

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}_{X1}) 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}_{Z1}) is along the mean earth north pole, and Y axis (\underline{u}_{Y1}) 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.

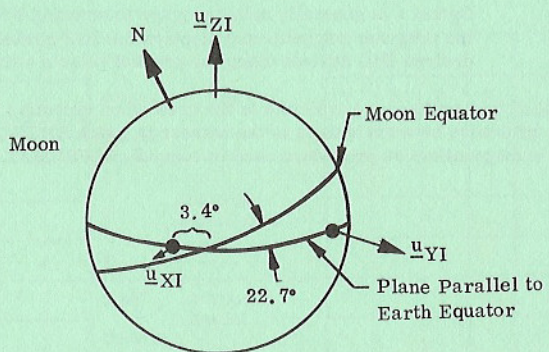
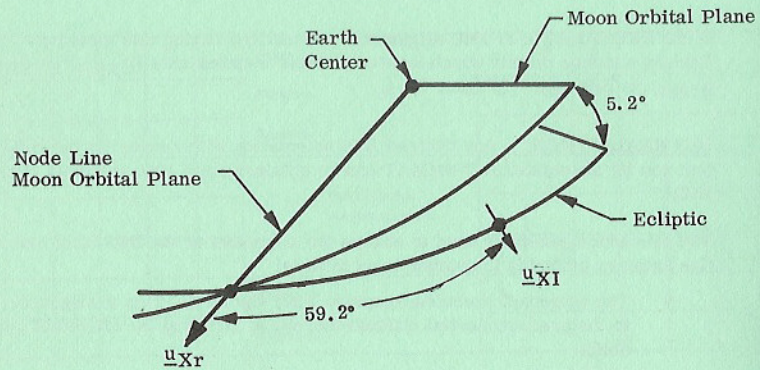
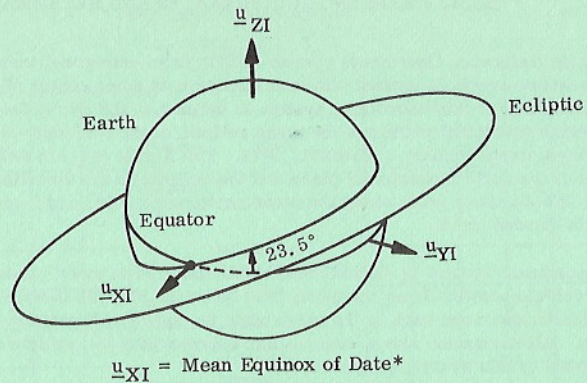
Nine REFSMMAT's or IMU alignments are utilized during this mission. Each is a unique matrix which locates a stable member axis (\underline{u}_{XSM} , \underline{u}_{YSM} , or \underline{u}_{ZSM}) in BRC space (Figure 3).

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

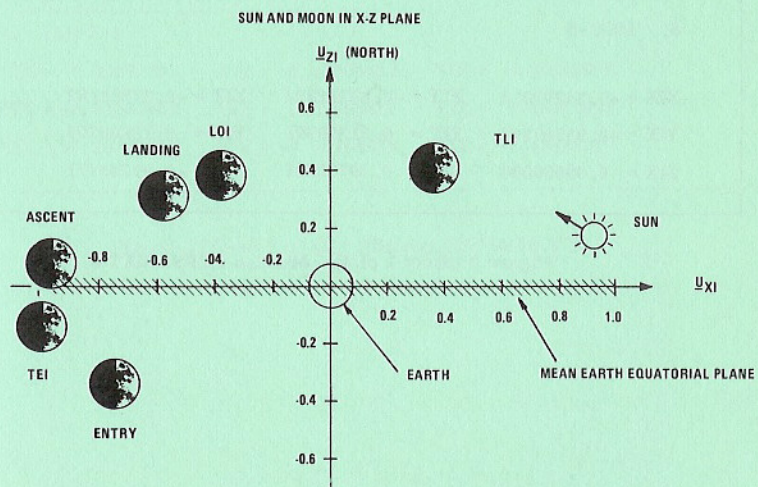
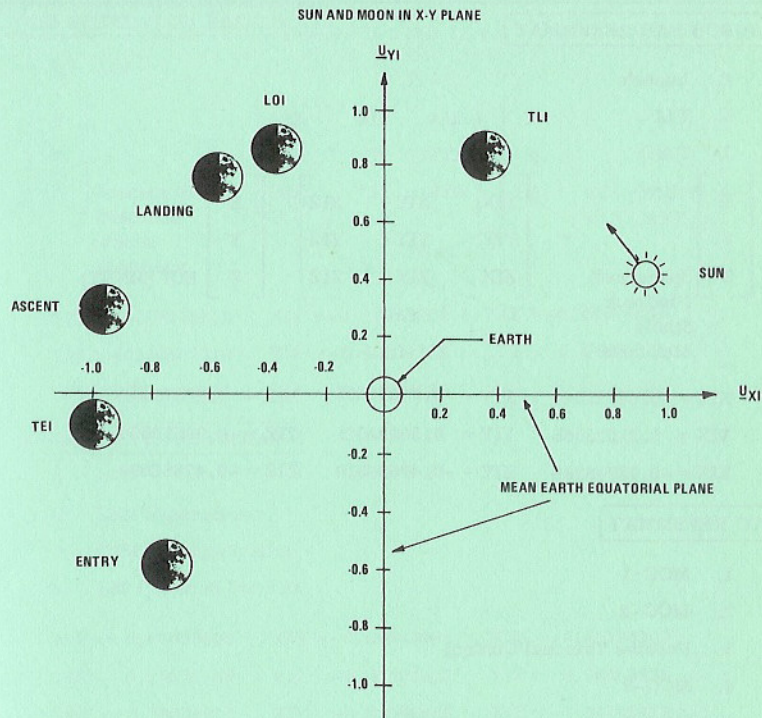


Figure 2. Lunar-Solar Ephemeris

LAUNCH PAD REFSMMAT

1. Launch
2. TLI
3. T & D

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

$$\begin{aligned} XIX &= -0.64021344 & XIY &= 0.71888605 & XIZ &= 0.27079443 \\ YIX &= 0.21522065 & YIY &= 0.50624021 & YIZ &= -0.83510534 \\ ZIX &= -0.73743260 & ZIY &= -0.47636510 & ZIZ &= -0.47882090 \end{aligned}$$

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

$$\begin{aligned} XIX &= -0.34202014 & XIY &= -0.86212824 & XIZ &= -0.37384102 \\ YIX &= -0.93969262 & YIY &= 0.31378901 & YIZ &= 0.13606700 \\ ZIX &= 0.00000000 & ZIY &= 0.39783331 & ZIZ &= -0.91745771 \end{aligned}$$

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

PREFERRED (LOI) REFSMMAT

1. LOI

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

$$\begin{aligned} XIX &= -0.99273112 & XIY &= -0.10086262 & XIZ &= -0.06566340 \\ YIX &= -0.00185316 & YIY &= -0.53271311 & YIZ &= 0.84629387 \\ ZIX &= -0.12033917 & ZIY &= 0.84026393 & ZIZ &= 0.52865396 \end{aligned}$$

LANDING SITE REFSMMAT

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

$$\begin{aligned} XIX &= 0.67000809 & XIY &= -0.59984984 & XIZ &= -0.43734347 \\ YIX &= 0.12951155 & YIY &= -0.48564437 & YIZ &= 0.86450928 \\ ZIX &= -0.73096912 & ZIY &= -0.63586926 & ZIZ &= -0.24769819 \end{aligned}$$

PREFERRED (LOPC) REFSMMAT

1. LOPC-1

$$\begin{aligned} XIX &= 0.19271396 & XIY &= -0.46004412 & XIZ &= 0.86672992 \\ YIX &= -0.96383853 & YIY &= 0.07693310 & YIZ &= 0.25514033 \\ ZIX &= -0.18405603 & ZIY &= -0.88455679 & ZIZ &= -0.42858217 \end{aligned}$$

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

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

$$\begin{aligned} XIX &= 0.97651225 & XIY &= -0.04048785 & XIZ &= -0.21162371 \\ YIX &= 0.16677693 & YIY &= -0.47981822 & YIZ &= 0.86137097 \\ ZIX &= -0.13641596 & ZIY &= -0.87643324 & ZIZ &= -0.46179592 \end{aligned}$$

PREFERRED (LOPC) REFSMMAT

1. LOPC-2

$$\begin{aligned} XIX &= -0.17472490 & XIY &= 0.45229768 & XIZ &= -0.87458447 \\ YIX &= -0.79685180 & YIY &= 0.45679535 & YIZ &= 0.39543043 \\ ZIX &= 0.57835837 & ZIY &= 0.76600575 & ZIZ &= 0.28060070 \end{aligned}$$

PREFERRED (TEI) REFSMMAT

1. TEI

$$\begin{aligned} XIX &= 0.06333484 & XIY &= 0.75647791 & XIZ &= 0.65094537 \\ YIX &= 0.21795169 & YIY &= -0.64699487 & YIZ &= 0.73068099 \\ ZIX &= 0.97390234 & ZIY &= 0.09559708 & ZIZ &= -0.20585295 \end{aligned}$$

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

ENTRY REFSMMAT

1. MCC-7
2. Entry

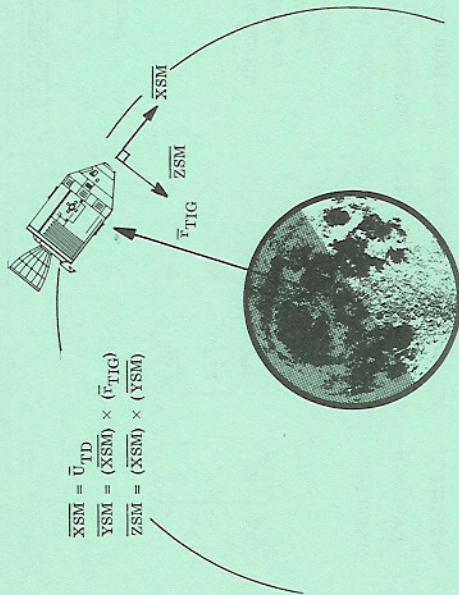
$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \text{Spacecraft Platform Stable Members} = \begin{bmatrix} XIX & XIY & XIZ \\ YIX & YIY & YIZ \\ ZIX & ZIY & ZIZ \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \text{ECI (MNBY)}$$

$$\begin{aligned} XIX &= 0.24623360 & XIY &= 0.46136661 & XIZ &= 0.85235547 \\ YIX &= -0.01381990 & YIY &= 0.88101469 & YIZ &= -0.47288702 \\ ZIX &= -0.96911196 & ZIY &= 0.10466121 & ZIZ &= 0.22331146 \end{aligned}$$

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

OPTION: 00001 (PREFERRED)

DESCRIPTION: Preferred Thrusting Illustrated



$$\begin{aligned} \underline{XSM} &= \underline{U}_{TD} \\ \underline{YSM} &= (\underline{XSM}) \times (\underline{r}_{TIG}) \\ \underline{ZSM} &= (\underline{XSM}) \times (\underline{YSM}) \end{aligned}$$

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 unlinked 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 unlinked 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:

$$\begin{bmatrix} \text{PREFERRED} \\ \text{REFSMMAT} \\ \text{(Thrusting)} \end{bmatrix} = \begin{bmatrix} \underline{XSM} \\ \underline{YSM} \\ \underline{ZSM} \end{bmatrix} = \begin{bmatrix} \underline{U}_{TD} \\ \text{Unit}(\underline{U}_{TD} \times \underline{r}_{TIG}) \\ \text{Unit}(\underline{U}_{TD} \times (\underline{U}_{TD} \times (\underline{r}_{TIG}))) \end{bmatrix}$$

where

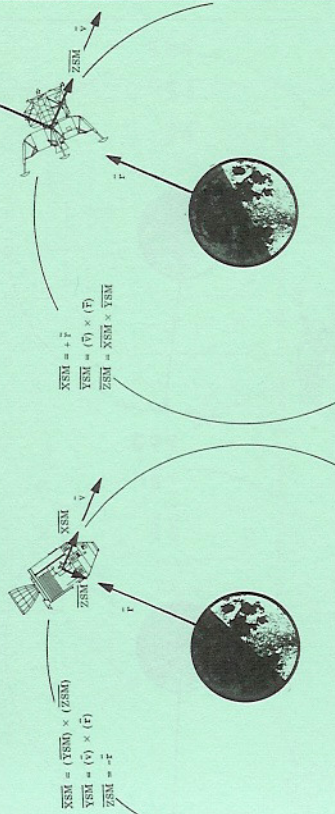
\underline{U}_{TD} is a unit vector in the desired thrust direction expressed in the basic reference system.

\underline{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



$$\begin{aligned} \underline{XSM} &= (\underline{YSM}) \times (\underline{ZSM}) \\ \underline{YSM} &= (\underline{v}) \times (\underline{r}) \\ \underline{ZSM} &= -\underline{r} \end{aligned}$$

The CMC requests the g. e. l. for which the vehicle \underline{r} and \underline{v} are to be selected to define the NOMINAL orientation,

CALCULATION OF ORIENTATION:

$$\begin{bmatrix} \text{Nominal} \\ \text{REFSMMAT} \end{bmatrix} = \begin{bmatrix} \underline{XSM} \\ \underline{YSM} \\ \underline{ZSM} \end{bmatrix} = \begin{bmatrix} \underline{XSM} \times \underline{ZSM} \\ \text{Unit}(\underline{v} \times \underline{r}) \\ \text{Unit}(-\underline{r}) \end{bmatrix} = \begin{bmatrix} \text{Unit}(\underline{r}) \\ \text{Unit}(\underline{v} \times \underline{r}) \\ \underline{XSM} \times \underline{YSM} \end{bmatrix}$$

where

\underline{r} \underline{v} are position and velocity vectors of vehicle at the time specified.

OPTION: 00003 (REFSMMAT)

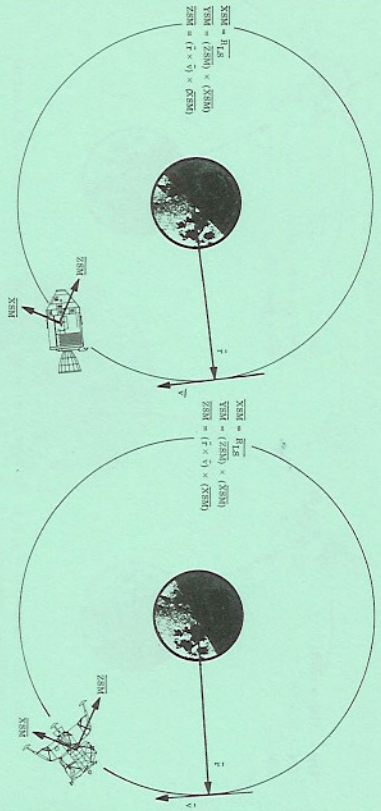
DESCRIPTION:

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.

$$\begin{bmatrix} \text{REFSMMAT} \end{bmatrix} = \begin{bmatrix} \underline{XSM} \\ \underline{YSM} \\ \underline{ZSM} \end{bmatrix} = \begin{bmatrix} \text{Currently maintained} \\ \text{CMC platform} \\ \text{Orientation} \end{bmatrix}$$

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 R_{LS} . The e, c, t , for which the CSM \bar{r} and \bar{v} are to be selected must also be entered.

$$\begin{bmatrix} \text{Landing Site} \\ \text{REFSMAT} \end{bmatrix} = \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix} = \begin{bmatrix} \text{Unit } (\bar{r}_{LS}) \\ \bar{r}_{SM} \times \bar{r}_{SM} \\ \text{Unit } (\bar{r} \times \bar{v}) \times \bar{r}_{SM} \end{bmatrix}$$

where

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

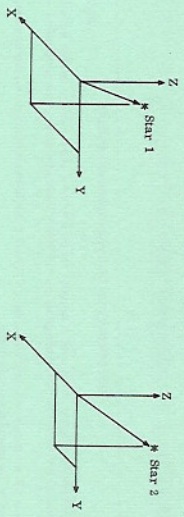
\bar{r} and \bar{v} are the CSM position and velocity vectors at the time specified.

PROCEDURE FOR SPECIFYING OPTIONS

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

Figure 4 (Sheet 3 of 3)

P51/P52 IMU ALIGNMENT



$$\underline{U}_{S1} = \begin{bmatrix} X_1 \\ Y_1 \\ Z_1 \end{bmatrix} \text{ ECI}$$

$$\underline{U}_{S2} = \begin{bmatrix} X_2 \\ Y_2 \\ Z_2 \end{bmatrix} \text{ ECI}$$

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

$$\underline{U}_{SIM} = \begin{bmatrix} X_{1M} \\ Y_{1M} \\ Z_{1M} \end{bmatrix} \text{ SM}$$

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

$$\underline{U}_{S1M} = \begin{bmatrix} X_{1M} \\ Y_{1M} \\ Z_{1M} \end{bmatrix} = \begin{bmatrix} A11 & A1M & A01 & A22 \end{bmatrix} \begin{bmatrix} \text{Cos AS Sin AT} \\ \text{Sin AS Sin AT} \\ \text{Cos AT} \end{bmatrix}$$

$i = 1 \text{ or } 2$

A1, AM, A0 are inner, middle, and outer gimbal angles at 1th mark time. AS and AT are SXT LOS slant and trimount at 1th mark time.

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

$$\begin{bmatrix} \underline{U}_{S1} \\ \underline{U}_{S2} \end{bmatrix} = \begin{bmatrix} \underline{U}_{S1M} \\ \underline{U}_{S2M} \end{bmatrix} \begin{bmatrix} \text{SM} \\ \text{SM} \end{bmatrix}$$

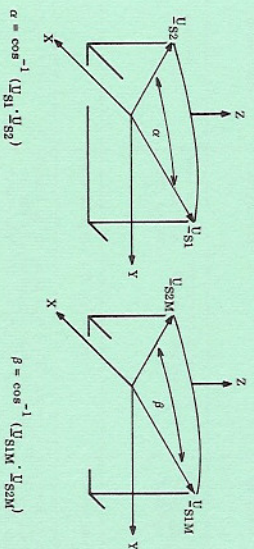
$$\begin{bmatrix} \underline{S}_A \\ \underline{S}_B \end{bmatrix} = \begin{bmatrix} \underline{U}_{S1} \\ \underline{U}_{S2} \end{bmatrix} \begin{bmatrix} \text{ECI} \\ \text{ECI} \end{bmatrix}$$

$$\begin{bmatrix} \underline{S}_A \\ \underline{S}_B \end{bmatrix} = \begin{bmatrix} \underline{U}_{S1M} \\ \underline{U}_{S2M} \end{bmatrix} \begin{bmatrix} \text{SM} \\ \text{SM} \end{bmatrix}$$

$$\begin{bmatrix} \underline{S}_A \\ \underline{S}_B \end{bmatrix} = \begin{bmatrix} \underline{U}_{S1} \\ \underline{U}_{S2} \end{bmatrix} \begin{bmatrix} \text{ECI} \\ \text{ECI} \end{bmatrix}$$

$$\begin{bmatrix} \underline{S}_A \\ \underline{S}_B \end{bmatrix} = \begin{bmatrix} \underline{S}_B \\ \underline{S}_A \end{bmatrix}$$

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



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

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

Figure 5. REFSMAT Computations

J-2 MISSION REFSMMAT SUMMARY, 16 APRIL LAUNCH

DETERMINATION OF GYRO TORQUING ANGLES

The star sighting data obtained during P02 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:

$$\begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix}_{Desired} = [P_X] [P_Z] [P_Y] \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix}_{Present}$$

$$\begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix}_{Desired} = \begin{bmatrix} \cos\phi_x \cos\phi_y & \sin\phi_z & 0 \\ (\sin\phi_x \sin\phi_y \cos\phi_z + \cos\phi_x \cos\phi_z) \cos\phi_x \cos\phi_y & \cos\phi_x \sin\phi_z \sin\phi_y & \sin\phi_x \sin\phi_z \sin\phi_y \\ (\sin\phi_x \sin\phi_y \cos\phi_z + \cos\phi_x \cos\phi_z) \sin\phi_x \sin\phi_y & \cos\phi_x \cos\phi_z \sin\phi_x \sin\phi_y & \sin\phi_x \sin\phi_z \cos\phi_y \end{bmatrix} \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix}_{Present}$$

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

$$\begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix}_{Desired} = [A]^{-1} [B] \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix}_{Present}$$

$$\begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix}_{Desired} = [C] \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix}_{Present}$$

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

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

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

For P52

$$S_A = [A] \begin{bmatrix} SM \\ SM \\ SM \end{bmatrix}_{Desired} \quad S_B = [B] \begin{bmatrix} SM \\ SM \\ SM \end{bmatrix}_{Present}$$

$$[A] \begin{bmatrix} SM \\ SM \\ SM \end{bmatrix}_{Desired} = [B] \begin{bmatrix} SM \\ SM \\ SM \end{bmatrix}_{Present}$$

$$\begin{bmatrix} SM \\ SM \\ SM \end{bmatrix}_{Desired} = [A]^{-1} [B] \begin{bmatrix} SM \\ SM \\ SM \end{bmatrix}_{Present}$$

The gyro torquing angles can be computed from any convenient element for element alignment between the matrices [C] and [P_X].

$$\phi_Y [P_Y] \text{ Gyro torquing angles are computed using the relationship:}$$

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

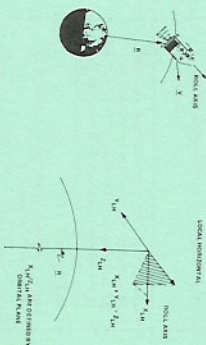
$$\phi_Z = \tan^{-1} \left(\frac{C(1,2) \cos\phi_Y}{C(1,1)} \right)$$

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

Applicable maneuvers	REFSMMAT	Alignment criteria (IMU axis)	Remarks
Launch TII TED	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° azimuth Pitch = 90° Yaw = 0
MCC-1 MCC-2 Passive thermal control MCC-3 MCC-4 SIM bay door Jettison	FTC (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 baroque mode, the spacecraft will maneuver to an FMAI display of: Roll = 0 Pitch = 90 Yaw = 0
LOI	Preferred (heads-down GSN)	X-axis aligned 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 GSN FMAI will display: Roll = 0 Pitch = 0 Yaw = 0
DOI Separation Circularization Powered descent	Landing site (CSM and IM)	X-axis along positive lunar radius vector at landing site at predicted landing time Z-axis in direction of flight parallel to the GSN orbital plane and perpendicular to X Y-axis completes the right-hand system	At nominal touchdown, the IM FMAI will display: Roll = 0 Pitch = 0 Yaw = 0
First GSN plane change	Preferred (CSM only) (heads down)	Same as above preferred alignment definition	At burn ignition, the FMAI will display: Roll = 0 Pitch = 0 Yaw = 0
IM ascent Rendezvous CSM sep after IM jettison IM deorbit Shaping burn Sub-orbitalite Jettison	Ascent (CSM and IM) Preferred (heads down)	X-axis along positive lunar radius vector at landing site at predicted lift-off time Z-axis down range parallel to the GSN orbital plane and perpendicular to X Y-axis completes the right-hand system	At nominal lift-off time, the IM FMAI will display: Roll = 359 Pitch = 359 Yaw = 005
Second GSN plane change	Preferred (heads down)	Same as above preferred alignment definition	At burn ignition, the FMAI will display: Roll = 0 Pitch = 0 Yaw = 0
TEI	Preferred (heads down)	Same as above preferred alignment definition. REFSMMAT defined at TEI ignition.	In a heads-down orientation at burn ignition, the FMAI will display: Roll = 180 Pitch = 0 Yaw = 0
MCC-5 MCC-6	FTC	Same as above FTC alignment	Same as above FTC alignment
MCC-7 Entry	Entry	X-axis is in local horizontal plane at 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 vector down, the FMAI will display: Roll = 0 Pitch = 180 Yaw = 0

DETERMINATION OF SIC ROLL AXIS WITH RESPECT TO A LOCAL HORIZONTAL COORDINATE SYSTEM

The procedure outlined below provides a method for determining the direction cosines of the GSM 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 GSM corresponding to the time of the gimbal angles.



The procedure is broken into two parts: the first defines the SIC axis with respect to the basic reference coordinate system; the second defines the SIC 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 SIC axes for the GSM, this transformation also defines the transformation from the stable member to the SIC [SMSC].

$$\begin{bmatrix} X_{SC} \\ Y_{SC} \\ Z_{SC} \end{bmatrix} = [A_0]^{-1} [A_m]^{-1} [A_1]^{-1} \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix} = [SMNB] \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix} = [SMSC] \begin{bmatrix} X_{SM} \\ Y_{SM} \\ Z_{SM} \end{bmatrix}$$

[SMSC] = $\begin{bmatrix} \cos\alpha & \cos\alpha\sin\beta & \cos\alpha\cos\beta & \sin\alpha & \cos\alpha\sin\alpha & \cos\alpha\sin\alpha\sin\beta & \cos\alpha\sin\alpha\cos\beta & \sin\alpha\sin\alpha & \cos\alpha\sin\alpha\sin\beta\sin\alpha & \cos\alpha\sin\alpha\cos\beta\sin\alpha & \sin\alpha\sin\alpha\cos\beta & \sin\alpha\sin\alpha\sin\beta & \sin\alpha\cos\beta & \sin\alpha\sin\beta & \sin\alpha\cos\beta\sin\alpha & \sin\alpha\sin\beta\sin\alpha \end{bmatrix}$

where A_0, A_1 and A_m are the outer, inner, and middle gimbal angles as displayed on the DSKY.

[REFSMAT] - 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.

[REFSMAT1] = $\begin{bmatrix} X_{IX} & X_{IY} & X_{IZ} \\ Y_{IX} & Y_{IY} & Y_{IZ} \\ Z_{IX} & Z_{IY} & Z_{IZ} \end{bmatrix}$

[REFSC] - the transformation from the basic reference coordinate system to the SIC axis.

[REFSC] = [SMSC] [REFSMAT1] = $\begin{bmatrix} \text{REFSC}(1,1) & \text{REFSC}(1,2) & \text{REFSC}(1,3) \\ \text{REFSC}(2,1) & \text{REFSC}(2,2) & \text{REFSC}(2,3) \\ \text{REFSC}(3,1) & \text{REFSC}(3,2) & \text{REFSC}(3,3) \end{bmatrix}$

where $X_{SC}/REF, Y_{SC}/REF$ and Z_{SC}/REF define the X, Y, and Z axes of the GSM with respect to the basic reference coordinate system.

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

[LHREF] = $\text{unit} \{ \underline{V} \times \underline{H} \} \times (\underline{R}_1)$ unit $\{ \underline{V} \times \underline{R}_1, \text{unit} \{ \underline{R}_1 \} \}$

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

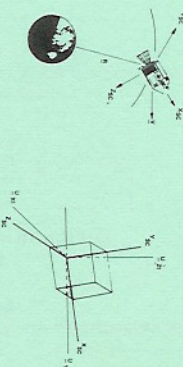
[LHSC] - the transformation from the local horizontal coordinate system to the GSM axis.

[LHSC] = [REFSC] [LHREF] = $\begin{bmatrix} X_{SC}/LH \\ Y_{SC}/LH \\ Z_{SC}/LH \end{bmatrix}$

where $X_{SC}/LH, Y_{SC}/LH$ and Z_{SC}/LH define the X, Y, and Z axes of the GSM with respect to the local horizontal coordinate system.

STEP 1. SIC AXES WRT BASIC REFERENCE COORDINATES

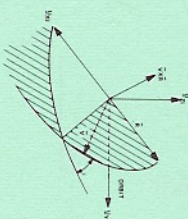
[REFSC] = [SMSC] [REFSMAT1]



REFSC (1, 1) = $\cos\alpha \cos\alpha \sin\beta + \sin\alpha \sin\alpha \cos\alpha \sin\beta$ - $\sin\alpha \cos\alpha \sin\alpha \sin\beta$ ZIX
 REFSC (1, 2) = $\cos\alpha \cos\alpha \sin\alpha \sin\beta + \sin\alpha \sin\alpha \cos\alpha \sin\beta$ - $\sin\alpha \sin\alpha \cos\alpha \sin\beta$ ZIY
 REFSC (1, 3) = $\cos\alpha \cos\alpha \sin\alpha \cos\beta + \sin\alpha \sin\alpha \cos\alpha \cos\beta$ - $\sin\alpha \sin\alpha \cos\alpha \cos\beta$ ZIZ
 REFSC (2, 1) = $\sin\alpha \sin\alpha \cos\alpha \sin\alpha \cos\alpha \sin\beta + \cos\alpha \sin\alpha \cos\alpha \sin\alpha \cos\alpha \sin\beta + \cos\alpha \sin\alpha \cos\alpha \sin\alpha \cos\beta + \cos\alpha \sin\alpha \cos\alpha \sin\alpha \sin\beta$ ZIX
 REFSC (2, 2) = $\sin\alpha \sin\alpha \cos\alpha \sin\alpha \cos\alpha \sin\alpha \sin\beta + \cos\alpha \sin\alpha \cos\alpha \sin\alpha \cos\alpha \sin\alpha \sin\beta + \cos\alpha \sin\alpha \cos\alpha \sin\alpha \cos\alpha \cos\beta + \cos\alpha \sin\alpha \cos\alpha \sin\alpha \cos\alpha \sin\beta$ ZIY
 REFSC (2, 3) = $\sin\alpha \sin\alpha \cos\alpha \sin\alpha \cos\alpha \sin\alpha \cos\beta + \cos\alpha \sin\alpha \cos\alpha \sin\alpha \cos\alpha \sin\alpha \cos\beta + \cos\alpha \sin\alpha \cos\alpha \sin\alpha \cos\alpha \sin\alpha \sin\beta + \cos\alpha \sin\alpha \cos\alpha \sin\alpha \cos\alpha \sin\alpha \cos\beta$ ZIZ
 REFSC (3, 1) = $\cos\alpha \sin\alpha \sin\alpha \cos\alpha \sin\alpha \cos\alpha \sin\beta + \cos\alpha \sin\alpha \cos\alpha \sin\alpha \cos\alpha \sin\alpha \cos\beta + \cos\alpha \sin\alpha \cos\alpha \sin\alpha \cos\alpha \sin\alpha \sin\beta + \cos\alpha \sin\alpha \cos\alpha \sin\alpha \cos\alpha \sin\alpha \cos\beta$ ZIX
 REFSC (3, 2) = $\cos\alpha \sin\alpha \sin\alpha \cos\alpha \sin\alpha \cos\alpha \sin\alpha \sin\beta + \cos\alpha \sin\alpha \cos\alpha \sin\alpha \cos\alpha \sin\alpha \cos\beta + \cos\alpha \sin\alpha \cos\alpha \sin\alpha \cos\alpha \sin\alpha \sin\beta + \cos\alpha \sin\alpha \cos\alpha \sin\alpha \cos\alpha \sin\alpha \cos\beta$ ZIY
 REFSC (3, 3) = $\cos\alpha \sin\alpha \sin\alpha \cos\alpha \sin\alpha \cos\alpha \sin\alpha \cos\beta + \cos\alpha \sin\alpha \cos\alpha \sin\alpha \cos\alpha \sin\alpha \cos\beta + \cos\alpha \sin\alpha \cos\alpha \sin\alpha \cos\alpha \sin\alpha \sin\beta + \cos\alpha \sin\alpha \cos\alpha \sin\alpha \cos\alpha \sin\alpha \cos\beta$ ZIZ

STEP 2. SIC AXES WRT LOCAL HORIZONTAL COORDINATES

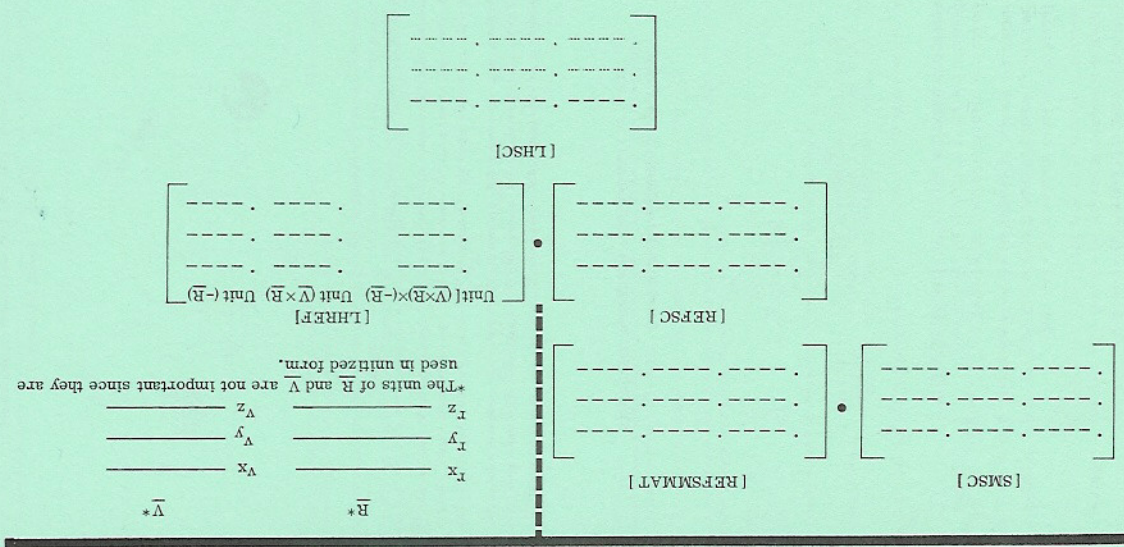
[LHSC] = [REFSC] [LHREF]



LHSC (1, 1) = {REFSC (1, 1), REFSC (1, 2), REFSC (1, 3)} \circ {unit {V X R1}, X (R1)}
 LHSC (1, 2) = {REFSC (1, 1), REFSC (1, 2), REFSC (1, 3)} \circ {unit {V X R1}}
 LHSC (1, 3) = {REFSC (1, 1), REFSC (1, 2), REFSC (1, 3)} \circ {unit {R1}}
 LHSC (2, 1) = {REFSC (2, 1), REFSC (2, 2), REFSC (2, 3)} \circ {unit {V X R1}, X (R1)}
 LHSC (2, 2) = {REFSC (2, 1), REFSC (2, 2), REFSC (2, 3)} \circ {unit {V X R1}}
 LHSC (2, 3) = {REFSC (2, 1), REFSC (2, 2), REFSC (2, 3)} \circ {unit {R1}}
 LHSC (3, 1) = {REFSC (3, 1), REFSC (3, 2), REFSC (3, 3)} \circ {unit {V X R1}, X (R1)}
 LHSC (3, 2) = {REFSC (3, 1), REFSC (3, 2), REFSC (3, 3)} \circ {unit {V X R1}}
 LHSC (3, 3) = {REFSC (3, 1), REFSC (3, 2), REFSC (3, 3)} \circ {unit {R1}}
 The XSC axis is the same as the roll axis and therefore the components of the roll axis of the SIC with respect to the local horizontal coordinate system are:
 LHSC (1, 3) - component of XSC along \underline{R}
 LHSC (1, 2) - component of XSC normal to orbital plane
 LHSC (1, 1) - component of XSC normal to \underline{R} and in plane

Data and Calculation Summary Sheet

A_0 (X/Roll) _____
 A_1 (Y/Pitch) _____
 A_m (Z/Yaw) _____
 TIME : : :



LHSC (1, 1) = _____ component of X_{sc} normal to $-\bar{R}$ and in plane
 LHSC (1, 2) = _____ component of X_{sc} normal to orbital plane
 LHSC (1, 3) = _____ component of X_{sc} along $-\bar{R}$

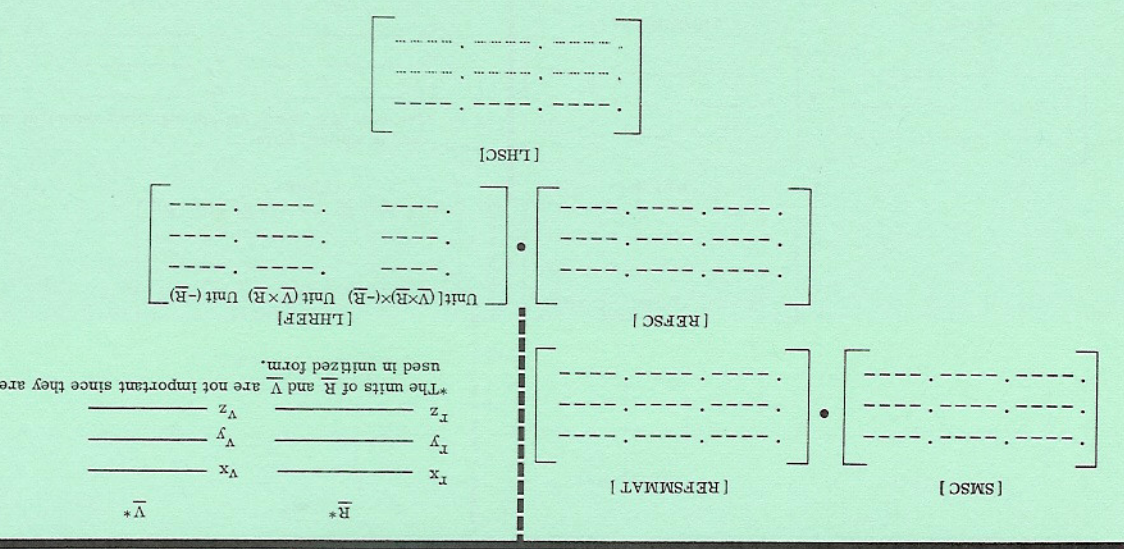
$$\text{Roll} = \tan^{-1} \frac{-\text{LHSC}(3, 2)}{\text{LHSC}(2, 2)}$$

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

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

Data and Calculation Summary Sheet

A_0 (X/Roll) _____
 A_1 (Y/Pitch) _____
 A_m (Z/Yaw) _____
 TIME : : :



LHSC (1, 1) = _____ component of X_{sc} normal to $-\bar{R}$ and in plane
 LHSC (1, 2) = _____ component of X_{sc} normal to orbital plane
 LHSC (1, 3) = _____ component of X_{sc} along $-\bar{R}$

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

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

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

Data and Calculation Summary Sheet

A₀ (X/Roll) _____ A₁ (Y/Pitch) _____
 A_m (Z/Yaw) _____

TIME ____ : ____ : ____

[SMSC]
 $\begin{bmatrix} \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \end{bmatrix}$

[REFSMMAT]
 $\begin{bmatrix} \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \end{bmatrix}$

[REFSC]
 $\begin{bmatrix} \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \end{bmatrix}$

R* V*
 r_x _____ v_x _____
 r_y _____ v_y _____
 r_z _____ v_z _____

*The units of R and V are not important since they are used in unitized form.

[LHREF]
 Unit[(V×R)×(-R)] Unit(V×R) Unit(-R)
 $\begin{bmatrix} \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \end{bmatrix}$

[LHSC]

$\begin{bmatrix} \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \end{bmatrix}$

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

LHSC (1, 1) = _____ component of X_{SC} normal to -R and in plane
 LHSC (1, 2) = _____ component of X_{SC} normal to orbital plane
 LHSC (1, 3) = _____ component of X_{SC} along -R

LB-76

Data and Calculation Summary Sheet

A₀ (X/Roll) _____ A₁ (Y/Pitch) _____
 A_m (Z/Yaw) _____

TIME ____ : ____ : ____

[SMSC]
 $\begin{bmatrix} \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \end{bmatrix}$

[REFSMMAT]
 $\begin{bmatrix} \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \end{bmatrix}$

[REFSC]
 $\begin{bmatrix} \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \end{bmatrix}$

R* V*
 r_x _____ v_x _____
 r_y _____ v_y _____
 r_z _____ v_z _____

*The units of R and V are not important since they are used in unitized form.

[LHREF]
 Unit[(V×R)×(-R)] Unit(V×R) Unit(-R)
 $\begin{bmatrix} \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \end{bmatrix}$

[LHSC]

$\begin{bmatrix} \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \end{bmatrix}$

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

LHSC (1, 1) = _____ component of X_{SC} normal to -R and in plane
 LHSC (1, 2) = _____ component of X_{SC} normal to orbital plane
 LHSC (1, 3) = _____ component of X_{SC} along -R

LB-77

PS2-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	0	X	0	0	0	0	0	0	0	0		
	+	0	0			GET	Hours Minutes Seconds									
	+	0	0	0												
	+	0	0	0												
X	0	0	0	0		N71	Celestial Body Code 1	X	0	0	0	0	0	0		
X	0	0	0	0		N71	Celestial Body Code 2	X	0	0	0	0	0	0		
						N05	Star Angle Difference (degrees)									
						N93	Gyro Torquing Angles (degrees)	X								
								Y								
								Z								
							Calculated Gyro Drift (meru)	X								
								Y								
								Z								

NOTES:

PS2-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	0	X	0	0	0	0	0	0	0	0		
	+	0	0			GET	Hours Minutes Seconds									
	+	0	0	0												
	+	0	0	0												
X	0	0	0	0		N71	Celestial Body Code 1	X	0	0	0	0	0	0		
X	0	0	0	0		N71	Celestial Body Code 2	X	0	0	0	0	0	0		
						N05	Star Angle Difference (degrees)									
						N93	Gyro Torquing Angles (degrees)	X								
								Y								
								Z								
							Calculated Gyro Drift (meru)	X								
								Y								
								Z								

NOTES:

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

NOTES:

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

NOTES:

P52-IMU REALIGN (GM)

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

NOTES:

P52-IMU REALIGN (GM)

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

NOTES:

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

X	0	0	0	0	0	P52 Option	X	0	0	0	0	0
+	0	0				Hours } Minutes } Seconds } GET	+	0	0			
+	0	0	0				+	0	0	0		
+	0						+	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 } Y } Z } Gyro Torquing Angles (degrees)	N93					
						X } Y } 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	0	P52 Option	X	0	0	0	0	0
+	0	0				Hours } Minutes } Seconds } GET	+	0	0			
+	0	0	0				+	0	0	0		
+	0						+	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 } Y } Z } Gyro Torquing Angles (degrees)	N93					
						X } Y } Z } Calculated Gyro Drift (meru)						

X	0	0	0	0	0	P52 Option	X	0	0	0	0	0
+	0	0				Hours } Minutes } Seconds } GET	+	0	0			
+	0	0	0				+	0	0	0		
+	0						+	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 } Y } Z } Gyro Torquing Angles (degrees)	N93					
						X } Y } 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	0	X	0	0	0	0	0	0	0	0
	+	0	0	0	0		+	0	0	0	0	0	0	0
	+	0	0	0	0		+	0	0	0	0	0	0	0
	+	0	0	0	0		+	0	0	0	0	0	0	0
	X	0	0	0	0		N71	X	0	0	0	0	0	0
	X	0	0	0	0		N71	X	0	0	0	0	0	0
							N05							
							N93							
							X							
							Y							
							Z							
							X							
							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	0	X	0	0	0	0	0	0	0	0
	+	0	0	0	0		+	0	0	0	0	0	0	0
	+	0	0	0	0		+	0	0	0	0	0	0	0
	+	0	0	0	0		+	0	0	0	0	0	0	0
	X	0	0	0	0		N71	X	0	0	0	0	0	0
	X	0	0	0	0		N71	X	0	0	0	0	0	0
							N05							
							N93							
							X							
							Y							
							Z							
							X							
							Y							
							Z							

NOTES:

X	0	0	0	0	0	X	0	0	0	0	0	0	0	0
	+	0	0	0	0		+	0	0	0	0	0	0	0
	+	0	0	0	0		+	0	0	0	0	0	0	0
	+	0	0	0	0		+	0	0	0	0	0	0	0
	X	0	0	0	0		N71	X	0	0	0	0	0	0
	X	0	0	0	0		N71	X	0	0	0	0	0	0
							N05							
							N93							
							X							
							Y							
							Z							
							X							
							Y							
							Z							

NOTES:

PB2-IMU REALIGN (LM)

V37 Enter, 52 Enter

V04 N06 Flashing

R1: 00001

R2: 0000X IMU Align Option

1 - Preferred, 2 - Nominal

3 - REFSMMA, 4 - Landing Site

V01 N70 Flashing

R1: 00CDE

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	0	PB2 Option	X	0	0	0	0	0	0	0	
+	0	0				GET	+	0	0						
+	0	0	0				+	0	0	0	0				
+	0						+	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								
						Gyro Torquing Angles (degrees)	N83								
					X										
					Y										
					Z										
						Calculated Gyro Drift (meru)									
					X										
					Y										
					Z										

X	0	0	0	0	0	PB2 Option	X	0	0	0	0	0	0	0	
+	0	0				GET	+	0	0						
+	0	0	0				+	0	0	0	0				
+	0						+	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								
						Gyro Torquing Angles (degrees)	N83								
					X										
					Y										
					Z										
						Calculated Gyro Drift (meru)									
					X										
					Y										
					Z										

NOTES: