BASIC REFERENCE COORDINATES AND REFSMMAT

The Basic Reference Coordinate system (BRC) is an orthogonal inertial coordinate system whose origin is located either at the earth or moon center of mass (Figure 1). The orientation of this coordinate system is defined by the line of intersection of the mean earth equatorial plane and the mean ecliptic at the beginning of the Besselian year which starts January 1.2516251, 1972. The X axis ($\underline{u}_{XI}$) is defined by the intersection of the earth's equatorial plane and the ecliptic in the direction of the ascending node. The Z axis ($\underline{u}_{ZI}$) is along the mean earth north pole, and Y axis ($\underline{u}_{YI}$) completes the right-handed triad.

This coordinate system is shifted from earth-centered to moon-centered when estimated vehicle position from the moon falls below 64,373,760 meters. It is likewise shifted from the moon back to the earth when the spacecraft position exceeds 64,373,760 meters. All navigation stars, lunar-solar ephemerides and vehicle state vectors are referenced to this system (Figure 2).

REFSMMAT. The matrix used to transform the elements of a vector given in BRC space to IMU space is known as REFSMMAT.

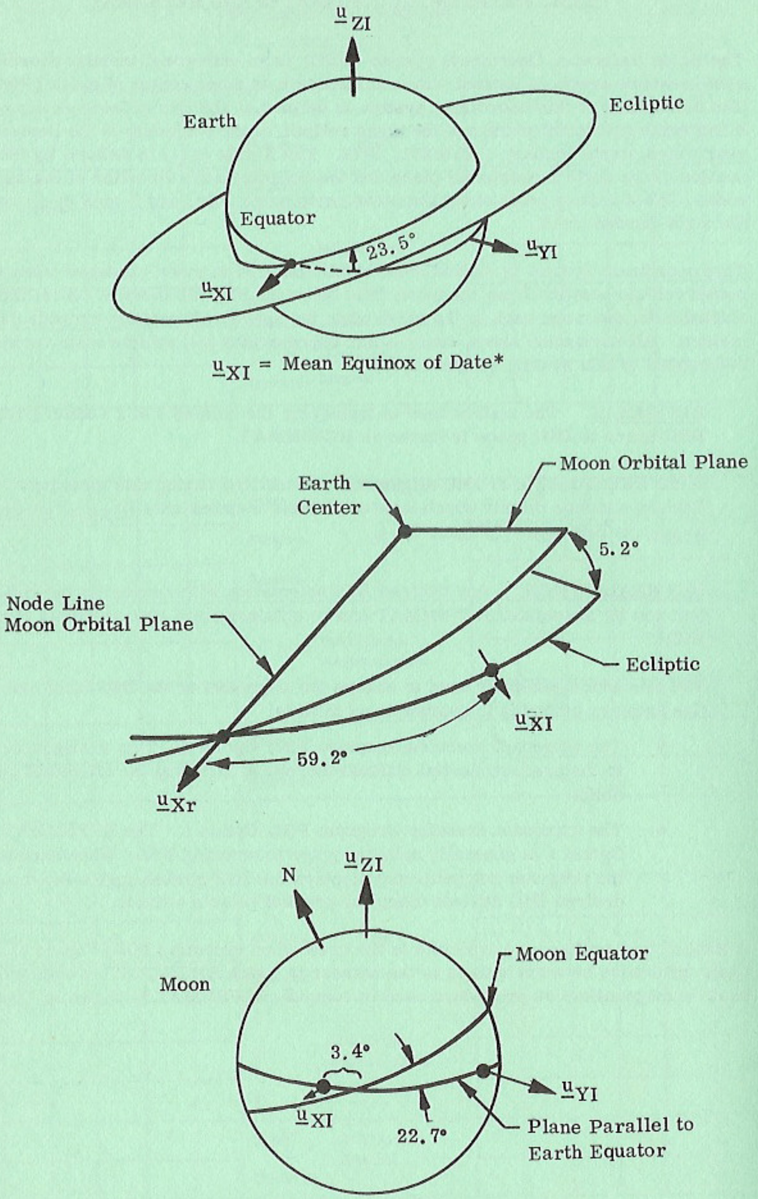
Nine REFSMMAT's or IMU alignments are utilized during this mission. Each is a unique matrix which locates a stable member axis ($\underline{u}_{XSM}$, $\underline{u}_{YSM}$, or $\underline{u}_{ZSM}$) in BRC space (Figure 3).

IMU REALIGNMENT. Any desired IMU orientation with respect to the BRC system and its associated REFSMMAT can be obtained from star sightings (Program P52).

The procedure generally used to change the alignment of the IMU from one of the five primary attitudes to another is as follows:

- The astronaut executes Program P52, Option 3. This realigns the IMU to the present inertial attitude thereby eliminating the effects of gyro drift.
- The astronaut executes Program P52, Option 1. The REFSMMAT for Option 1 is generally uplinked prior to entering P52. When executed, the program computes and displays the IMU gimbal angles for the desired IMU attitude using the present vehicle attitude.

A total of four options are available to the crew when executing P52 (Figure 4). The basic difference between options is the manner in which REFSMMAT is obtained. The basic orthogonalization procedure used to compute REFSMMAT is shown in Figure 5.



*Besselian year starting January 1.2516251, 1972

Figure 1. Basic Reference Coordinate System

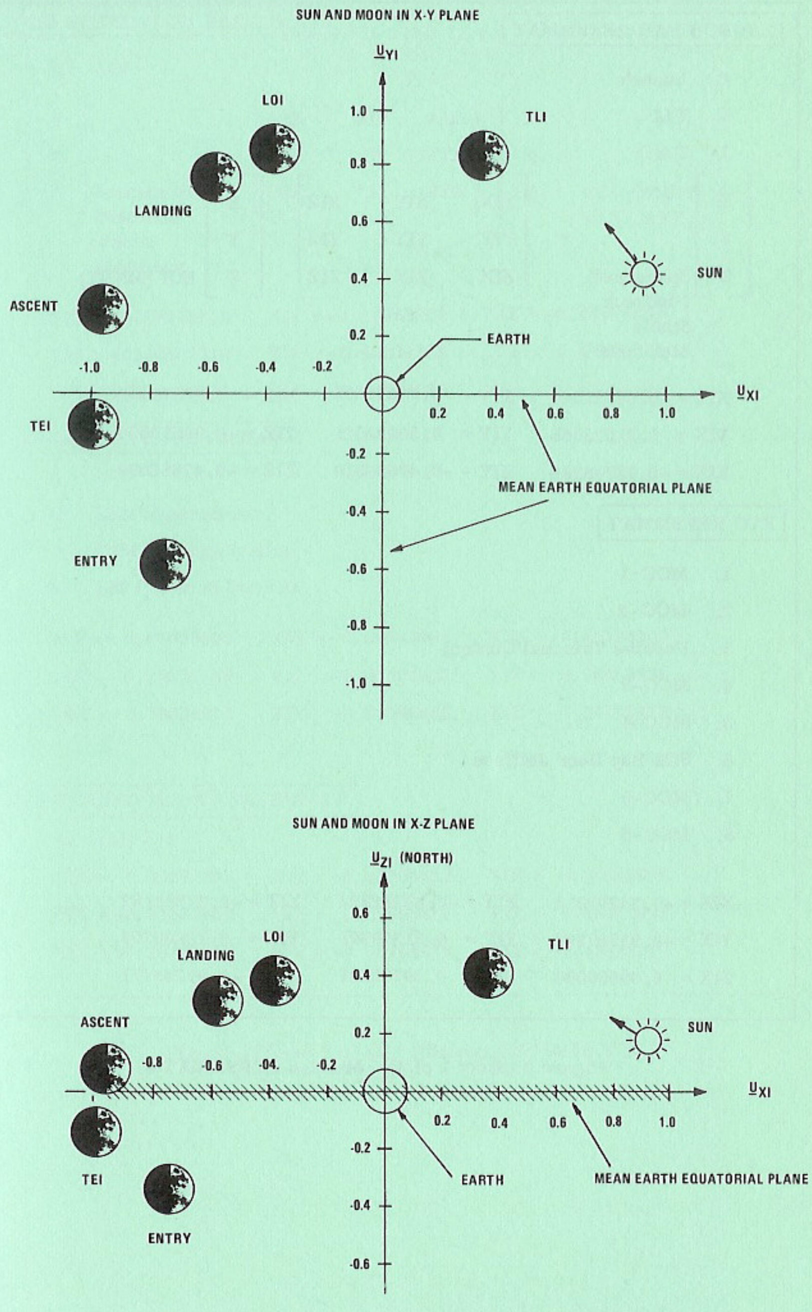


Figure 2. Lunar-Solar Ephemeris

LAUNCH PAD REFSMMAT

1. Launch
2. TLI
3. T & D

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{\text{Spacecraft Platform Stable Members}} = \begin{bmatrix} XIX & XIY & XIZ \\ YIX & YIY & YIZ \\ ZIX & ZIY & ZIZ \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{\text{ECI (MNBY)}}$$

XIX = -0.64021344	XIY = 0.71888605	XIZ = 0.27079443
YIX = 0.21522065	YIY = 0.50624021	YIZ = -0.83510534
ZIX = -0.73743260	ZIY = -0.47636510	ZIZ = -0.47882090

PTC REFSMMAT

1. MCC-1
2. MCC-2
3. Passive Thermal Control
4. MCC-3
5. MCC-4
6. SIM Bay Door Jettison
7. MCC-5
8. MCC-6

XIX = -0.34202014	XIY = -0.86212824	XIZ = -0.37384102
YIX = -0.93969262	YIY = 0.31378901	YIZ = 0.13606700
ZIX = 0.00000000	ZIY = 0.39783331	ZIZ = -0.91745771

Figure 3 (Sheet 1 of 4). Mission REFSMMAT's

PREFERRED (LOI) REFSMMAT

1. LOI

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{\text{Spacecraft Platform Stable Members}} = \begin{bmatrix} XIX & XIY & XIZ \\ YIX & YIY & YIZ \\ ZIX & ZIY & ZIZ \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{\text{ECI (MNBY) or MCI (MNBY)}}$$

XIX = -0.99273112	XIY = -0.10086262	XIZ = -0.06566340
YIX = -0.00185316	YIY = -0.53271311	YIZ = 0.84629387
ZIX = -0.12033917	ZIY = 0.84026393	ZIZ = 0.52865396

LANDING SITE REFSMMAT

1. DOI
2. CSM Separation
3. CSM Circularization
4. LM Powered Descent

XIX = 0.67000809	XIY = -0.59984984	XIZ = -0.43734347
YIX = 0.12951155	YIY = -0.48564437	YIZ = 0.86450928
ZIX = -0.73096912	ZIY = -0.63586926	ZIZ = -0.24769819

PREFERRED (LOPC) REFSMMAT

1. LOPC-1

XIX = 0.19271396	XIY = -0.46004412	XIZ = 0.86672992
YIX = -0.96383853	YIY = 0.07693310	YIZ = 0.25514033
ZIX = -0.18405603	ZIY = -0.88455679	ZIZ = -0.42858217

Figure 3 (Sheet 2 of 4). Mission REFSMMAT's

LM ASCENT REFSMMAT

1. LM Ascent
2. TPI
3. CSM Separation following LM Jettison
4. LM Deorbit
5. SHAPING
6. Subsatellite Jettison

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{\text{Spacecraft Platform Stable Members}} = \begin{bmatrix} XIX & XIY & XIZ \\ YIX & YIY & YIZ \\ ZIX & ZIY & ZIZ \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{\text{ECI (MNBY) or MCI (MNBY)}}$$

XIX = 0.97651225 XIY = -0.04048785 XIZ = -0.21162371

YIX = 0.16677693 YIY = -0.47981822 YIZ = 0.86137097

ZIX = -0.13641596 ZIY = -0.87643324 ZIZ = -0.46179592

PREFERRED (LOPC) REFSMMAT

1. LOPC-2

XIX = -0.17472490 XIY = 0.45229768 XIZ = -0.87458447

YIX = -0.79685180 YIY = 0.45679535 YIZ = 0.39543043

ZIX = 0.57835837 ZIY = 0.76600575 ZIZ = 0.28060070

PREFERRED (TEI) REFSMMAT

1. TEI

XIX = 0.06333484 XIY = 0.75647791 XIZ = 0.65094537

YIX = 0.21795169 YIY = -0.64699487 YIZ = 0.73068099

ZIX = 0.97390234 ZIY = 0.09559708 ZIZ = -0.20585295

Figure 3 (Sheet 3 of 4). Mission REFSMMAT's

ENTRY REFSMMAT

1. MCC-7
2. Entry

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{\text{Spacecraft Platform Stable Members}} = \begin{bmatrix} XIX & XIY & XIZ \\ YIX & YIY & YIZ \\ ZIX & ZIY & ZIZ \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{\text{ECI (MNBY)}}$$

XIX = 0.24623360 XIY = 0.46136661 XIZ = 0.85235547

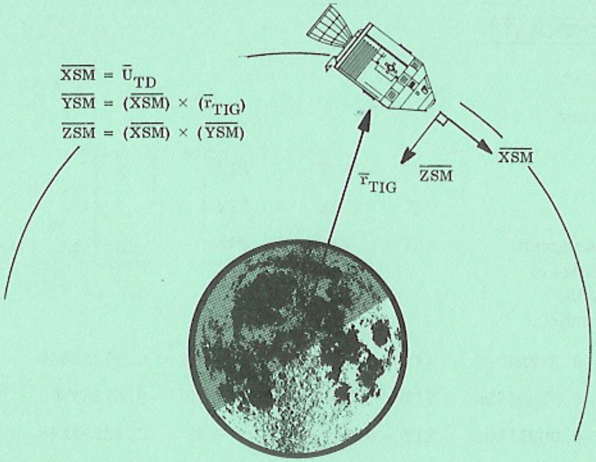
YIX = -0.01381990 YIY = 0.88101469 YIZ = -0.47288702

ZIX = -0.96911196 ZIY = 0.10466121 ZIZ = 0.22331146

Figure 3 (Sheet 4 of 4). Mission REFSMMAT's

OPTION: 00001 (PREFERRED)

DESCRIPTION: Preferred Thrusting Illustrated



The PREFERRED option refers to one of two possibilities:

a. The PREFERRED thrusting orientation which is calculated and stored by P40 and P41.

b. Any orientation uplinked by MSFN via P27.

The CMC is unable to distinguish between a and b. Whenever a PREFERRED orientation has been computed by P40 or P41 and stored, or uplinked by MSFN via P27, the PREFERRED ATTITUDE flag is set. This flag indicates to the CMC that a usable platform orientation has been stored in the locations allotted to PREFERRED ATTITUDE. The PREFERRED ATTITUDE flag being reset indicates the information in the PREFERRED ATTITUDE locations is unusable. The PREFERRED ATTITUDE flag is reset by P40 and P41 at TIG - 30 seconds.

CALCULATION OF ORIENTATION:

$$\begin{bmatrix} \text{PREFERRED} \\ \text{REFSMMAT} \\ \text{(Thrusting)} \end{bmatrix} = \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix} = \begin{bmatrix} \overline{U}_{TD} \\ \text{Unit } (\overline{U}_{TD} \times \overline{r}_{TIG}) \\ \text{Unit } (\overline{U}_{TD} \times (\overline{U}_{TD} \times (\overline{r}_{TIG})) \end{bmatrix}$$

where

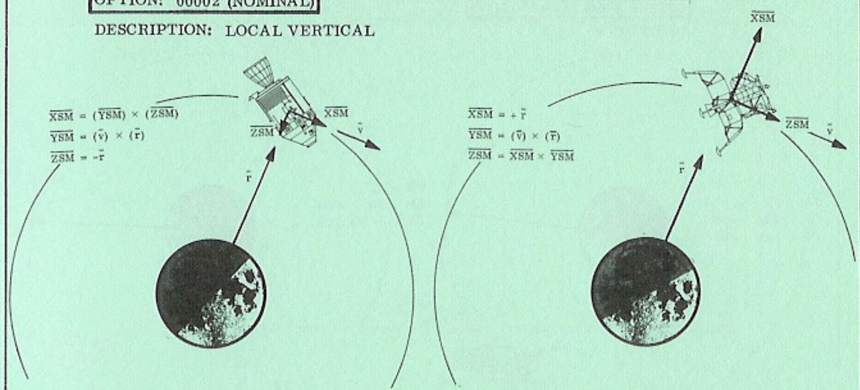
$\overline{U}_{TD}$ is a unit vector in the desired thrust direction expressed in the basic reference system.

$\overline{r}_{TIG}$ is the position vector of the vehicle at ignition expressed in the basic reference system.

Figure 4 (Sheet 1 of 3)

OPTION: 00002 (NOMINAL)

DESCRIPTION: LOCAL VERTICAL



The CMC requests the g.e.t. for which the vehicle $\overline{r}$ and $\overline{v}$ are to be selected to define the NOMINAL orientation.

CALCULATION OF ORIENTATION:

$$\begin{bmatrix} \text{Nominal} \\ \text{REFSMMAT} \end{bmatrix} = \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix} = \overset{\text{CSM}}{\begin{bmatrix} \underline{Y}_{SM} \times \underline{Z}_{SM} \\ \text{Unit } (\overline{v} \times \overline{r}) \\ \text{Unit } (-\overline{r}) \end{bmatrix}} = \overset{\text{LM}}{\begin{bmatrix} \text{Unit } (\overline{r}) \\ \text{Unit } (\overline{v} \times \overline{r}) \\ \underline{X}_{SM} \times \underline{Y}_{SM} \end{bmatrix}}$$

where

$\left.\begin{matrix} \overline{r} \\ \overline{v} \end{matrix}\right\}$ are position and velocity vectors of vehicle at the time specified.

OPTION: 00003 (REFSMMAT)

DESCRIPTION:

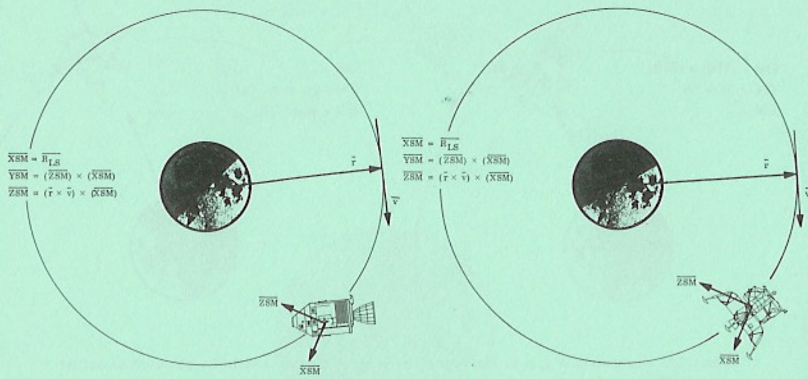
This option is used for gyro drift determination. This option realigns the platform to the platform orientation currently maintained in the CMC. The actual platform orientation differs from the CMC maintained orientation due to gyro drift.

$$\begin{bmatrix} \text{REFSMMAT} \end{bmatrix} = \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix} = \begin{bmatrix} \text{Currently maintained} \\ \text{CMC platform} \\ \text{Orientation} \end{bmatrix}$$

Figure 4 (Sheet 2 of 3)

OPTION: 00004 (LANDING SITE)

DESCRIPTION:



The latitude, longitude/2, and altitude above the mean lunar radius of the landing site must be entered to determine $\overline{R}_{LS}$. The g. e. t. for which the CSM $\overline{r}$ and $\overline{v}$ are to be selected must also be entered.

$$\begin{bmatrix} \text{Landing Site} \\ \text{REFSMMAT} \end{bmatrix} = \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix} = \begin{bmatrix} \text{Unit } (\overline{R}_{LS}) \\ \overline{Z}_{SM} \times \overline{X}_{SM} \\ \text{Unit } [(\overline{r} \times \overline{v}) \times \overline{X}_{SM}] \end{bmatrix}$$

where

$\overline{R}_{LS}$ is the landing site position vector, defined by the latitude, longitude, and altitude, specified in the basic reference system.

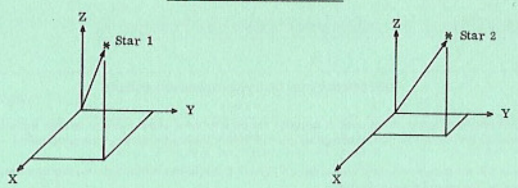
$\overline{r}$ and $\overline{v}$ are the CSM position and velocity vectors at the time specified.

PROCEDURE FOR SPECIFYING OPTIONS

a. When P52 is entered, the CMC checks the PREFERRED ATTITUDE flag.
b. If the flag is set, the DSKY flashes Verb 04, Noun 06, R2 = 00001, indicating the PREFERRED option may be selected.
c. If the flag is not set, the DSKY flashes Verb 04, Noun 06, R2 = 00003, indicating the PREFERRED option may not be selected.
d. The desired option is loaded into R2 via Verb 22.

Figure 4 (Sheet 3 of 3)

P51/P52 IMU ALIGNMENT



$$\underline{U}_{S1} = \begin{bmatrix} X_1 \\ Y_1 \\ Z_1 \end{bmatrix}_{ECI} \qquad \underline{U}_{S2} = \begin{bmatrix} X_2 \\ Y_2 \\ Z_2 \end{bmatrix}_{ECI}$$

$\underline{U}_{S1}$ and $\underline{U}_{S2}$ are known unit vectors in ECI space of the stars and are stored in the AGC.

$$\underline{U}_{S1M} = \begin{bmatrix} X_{1M} \\ Y_{1M} \\ Z_{1M} \end{bmatrix}_{SM} \qquad \underline{U}_{S2M} = \begin{bmatrix} X_{2M} \\ Y_{2M} \\ Z_{2M} \end{bmatrix}_{SM}$$

$$\underline{U}_{SiM} = \begin{bmatrix} X_{iM} \\ Y_{iM} \\ Z_{iM} \end{bmatrix}_{i = 1 \text{ or } 2} = [\,AI\,]\,[\,AM\,]\,[\,AO\,]\,[\,32°\,] \begin{bmatrix} \text{Cos AS Sin AT} \\ \text{Sin AS Sin AT} \\ \text{Cos AT} \end{bmatrix}$$

AI, AM, AO are inner, middle, and outer gimbal angles at i th mark time. AS and AT are SXT LOS shaft and trunnion at i th mark time.

$\underline{U}_{S1M}$ and $\underline{U}_{S2M}$ are the measured unit vectors (optics mark) in stable member (SM) space of the stars.

$$[\,S_A\,] = \begin{bmatrix} \underline{U}_{S1} \\ (\underline{U}_{S1} \times \underline{U}_{S2}) \times \underline{U}_{S1} \\ \underline{U}_{S1} \times \underline{U}_{S2} \end{bmatrix} [\,ECI\,] \qquad [\,S_B\,] = \begin{bmatrix} \underline{U}_{S1M} \\ (\underline{U}_{S1M} \times \underline{U}_{S2M}) \times \underline{U}_{S1M} \\ \underline{U}_{S1M} \times \underline{U}_{S2M} \end{bmatrix} [\,SM\,]$$

$$[\,S_A\,] = [\,A\,]\ [\,ECI\,] \qquad [\,S_B\,] = [\,B\,]\ [\,SM\,]$$

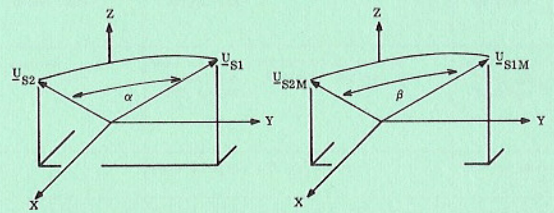
$$[\,S_A\,] = [\,S_B\,]$$

$$[\,A\,]\ [\,ECI\,] = [\,B\,]\ [\,SM\,]$$

$$[\,SM\,] = [\,B\,]^{-1}\,[\,A\,]\ [\,ECI\,]$$

$$[\,REFSMMAT\,] = [\,B\,]^{-1}\ [\,A\,]$$

NOTE: For P52, $\underline{U}_{S1}$ and $\underline{U}_{S2}$ are first transformed to SM space using the desired REFSMMAT. $[B]^{-1}[A]$ is then a characterization of realignment gyro torquing angles.



$$\alpha = \cos^{-1}(\underline{U}_{S1} \cdot \underline{U}_{S2}) \qquad \beta = \cos^{-1}(\underline{U}_{S1M} \cdot \underline{U}_{S2M})$$

Star Angle Difference = $\alpha - \beta$

Figure 5. REFSMMAT Computations

DETERMINATION OF GYRO TORQUING ANGLES

The star sighting data obtained during P52 is used to calculate the gyro torquing angles required to align the stable member from its present orientation to the desired orientation as defined by the REFSMMAT presently stored in the computer.

Since the gyros in the IMU are always torqued in the sequence Y, Z, and X, the transformation from the present orientation to the desired orientation is defined by the permutation shown below:

$$\begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix}_{\text{Desired}} = [\phi_X][\phi_Z][\phi_Y] \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix}_{\text{Present}}$$

$$\begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix}_{\text{Desired}} = \begin{bmatrix} \cos\phi_z \cos\phi_y & \sin\phi_z & -\cos\phi_z \sin\phi_y \\ (\sin\phi_x \sin\phi_y - \cos\phi_x \sin\phi_z \cos\phi_y) & \cos\phi_x \cos\phi_z & (\cos\phi_x \sin\phi_z \sin\phi_y + \sin\phi_x \cos\phi_y) \\ (\sin\phi_x \sin\phi_z \cos\phi_y + \cos\phi_x \sin\phi_y) & -\sin\phi_x \cos\phi_z & (\cos\phi_x \cos\phi_y - \sin\phi_x \sin\phi_z \sin\phi_y) \end{bmatrix} \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix}_{\text{Present}}$$

A transformation equivalent to the above transformation is obtainable from the star sighting data of the P52 program.

$$\begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix}_{\text{Desired}} = [A]^{-1}[B] \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix}_{\text{Present}} = [C] \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix}_{\text{Present}} = \begin{bmatrix} C(1,1) & C(1,2) & C(1,3) \\ C(2,1) & C(2,2) & C(2,3) \\ C(3,1) & C(3,2) & C(3,3) \end{bmatrix} \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix}_{\text{Present}}$$

For P52

$$\underline{S}_A = [A]\,\underline{SM}_{\text{Desired}} \qquad \underline{S}_B = [B]\,\underline{SM}_{\text{Present}}$$

$$[A]\,\underline{SM}_{\text{Desired}} = [B]\,\underline{SM}_{\text{Present}}$$

$$\underline{SM}_{\text{Desired}} = [A]^{-1}[B]\,\underline{SM}_{\text{Present}}$$

The gyro torquing angles can be computed from any convenient element for element assignment between the matrices [C] and $[\phi_X][\phi_Z][\phi_Y]$. Gyro torquing angles are computed using the relationship:

$$\phi_y = \tan^{-1}\left(\frac{-C(1,3)}{C(1,1)}\right)$$

$$\phi_z = \tan^{-1}\left(\frac{C(1,2)\cos\phi_y}{C(1,1)}\right)$$

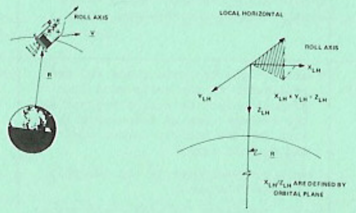
$$\phi_x = \tan^{-1}\left(\frac{-C(3,2)}{C(2,2)}\right)$$

J-2 MISSION REFSMMAT SUMMARY, 16 APRIL LAUNCH

Applicable maneuvers	REFSMMAT	Alinement criteria (IMU axis)	Remarks
Launch TLI T&D	Launch pad	X-axis along flight azimuth at launch Z-axis along negative radius vector Y-axis completes right-hand system	At earth launch the FDAI will display: Roll = 90+ flight azimuth Pitch = 90 Yaw = 0
MCC-1 MCC-2 Passive thermal control MCC-3 MCC-4 SIM bay door jettison	PTC (passive thermal control)	X-axis in the ecliptic plane and perpendicular to the earth-moon line projection in the ecliptic plane at the average time of transearth injection for the monthly launch window and azimuth range Z-axis perpendicular to the ecliptic and directed south Y-axis completes the right-hand system	At the beginning of the barbeque mode, the spacecraft will maneuver to an FDAI display of: Roll = 0 Pitch = 90 Yaw = 0
LOI	Preferred (heads-down CSM)	X-axis alined with the spacecraft X-body axis at the vehicle attitude for ignition with the thrust directed through the center of gravity Z-axis in the plane formed by the X-axis and the position vector. Positive direction away from moon for a heads-down attitude. Positive direction towards moon for heads-up attitude. Y-axis completes the right-hand system	In a heads-down orientation at burn ignition, the CSM FDAI will display: Roll = 0 Pitch = 0 Yaw = 0
DOI Separation Circularization Powered descent	Landing site (CSM and LM)	X-axis along positive lunar radius vector at landing site at predicted landing time Z-axis in direction of flight parallel to the CSM orbital plane and perpendicular to X Y-axis completes the right-hand system	At nominal touchdown, the LM FDAI will display: Roll = 0 Pitch = 0 Yaw = 0
First CSM plane change	Preferred (CSM only) (heads down)	Same as above preferred alinement definition	At burn ignition, the FDAI will display: Roll = 0 Pitch = 0 Yaw = 0
LM ascent Rendezvous CSM sep after LM jettison LM deorbit Shaping burn Subsatellite jettison	Ascent (CSM and LM)	X-axis along positive lunar radius vector at landing site at predicted lift-off time Z-axis down range parallel to the CSM orbital plane and perpendicular to X Y-axis completes the right-hand system	At nominal lift-off time, the LM FDAI will display: Roll = 359 Pitch = 359 Yaw = 005
Second CSM plane change	Preferred (heads down)	Same as above preferred alinement definition	At burn ignition, the FDAI will display: Roll = 0 Pitch = 0 Yaw = 0
TEI	Preferred (heads down)	Same as above preferred alinement definition. REFSMMAT defined at TEI ignition.	In a heads-down orientation at burn ignition, the FDAI will display: Roll = 180 Pitch = 0 Yaw = 0
MCC-5 MCC-6	PTC	Same as above PTC alinement	Same as above PTC alinement
MCC-7 Entry	Entry	X-axis is in local horizontal plane in the direction of flight at entry interface (400 000 ft) Z-axis is down along negative radius at entry interface Y-axis completes the right-hand system	At entry interface with wings level local horizontal, heat shield forward, inplane, lift up, heads down, the FDAI will display: Roll = 0 Pitch = 180 Yaw = 0

DETERMINATION OF S/C ROLL AXIS WITH RESPECT TO A LOCAL HORIZONTAL COORDINATE SYSTEM

The procedure outlined below provides a method for determining the direction cosines of the CSM roll axis with respect to the local horizontal coordinate system. This procedure requires knowing the IMU gimbal angles, the REFSMMAT to which the stable member is aligned, and the state vector (expressed in reference coordinates) of the CSM corresponding to the time of the gimbal angles.



The procedure is broken into two parts: the first defines the S/C axis with respect to the basic reference coordinate system; the second defines the S/C axis with respect to the local horizontal coordinate system.

The following transformations are used in the development of the procedure and are defined here for completeness.

[SMNB] - the transformation from the stable member to the navigation base of the G&N system. Since the navigation base axes are colinear with S/C axes for the CSM, this transformation also defines the transformation from the stable member to the S/C ([SMSC]).

$$\begin{bmatrix} X_{SC} \\ Y_{SC} \\ Z_{SC} \end{bmatrix} = [A_o]^{-1}[A_m]^{-1}[A_i]^{-1} \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix} = [SMNB] \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix} = [SMSC] \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix}$$

$$[SMSC] = \begin{bmatrix} \cos A_i \cos A_m & \sin A_m & -\sin A_i \cos A_m \\ (\sin A_i \sin A_o - \cos A_i \sin A_m \cos A_o) & \cos A_m \cos A_o & (\sin A_i \sin A_m \cos A_o + \cos A_i \sin A_o) \\ (\cos A_i \sin A_m \sin A_o + \sin A_i \cos A_o) & -\cos A_m \sin A_o & (\cos A_i \cos A_o - \sin A_i \sin A_m \sin A_o) \end{bmatrix}$$

where Ao, Ai, and Am are the outer, inner, and middle gimbal angles as displayed on the DSKY.

[REFSMMAT] - the transformation from the basic reference coordinate system to the stable member. There are several different types of REFSMMAT and they are defined elsewhere in this section.

$$[REFSMMAT] = \begin{bmatrix} XIX & XIY & XIZ \\ YIX & YIY & YIZ \\ ZIX & ZIY & ZIZ \end{bmatrix}$$

[REFSC] - the transformation from the basic reference coordinate system to the S/C axes.

$$[REFSC] = [SMSC]\,[REFSMMAT] = \begin{bmatrix} \underline{X}_{SC/REF} \\ \underline{Y}_{SC/REF} \\ \underline{Z}_{SC/REF} \end{bmatrix} = \begin{bmatrix} REFSC(1,1) & REFSC(1,2) & REFSC(1,3) \\ REFSC(2,1) & REFSC(2,2) & REFSC(2,3) \\ REFSC(3,1) & REFSC(3,2) & REFSC(3,3) \end{bmatrix}$$

where $\underline{X}_{SC/REF}$, $\underline{Y}_{SC/REF}$, and $\underline{Z}_{SC/REF}$ define the X, Y, and Z axes of the CSM with respect to the basic reference coordinate system.

[LHREF] - the transformation from the local horizontal coordinate system to the basic reference coordinate system.

$$[LHREF] = [\text{unit}\{(\underline{V} \times \underline{R}) \times (-\underline{R})\},\ \text{unit}\ (\underline{V} \times \underline{R}),\ \text{unit}\ (-\underline{R})\ ]$$

where $\underline{R}$ and $\underline{V}$ are the state vector of the CSM at the time of the gimbal angles.

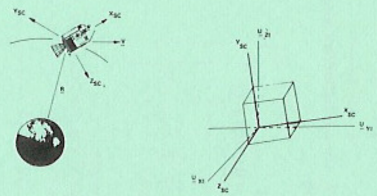
[LHSC] - the transformation from the local horizontal coordinate system to the CSM axes.

$$[LHSC] = [REFSC]\,[LHREF] = \begin{bmatrix} \underline{X}_{SC/LH} \\ \underline{Y}_{SC/LH} \\ \underline{Z}_{SC/LH} \end{bmatrix}$$

where $\underline{X}_{SC/LH}$, $\underline{Y}_{SC/LH}$, and $\underline{Z}_{SC/LH}$ define the X, Y, and Z axes of the CSM with respect to the local horizontal coordinate system.

STEP 1. S/C AXES WRT BASIC REFERENCE COORDINATES

[REFSC] = [SMSC] [REFSMMAT]



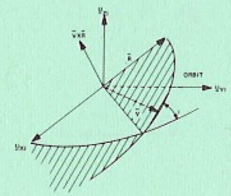
$$\left.\begin{aligned} REFSC(1,1) &= \cos A_i \cos A_m\, XIX + \sin A_m\, YIX - \sin A_i \cos A_m\, ZIX \\ REFSC(1,2) &= \cos A_i \cos A_m\, XIY + \sin A_m\, YIY - \sin A_i \cos A_m\, ZIY \\ REFSC(1,3) &= \cos A_i \cos A_m\, XIZ + \sin A_m\, YIZ - \sin A_i \cos A_m\, ZIZ \end{aligned}\right\} = \underline{X}_{SC/REF}$$

$$\left.\begin{aligned} REFSC(2,1) &= (\sin A_i \sin A_o - \cos A_i \sin A_m \cos A_o)\, XIX + \cos A_m \cos A_o\, YIX + (\sin A_i \sin A_m \cos A_o + \cos A_i \sin A_o)\, ZIX \\ REFSC(2,2) &= (\sin A_i \sin A_o - \cos A_i \sin A_m \cos A_o)\, XIY + \cos A_m \cos A_o\, YIY + (\sin A_i \sin A_m \cos A_o + \cos A_i \sin A_o)\, ZIY \\ REFSC(2,3) &= (\sin A_i \sin A_o - \cos A_i \sin A_m \cos A_o)\, XIZ + \cos A_m \cos A_o\, YIZ + (\sin A_i \sin A_m \cos A_o + \cos A_i \sin A_o)\, ZIZ \end{aligned}\right\} = \underline{Y}_{SC/REF}$$

$$\left.\begin{aligned} REFSC(3,1) &= (\cos A_i \sin A_m \sin A_o + \sin A_i \cos A_o)\, XIX - \cos A_m \sin A_o\, YIX + (\cos A_i \cos A_o - \sin A_i \sin A_m \sin A_o)\, ZIX \\ REFSC(3,2) &= (\cos A_i \sin A_m \sin A_o + \sin A_i \cos A_o)\, XIY - \cos A_m \sin A_o\, YIY + (\cos A_i \cos A_o - \sin A_i \sin A_m \sin A_o)\, ZIY \\ REFSC(3,3) &= (\cos A_i \sin A_m \sin A_o + \sin A_i \cos A_o)\, XIZ - \cos A_m \sin A_o\, YIZ + (\cos A_i \cos A_o - \sin A_i \sin A_m \sin A_o)\, ZIZ \end{aligned}\right\} = \underline{Z}_{SC/REF}$$

STEP 2. S/C AXES WRT LOCAL HORIZONTAL COORDINATES

[LHSC] = [REFSC] [LHREF]



$$\left.\begin{aligned} LHSC(1,1) &= \{REFSC(1,1), REFSC(1,2), REFSC(1,3)\} \circ \{\text{unit}\ [(\underline{V} \times \underline{R}) \times (-\underline{R})]\} \\ LHSC(1,2) &= \{REFSC(1,1), REFSC(1,2), REFSC(1,3)\} \circ \{\text{unit}\ (\underline{V} \times \underline{R})\} \\ LHSC(1,3) &= \{REFSC(1,1), REFSC(1,2), REFSC(1,3)\} \circ \{\text{unit}\ (-\underline{R})\} \end{aligned}\right\} = \underline{X}_{SC/LH}$$

$$\left.\begin{aligned} LHSC(2,1) &= \{REFSC(2,1), REFSC(2,2), REFSC(2,3)\} \circ \{\text{unit}\ [(\underline{V} \times \underline{R}) \times (-\underline{R})]\} \\ LHSC(2,2) &= \{REFSC(2,1), REFSC(2,2), REFSC(2,3)\} \circ \{\text{unit}\ (\underline{V} \times \underline{R})\} \\ LHSC(2,3) &= \{REFSC(2,1), REFSC(2,2), REFSC(2,3)\} \circ \{\text{unit}\ (-\underline{R})\} \end{aligned}\right\} = \underline{Y}_{SC/LH}$$

$$\left.\begin{aligned} LHSC(3,1) &= \{REFSC(3,1), REFSC(3,2), REFSC(3,3)\} \circ \{\text{unit}\ [(\underline{V} \times \underline{R}) \times (-\underline{R})]\} \\ LHSC(3,2) &= \{REFSC(3,1), REFSC(3,2), REFSC(3,3)\} \circ \{\text{unit}\ (\underline{V} \times \underline{R})\} \\ LHSC(3,3) &= \{REFSC(3,1), REFSC(3,2), REFSC(3,3)\} \circ \{\text{unit}\ (-\underline{R})\} \end{aligned}\right\} = \underline{Z}_{SC/LH}$$

The $\underline{X}_{SC}$ axis is the same as the roll axis and therefore the components of the roll axis of the S/C with respect to the local horizontal coordinate system are:

LHSC (1, 3) — component of X_{SC} along $-\underline{R}$

LHSC (1, 2) — component of X_{SC} normal to orbital plane

LHSC (1, 1) — component of X_{SC} normal to $-\underline{R}$ and in plane.

Data and Calculation Summary Sheet

A_o (X/Roll) ___ . __ A_i (Y/Pitch) ___ . __   TIME ___ : __ : __

A_m (Z/Yaw) ___ . __

[SMSC] • [REFSMMAT]

$$\begin{bmatrix} .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \\ .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \\ .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \end{bmatrix} \bullet \begin{bmatrix} .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \\ .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \\ .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \end{bmatrix}$$

$\underline{R}$*		$\underline{V}$*	
r_x	______	v_x	______
r_y	______	v_y	______
r_z	______	v_z	______

*The units of $\underline{R}$ and $\underline{V}$ are not important since they are used in unitized form.

[REFSC] • [LHREF]

$$\begin{bmatrix} .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \\ .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \\ .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \end{bmatrix} \bullet \begin{array}{ccc} \text{Unit}[(\underline{V}\times\underline{R})\times(-\underline{R})] & \text{Unit}(\underline{V}\times\underline{R}) & \text{Unit}(-\underline{R}) \end{array} \begin{bmatrix} .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \\ .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \\ .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \end{bmatrix}$$

[LHSC]

$$\begin{bmatrix} .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \\ .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \\ .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \end{bmatrix}$$

$$\text{Roll} = \tan^{-1}\left(\frac{-\text{LHSC}(3,\ 2)}{\text{LHSC}(2,\ 2)}\right)$$

$$\text{Yaw} = \tan^{-1}\left(\frac{\text{LHSC}(1,\ 2)\cdot\cos\text{Roll}}{\text{LHSC}(2,\ 2)}\right)$$

$$\text{Pitch} = \tan^{-1}\left(\frac{-\text{LHSC}(1,\ 3)}{\text{LHSC}(1,\ 1)}\right)$$

LHSC (1, 1) = . ____ component of X_{sc} normal to $-\underline{R}$ and in plane

LHSC (1, 2) = . ____ component of X_{sc} normal to orbital plane

LHSC (1, 3) = . ____ component of X_{sc} along $-\underline{R}$

Data and Calculation Summary Sheet

A_o (X/Roll) ___ . __ A_i (Y/Pitch) ___ . __   TIME ___ : __ : __

A_m (Z/Yaw) ___ . __

[SMSC] • [REFSMMAT]

$$\begin{bmatrix} .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \\ .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \\ .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \end{bmatrix} \bullet \begin{bmatrix} .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \\ .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \\ .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \end{bmatrix}$$

$\underline{R}$*		$\underline{V}$*	
r_x	______	v_x	______
r_y	______	v_y	______
r_z	______	v_z	______

*The units of $\underline{R}$ and $\underline{V}$ are not important since they are used in unitized form.

[REFSC] • [LHREF]

$$\begin{bmatrix} .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \\ .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \\ .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \end{bmatrix} \bullet \begin{array}{ccc} \text{Unit}[(\underline{V}\times\underline{R})\times(-\underline{R})] & \text{Unit}(\underline{V}\times\underline{R}) & \text{Unit}(-\underline{R}) \end{array} \begin{bmatrix} .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \\ .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \\ .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \end{bmatrix}$$

[LHSC]

$$\begin{bmatrix} .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \\ .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \\ .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \end{bmatrix}$$

$$\text{Roll} = \tan^{-1}\left(\frac{-\text{LHSC}(3,\ 2)}{\text{LHSC}(2,\ 2)}\right)$$

$$\text{Yaw} = \tan^{-1}\left(\frac{\text{LHSC}(1,\ 2)\cdot\cos\text{Roll}}{\text{LHSC}(2,\ 2)}\right)$$

$$\text{Pitch} = \tan^{-1}\left(\frac{-\text{LHSC}(1,\ 3)}{\text{LHSC}(1,\ 1)}\right)$$

LHSC (1, 1) = . ____ component of X_{sc} normal to $-\underline{R}$ and in plane

LHSC (1, 2) = . ____ component of X_{sc} normal to orbital plane

LHSC (1, 3) = . ____ component of X_{sc} along $-\underline{R}$

Data and Calculation Summary Sheet

A_o (X/Roll) ___ . __ A_i (Y/Pitch) ___ . __ TIME ___ : __ : __

A_m (Z/Yaw) ___ . __

[SMSC] • [REFSMMAT]

$$\begin{bmatrix} .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \\ .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \\ .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \end{bmatrix} \bullet \begin{bmatrix} .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \\ .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \\ .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \end{bmatrix}$$

$\underline{R}$*		$\underline{V}$*	
r_x	________	v_x	________
r_y	________	v_y	________
r_z	________	v_z	________

*The units of $\underline{R}$ and $\underline{V}$ are not important since they are used in unitized form.

[REFSC] • [LHREF]

$$\begin{bmatrix} .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \\ .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \\ .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \end{bmatrix} \bullet \begin{array}{ccc} \text{Unit}[(\underline{V}\times\underline{R})\times(-\underline{R})] & \text{Unit}(\underline{V}\times\underline{R}) & \text{Unit}(-\underline{R}) \\ \multicolumn{3}{c}{\begin{bmatrix} .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \\ .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \\ .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \end{bmatrix}} \end{array}$$

[LHSC]

$$\begin{bmatrix} .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \\ .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \\ .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \end{bmatrix}$$

$$\text{Roll} = \tan^{-1}\left(\frac{-\text{LHSC}(3,\ 2)}{\text{LHSC}(2,\ 2)}\right)$$

$$\text{Yaw} = \tan^{-1}\left(\frac{\text{LHSC}(1,\ 2)\cdot\cos\text{Roll}}{\text{LHSC}(2,\ 2)}\right)$$

$$\text{Pitch} = \tan^{-1}\left(\frac{-\text{LHSC}(1,\ 3)}{\text{LHSC}(1,\ 1)}\right)$$

LHSC (1, 1) = . ____ component of X_{sc} normal to $-\underline{R}$ and in plane

LHSC (1, 2) = . ____ component of X_{sc} normal to orbital plane

LHSC (1, 3) = . ____ component of X_{sc} along $-\underline{R}$

Data and Calculation Summary Sheet

A_o (X/Roll) ___ . __ A_i (Y/Pitch) ___ . __ TIME ___ : __ : __

A_m (Z/Yaw) ___ . __

[SMSC] • [REFSMMAT]

$$\begin{bmatrix} .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \\ .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \\ .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \end{bmatrix} \bullet \begin{bmatrix} .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \\ .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \\ .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \end{bmatrix}$$

$\underline{R}$*		$\underline{V}$*	
r_x	________	v_x	________
r_y	________	v_y	________
r_z	________	v_z	________

*The units of $\underline{R}$ and $\underline{V}$ are not important since they are used in unitized form.

[REFSC] • [LHREF]

$$\begin{bmatrix} .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \\ .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \\ .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \end{bmatrix} \bullet \begin{array}{ccc} \text{Unit}[(\underline{V}\times\underline{R})\times(-\underline{R})] & \text{Unit}(\underline{V}\times\underline{R}) & \text{Unit}(-\underline{R}) \\ \multicolumn{3}{c}{\begin{bmatrix} .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \\ .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \\ .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \end{bmatrix}} \end{array}$$

[LHSC]

$$\begin{bmatrix} .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \\ .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \\ .\_\_\_\_ & .\_\_\_\_ & .\_\_\_\_ \end{bmatrix}$$

$$\text{Roll} = \tan^{-1}\left(\frac{-\text{LHSC}(3,\ 2)}{\text{LHSC}(2,\ 2)}\right)$$

$$\text{Yaw} = \tan^{-1}\left(\frac{\text{LHSC}(1,\ 2)\cdot\cos\text{Roll}}{\text{LHSC}(2,\ 2)}\right)$$

$$\text{Pitch} = \tan^{-1}\left(\frac{-\text{LHSC}(1,\ 3)}{\text{LHSC}(1,\ 1)}\right)$$

LHSC (1, 1) = . ____ component of X_{sc} normal to $-\underline{R}$ and in plane

LHSC (1, 2) = . ____ component of X_{sc} normal to orbital plane

LHSC (1, 3) = . ____ component of X_{sc} along $-\underline{R}$

P52–IMU REALIGN (CM)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 0 0 0 0 1

R2: 0 0 0 0 X IMU Align Option

1 – Preferred, 2 – Nominal,
3 – REFSMMAT, 4 – Landing Site

V51 Flashing – Please Mark

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours (GET)		+	0	0			
+	0	0	0			Minutes (GET)		+	0	0	0		
+	0					Seconds (GET)		+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X Gyro Torquing Angles (degrees)	N93						
						Y Gyro Torquing Angles (degrees)							
						Z Gyro Torquing Angles (degrees)							
						X Calculated Gyro Drift (meru)							
						Y Calculated Gyro Drift (meru)							
						Z Calculated Gyro Drift (meru)							

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours (GET)		+	0	0			
+	0	0	0			Minutes (GET)		+	0	0	0		
+	0					Seconds (GET)		+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X Gyro Torquing Angles (degrees)	N93						
						Y Gyro Torquing Angles (degrees)							
						Z Gyro Torquing Angles (degrees)							
						X Calculated Gyro Drift (meru)							
						Y Calculated Gyro Drift (meru)							
						Z Calculated Gyro Drift (meru)							

NOTES:

P52–IMU REALIGN (CM)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 0 0 0 0 1

R2: 0 0 0 0 X IMU Align Option

1 – Preferred, 2 – Nominal,
3 – REFSMMAT, 4 – Landing Site

V51 Flashing – Please Mark

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours (GET)		+	0	0			
+	0	0	0			Minutes (GET)		+	0	0	0		
+	0					Seconds (GET)		+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X Gyro Torquing Angles (degrees)	N93						
						Y Gyro Torquing Angles (degrees)							
						Z Gyro Torquing Angles (degrees)							
						X Calculated Gyro Drift (meru)							
						Y Calculated Gyro Drift (meru)							
						Z Calculated Gyro Drift (meru)							

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours (GET)		+	0	0			
+	0	0	0			Minutes (GET)		+	0	0	0		
+	0					Seconds (GET)		+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X Gyro Torquing Angles (degrees)	N93						
						Y Gyro Torquing Angles (degrees)							
						Z Gyro Torquing Angles (degrees)							
						X Calculated Gyro Drift (meru)							
						Y Calculated Gyro Drift (meru)							
						Z Calculated Gyro Drift (meru)							

NOTES:

P52–IMU REALIGN (CM)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 0 0 0 0 1

R2: 0 0 0 0 X IMU Align Option

1 – Preferred, 2 – Nominal,
3 – REFSMMAT, 4 – Landing Site

V51 Flashing – Please Mark

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				GET Hours		+	0	0			
+	0	0	0			GET Minutes		+	0	0	0		
+	0					GET Seconds		+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						Gyro Torquing Angles (degrees) X	N93						
						Gyro Torquing Angles (degrees) Y							
						Gyro Torquing Angles (degrees) Z							
						Calculated Gyro Drift (meru) X							
						Calculated Gyro Drift (meru) Y							
						Calculated Gyro Drift (meru) Z							

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				GET Hours		+	0	0			
+	0	0	0			GET Minutes		+	0	0	0		
+	0					GET Seconds		+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						Gyro Torquing Angles (degrees) X	N93						
						Gyro Torquing Angles (degrees) Y							
						Gyro Torquing Angles (degrees) Z							
						Calculated Gyro Drift (meru) X							
						Calculated Gyro Drift (meru) Y							
						Calculated Gyro Drift (meru) Z							

NOTES:

P52–IMU REALIGN (CM)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 0 0 0 0 1

R2: 0 0 0 0 X IMU Align Option

1 – Preferred, 2 – Nominal,
3 – REFSMMAT, 4 – Landing Site

V51 Flashing – Please Mark

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				GET Hours		+	0	0			
+	0	0	0			GET Minutes		+	0	0	0		
+	0					GET Seconds		+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						Gyro Torquing Angles (degrees) X	N93						
						Gyro Torquing Angles (degrees) Y							
						Gyro Torquing Angles (degrees) Z							
						Calculated Gyro Drift (meru) X							
						Calculated Gyro Drift (meru) Y							
						Calculated Gyro Drift (meru) Z							

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				GET Hours		+	0	0			
+	0	0	0			GET Minutes		+	0	0	0		
+	0					GET Seconds		+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						Gyro Torquing Angles (degrees) X	N93						
						Gyro Torquing Angles (degrees) Y							
						Gyro Torquing Angles (degrees) Z							
						Calculated Gyro Drift (meru) X							
						Calculated Gyro Drift (meru) Y							
						Calculated Gyro Drift (meru) Z							

NOTES:

P52–IMU REALIGN (CM)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 0 0 0 0 1

R2: 0 0 0 0 X IMU Align Option

1 – Preferred, 2 – Nominal,
3 – REFSMMAT, 4 – Landing Site

V51 Flashing – Please Mark

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours (GET)		+	0	0			
+	0	0	0			Minutes (GET)		+	0	0	0		
+	0					Seconds (GET)		+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X Gyro Torquing Angles (degrees)	N93						
						Y Gyro Torquing Angles (degrees)							
						Z Gyro Torquing Angles (degrees)							
						X Calculated Gyro Drift (meru)							
						Y Calculated Gyro Drift (meru)							
						Z Calculated Gyro Drift (meru)							

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours (GET)		+	0	0			
+	0	0	0			Minutes (GET)		+	0	0	0		
+	0					Seconds (GET)		+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X Gyro Torquing Angles (degrees)	N93						
						Y Gyro Torquing Angles (degrees)							
						Z Gyro Torquing Angles (degrees)							
						X Calculated Gyro Drift (meru)							
						Y Calculated Gyro Drift (meru)							
						Z Calculated Gyro Drift (meru)							

NOTES:

P52–IMU REALIGN (CM)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 0 0 0 0 1

R2: 0 0 0 0 X IMU Align Option

1 – Preferred, 2 – Nominal,
3 – REFSMMAT, 4 – Landing Site

V51 Flashing – Please Mark

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours (GET)		+	0	0			
+	0	0	0			Minutes (GET)		+	0	0	0		
+	0					Seconds (GET)		+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X Gyro Torquing Angles (degrees)	N93						
						Y Gyro Torquing Angles (degrees)							
						Z Gyro Torquing Angles (degrees)							
						X Calculated Gyro Drift (meru)							
						Y Calculated Gyro Drift (meru)							
						Z Calculated Gyro Drift (meru)							

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours (GET)		+	0	0			
+	0	0	0			Minutes (GET)		+	0	0	0		
+	0					Seconds (GET)		+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X Gyro Torquing Angles (degrees)	N93						
						Y Gyro Torquing Angles (degrees)							
						Z Gyro Torquing Angles (degrees)							
						X Calculated Gyro Drift (meru)							
						Y Calculated Gyro Drift (meru)							
						Z Calculated Gyro Drift (meru)							

NOTES:

P52–IMU REALIGN (CM)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 0 0 0 0 1

R2: 0 0 0 0 X IMU Align Option

1 – Preferred, 2 – Nominal,
3 – REFSMMAT, 4 – Landing Site

V51 Flashing – Please Mark

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours (GET)		+	0	0			
+	0	0	0			Minutes (GET)		+	0	0	0		
+	0					Seconds (GET)		+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X Gyro Torquing Angles (degrees)	N93						
						Y							
						Z							
						X Calculated Gyro Drift (meru)							
						Y							
						Z							

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours (GET)		+	0	0			
+	0	0	0			Minutes (GET)		+	0	0	0		
+	0					Seconds (GET)		+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X Gyro Torquing Angles (degrees)	N93						
						Y							
						Z							
						X Calculated Gyro Drift (meru)							
						Y							
						Z							

NOTES:

P52–IMU REALIGN (CM)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 0 0 0 0 1

R2: 0 0 0 0 X IMU Align Option

1 – Preferred, 2 – Nominal,
3 – REFSMMAT, 4 – Landing Site

V51 Flashing – Please Mark

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours (GET)		+	0	0			
+	0	0	0			Minutes (GET)		+	0	0	0		
+	0					Seconds (GET)		+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X Gyro Torquing Angles (degrees)	N93						
						Y							
						Z							
						X Calculated Gyro Drift (meru)							
						Y							
						Z							

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours (GET)		+	0	0			
+	0	0	0			Minutes (GET)		+	0	0	0		
+	0					Seconds (GET)		+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X Gyro Torquing Angles (degrees)	N93						
						Y							
						Z							
						X Calculated Gyro Drift (meru)							
						Y							
						Z							

NOTES:

P52–IMU REALIGN (CM)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 0 0 0 0 1

R2: 0 0 0 0 X IMU Align Option

1 – Preferred, 2 – Nominal,
3 – REFSMMAT, 4 – Landing Site

V51 Flashing – Please Mark

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours (GET)		+	0	0			
+	0	0	0			Minutes (GET)		+	0	0	0		
+	0					Seconds (GET)		+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X Gyro Torquing Angles (degrees)	N93						
						Y							
						Z							
						X Calculated Gyro Drift (meru)							
						Y							
						Z							

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours (GET)		+	0	0			
+	0	0	0			Minutes (GET)		+	0	0	0		
+	0					Seconds (GET)		+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X Gyro Torquing Angles (degrees)	N93						
						Y							
						Z							
						X Calculated Gyro Drift (meru)							
						Y							
						Z							

NOTES:

P52–IMU REALIGN (CM)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 0 0 0 0 1

R2: 0 0 0 0 X IMU Align Option

1 – Preferred, 2 – Nominal,
3 – REFSMMAT, 4 – Landing Site

V51 Flashing – Please Mark

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours (GET)		+	0	0			
+	0	0	0			Minutes (GET)		+	0	0	0		
+	0					Seconds (GET)		+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X Gyro Torquing Angles (degrees)	N93						
						Y							
						Z							
						X Calculated Gyro Drift (meru)							
						Y							
						Z							

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours (GET)		+	0	0			
+	0	0	0			Minutes (GET)		+	0	0	0		
+	0					Seconds (GET)		+	0				
X	0	0	0			Celestial Body Code 1	N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2	N71	X	0	0	0		
						Star Angle Difference (degrees)	N05						
						X Gyro Torquing Angles (degrees)	N93						
						Y							
						Z							
						X Calculated Gyro Drift (meru)							
						Y							
						Z							

NOTES:

P52–IMU REALIGN (CM)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 00001

R2: 0000X IMU Align Option

1 – Preferred, 2 – Nominal,
3 – REFSMMAT, 4 – Landing Site

V51 Flashing – Please Mark

X	0	0	0	0		P52 Option			X	0	0	0	0	
+	0	0				Hours			+	0	0			
+	0	0	0			Minutes	GET		+	0	0	0		
+	0					Seconds			+	0				
X	0	0	0			Celestial Body Code 1		N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2		N71	X	0	0	0		
						Star Angle Difference (degrees)		N05						
						X		N93						
						Y	Gyro Torquing Angles (degrees)							
						Z								
						X								
						Y	Calculated Gyro Drift (meru)							
						Z								

X	0	0	0	0		P52 Option			X	0	0	0	0	
+	0	0				Hours			+	0	0			
+	0	0	0			Minutes	GET		+	0	0	0		
+	0					Seconds			+	0				
X	0	0	0			Celestial Body Code 1		N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2		N71	X	0	0	0		
						Star Angle Difference (degrees)		N05						
						X		N93						
						Y	Gyro Torquing Angles (degrees)							
						Z								
						X								
						Y	Calculated Gyro Drift (meru)							
						Z								

NOTES:

P52–IMU REALIGN (CM)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 00001

R2: 0000X IMU Align Option

1 – Preferred, 2 – Nominal,
3 – REFSMMAT, 4 – Landing Site

V51 Flashing – Please Mark

X	0	0	0	0		P52 Option			X	0	0	0	0	
+	0	0				Hours			+	0	0			
+	0	0	0			Minutes	GET		+	0	0	0		
+	0					Seconds			+	0				
X	0	0	0			Celestial Body Code 1		N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2		N71	X	0	0	0		
						Star Angle Difference (degrees)		N05						
						X		N93						
						Y	Gyro Torquing Angles (degrees)							
						Z								
						X								
						Y	Calculated Gyro Drift (meru)							
						Z								

X	0	0	0	0		P52 Option			X	0	0	0	0	
+	0	0				Hours			+	0	0			
+	0	0	0			Minutes	GET		+	0	0	0		
+	0					Seconds			+	0				
X	0	0	0			Celestial Body Code 1		N71	X	0	0	0		
X	0	0	0			Celestial Body Code 2		N71	X	0	0	0		
						Star Angle Difference (degrees)		N05						
						X		N93						
						Y	Gyro Torquing Angles (degrees)							
						Z								
						X								
						Y	Calculated Gyro Drift (meru)							
						Z								

NOTES:

P52–IMU REALIGN (LM)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 0 0 0 0 1

R2: 0 0 0 0 X   IMU Align Option

1 – Preferred, 2 – Nominal
3 – REFSMMAT, 4 – Landing Site

V01 N70 Flashing

R1: 0 0 C D E

C – AOT Detent
0–COAS CAL, 1 – FL, 2 – FC, 3 – FR,
4 – RR, 5 – RC, 6 – RL, 7 – COAS

DE – Celestial Body Code

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours		+	0	0			
+	0	0	0			Minutes	GET	+	0	0	0		
+	0					Seconds		+	0				
X	0	0				AOT Detent and Star 1 ID	N71	X	0	0			
X	0	0				AOT Detent and Star 2 ID	N71	X	0	0			
						Star Angle Difference (degrees)	N05						
						X	N93						
						Y – Gyro Torquing Angles (degrees)							
						Z							
						X							
						Y – Calculated Gyro Drift (meru)							
						Z							

X	0	0	0	0		P52 Option		X	0	0	0	0	
+	0	0				Hours		+	0	0			
+	0	0	0			Minutes	GET	+	0	0	0		
+	0					Seconds		+	0				
X	0	0				AOT Detent and Star 1 ID	N71	X	0	0			
X	0	0				AOT Detent and Star 2 ID	N71	X	0	0			
						Star Angle Difference (degrees)	N05						
						X	N93						
						Y – Gyro Torquing Angles (degrees)							
						Z							
						X							
						Y – Calculated Gyro Drift (meru)							
						Z							

NOTES: