simulation, then the difference between the navigation vector and the target vector at touchdown is due to overcontrol or undercontrol. This difference is $\Delta P_{c,o}$.

Then: $\vec{P}_{nav,o} = \vec{P}_{tar} + \Delta\vec{P}_{c,o}$ (C-2)

where the subscript "o" denotes nominal conditions.

The actual vector at touchdown (for this nominal entry) will differ from the navigation computed vector because of the approximations made in the guidance equations. This difference is $\Delta P_{n,o}$.

Then: $\vec{P}_{act,o} = \vec{P}_{nav,o} + \Delta\vec{P}_{n,o}$ (C-3)

Since $\vec{P}_{act,o}$ is the nominal touchdown point, $\vec{P}_{nom}$ is equal to $\vec{P}_{act,o}$. Substituting for $\vec{P}_{nav,o}$, equation C-3 becomes:

$$\vec{P}_{nom} = \vec{P}_{tar} + \Delta\vec{P}_{c,o} + \Delta\vec{P}_{n,o} \quad \text{(C-4)}$$

For a perturbation case, the computed navigation touchdown vector will differ from the target vector by $\Delta\vec{P}_c$ due to control errors, or:

$$\vec{P}_{nav} = \vec{P}_{tar} + \Delta\vec{P}_c \quad \text{(C-5)}$$

and the actual touchdown vector will differ from the navigation vector by the nominal ($\Delta\vec{P}_{n,o}$) in addition to the error induced by the perturbation ($\Delta\vec{P}_p$).

$$\vec{P}_{act} = \vec{P}_{nav} + \Delta\vec{P}_{n,o} + \Delta\vec{P}_p \quad \text{(C-6)}$$

or: $$\vec{P}_{act} = \vec{P}_{tar} + \Delta\vec{P}_c + \Delta\vec{P}_{n,o} + \Delta\vec{P}_p \quad \text{(C-7)}$$

Equations C-2, C-4, C-5, and C-7 are used to form the three comparison vectors. The following definitions are used in the analysis:

NOM = $\vec{P}_{nom}$; Equation C-4

NAV = $\vec{P}_{nav}$; Equation C-5

ACT = $\vec{P}_{act}$; Equation C-7

1) To form the NAV-NOM vector:

$$\begin{aligned}\vec{P}_{nav} - \vec{P}_{nom} &= \vec{P}_{tar} + \Delta\vec{P}_c - \vec{P}_{tar} - \Delta\vec{P}_{c,o} - \Delta\vec{P}_{n,o} \\ &= \Delta\vec{P}_c - \Delta\vec{P}_{c,o} - \Delta\vec{P}_{n,o}\end{aligned} \quad \text{(C-8)}$$

The presence of $\Delta\vec{P}_c$ and $\Delta\vec{P}_{c,o}$ in the above equation causes the non-linearity of this vector. From equations C-2 and C-5

$$\Delta\vec{P}_c - \Delta\vec{P}_{c,o} = \vec{P}_{nav} - \vec{P}_{tar} - \vec{P}_{nav,o} + \vec{P}_{tar} = \vec{P}_{nav} - \vec{P}_{nav,o} \quad \text{(C-9)}$$

Substituting equation C-9 into C-8:

$$\vec{P}_{nav} - \vec{P}_{nom} = \vec{P}_{nav} - \vec{P}_{nav,o} - \Delta\vec{P}_{n,o} \quad \text{(C-10)}$$

2) To form the NAV-ACT vector:

$$\vec{P}_{nav} - \vec{P}_{act} = \vec{P}_{tar} + \Delta\vec{P}_{c} - \vec{P}_{tar} - \Delta\vec{P}_{c} - \Delta\vec{P}_{n,o} - \Delta\vec{P}_{p} \tag{C-11}$$
$$= -(\Delta\vec{P}_{n,o} + \Delta\vec{P}_{p})$$

To find the effect of only the initialization or IMU error, it is necessary to subtract from equation C-11 the NAV-ACT vector for the nominal case:

$$\vec{P}_{nav,o} - \vec{P}_{act,o} = \vec{P}_{tar} + \Delta\vec{P}_{c,o} - \vec{P}_{tar} - \Delta\vec{P}_{c,o} - \Delta\vec{P}_{n,o} = -\Delta P_{n,o} \tag{C-12}$$

Subtracting C-12 from C-11:

$$(\vec{P}_{nav} - \vec{P}_{act}) - (\vec{P}_{nav,o} - \vec{P}_{act,o}) = -\Delta\vec{P}_{n,o} - \Delta\vec{P}_{p} + \Delta\vec{P}_{n,o} = -\Delta\vec{P}_{p} \tag{C-13}$$

In equation C-11 the effect of $\Delta\vec{P}_{c}$ was cancelled as was the effect of $\Delta\vec{P}_{c,o}$ in equation C-12. The cancellation of these two vectors causes the NAV-ACT comparison vector to be linear.

3) To form the ACT-NOM vector:

$$\vec{P}_{act} - \vec{P}_{nom} = \vec{P}_{tar} + \Delta\vec{P}_{c} + \Delta\vec{P}_{n,o} + \Delta\vec{P}_{p} - \Delta\vec{P}_{tar} - \Delta\vec{P}_{c,o} - \Delta\vec{P}_{n,o}$$
$$= \Delta\vec{P}_{c} - \Delta\vec{P}_{c,o} + \Delta\vec{P}_{p} \tag{C-14}$$

Substituting equation C-9 into equation C-14:

$$\vec{P}_{act} - \vec{P}_{nom} = \vec{P}_{nav} - \vec{P}_{nav,o} + \Delta\vec{P}_{p} \tag{C-15}$$

This comparison vector is also nonlinear due to the presence of $\Delta\vec{P}_{c}$ and $\Delta\vec{P}_{c,o}$ in its derivation (equation C-14).

Due to the linearity of the NAV-ACT vector, the following may be assumed:

$$\Delta\vec{P}_{p} = \frac{\partial\vec{P}_{p}}{\partial x_{n}}\Delta x_{n} + \frac{\partial\vec{P}_{p}}{\partial y_{n}}\Delta y_{n} + \frac{\partial\vec{P}_{p}}{\partial z_{n}}\Delta z_{n} + \frac{\partial\vec{P}_{p}}{\partial \dot{x}_{n}}\Delta \dot{x}_{n} + \frac{\partial\vec{P}_{p}}{\partial \dot{y}_{n}}\Delta \dot{y}_{n} + \frac{\partial\vec{P}_{p}}{\partial \dot{z}_{n}}\Delta \dot{z}_{n} \tag{C-16}$$

where

$(\Delta x_{n}, \Delta\dot{x}_{n})$ The amount by which the navigation x-platform component of the position vector and velocity vector is respectively perturbed in the CMC.

$(\Delta y_n, \Delta \dot{y}_n)$ The amount by which the navigation y-platform component of the position vector and velocity vector is respectively perturbed in the CMC.

$(\Delta z_n, \Delta \dot{z}_n)$ The amount by which the navigation z-platform component of the position vector and velocity vector is respectively perturbed in the CMC.

Separating the vector $\Delta \vec{P}_p$ into its downrange and crossrange components equation (C-16) can be represented by the following matrix notation:

$$\begin{bmatrix} \Delta u' \\ \Delta v' \end{bmatrix} = \begin{bmatrix} \frac{\partial u'}{\partial x_n} & \frac{\partial u'}{\partial y_n} & \frac{\partial u'}{\partial z_n} & \frac{\partial u'}{\partial \dot{x}_n} & \frac{\partial u'}{\partial \dot{y}_n} & \frac{\partial u'}{\partial \dot{z}_n} \\ \frac{\partial v'}{\partial x_n} & \frac{\partial v'}{\partial y_n} & \frac{\partial v'}{\partial z_n} & \frac{\partial v'}{\partial \dot{x}_n} & \frac{\partial v'}{\partial \dot{y}_n} & \frac{\partial v'}{\partial \dot{z}_n} \end{bmatrix} \cdot \begin{bmatrix} \Delta x_n \\ \Delta y_n \\ \Delta z_n \\ \Delta \dot{x}_n \\ \Delta \dot{y}_n \\ \Delta \dot{z}_n \end{bmatrix} \quad \text{(C-17)}$$

For the IMU errors equation C-16 takes the form:

$$\Delta \vec{P}_p = \sum_{i=1}^{n} \frac{\partial P_p}{\partial \alpha(i)} \cdot \Delta \alpha(i) \quad \text{(C-18)}$$

where $\alpha(i)$ is the IMU error source and $\Delta\alpha(i)$ is the error magnitude.

When considering IMU errors equation C-17 takes the form:

$$\begin{bmatrix} \Delta u' \\ \\ \Delta v' \end{bmatrix} = \begin{bmatrix} \frac{\partial u'}{\partial \alpha(1)} & \text{---} & \frac{\partial u'}{\partial \alpha(i)} \\ \\ \frac{\partial v'}{\partial \alpha(1)} & \text{---} & \frac{\partial v'}{\partial \alpha(i)} \end{bmatrix} \begin{bmatrix} \Delta\alpha(1) \\ \vdots \\ \Delta\alpha(i) \end{bmatrix} \quad \text{(C-19)}$$

The partials shown in equations C-17 and C-19 were determined and are shown in Tables 3 and 4 for 1250, 1500, 2000, and 2500 nautical mile ranges.

Small perturbations for the sensitive parameters are assumed in the above analysis since extrememly large parameter perturbations result in two problems. The first is that the CMC simulation loses control. The second is that in some simulations the navigation computed altitude may differ by a large amount from the altitude at actual drogue deployment. This condition presents the navigation correction logic with erroneous data causing over or under corrections which may be termed due to the geometric effect.

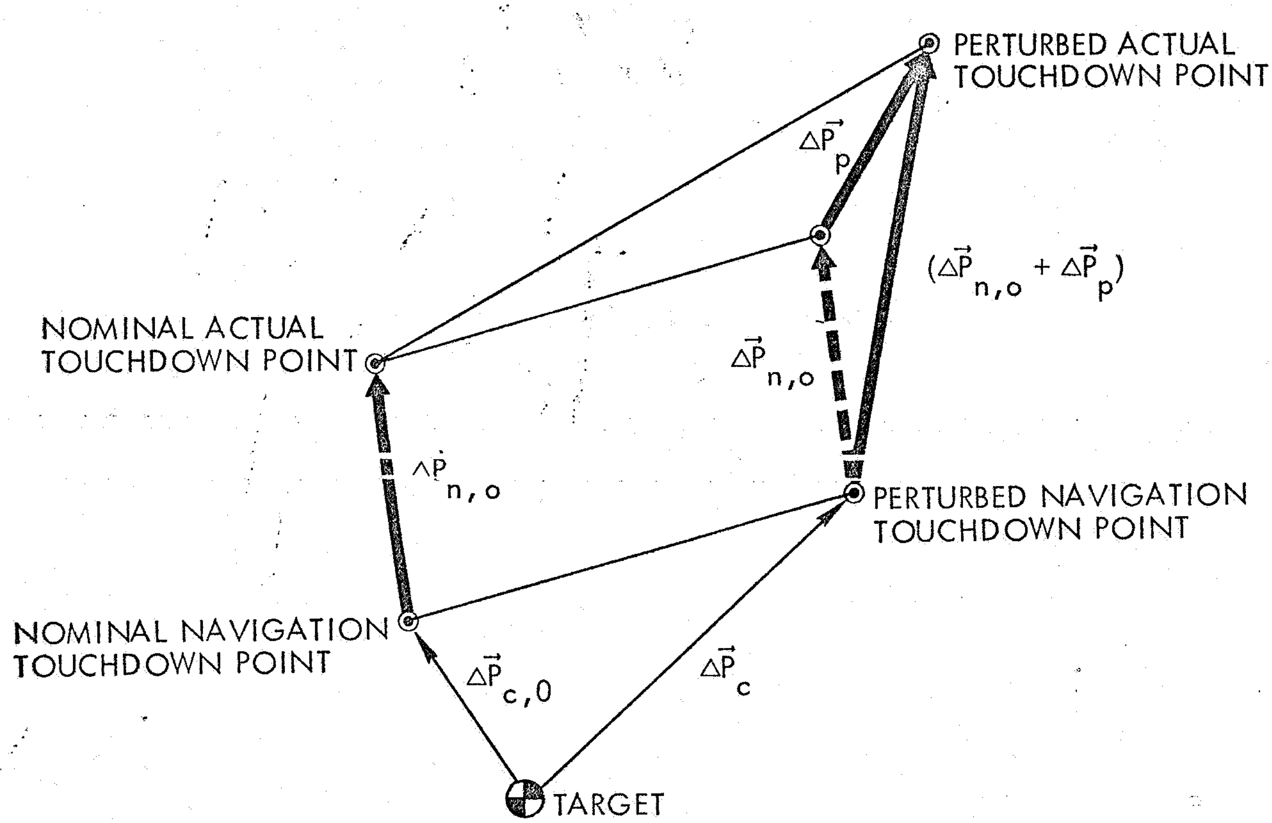

Figure C-1. Relation Between Splashdown Points

Table 1. Initial Condition Data

INITIALIZATION PARAMETERS	RANGE (NAUTICAL MILES)			
	1250	1500	2000	2500
ENTRY POSITION				
Platform Coordinates				
X (Ft)	20839254.	20839254.	20839254.	20839254.
Y (Ft)	13938.364	13938.364	13938.364	13938.364
Z (Ft)	4433781.2	4433781.2	4433781.2	4433781.2
$\dot{X}$ (Ft/Sec)	-6269.0488	-6165.0768	-5895.6685	-5829.6409
$\dot{Y}$ (Ft/Sec)	25.418624	25.492211	25.680484	25.726104
$\dot{Z}$ (Ft/Sec)	25122.776	25148.492	25213.011	25228.360
Geodetic Coordinates				
Altitude (Ft)	400100.0	400100.0	400100.44	400100.44
Latitude (Deg)	32.328851	32.328851	32.328851	32.328851
Longitude (Deg W)	98.875326	98.875326	98.875326	98.875326
Velocity (Ft/Sec)	25893.156	25893.156	25893.156	25893.156
Flight-path Angle (Deg)	-2.00	-1.763	-1.15	-1.00
Azimuth (Deg)	99.330179	99.330179	99.330179	99.330179
TARGET COORDINATES (GEODETIC)				
Latitude (Deg)	26.616	24.921	21.146	16.966
Longitude (Deg W)	76.029	71.710	63.608	55.861
Altitude (Ft)	23500.0	23500.0	23500.0	23500.0
VEHICLE CONSTANTS AND ENVIRONMENT				
Lift-to-Drag (L/D) Ratio	0.302	0.302	0.302	0.302
Weight (Lb)	12486.0	12486.0	12486.0	12486.0
Atmosphere	Standard	Standard	Standard	Standard

Table 2. IMU Hardware Error Definition and 1σ Values

ERROR	DEFINITION	MAGNITUDE	UNITS
THETAP	Initial Gyro Misalignment	40.0	Arc-Sec
GCDR	Uncompensated Gyro Drift Rate	2.0	MERU
GIAU	Gyro Drift Rate Due To Acceleration Along Spin Axis.	8.0	MERU/g
GSAU	Gyro Drift Rate Due To Acceleration Along Input Axis.	5.0	MERU/g
GANI	Gyro Drift Rate Due to Acceleration Along Input and Spin Axes.	0.3	$MERU/g^2$
QUAD	Accelerometer Non-Linearity	10.0	$\mu g/g^2$
EPS	Accelerometer Mis-Alignment	20.0	Arc-Sec
B	Accelerometer Bias	0.2	Cm/Sec^2
SF	Accelerometer Scale Factor	116.0	PPM

Table 3a. Partial Derivatives Relating IMU Errors in the Navigation Coordinate System to Touchdown Errors in the Topocentric Coordinate System (NAV - ACT) Vector

	RANGE = 1250 N.MI.		RANGE = 1500 N.MI.		RANGE = 2000 N.MI.		RANGE = 2500 N.MI.		
ERROR SOURCE	DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	UNITS
THETAP(X)	4.4967052E-01	1.6229650E+01	6.1109923E-01	1.6464321E+01	4.6448383E-01	1.5874542E+01	3.5780562E-01	1.0805244E+01	Ft/Arc-Sec
THETAP(Y)	2.2582616E+00	-6.0431898E-02	2.5889283E+00	-1.2327802E-01	3.7032087E+00	-1.8767919E-01	1.3899567E+00	1.0696619E+01	↓
THETAP(Z)	3.7355976E-01	1.3705444E+01	5.0311298E-01	1.6538154E+01	5.795720eE-01	2.3092622E+01	6.0229445E-01	1.8869891E+01	↓
GCDR(X)*	9.9847990E-01	6.7279625E+01	3.0948172E+00	8.0145474E+01	2.6843453E+00	9.5471049E+01	2.6580797E+00	8.9696286E+01	Ft/Meru
GCDR(Y)*	1.2766308E+01	4.2269098E-03	1.7453644E+01	-7.9559016E-01	3.0491006E+01	-1.1414301E+00	1.6968499E+01	8.8757423E+01	↓
GCDR(Z)*	-1.3734786E+00	-6.0415760E-01	-1.9974701E+00	-8.5626231E+01	-3.7001384E+00	-1.5006887E+02	-4.4451226E+00	-1.6577858E+02	↓
GCDR(X)**	4.1807936E+01	1.4894534E+03	5.5024164E+01	1.5205311E+03	4.5267133E+01	1.4854614E+03	3.8425557E+01	1.0335117E+03	↓
GCDR(Y)**	2.1217101E+02	-7.1853352E+00	2.4564838E+02	-2.1386752E+01	3.5608318E+02	-1.4697836E+01	1.3697050E+02	-9.1065401E+03	↓
GCDR(Z)**	2.9314096E+01	1.1406072E+03	4.3461337E+01	1.3615008E+03	4.9919040E+01	1.8724106E+03	4.8060355E+01	1.4850806E+03	↓
GIAU(X)	1.0512940E-01	3.9635655E+00	2.4155875E-01	3.0045049E+00	4.9899042E-04	1.2425068E+00	-1.2589251E-01	2.3991872E+00	Ft/Meru/G
GIAU(Y)	1.5936465E+01	-3.6685736E-01	1.6176272E+01	-4.8655428E-01	1.5173948E+01	-4.4018122E-01	9.5902516E+00	-2.7968679E-01	↓
GIAU(Z)	-2.6314171E-02	-3.0217844E+00	-1.6288649E-01	-2.5524313E+00	-2.3489933E-02	-2.0099349E+00	1.1375537E-02	-4.7542649E+00	↓
GSAU(X)	1.1401844E+00	3.9637532E+01	2.7697434E-01	4.2357075E+01	8.5402910E-01	4.4823325E+01	-9.5621236E-01	2.9325515E+01	↓
GSAU(Y)	-2.6807523E-01	-8.9498387E-03	-3.9133099E-02	5.7379759E-03	-8.2913994E-01	3.2221269E-03	-7.1373645E-01	3.8453890E-02	↓
GSAU(Z)	9.7543044E-01	-5.6652862E-01	-3.7530530E-02	-5.9985022E+01	-1.0538987E+00	-6.0643246E+01	3.0780397E-01	-4.9543075E+01	↓
GANI(X)	4.5393170E+00	-1.0838177E+01	-1.6937702E+00	-9.8285625E+00	-2.5057918E+00	-4.8810261E+00	9.4466028E-01	8.0810481E-01	Ft/Meru/G²
GANI(Y)	1.7753141E+00	-1.5745828E-02	2.5428436E+00	-5.8230563E-02	2.2620576E+00	-1.1288422E-01	-9.0516428E-01	2.2742905E-01	↓
GANI(Z)	7.3712913E-02	8.4648130E+00	5.8009075E-01	8.8623055E+00	4.0646273E-02	5.5108617E+00	-1.8441471E+00	-9.5286143E-01	↓

Table 3a. Partial Derivatives Relating IMU Errors in the Navigation Coordinate System to Touchdown Errors in the Topocentric Coordinate System (NAV - ACT) Vector (Continued)

ERROR SOURCE	RANGE = 1250 N.MI. DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	RANGE = 1250 N.MI. CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	RANGE = 1500 N.MI. DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	RANGE = 1500 N.MI. CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	RANGE = 2000 N.MI. DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	RANGE = 2000 N.MI. CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	RANGE = 2500 N.MI. DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	RANGE = 2500 N.MI. CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	UNITS
QUAD(X)	-4.4105740E+00	2.0403124E-02	4.8120888E+00	2.6494230E-02	-6.4597958E+00	3.0258594E-02	-1.1036810E+01	6.6776227E-03	Ft/μg/g²
QUAD(Y)	-1.3034898E-02	-1.4968608E+00	4.2116201E-03	-1.1214588E+00	-7.9568737E-02	-7.4230693E-01	-6.1602390E-02	-1.2775834E+00	
QUAD(Z)	8.3858357E+00	-8.1363799E-02	5.3644004E+00	-5.4076702E-02	2.3364827E+00	-4.1245101E-02	1.7927473E+00	2.6104872E-04	
EPS(1)	-4.0163187E+00	1.3700576E+01	-1.5001293E-01	-1.6559285E+01	-1.3712659E-01	-2.3144666E+01	-9.4845829E-02	-1.8869482E+01	Ft/Arc-Sec
EPS(2)	-1.1301952E+01	1.1789754E-01	-1.2865826E+01	1.6876330E-01	-1.5423854E+01	1.9074953E-01	-1.0468465E+01	1.0128151E-01	
EPS(3)	-2.5425188E-01	-4.7389305E-03	-3.6984981E-01	1.9498736E-03	-4.8504425E-01	4.2186908E-03	-5.4209111E-01	6.1499151E-05	
EPS(4)	-3.4307056E-01	2.5685360E-03	-4.6643986E-01	1.2037155E-02	-4.3998382E-01	4.3184131E-03	-2.7523346E-01	8.4731562E-03	
EPS(5)	9.114354E+00	-4.6137986E-02	1.0401337E+01	-2.8167516E-02	1.1899726E+01	-4.4755459E-02	8.9947008E+00	-2.5937585E-02	
EPS(6)	-1.6962577E-01	-1.6235372E+01	-1.4928082E-01	-1.6482288E+01	-1.2063147E-01	-1.5885392E+01	-1.0962942E-01	-1.0832512E+01	
B(X)	-2.0975510E+03	8.8303845E+00	-3.1638177E+03	1.5155793E+01	-6.1024388E+03	1.4572589E+01	-8.4853499E+03	1.8689670E+01	Ft/Cm/Sec²
B(Y)	-3.4783719E+01	-3.6700258E+01	-5.0152018E+01	-4.9438811E+03	-5.8763886E+01	-7.9672655E+03	-5.9775468E+01	-9.6841532E+03	
B(Z)	3.0136300E+03	-2.8362716E-01	3.8210133E+03	-4.9398860E+01	5.2125251E+03	-6.6094740E+01	5.0260513E+03	-6.1846112E+01	
SF(X)	-1.5710663E+00	7.0265656E-03	-2.0767719E+00	8.1512063E-03	-3.4551547E+00	1.3355713E-02	-3.1492051E+00	6.0375108E-03	Ft/PPM
SF(Y)	-4.1012954E-03	8.8266629E-02	2.3851847E-03	1.1599127E-01	-5.5552814E-03	1.1281815E-01	-1.6082848E-02	1.2347004E-01	
SF(Z)	-2.6857500E+00	2.8116162E-02	-2.5626317E+00	3.4396183E-02	-2.1098833E+00	2.8846034E-02	-1.2032332E+00	1.2148864E-02	

* Uncompensated drift initiated at entry

** Uncompensated drift initiated 100 minutes before entry

Table 3b1. Partial Derivatives Relating IMU Errors in the Navigation Coordinate System to Touchdown Errors in the Topocentric Coordinate System (Range = 1250 n mi)

	(ACT-NOM)				(NAV-NOM)				
	+ IMU ERRORS		- IMU ERRORS		+ IMU ERRORS		- IMU ERRORS		
ERROR SOURCE	DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	UNITS
THETAP(X)	-1.4612913E+01	-1.6908728E+01	1.0326539E+01	1.7890996E+01	-1.4105123E+01	-4.5899630E-01	9.8448756E+00	1.8840974E+00	Ft/Arc-Sec
THETAP(Y)	-1.4666285E+02	-1.7936744E+02	-4.1233969E+00	1.1099471E+01	-1.4446703E+02	-1.7920779E+02	-6.2310994E+00	1.0495603E+01	
THETAP(Z)	-1.6780668E+01	-2.5900511E+01	-3.5884459E+01	2.5664068E+01	-1.6348989E+01	-1.1974985E+01	-3.6221694E+01	1.2172317E+01	
GCDR(X)*	-2.4779495E+02	-3.1060339E+02	6.8971855E+02	1.2627536E+02	-2.4563409E+02	-2.3892211E+02	6.8946967E+02	6.3377127E+01	Ft/Meru
GCDR(Y)*	-3.3077043E+03	-4.1684399E+03	2.9821578E+02	-3.7763358E+02	-3.2886926E+03	-4.1900460E+03	2.8622276E+02	-3.7284759E+02	
GCDR(Z)*	-4.0116220E+02	1.1911992E+02	-4.7858497E+02	-8.1566906E+01	-4.0137330E+02	6.3105808E+01	-4.7689681E+02	-1.6786939E+01	
GCDR(X)**	-2.7588959E+03	-4.5250116E+03	-2.6321192E+03	-2.4184435E+03	-2.7159256E+03	-3.0311566E+03	-2.6743032E+03	-3.9030404E+03	
GCDR(Y)**	-1.1460282E+02	-1.7145683E+02	-6.8624371E+02	-1.9158487E+01	-8.4533063E+01	-1.7424052E+02	-8.8109941E+02	-7.5243708E+00	
GCDR(Z)**	-2.8487028E+03	-4.3887735E+03	-6.1065939E+02	7.4532184E+02	-2.8182264E+03	-3.2437646E+03	-6.4162181E+02	-3.8929201E+02	
GIAU(X)	-1.0439513E+02	4.8939618E+00	1.3089994E+02	1.8568559E+01	-1.0399941E+02	9.9579392E+00	1.3091178E+02	1.5721595E+01	Ft/(Meru/G)
GIAU(Y)	-3.6969880E+01	-2.5098583E+01	-8.4542774E+01	2.9903615E+01	-2.0972690E+01	-2.6993736E+01	-9.9921624E+01	3.1353577E+01	
GIAU(Z)	-8.5240711E+01	3.8484035E+01	1.5339854E+02	2.5896271E+01	-8.4976432E+01	3.6562663E+01	1.5381838E+02	2.9992221E+01	
GSAU(X)	-1.5566777E+02	3.1029376E+00	8.4436010E+01	7.5396746E+01	-1.5634300E+02	4.4519130E+01	8.5815591E+01	3.7566980E+01	
GSAU(Y)	-9.0946300E+01	1.0855062E+02	-2.5580514E+01	-5.6169362E+01	-9.0749424E+01	1.0576942E+02	-2.4569857E+01	-5.4444600E+01	
GSAU(Z)	-1.6876425E+02	4.5260173E+01	-2.0325101E+02	-8.7506825E+01	-1.6732386E+02	-9.6320305E+00	-2.0392646E+02	-2.9084998E+01	
GANI(X)	-2.9131310E+03	7.3059633E+02	-1.4120732E+02	-3.8801524E+02	-2.9008425E+03	7.4910246E+02	-1.3336175E+02	-3.4760205E+02	$Ft/(Meru/G^2)$
GANI(Y)	-3.1608110E+03	-4.4493164E+02	-2.8001596E+03	5.0275240E+02	-3.1512865E+03	-4.1098412E+02	-2.7960280E+03	5.3216977E+02	
GANI(Z)	2.3923732E+03	-1.8337411E+02	2.9230095E+03	-1.6973233E+03	2.4001961E+03	-1.4556498E+02	2.9306915E+03	-1.6757000E+03	

Table 3b1. Partial Derivatives Relating IMU Errors in the Navigation Coordinate System to Touchdown Errors in the Topocentric Coordinate System (Range = 1250 n mi) (Continued)

ERROR SOURCE	+ IMU ERRORS DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	+ IMU ERRORS CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	- IMU ERRORS DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	- IMU ERRORS CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	+ IMU ERRORS DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	+ IMU ERRORS CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	- IMU ERRORS DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	- IMU ERRORS CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	UNITS
QUAD(X)	3.3250362E+00	1.1175981E+01	4.3653541E+01	3.7379925E+01	-8.5306247E-01	1.2076714E+01	4.8266083E+01	3.8234594E+01	Ft/(μg/g²)
QUAD(Y)	-2.5338789E+00	3.2254314E+00	-1.7820227E+02	8.1598747E+00	-2.3144385E+00	2.6088999E+00	-1.7795671E+02	1.0542924E+01	
QUAD(Z)	5.4403363E+01	-1.8005087E+01	5.1342555E+01	2.5516182E+01	6.3021674E+01	-1.7206122E+01	4.3050224E+01	2.6482575E+01	
EPS(1)	5.7101107E+01	1.4435904E+01	-2.7322130E+01	-3.5737343E+01	5.7126283E+01	1.1754926E+00	-2.7114756E+01	-2.1587935E+01	Ft/Arc-Sec
EPS(2)	7.3523119E+00	-5.2513881E+00	2.0740720E+01	2.3107994E+01	-3.8334023E+00	-4.6933258E+00	3.2102326E+01	2.3419677E+01	
EPS(3)	-5.2190887E+00	-1.6948395E+00	1.8946418E+01	1.8215173E+01	-5.3571030E+00	-1.2594137E+00	-1.8673797E+01	1.8646612E+01	
EPS(4)	2.5400458E+01	1.0529855E+01	-4.4970191E+01	-4.2353363E+00	2.5173625E+01	1.0972589E+01	-4.4523951E+01	-3.8040183E+00	
EPS(5)	-4.3239927E+01	1.5602799E+00	-3.1039295E+02	-3.2711062E+02	-3.4009334E+01	1.9543066E+00	-3.1950386E+02	-3.2660198E+02	
EPS(6)	2.0576806E+01	2.8805596E+01	-2.5266611E+01	-3.2588074E+01	2.0523418E+01	1.3010390E+01	-2.5008976E+01	-1.5910653E+01	
B(X)	3.6485514E+02	-1.1795945E+03	-3.1708460E+04	-3.5356056E+04	-1.7210720E+03	-1.1267476E+03	-2.9593834E+04	-3.5318270E+04	Ft/(Cm/Sec)
B(Y)	-3.1822935E+04	-2.4876826E+04	-1.6475596E+04	-5.6452027E+03	-3.1846096E+04	-2.8502835E+04	-1.6430698E+04	-1.9295873E+03	
B(Z)	-3.2679448E+04	-3.5119435E+04	-2.8291100E+04	-3.6856653E+04	-2.9654164E+04	-3.5103782E+04	-3.1293266E+04	-3.6777180E+04	
SF(X)	1.6561619E+00	3.2650979E-01	2.9683870E+00	3.7851874E+00	1.0513654E-01	4.0942682E-01	4.5280291E+00	3.8538539E+00	Ft/PPM
SF(Y)	-7.5087859E+00	6.5756456E-01	-6.6784234E+00	1.8482007E+00	-7.4928463E+00	8.2172167E-01	-6.6520397E+00	1.8355348E+00	
SF(Z)	1.1221762E+00	-8.2685373E-01	-5.3982425E+01	-5.3934073E+01	-1.5435329E+00	-7.2284710E-01	-5.1295692E+01	-5.3881731E+01	

* Uncompensated drift initiated at entry

** Uncompensated drift initiated 100 minutes before entry

Table 3b2. Partial Derivatives Relating IMU Errors in the Navigation Coordinate System to Touchdown Errors in the Topocentric Coordinate System (Range = 1500 n mi)

ERROR SOURCES	(ACT-NOM) + IMU ERRORS DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	(ACT-NOM) + IMU ERRORS CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	(ACT-NOM) − IMU ERRORS DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	(ACT-NOM) − IMU ERRORS CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	(NAV-NOM) + IMU ERRORS DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	(NAV-NOM) + IMU ERRORS CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	(NAV-NOM) − IMU ERRORS DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	(NAV-NOM) − IMU ERRORS CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	UNITS
THETAP(X)	-1.8100029E+01	-6.6030554E-01	-2.1796606E+01	4.4162836E+01	-1.7809035E+01	1.6075038E+01	-2.2236135E+01	2.7965359E+01	Ft/Arc-Sec
THETAP(Y)	1.3960669E+01	5.8525302E+00	-8.7691615E+00	3.8068068E+01	1.6631207E+01	5.9960884E+00	-1.1010600E+01	3.8449296E+02	↓
THETAP(Z)	1.5798442E+01	-1.0603492E+01	9.9483371E+00	1.5970399E+01	1.6532245E+01	6.1966389E+00	9.6167951E+00	-3.0091925E-01	↓
GCDR(X)*	1.7043208E+02	3.3038413E+02	-1.2755913E+02	-6.7207067E+01	1.7610572E+02	4.1580079E+02	-1.2722253E+02	-1.4201581E+02	Ft/Meru
GCDR(Y)*	1.8162917E+02	3.9756253E+02	2.4709071E+02	1.6944604E+02	2.0284192E+02	4.0210909E+02	2.3383050E+02	1.7536691E+02	↓
GCDR(Z)*	-8.0172930E+02	1.2945006E+02	1.2165538E+02	1.4747644E+02	-8.0051963E+02	4.9039014E+01	1.2708427E+02	2.3843940E+02	↓
GCDR(X)**	-5.5074095E+02	-1.0256718E+03	3.2628937E+02	1.2883521E+03	-4.9250054E+02	5.0103240E+02	2.7469663E+02	-2.2684228E+02	↓
GCDR(Y)**	-3.6824814E+01	1.8384624E+02	-6.1061403E+02	-2.9117204E+02	2.7432016E+02	1.6779622E+02	-8.3781340E+02	-2.7495132E+02	↓
GCDR(Z)**	-5.1529484E+02	-9.2063186E+02	1.0053496E+02	1.4990283E+03	-4.6784593E+02	4.4638332E+02	6.0505038E+01	1.4286417E+02	↓
GIAU(X)	-8.0751510E+01	-2.7128291E+01	1.1503203E+02	3.4557354E+0[illegible]	-7.9786680E+01	-2.2810367E+01	1.1564832E+02	3.2887030E+01	Ft/Meru/G
GIAU(Y)	1.5683608E+01	7.6665308E+01	-1.3206741E+02	2.4287847E+0[illegible]	2.9246409E+01	7.7539980E+01	-1.4682173E+02	2.6071240E+01	↓
GIAU(Z)	5.7914852E+01	1.7802198E+01	5.2715730E+01	3.8488913E-0[illegible]	5.8729604E+01	1.6558802E+01	5.3736471E+01	4.2375525E+01	↓
GSAU(X)	4.1150580E+01	4.5835693E+01	-1.1307250E+01	-1.5253150E-0[illegible]	4.2896471E+01	9.0362319E+01	-1.0211657E+01	-5.5475536E+01	↓
GSAU(Y)	-4.6604901E+01	-1.4638643E+01	-6.2216251E+01	-1.6392588E-0[illegible]	-4.5212407E+01	-1.2205918E+01	-6.0708361E+01	-1.6177886E+02	↓
GSAU(Z)	1.2248549E+02	7.3129417E+01	-4.7773849E+01	1.2901187E-0[illegible]	1.2376132E+02	1.5309885E+01	-4.6363752E+01	6.3409830E+01	↓
GANI(X)	0.000000E+00	0.0000000E+00	-5.6557344E+02	-4.5793468E-0[illegible]	2.0192233E+01	2.5911397E+01	-5.4100356E+02	-4.1252796E+02	Ft/Meru/G^2
GANI(Y)	-2.1992227E+03	-8.0692154E+02	-2.4517489E+02	2.8720278E+0[illegible]	-2.1737038E+03	-7.6599929E+02	-2.2384162E+02	3.1695788E+02	↓
GANI(Z)	0.0000000E+00	0.0000000E+00	-7.6762424E+02	4.0838096E+0[illegible]	2.2957668E+01	4.4155174E+01	-7.4532822E+02	4.3509682E+02	↓

Table 3b2. Partial Derivatives Relating IMU Errors in the Navigation Coordinate System to Touchdown Errors in the Topocentric Coordinate System (Range = 1500 n mi) (Continued)

	(ACT-NOM)				(NAV-NOM)				
	+ IMU ERRORS		- IMU ERRORS		+ IMU ERRORS		- IMU ERRORS		
ERROR SOURCES	DOWNRANGE PARTIAL DERIVATIVE $\partial u'/\partial(\ )$	CROSSRANGE PARTIAL DERIVATIVE $\partial v'/\partial(\ )$	DOWNRANGE PARTIAL DERIVATIVE $\partial u'/\partial(\ )$	CROSSRANGE PARTIAL DERIVATIVE $\partial v'/\partial(\ )$	DOWNRANGE PARTIAL DERIVATIVE $\partial u'/\partial(\ )$	CROSSRANGE PARTIAL DERIVATIVE $\partial v'/\partial(\ )$	DOWNRANGE PARTIAL DERIVATIVE $\partial u'/\partial(\ )$	CROSSRANGE PARTIAL DERIVATIVE $\partial v'/\partial(\ )$	UNITS
QUAD(X)	1.1071048E+01	-5.8872477E+01	-1.3267087E+01	6.3290643E+00	6.9783907E+00	-5.7777286E+01	-7.7687144E+00	7.3699149E+00	$\frac{Ft}{\mu g/g^2}$
QUAD(Y)	3.7593932E-01	2.1232238E-01	8.0708034E+01	4.2874227E+01	1.0364905E+00	1.3777077E-01	8.1390106E+01	4.5063031E+01	↓
QUAD(Z)	5.3600336E+01	1.4191716E+01	-8.9980353E+00	1.0633638E+01	5.9651075E+01	1.5162428E+01	-1.3658352E+01	1.1755059E+01	↓
EPS(1)	-7.1320490E+01	5.6075242E+01	-4.1983662E+01	-1.6219306E+01	-7.1103146E+01	4.0071820E+01	-4.1490507E+01	8.7365188E-01	$\frac{Ft}{Arc\text{-}Sec}$
EPS(2)	-6.7453344E+01	-4.1857752E+00	-2.3323270E+01	1.6586095E+01	-7.9920508E+01	-4.1056427E+00	-1.0114303E+01	1.6951004E+01	↓
EPS(3)	-7.8683706E+00	2.0074373E+01	-6.0975272E+01	1.2577612E+01	-7.9414115E+00	2.0608315E+01	-6.0262281E+01	1.3109334E+01	↓
EPS(4)	-1.7525393E+01	3.1243634E+01	1.4442594E+01	3.5342497E+01	-1.7695057E+01	3.1784195E+01	1.5253176E+01	3.5864131E+01	↓
EPS(5)	-1.2281443E+02	7.3681433E+01	3.3845382E+01	4.8764730E+01	-1.1205346E+02	7.4178971E+01	2.3787187E+01	4.9326570E+01	↓
EPS(6)	1.9261378E+01	3.1688351E+01	7.1748934E+00	1.4622309E+01	1.9409054E+01	1.5753484E+01	7.6673160E+00	3.1638268E+01	↓
B(X)	1.8234765E+03	1.2715973E+03	-7.6360547E+02	1.0516727E+03	-1.3058803E+03	1.3377599E+03	2.4345265E+03	1.0898842E+03	$\frac{Ft}{Cm/Sec^2}$
B(Y)	-5.0212566E+03	4.6196292E+03	1.4449436E+03	2.8062078E+03	-5.0315616E+03	-2.7214128E+02	1.5294098E+03	7.8034561E+03	↓
B(Z)	-6.6543153E+03	2.7098946E+03	3.9800954E+02	2.4293797E+03	-2.8128889E+03	2.7132268E+03	-3.3886896E+03	2.5321458E+03	↓
SF(X)	3.7669508E+00	1.2141578E+00	5.8680470E-01	2.8873615E+00	1.7400583E+00	1.3127466E+00	2.7227389E+00	2.9712228E+00	$\frac{Ft}{PPM}$
SF(Y)	-1.7099405E+00	2.3361903E-01	-1.4041323E+00	1.488450E+00	-1.6442567E+00	4.4135758E-01	-1.3473551E+00	1.1248662E+00	↓
SF(Z)	-1.9016187E+00	-1.0187415E+00	-9.4306858E+00	2.0605716E+00	-4.3942747E+00	-8.9536104E-01	-6.8088916E+00	2.1181879E+00	↓

* Uncompensated drift initiated at entry

** Uncompensated drift initiated 100 minutes before entry

Table 3b3. Partial Derivatives Relating IMU Errors in the Navigation Coordinate System to Touchdown Errors in the Topocentric Coordinate System (Range = 2000 n mi)

	(ACT-NOM)				(NAV-NOM)				
	+ IMU ERRORS		- IMU ERRORS		+ IMU ERRORS		- IMU ERRORS		
ERROR SOURCE	DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	UNITS
THETAP(X)	1.6375779E+01	2.3478154E+01	-6.2969722E+00	2.6291896E+00	9.0512612E-01	3.982282E+01	-6.5227601E+00	-8.1950223E+00	Ft/Arc-Sec
THETAP(Y)	-2.2361550E+01	4.3726819E+01	-2.5568107E+01	2.4178125E+01	-1.6841273E+01	-2.7854268E+01	-2.8675553E+01	-1.9564986E+01	↓
THETAP(Z)	1.1674602E+02	2.1436404E+02	-1.5959942E+01	5.3153489E+00	1.1760248E+02	2.3792678E+02	-1.6204103E+01	-7.7983878E+00	↓
GCDR(X)*	-2.6400207E+02	1.2428394E+02	-3.2954535E+02	5.2209547E+01	-2.5578003E+02	2.2915745E+02	-3.2931785E+02	-1.537164E+01	Ft/Meru
GCDR(Y)*	3.0332787E+03	5.4978367E+03	-4.5658192E+02	-7.2192271E+02	3.1298074E+02	5.4475860E+02	-4.8988934E+02	-7.1970081E+02	↓
GCDR(Z)*	-4.6042161E+02	3.4092966E+02	-4.2640171E+02	-7.5573885E+02	-4.5858406E+02	2.0026325E+02	-4.2188335E+02	-6.5252186E+02	↓
GCDR(X)**	-2.7672847E+02	-1.1985455E+03	-1.0646508E+02	1.0708433E+03	-2.2592364E+02	2.9631835E+02	-1.3554677E+02	2.1149265E+01	↓
GCDR(Y)**	2.2431568E+01	3.8105927E+02	-5.7088347E+00	-4.8509196E+02	2.6055985E+03	5.3597797E+03	-6.4727226E+02	-4.7261396E+02	↓
GCDR(Z)**	3.2087064E+03	3.7480839E+03	-5.8476789E+01	8.5652833E+02	3.2641631E+03	5.6298970E+03	-8.6540680E+01	-2.2281338E+02	↓
GIAU(X)	1.3056477E+02	3.8709404E+02	-4.9506060E+01	6.0026084E+01	1.3194969E+02	3.9068716E+02	-4.8951602E+01	6.0162944E+01	Ft/Meru/G
GIAU(Y)	-4.0620131E+01	7.3424329E+02	-1.1731574E+02	-1.2910468E+02	-2.3091247E+01	7.6482173E+02	-1.2512074E+02	-1.2690568E+02	↓
GIAU(Z)	-1.0880292E+02	1.6896907E+02	-4.9925025E+01	5.0517139E+01	-1.0744199E+02	1.6930976E+02	-4.9527986E+01	5.4972497E+01	↓
GSAU(X)	-8.3926238E+01	5.1492570E+01	-1.9837885E+01	-2.2220249E+01	-8.0857132E+01	1.0007688E+02	-1.8663281E+01	-4.8466579E+01	↓
GSAU(Y)	-9.4199702E+01	3.1255833E+01	-7.1173508E+01	-3.9019060E+01	-9.6137740E+01	1.9445052E+02	-7.3797467E+01	-3.5881100E+01	↓
GSAU(Z)	-1.0796856E+01	-8.3329754E+00	-7.8846034E+01	9.6042924E+01	-9.6356791E+00	-6.5215237E+01	-7.8192978E+01	1.4321387E+02	↓
GANI(X)	-1.8648081E+03	8.4310418E+02	-1.7354626E+03	1.1292832E+02	-1.8303959E+03	9.0090624E+02	-1.7204353E+03	1.7100106E+02	Ft/Meru/G²
GANI(Y)	-2.2887768E+03	4.0405078E+03	-9.4922817E+02	-1.7154488E+02	-2.2575919E+03	4.1051197E+02	-9.6236162E+02	-1.1812664E+02	↓
GANI(Z)	5.1296968E+01	2.4684021E+01	-1.9681296E+03	1.2400648E+03	3.6958577E+01	6.8193944E+01	-1.9556031E+03	1.2887943E+03	↓

Table 3b3. Partial Derivatives Relating IMU Errors in the Navigation Coordinate System to Touchdown Errors in the Topocentric Coordinate System (Range = 2000 n mi) (Continued)

	(ACT-NOM)				(NAV-NOM)				
	+ IMU ERRORS		- IMU ERRORS		+ IMU ERRORS		- IMU ERRORS		
ERROR SOURCE	DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	UNITS
QUAD(X)	-6.9377379E+01	3.856939E+01	-3.5097290E+01	5.4857058E+01	-7.4729637E+01	4.0480141E+01	-2.7189553E+01	5.6416481E+01	Ft / $\mu g/g^2$
QUAD(Y)	-9.6173158E+01	1.3113325E+02	-1.0004470E+01	1.0995943E+01	-9.5145190E+01	1.3227144E+02	-9.5492031E+00	1.3734109E+01	↓
QUAD(Z)	-1.0647184E+02	1.1409066E+02	-3.2115014E+01	1.0553539E+01	-1.0302782E+02	1.1592990E+02	-3.5445096E+01	1.2179187E+01	↓
EPS(1)	-7.4619342E+01	7.9395489E+00	-5.9377090E+01	-8.4141707E+01	-7.4202699E+01	-1.4264871E+01	-5.9091938E+01	-6.9822448E+01	Ft / Arc-Sec
EPS(2)	-2.6015184E+01	9.3009232E+01	-3.3856817E+01	3.9667508E+00	-4.0885268E+01	9.4140228E+01	-2.4598639E+01	4.7002416E+00	↓
EPS(3)	-5.2079838E+01	4.6124017E+01	-3.7884879E+01	1.7764732E+00	-5.2011114E+01	4.7068482E+01	-3.7327792E+01	2.5755452E+00	↓
EPS(4)	-2.2709699E+01	5.5711695E+01	-1.4993625E+01	3.0604241E+01	-2.2595914E+00	5.6656260E+01	-1.4532288E+01	3.1397134E+01	↓
EPS(5)	-4.9953578E+01	9.1720814E+01	-1.7962589E+01	-7.9073817E+00	-3.7500083E+01	9.2616304E+01	-2.6083592E+01	-7.0873366E+00	↓
EPS(6)	-1.5919263E+01	-9.5587926E+00	-5.0762093E+01	-9.0249851E+01	-1.5486125E+01	-2.4503939E+01	-5.0487109E+01	-7.8219599E+01	↓
B(X)	3.4374384E+04	4.6904423E+04	-8.8139489E+03	5.1788532E+02	2.8327322E+04	4.7013021E+04	-3.9498857E+03	5.8778322E+02	Ft / Cm/Sec^2
B(Y)	2.3482565E+04	5.5582515E+04	-3.0871563E+03	-8.9652397E+03	2.3479178E+04	4.7709274E+04	-3.0433626E+03	-2.5040094E+03	↓
B(Z)	-8.1167161E+03	5.8139934E+03	3.0313099E+02	-2.8018560E+02	-2.8488141E+03	5.8419233E+03	-3.8967472E+03	-1.6963922E+02	↓
SF(X)	2.2622316E+00	5.5142885E-03	-1.0236425E+01	-1.0614702E+01	-1.0975456E+00	1.8098142E-01	-8.1925861E+00	-1.0480042E+01	Ft / PPM
SF(Y)	-5.8770757E+00	3.6392927E+00	-5.4743694E+00	5.9771591E+00	-5.7871536E+00	3.9142223E+00	-5.4301054E+00	6.0329472E+00	↓
SF(Z)	-1.6054510E-01	7.1512596E+00	-5.6430634E+00	-2.4260112E+00	-2.1749509E+00	7.3422171E+00	-4.0933857E+00	-2.3003606E+00	↓

* Uncompensated drift initiated at entry

** Uncompensated drift initiated 100 minutes before entry

Table 3b4. Partial Derivatives Relating IMU Errors in the Navigation Coordinate System to Touchdown Errors in the Topocentric Coordinate System (Range = 2500 n mi)

ERROR SOURCE	(ACT-NOM) + IMU ERRORS DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	(ACT-NOM) + IMU ERRORS CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	(ACT-NOM) − IMU ERRORS DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	(ACT-NOM) − IMU ERRORS CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	(NAV-NOM) + IMU ERRORS DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	(NAV-NOM) + IMU ERRORS CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	(NAV-NOM) − IMU ERRORS DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	(NAV-NOM) − IMU ERRORS CROSSRANGE PARTIAL DERIVATIVE ∂u'/∂( )	UNITS
THETAP(X)	4.3008707E+00	-2.3597847E+00	9.9590225E+01	1.7679259E+02	4.821127E+00	9.0165601E+00	9.9326175E+01	1.6655184E+02	Ft/Arc-Sec
THETAP(Y)	1.4215319E+02	1.8848281E+02	8.5979193E+01	1.5346561E+02	1.4367217E+02	1.8895642E+02	8.4826735E+01	1.5412296E+02	
THETAP(Z)	-1.9498273E+01	-3.8732909E+01	1.0024024E+02	1.7758727E+02	-1.8733528E+01	-1.9291916E+01	9.9751994E+01	1.5929499E+02	
GCDR(X)*	-1.8812577E+02	5.8512966E+02	2.6310124E+03	3.4192004E+03	-1.8221868E+02	6.8624796E+02	2.6304989E+03	3.3407617E+03	Ft/Meru
GCDR(Y)*	2.3472406E+03	3.6224104E+03	1.7232579E+03	2.9551631E+03	2.3671487E+03	3.6329576E+03	1.7097187E+03	2.9673366E+03	
GCDR(Z)*	-2.0200446E+01	7.5774482E+02	-1.308009E+02	3.2429901E+02	-2.1396556E+01	6.0338826E+02	-1.2282399E+02	5.0161704E+02	
GCDR(X)**	2.9087956E+03	3.3419193E+03	1.873126E+03	4.3626584E+03	2.9504701E+03	4.3868531E+03	1.8372513E+03	3.3395015E+03	
GCDR(Y)**	1.4334419E+03	3.0152921E+03	-1.7404148E+02	-1.9028853E+02	1.5736067E+03	3.0176076E+03	-3.0464708E+02	-1.6953530E+02	
GCDR(Z)**	-2.0086943E+02	-1.4804228E+03	2.4069489E+03	4.7247231E+03	-1.4956006E+02	1.6079757E+01	2.459093E+03	3.2528954E+03	
GIAU(X)	-5.2720289E+01	1.5659676E+02	5.9970294E-01	-9.9627279E+00	-5.2033928E+01	1.6185147E+02	1.4351829E+00	-9.5037474E+00	Ft/Meru/G
GIAU(Y)	-1.2351136E+01	2.3862027E+02	-1.3166191E+01	6.3667134E+01	-2.0554219E+00	2.4119844E+02	-2.0940056E+01	6.6804229E+01	
GIAU(Z)	-9.3051084E+00	9.410802E+01	1.3298268E+00	1.6516101E+00	-8.4814795E+00	9.2209261E+01	2.2013608E+00	9.2835375E+00	
GSAU(X)	-1.9986699E+02	-2.6108384E+02	7.7306897E+02	1.3941126E+03	-1.995236E+02	-2.2718952E+02	7.7499388E+02	1.3693929E+03	
GSAU(Y)	1.8300543E+01	-1.8854119E+01	-1.1448732E+00	2.6893608E+02	1.8899310E+01	-1.4246856E+01	1.0791707E+00	2.7353933E+02	
GSAU(Z)	7.8875536E+02	1.4382651E+03	4.4165239E+01	-2.0122141E+01	7.9036276E+02	1.3932908E+03	4.5213185E+01	3.3931787E+01	
GANI(X)	-1.0241751E+02	1.4830554E+02	-7.9181686E+02	2.3136031E+03	-7.9812761E+01	2.3526047E+02	-7.7015629E+02	2.3898443E+03	Ft/Meru/G^2
GANI(Y)	1.3258324E+03	-1.6370966E+03	-9.4711925E+02	2.1178689E+03	1.3465948E+03	-1.5607266E+03	-9.2728673E+02	2.1963603E+03	
GANI(Z)	1.8392549E+00	-2.04257E-02	1.8392549E+00	-2.04257E-02	2.1655199E+01	7.517354E+01	2.1665081E+01	7.7139645E+01	

Table 3b4. Partial Derivatives Relating IMU Errors in the Navigation Coordinate System to Touchdown Errors in the Topocentric Coordinate System (Range = 2500 n mi) (Continued)

	(ACT-NOM)				(NAV-NOM)				
	+ IMU ERRORS		- IMU ERRORS		+ IMU ERRORS		- IMU ERRORS		
ERROR SOURCE	DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	UNITS
QUAD(X)	-2.8564849E+01	5.6645353E+01	-4.1368186E+01	5.5375762E+01	-3.8951857E+01	5.8936436E+01	-2.9736843E+01	5.763584E+01	Ft/μg/g²
QUAD(Y)	-2.6684644E+01	6.5684576E+01	6.0310873E+00	-7.3508321E-01	-2.6096444E+01	6.6691396E+01	6.7156501E+00	2.850882E+00	
QUAD(Z)	3.0274764E+00	8.6210798E+01	-4.55498E-01	-4.2939629E+00	5.4700266E+00	8.8495464E+01	-1.8472466E+00	-1.9825888E+00	
EPS(1)	-4.2971054E+01	-2.3672527E+01	-1.00611E+01	2.9566542E+01	-4.2740999E+01	-4.1399806E+01	-9.6689083E+00	4.9585076E+01	Ft/Arc-Sec
EPS(2)	2.0702846E+02	3.1262607E+02	2.457645E+02	3.285338E+02	1.968849E+02	3.1386856E+02	2.5648846E+02	3.2955047E+02	
EPS(3)	1.1980526E+01	6.1751018E+00	-8.7547224E+00	2.281182E+01	1.1763336E+01	7.3173657E+00	-7.9428706E+00	2.3961946E+01	
EPS(4)	-1.3162334E+00	4.7938257E+00	7.6042029E+00	4.7001691E+01	-1.2665655E+00	5.9445013E+00	8.2191135E+00	4.8143234E+01	
EPS(5)	2.3141842E+02	3.5286074E+02	2.7332521E+02	3.5050119E+02	2.4073801E+02	3.53977E+02	2.6461492E+02	3.5165901E+02	
EPS(6)	2.5621308E+02	3.8939523E+02	3.5598144E+00	-2.7409301E+00	2.5642835E+02	3.7970491E+02	3.9531509E+00	9.2094103E+00	
B(X)	5.905728E+03	2.3047562E+03	1.7607849E+04	3.1063657E+04	-2.5471316E+03	2.4376661E+03	2.6097987E+04	3.116186E+04	Ft/Cm/Sec²
B(Y)	2.1130487E+04	3.7855337E+04	-3.4437428E+03	-4.1458023E+03	2.1103202E+04	2.8285404E+04	-3.3583988E+03	5.6540422E+03	
B(Z)	2.2468606E+04	3.6965644E+04	3.2633814E+04	3.6390211E+04	2.7527148E+04	3.7018018E+04	2.7602906E+04	3.6565059E+04	
SF(X)	5.1256143E+01	5.4084821E+01	4.2658967E+01	4.9671108E+01	4.8162955E+01	5.428779E+01	4.586186E+01	4.9860861E+01	Ft/PPM
SF(Y)	-2.2527198E+00	5.5769081E+00	-2.1564758E+00	5.291215E+00	-2.2127851E+00	5.8973096E+00	-2.101056E+00	5.3692441E+00	
SF(Z)	5.2414911E+01	5.7797381E+01	-1.2381973E+01	-4.2559849E+00	5.1267695E+01	5.8006462E+01	-1.1139404E+01	-4.0668368E+00	

* Uncompensated drift initiated at entry

** Uncompensated drift initiated 100 minutes before entry

Table 4a1. Partial Derivatives Relating Initialization Errors in the Navigation Coordinate System to Touchdown Errors in the Topocentric Coordinate System (NAV - ACT) Vector

ERROR SOURCE IN NAVIGATION COORDINATES	RANGE = 1250 N.MI. DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	RANGE = 1250 N.MI. CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	RANGE = 1500 N.MI. DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	RANGE = 1500 N.MI. CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	RANGE = 2000 N.MI. DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	RANGE = 2000 N.MI. CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	RANGE = 2500 N.MI. DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	RANGE = 2500 N.MI. CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	UNITS
X	5.6706071E-01	-2.5190860E-03	7.4085356E-01	-3.5023262E-01	7.0923699E-01	-2.3486674E-01	-1.0030154E+00	7.3106661E-03	Ft/Ft
Y	7.7656880E-03	8.2812125E-01	-1.3769161E-01	9.5029398E-01	-8.5413292E-01	-8.1037797E-01	-4.2050034E-03	-5.6318593E-01	↓
Z	-6.5014343E-01	7.5196605E-03	-5.4223506E-01	3.1415105E-01	-7.4100135E-01	-1.1802713E-01	7.3993895E-02	-1.5645303E-03	↓
$\dot{X}$	2.6903701E+02	-1.1450481E+00	3.4439088E+02	-4.8640031E+02	4.6472788E+02	-1.0058899E+00	6.9962013E+02	-1.1298293E+02	Ft/(Ft/Sec)
$\dot{Y}$	4.5479774E+00	4.5940469E+02	5.9703999E+00	5.2522929E+02	2.9724884E+00	5.7695577E+02	-2.0539756E+03	-5.0117373E+02	↓
$\dot{Z}$	-3.7497870E+02	4.2959909E+00	-4.0129666E+02	2.3714159E+01	-3.6855507E+02	2.8735175E+00	2.6547953E+02	9.4825292E-01	↓

Table 4a2. Partial Derivatives Relating Initialization Errors in the Orbit Plane Coordinate System to Touchdown Errors in the Topocentric Coordinate System (NAV - ACT) Vector

ERROR SOURCE IN ORBIT PLANE COORDINATES	RANGE = 1250 N.MI. DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	RANGE = 1250 N.MI. CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	RANGE = 1500 N.MI. DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	RANGE = 1500 N.MI. CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	RANGE = 2000 N.MI. DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	RANGE = 2000 N.MI. CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	RANGE = 2500 N.MI. DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	RANGE = 2500 N.MI. CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	UNITS
U	1.0110103E-02	-5.1603598E-01	-1.3161400E-01	-5.1595421E-01	5.0970589E-01	-4.8745501E-01	5.4594535E-01	3.4569405E-01	Ft/Ft
V	-7.9855356E-01	-2.5088318E-01	-7.3770754E-01	-2.3080941E-01	-6.6824881E-01	-2.1835937E-01	4.9873887E-01	1.7117701E-01	↓
W	3.2685596E-01	-5.9732241E-01	5.6062783E-01	-8.9723305E-01	1.0369862E+00	-7.2463824E-01	-6.8060607E-01	4.1039388E-01	↓
$\dot{U}$	3.9363946E+02	-2.8638193E+02	1.1291448E+01	1.4178967E+02	-7.6613562E+01	-3.5859573E+02	7.2711708E+02	3.7569883E+02	Ft/(Ft/Sec)
$\dot{V}$	-4.3537188E+02	-1.3918375E+02	-4.8941239E+02	1.6768386E+02	-5.1461759E+02	-1.7712824E+02	5.5996576E+02	2.0637891E+02	↓
$\dot{W}$	1.4884635E+02	-3.3118298E+02	2.0019774E+02	-4.8107242E+02	2.8481004E+02	-4.1583207E+02	1.9840573E+03	2.8318171E+02	↓

Table 4b1. Partial Derivatives Relating Initialization Errors in the Navigation Coordinate System to Touchdown Errors in the Topocentric Coordinate System (Range = 1250 n mi)

ERROR SOURCE	(ACT-NOM) + INITIALIZATION ERRORS DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	(ACT-NOM) + INITIALIZATION ERRORS CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	(ACT-NOM) − INITIALIZATION ERRORS DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	(ACT-NOM) − INITIALIZATION ERRORS CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	(NAV-NOM) + INITIALIZATION ERRORS DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	(NAV-NOM) + INITIALIZATION ERRORS CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	(NAV-NOM) − INITIALIZATION ERRORS DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	(NAV-NOM) − INITIALIZATION ERRORS CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	UNITS
X	7.0865049E-01	-1.3827950E-02	-4.9712551E-01	2.3478642E-03	1.4152264E-01	-1.1052997E-02	6.9912357E-02	2.7835660E-04	Ft/Ft
Y	9.8646477E-02	9.2335258E-01	1.8396096E-01	-8.0617867E-01	9.0605828E-02	9.4329977E-02	1.9120482E-01	2.1006905E-02	↓
Z	-3.9911804E-01	1.4724891E-01	5.7381205E-01	2.0261871E-01	2.5065240E-01	1.3843946E-01	-7.6899974E-02	2.0903081E-01	↓
$\dot{X}$	8.4919906E+02	6.9756598E+02	-2.7497781E+02	-5.2632006E+01	5.8021682E+02	6.9896630E+02	-5.5755634E+00	-5.3644478E+01	Ft/(Ft/Sec)
$\dot{Y}$	2.8977025E+02	8.8922589E+02	5.6975639E+01	-3.3441792E+02	2.8502884E+02	4.2891949E+02	6.1033118E+01	1.2409986E+02	↓
$\dot{Z}$	2.4167426E+02	7.0484225E+02	5.7844470E+02	9.2823774E+01	6.1637618E+02	6.9925610E+02	2.0309431E+01	9.5860431E+01	↓

Table 4b2. Partial Derivatives Relating Initialization Errors in the Navigation Coordinate System to Touchdown Errors in the Topocentric Coordinate System (Range = 1500 n mi)

ERROR SOURCE	(ACT-NOM) + INITIALIZATION ERRORS DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	(ACT-NOM) + INITIALIZATION ERRORS CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	(ACT-NOM) − INITIALIZATION ERRORS DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	(ACT-NOM) − INITIALIZATION ERRORS CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	(NAV-NOM) + INITIALIZATION ERRORS DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	(NAV-NOM) + INITIALIZATION ERRORS CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	(NAV-NOM) − INITIALIZATION ERRORS DOWNRANGE PARTIAL DERIVATIVE ∂u'/∂( )	(NAV-NOM) − INITIALIZATION ERRORS CROSSRANGE PARTIAL DERIVATIVE ∂v'/∂( )	UNITS
X	7.9949319E-01	4.5970479E-01	-2.6055843E-01	4.3904173E-01	-5.9006445E-02	2.6741255E-01	-1.5688980E-01	1.0253906E+00	Ft/Ft
Y	-5.8873422E-01	4.8376755E-01	4.0544133E-01	-1.0972420E+00	-4.5235118E-01	1.0264883E-02	-2.3112893E-01	1.2413940E+00	↓
Z	-9.8547624E-01	-2.0848986E-01	-1.4095438E-01	-5.8174601E-01	-4.4512700E-01	-2.1061477E-01	-1.8379450E-01	6.5119934E-01	↓
$\dot{X}$	5.8536961E+02	4.7240937E+03	-2.8850958E+02	-6.8397594E-01	2.4134894E+02	5.2104863E+03	-1.4854871E+02	5.8818750E+02	Ft/(Ft/Sec)
$\dot{Y}$	-2.9524308E+02	2.5823423E+03	-3.4404961E+02	-6.2471246E+02	-2.9822771E+02	2.3762008E+03	-1.6849722E+01	1.6359375E+02	↓
$\dot{Z}$	-5.7470694E+02	2.5623242E+04	4.6837672E+01	-9.3964518E+01	-1.7528119E+02	2.5599568E+04	-4.8072632E+01	8.0937500E+00	↓

Table 4b3. Partial Derivatives Relating Initialization Errors in the Navigation Coordinate System to Touchdown Errors in the Topocentric Coordinate System (Range = 2000 n mi)

ERROR SOURCE	(ACT-NOM) + INITIALIZATION ERRORS		(ACT-NOM) − INITIALIZATION ERRORS		(NAV-NOM) + INITIALIZATION ERRORS		(NAV-NOM) − INITIALIZATION ERRORS		UNITS
	DOWNRANGE PARTIAL DERIVATIVE $\partial u'/\partial(\ )$	CROSSRANGE PARTIAL DERIVATIVE $\partial v'/\partial(\ )$	DOWNRANGE PARTIAL DERIVATIVE $\partial u'/\partial(\ )$	CROSSRANGE PARTIAL DERIVATIVE $\partial v'/\partial(\ )$	DOWNRANGE PARTIAL DERIVATIVE $\partial u'/\partial(\ )$	CROSSRANGE PARTIAL DERIVATIVE $\partial v'/\partial(\ )$	DOWNRANGE PARTIAL DERIVATIVE $\partial u'/\partial(\ )$	CROSSRANGE PARTIAL DERIVATIVE $\partial v'/\partial(\ )$	
X	7.0784252E-01	-8.7470748E-02	-8.4738553E-02	1.7268449E-01	-1.2681950E-03	-5.1016070E-02	-1.7051555E-01	-6.1754179E-02	Ft/Ft
Y	-9.5496208E-01	1.0885239E-01	-4.5291502E-01	-6.0396089E-01	-1.0127518E-01	-3.2354591E-01	1.0691431E-01	2.0490510E-01	↓
Z	-5.7840582E-01	8.1482588E-02	8.8840797E-02	1.5821851E-01	1.6195740E-01	1.9734634E-01	4.3812088E-01	3.8565967E-01	↓
$\dot{X}$	3.8517038E+02	-1.1859636E+02	-3.2907694E+02	2.8031643E+02	-7.9432733E+01	-1.1719227E+01	1.3599755E+02	2.7973863E+02	Ft/(Ft/Sec)
$\dot{Y}$	2.6749903E+01	6.1289835E+02	5.0467117E+01	-3.7080926E+02	2.3336740E+01	3.4430577E+01	5.2220552E+01	2.0434327E+02	↓
$\dot{Z}$	-2.9323144E+02	8.0527926E+01	2.8007573E+02	-3.0860528E+02	7.4693108E+01	7.5490993E+01	-8.9726329E+01	-3.0792897E+02	↓

Table 4b4. Partial Derivatives Relating Initialization Errors in the Navigation Coordinate System to Touchdown Errors in the Topocentric Coordinate System (Range = 2500 n mi)

ERROR SOURCE	(ACT-NOM) + INITIALIZATION ERRORS		(ACT-NOM) − INITIALIZATION ERRORS		(NAV-NOM) + INITIALIZATION ERRORS		(NAV-NOM) − INITIALIZATION ERRORS		UNITS
	DOWNRANGE PARTIAL DERIVATIVE $\partial u'/\partial(\ )$	CROSSRANGE PARTIAL DERIVATIVE $\partial v'/\partial(\ )$	DOWNRANGE PARTIAL DERIVATIVE $\partial u'/\partial(\ )$	CROSSRANGE PARTIAL DERIVATIVE $\partial v'/\partial(\ )$	DOWNRANGE PARTIAL DERIVATIVE $\partial u'/\partial(\ )$	CROSSRANGE PARTIAL DERIVATIVE $\partial v'/\partial(\ )$	DOWNRANGE PARTIAL DERIVATIVE $\partial u'/\partial(\ )$	CROSSRANGE PARTIAL DERIVATIVE $\partial v'/\partial(\ )$	
X	1.2631878E+00	2.0264453E-01	-7.3302478E-01	1.9302930E-01	2.6092208E-01	2.1059320E-01	2.7015605E-01	1.8595066E-01	Ft/Ft
Y	-4.8188768E-01	-4.4599406E-02	-6.1437182E-01	-1.2234173E+00	-4.8645155E-01	-6.1003881E-01	-6.1075098E-01	-6.6266461E-01	↓
Z	-3.7969039E-02	9.4866350E-03	-4.7363628E-01	-9.3258975E-01	3.3008573E-02	4.6977778E-03	-5.4846600E-01	-9.3402374E-01	↓
$\dot{X}$	6.0964702E+02	4.9664140E+02	-3.3690207E+02	-1.0882834E+02	1.3094329E+03	3.8429643E+02	8.5014010E+02	1.1022739E+03	Ft/(Ft/Sec)
$\dot{Y}$	5.6858990E+02	3.4324143E+02	-6.2403123E+02	-7.6467281E+02	-1.4859713E+03	-1.6018561E+02	-1.4200132E+03	-1.9233244E+03	↓
$\dot{Z}$	-6.5565150E+02	-6.2876663E+02	-4.5891452E+02	-1.0220808E+03	-3.9100979E+02	-6.3104243E+02	-7.9965475E+02	-1.0694645E+03	↓

REFERENCES

1. "Task Agreement for Reentry Mission Planning, Flight Support and Postflight Analysis for Mission C/CSM-101 and Mission D/CSM-104/LM-3," MSC/TRW Task A-190, Amendment 1, 28 October 1968.

2. Simpson, E. M., "Reentry Dispersion Evaluation (A-148)," TRW Note No. 68-FMT-617, (05952-H374-R8-00), 23 January 1968.

3. Scott, J. L., Apollo Reentry Simulation Program ARS04 Users Manual, TRW Note No. 69-FMT-739, (11176-H152-R0-00), 28 February 1969.

4. Cox, B. A., "Parametric Data Required for SSR Support (A-190)," TRW IOC 3353.1-34, 9 October 1968.

5. "Apollo VII Guidance, Navigation, and Control System Performance Analysis - Final Report," TRW 11176-H095-R0-00, 20 December 1968.