PROPOSAL FOR LEM MISSION SIMULATOR volume II technical
addendum: glossary of symbols

## PROPOSAL FOR LEM MISSION SIMULATOR <br> Prepared for Grumman Aircraft Engineering Corp.,Bethpage,Long Island, New York

addendum: glossary of symbols

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## FOREWORD


#### Abstract

This addendum defines the symbols used in the math-flow diagrams in the LMS technical proposal. For convenience, the definitions are grouped according to the figures in which the symbols occur, and the figures themselves are included as part of the glossary. To show the complete equation structure on which the LMS computer loading estimates were based, the portion of the glossary devoted to the LEM and CSM equations of motion has been expanded to include the subsidiary groups of equations necessary for weight and balance computation and command module control by the LMS instructor.


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## 1. LMS AXIS SYSTEMS (EQUATIONREFERENCE FRAMES)

The LMS axis systems, all right-handed orthogonal triads, are defined as follows:
I-frame
$I_{E^{-f r a m e ~}}$
$I_{M^{-f r a m e ~}}$
E-frame
B-frame

FB-frame

H-frame
$J^{\prime}$-frame
The origin of the I-frame is at the center of mass of the sun. The $X_{I}, Y_{I}$, and $Z_{I}$ axes are fixed in orientation with respect to the "fixed" stars. This axis system may be chosen to represent the primary inertial system for the four-body problem under consideration.

The origin of the $I_{E}$-frame is at the center of mass of the earth. The $X_{I_{E}}$ and $Y_{I_{E}}$ axes are in the equatorial plane of the earth. The $\mathrm{Z}_{\mathrm{I}_{\mathrm{E}}}$ axis is directed toward the north pole. The orientation of the $\mathrm{X}_{\mathrm{I}_{\mathrm{E}}}, \mathrm{Y}_{\mathrm{I}_{\mathrm{E}}}$, and $\mathrm{Z}_{\mathrm{I}_{\mathrm{E}}}$ axes is fixed with respect to the "fixed" stars.

The origin of the $\mathrm{I}_{\mathrm{M}}$-frame is at the center of mass of the moon. The $\mathrm{X}_{\mathrm{I}_{M}}, \mathrm{Y}_{\mathrm{I}_{\mathrm{M}}}$, and $\mathrm{Z}_{\mathrm{I}_{M}}$ axes are defined to be parallel to the $\mathrm{X}_{\mathrm{E}}, \mathrm{Y}_{\mathrm{I}_{\mathrm{E}}}$, and $\mathrm{Z}_{\mathrm{I}_{\mathrm{E}}}$ axes.

The origin of the E-frame is at the center of mass of the spacecraft. The $\mathbf{X}_{\mathrm{E}}$ axis is coplanar with the geographic polar axis of the earth or moon, depending on whether the computation is for earth orbit or for motion during the lunar phase. The $\mathrm{X}_{\mathrm{E}}$ and $\mathrm{Y}_{\mathrm{E}}$ axes lie in a plane which is perpendicular to the radius vector, with positive $\mathrm{X}_{\mathrm{E}}$ directed toward the north and positive $\mathrm{Y}_{\mathrm{E}}$ directed toward the east. By virtue of the directions assigned to $\mathrm{X}_{\mathrm{E}}$ and $\mathrm{Y}_{\mathrm{E}}$, positive $\mathrm{Z}_{\mathrm{E}}$ is directed toward the center of the earth or moon.

The origin of the B-frame is at the vehicle center of gravity. The $X_{B}$ and $Z_{B}$ axes form a plane which is parallel to some reference plane which is fixed with respect to the configuration of the vehicle. $\mathrm{X}_{\mathrm{B}}$ and $\mathrm{Z}_{\mathrm{B}}$ are fixed in direction by considering them to be parallel to some reference directions which are arbitrarily assigned to the reference plane.

The origin of the fixed body frame is at some fixed point in the vehicle. The fixed body frame is denoted by $X_{F B}, Y_{F B}$, and $\mathrm{Z}_{\mathrm{FB}}$ and is parallel to the body frame.

The origin of the H-frame is at the vehicle ${ }^{9}$ s center of gravity. The $\mathrm{X}_{\mathrm{H}}$ and $\mathrm{Y}_{\mathrm{H}}$ axes lie in the plane which is perpendicular to the vehicle's radius vector, with positive $X_{H}$ directed along the projection of the translational velocity vector on this plane. Positive $\mathrm{Z}_{\mathrm{H}}$ is directed toward the center of the earth or moon along the vehicle ${ }^{\text {i }}$ s radius vector.

The $\mathrm{J}^{\dagger}$-frame is coincident with the $\mathrm{I}_{\mathrm{E}}$-frame during earth orbital computation. During computation of vehicle motion in the lunar phase the $J^{\prime}$-frame is referenced to the equatorial plane of the moon. The origin of the $\mathrm{J}^{\mathbf{t}}$-frame is at the center of mass of the moon. The $X$ and $Y J^{\prime}$-frame axes lie in the moon's equatorial plane. The $\mathrm{Z} \mathrm{J}^{\prime}$-frame axis is positive out the north pole of the moon. The orientation of the $J^{\prime}$-frame is fixed with respect to the fixed stars.
$J_{R}^{\prime}$-frame
$\mathrm{J}_{\mathrm{R}}{ }^{\prime \prime}$ frame

Ecliptic-frame

The $J_{R}^{\prime}$-frame differs from the $J^{\prime}$-frame only in that it rotates with the surface of the earth during earth orbital computation and with the surface of the moon during lunar phase computation.

The $J_{R}^{\prime \prime}$-frame, is defined in a complimentary fashion to the $J_{R^{-}}^{\prime}$ frame. The $\mathrm{J}_{\mathrm{R}}$-frame rotates with the moon during earth orbital computation and with the earth during lunar phase computation.

This is an inertial frame of reference whose directions are fixed with respect to the ecliptic.

## 2. 1 SYMBOLS ASSOCIATED WITH FIGURE 19

| $\mathrm{a}_{11}, \mathrm{a}_{12},{ }^{a_{13}}$ |
| :---: |
| $\mathrm{a}_{21}, \mathrm{a}_{22}, \mathrm{a}_{23}$ |
| $\mathrm{a}_{31}, \mathrm{a}_{32}, \mathrm{a}_{33}$ |
| $\mathrm{A}_{\mathrm{X}_{\mathrm{b}}},{ }^{\mathrm{Y}_{\mathrm{b}}}, \mathrm{A}_{\mathrm{Z}_{\mathrm{b}}}$ |
| $\mathrm{b}_{11}, \mathrm{~b}_{12}, \mathrm{~b}_{13}$ |
| $\mathrm{b}_{21}, \mathrm{~b}_{22}, \mathrm{~b}_{23}$ |
| $\mathrm{b}_{31}, \mathrm{~b}_{32}, \mathrm{~b}_{33}$ |
| $\mathrm{c}_{11}, \mathrm{c}_{12}, \mathrm{c}_{13}$ |
| $\mathrm{c}_{21}, \mathrm{c}_{22}, \mathrm{c}_{23}$ |
| $\mathrm{c}_{31}, \mathrm{c}_{32}, \mathrm{c}_{33}$ |
| $\begin{aligned} & \mathrm{C}_{\mathrm{D}} \\ & \left(\mathrm{C}_{1}\right)_{18},\left(\mathrm{C}_{2}\right)_{18},\left(\mathrm{C}_{3}\right)_{18} \end{aligned}$ |
| $\mathrm{d}_{11}, \mathrm{~d}_{12}, \mathrm{~d}_{13}$ |
| $\mathrm{d}_{21}, \mathrm{~d}_{22}, \mathrm{~d}_{23}$ |
| $\mathrm{d}_{31}, \mathrm{~d}_{32}, \mathrm{~d}_{33}$ |
| $\mathrm{D}_{\mathrm{X}_{\mathrm{b}}}, \mathrm{D}_{\mathrm{Y}_{\mathrm{b}}}, \mathrm{D}_{\mathrm{Z}_{\mathrm{b}}}$ |
| $\mathrm{D}_{\mathrm{X}_{\mathrm{h}}}, \mathrm{D}_{\mathrm{Y}_{\mathrm{h}}}, \mathrm{D}_{\mathrm{Z}_{\mathrm{h}}}$ |

The magnitudes of the projections of a unit vector along the LEM B-frame X axis on the $\mathrm{I}_{\mathrm{E}}$-frame or $\mathrm{I}_{\mathrm{M}}$-frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes.

The magnitudes of the projections of a unit vector along the LEM B-frame $Y$ axis on the $\mathrm{I}_{\mathrm{E}}$-frame or $\mathrm{I}_{\mathrm{M}}$-frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes.

The magnitudes of the projections of a unit vector along the LEM B-frame Z axis on the $\mathrm{I}_{\mathrm{E}}$-frame or $\mathrm{I}_{\mathrm{M}}$-frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes.

The body axes components of the distance vector measured from the origin of the body axes to the origin of the fixed body axes. (ft)

The magnitudes of the projections of a unit vector along the $\mathrm{I}_{\mathrm{E}}$-frame or $\mathrm{I}_{\mathrm{M}}$-frame X axis on the LEM E-frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes.

The magnitudes of the projections of a unit vector along the $\mathrm{I}_{\mathrm{E}}$-frame or $\mathrm{I}_{\mathrm{M}}$-frame Y axis on the LEM E-frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes.

The magnitudes of the projections of a unit vector along the $\mathrm{I}_{\mathrm{E}}$-frame or $\mathrm{I}_{\mathrm{M}}$-frame Z axis on the LEM E-frame axes.

The magnitudes of the projections of a unit vector along the LEM B-frame X axis on the LEM E-frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes.

The magnitudes of the projections of a unit vector along the LEM B-frame Y axis on the LEM E-frame $\mathrm{X}, \mathrm{Y}$, Z axes.

The magnitudes of the projections of a unit vector along the LEM B-frame Z axis on the LEM E-frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes.

Orbital drag coefficient.
Magnitudes of the projections of the distance vector measured from the origin of the fixed body axis to the center of rotation of the gimbaled descent engine on the $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes of the LEM FB-frame. (ft)

The magnitudes of the projections of a unit vector along the $\mathrm{I}_{\mathrm{E}}$-frame or $\mathrm{I}_{\mathrm{M}}$-frame X axis on the $\mathrm{J}^{\prime}$-frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes.

The magnitudes of the projections of a unit vector along the $\mathrm{I}_{\mathrm{E}}$-frame or $\mathrm{I}_{\mathrm{M}}$-frame Y axis on the $\mathrm{J}^{\prime}$-frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes.

The magnitudes of the projections of a unit vector along the $\mathrm{I}_{\mathrm{E}}$-frame or $\mathrm{I}_{\mathrm{M}}$-frame Z axis on the $\mathrm{J}^{\prime}$-frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes.

The magnitudes of the projections of the orbital drag force on the B-frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes. (ib)

The magnitudes of the projections of the orbital drag force on the H -frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes. (ib)

| $\left(\mathrm{D}_{1}\right)_{17},\left(\mathrm{D}_{2}\right)_{17},{ }^{\left(\mathrm{D}_{3}\right)_{17}}$ | Effective moment arms of the ascent thruster with respect to the LEM B-frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes. (An effective moment arm about all three axes is represented in order to account for possible thruster misalignment.) (ft) |
| :---: | :---: |
| $e_{1}, e_{2}, e_{3}, e_{4}$ | LEM I-frame to B-frame quaternion parameter notation. (See WADC Technical Report 58-17, "On the use of Quaternions in Simulation of Rigid-Body Motion, " by Alfred C. Robinson.) |
| ${ }_{11}, e_{12},{ }^{e}{ }_{13}$ | The magnitudes of the projections of a unit vector along the J' -frame X axis on the LEM E-frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes. |
| $\mathrm{e}_{21}, \mathrm{e}_{22}, \mathrm{e}_{23}$ | The magnitudes of the projections of a unit vector along the J '-frame Y axis on the LEM E-frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes. |
| $e_{31}, e_{32}, e_{33}$ | The magnitudes of the projections of a unit vector along the J '-frame Z axis on the LEM E-frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes. |
| $\mathrm{F}_{\mathrm{X}_{\mathrm{b}}^{\prime}}, \mathrm{F}_{\mathrm{Y}_{\mathrm{b}}^{\prime}}, \mathrm{F}_{\mathrm{Z}_{\mathrm{b}}^{\prime}}$ | The magnitudes of the projections of the LEM total applied force vector minus the gravitational force vector on the LEM B-frame X, Y, Z axes. (lb) |
| $\mathrm{F}_{\mathrm{X}_{\mathrm{e}}}, \mathrm{F}_{\mathrm{Y}_{\mathrm{e}}}, \mathrm{F}_{\mathrm{Z}_{\mathrm{e}}}$ | The magnitudes of the projections of the total applied force vector on the E-frame X, Y, Z axes. (lb) |
| $\mathrm{F}_{\mathrm{X}_{\mathrm{h}}}, \mathrm{F}_{\mathrm{Y}_{\mathrm{h}}}, \mathrm{F}_{\mathrm{Z}_{\mathrm{h}}}$ | The magnitudes of the projections of the total applied force vector on the H -frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes. (lb) |
| $\mathrm{G}_{\mathrm{X}_{\mathrm{e}}}, \mathrm{G}_{\mathrm{Y}_{\mathrm{e}}}, \mathrm{G}_{\mathrm{Z}_{\mathrm{e}}}$ | The magnitudes of the projections of the gravitational force vector on the E-frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes. (lb) |
| $\mathrm{GXX}_{\mathrm{e}}^{\prime}, \mathrm{G}_{\mathrm{Y}_{\mathrm{e}}^{\prime}}, \mathrm{G}_{\mathrm{Z}}^{\prime}{ }_{\mathrm{e}}^{\prime}$ | The magnitudes of the projections of the force vector which includes the gravitational effects of the earth, moon, and sun on the E-frame X, Y, Z axes. (lb) |
| $\mathrm{G}_{\mathrm{X}_{\mathrm{h}}^{\prime}}, \mathrm{G}_{\mathrm{Y}_{\mathrm{h}}^{\prime}}, \mathrm{G}_{\mathrm{Z}_{\mathrm{h}}^{\prime}}$ | The magnitudes of the projections of the force vector which includes the gravitational effects of the earth, moon, and sun on the H -frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes. (lb) |
| h | Vehicle altitude above the earth's or moon's surface measured along the radius vector. <br> (ft) |
| $\mathrm{I}_{\mathrm{XX}}$ | Moment of inertia about the B-frame X axis. ( $\mathrm{slug-ft}{ }^{2}$ ) |
| $\mathrm{I}_{\mathrm{YY}}$ | Moment of inertia about the B-frame Y axis. (slug-ft ${ }^{2}$ ) |
| $\mathrm{I}_{\mathrm{ZZ}}$ | Moment of inertia about the B-frame Z axis. (slug-ft ${ }^{2}$ ) |
| $\mathrm{I}_{X Y}$ | Product of inertia due to nonsymmetric mass distribution with respect to XZ B-frame plane. (slug-ft ${ }^{2}$ ) |
| $\mathrm{I}_{\mathrm{XZ}}$ | Product of inertia due to nonsymmetric mass distribution with respect to the XY B-frame plane. (slug-ft ${ }^{2}$ ) |
| $\mathrm{I}_{\mathrm{YZ}}$ | Product of inertia due to nonsymmetric mass distribution with respect to the XZ B-frame plane. (slug-ft ${ }^{2}$ ) |
| $\mathrm{K}^{2}$ |  |
| $\left(\mathrm{K}_{1}\right)_{17},\left(\mathrm{~K}_{2}\right)_{17},\left(\mathrm{~K}_{3}\right)_{17}$ | The direction cosines of the line of action of the ascent thruster with respect to the LEM B-frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes. (In order to account for possible misalignments of this thruster, all three direction cosines are used in projecting the thrust associated with the ascent engine.) |


| L | The angle of latitude with respect to the $\mathrm{J}^{\text {¢ }}$-frame. (rad) |
| :---: | :---: |
| $\lambda$ | The angle of longitude with respect to the $J^{\dagger}$-frame. (rad) |
| $\lambda^{R}$ | Longitude measured with respect to the earth's or moon's surface. (rad) |
| m | Vehicle mass. (slugs) |
| $\mathrm{m}_{11}, \mathrm{~m}_{12}, \mathrm{~m}_{13}$ | The magnitudes of the projections of a unit vector along the $J^{\prime}$-frame X axis on the CM X, Y, Z E-frame axes. |
| $\mathrm{m}_{21}, \mathrm{~m}_{22}, \mathrm{~m}_{23}$ | The magnitudes of the projections of a unit vector along the J'-frame Y axis on the CM X, Y, Z E-frame axes. |
| $\mathrm{m}_{31}, \mathrm{~m}_{32}, \mathrm{~m}_{33}$ | The magnitudes of the projections of a unit vector along the $J^{\prime}$-frame $X$ axis on the CM X, Y, Z E-frame axes. |
| $\mathrm{M}_{\mathrm{X}_{\mathrm{b}}}, \mathrm{M}_{\mathrm{Y}_{\mathrm{b}}}, \mathrm{M}_{\mathrm{Z}_{\mathrm{b}}}$ | The magnitudes of the projections of the total applied moment vector on the B-frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes. (ft-lb) |
| $\mathrm{n}_{11}, \mathrm{n}_{12}, \mathrm{n}_{13}$ | The magnitudes of the projections of a unit vector along the $\mathrm{I}_{\mathrm{E}}$-frame or $\mathrm{I}_{\mathrm{M}}$-frame X axis on the $\mathrm{X}, \mathrm{Y}, \mathrm{Z} \mathrm{CM} \mathrm{E-frame}$ axes. |
| $\mathrm{n}_{21}, \mathrm{n}_{22}, \mathrm{n}_{23}$ | The magnitudes of the projections of a unit vector along the $\mathrm{I}_{\mathrm{E}}$-frame or $\mathrm{I}_{\mathrm{M}}$-frame Y axis on the $\mathrm{X}, \mathrm{Y}, \mathrm{Z} \mathrm{CM} \mathrm{E-frame}$ axes. |
| $\mathrm{n}_{31}, \mathrm{n}_{32}, \mathrm{n}_{33}$ | The magnitudes of the projections of a unit vector along the $\mathrm{I}_{\mathrm{E}}$-frame or $\mathrm{I}_{\mathrm{M}}$-frame X axis on the $\mathrm{X}, \mathrm{Y}$, Z CM E-frame axes. |
| $\omega_{\mathrm{e}}$ | The magnitude of the rotational velocity of the earth. (rad/sec) |
| $\omega_{\mathrm{m}}$ | The magnitude of the rotational velocity of the moon. (rad/sec) |
| $\mathrm{p}_{\mathrm{b}}$ | The magnitude of the projection of the absolute rotational velocity vector of the $B$-frame on the $B$-frame $X$ axis. (rad/sec) |
| $\psi_{\mathrm{B} / \mathrm{I}},{ }^{(1)} \mathrm{B} / \mathrm{I}, \phi_{\mathrm{B} / \mathrm{I}}$ | LEM B-frame to I-frame Euler angles. These angles are those obtained by three successive rotations of the B-frame with respect to the I-frame, the rotations commencing with the B-frame parallel to the I-frame. The first rotation, through $\psi_{\mathrm{B} / \mathrm{I}}$, is about the position the B -frame Z axis has when the B -frame is parallel to the I-frame. The second rotation, through $\theta_{\mathrm{B} / \mathrm{I}}$, is about the position the B -frame Y axis assumes as a result of the first rotation. The third rotation, through $\phi_{\mathrm{B}} / \mathrm{I}$, is about the position the B -frame X axis assumes as a result of the second rotation. (rad) |
| $\psi_{\mathrm{h}}$ | The heading angle of the H-frame. This is the angle the H -frame X axis makes with the E -frame X axis. (rad) |
| q | Dynamic pressure. ( $\mathrm{lb} / \mathrm{ft}^{2}$ ) |
| $q_{b}$ | The magnitude of the projection of the absolute rotational velocity vector of the $B$-frame on the $B$-frame $Y$ axis. (rad/sec) |



The magnitude of the radius of the vehicle as measured in the $\mathrm{I}_{\mathrm{E}}$-frame or $\mathrm{I}_{\mathrm{M}}$-frame. This quantity is measured in the $\mathrm{I}_{\mathrm{E}}$-frame during earth orbital computation and in the $\mathrm{I}_{\mathrm{M}^{-}}$ frame during lunar phase computation. (ft)

The magnitude of the radius of the CM as measured in the I-frame. $r_{C M}^{\prime}$ denotes the value of this quantity during earth orbital computation, and $\mathrm{r}_{\mathrm{CM}}{ }^{\prime}$ denotes the value of this quantity during lunar phase computation. (ft)

The magnitude of the radius of the CM as measured in the $\mathrm{I}_{\mathrm{E}}$-frame. This quantity is of interest during lunar phase computation and, hence, must be differentiated from $\mathbf{r}_{\mathrm{CM}}$, which is the magnitude of the radius of the CM as measured in the $I_{M}$-frame during lunar phase computation. (ft)

The magnitude of the radius of the CM as measured in the $\mathrm{I}_{\mathrm{M}}$-frame. This quantity is of interest during earth orbital computation and, hence, must be differentiated from rCM , which is the magnitude of the radius of the CM as measured in the $\mathrm{I}_{\mathrm{M}}$-frame during earth orbital computation. (ft)

The magnitude of the radius of the moon as measured in the $\mathrm{I}_{\mathrm{E}}$-frame. (ft)

The magnitude of the radius of the sunas measured in the $\mathrm{I}_{\mathrm{E}}$-frame. (ft)

The magnitude of the radius of the sun as measured in the $\mathrm{I}_{\mathrm{M}}$-frame. (ft)

The magnitude of the radius of the LEM as measured in the I-frame. $r_{V}^{\prime}$ denotes the value of this quantity during earth orbital computation, and $r_{V}^{\prime \prime}$ denotes the value of this quantity during lunar phase computation. (ft)

The magnitude of the radius of the LEM as measured in the $\mathrm{I}_{\mathrm{E}}$-frame. This quantity is of interest during lunar phase computation and, hence, must be differentiated from $r$, which is the magnitude of the radius of the LEM as measured in the $\mathrm{I}_{\mathrm{M}}$-frame during lunar phase computation. (ft)

The magnitude of the radius of the LEM as measured in the $\mathrm{I}_{\mathbf{M}}$-frame. This quantity is of interest during earth orbital computation and, hence, must be differentiated from $r$, which is the magnitude of the radius of the LEM as measured in the $I_{E}$-frame during earth orbital computation. (ft)

The magnitude of the distance from the LEM to the CM. (ft)
The magnitude of the projection of the absolute rotational velocity vector of the B -frame on the B -frame Z axis. (rad/sec)

Atmospheric density. (slug $/ \mathrm{ft}^{3}$ )
The reference area for the orbital drag coefficient. ( $\mathrm{ft}{ }^{2}$ )
The angle between the $\mathrm{X}_{\mathrm{B}}-\mathrm{Y}_{\mathrm{B}}$ plane and the axis of the 18th thruster. (rad)

| $\sigma_{\psi}$ | The angle between the $\mathrm{X}_{\mathrm{B}}-\mathrm{Z}_{\mathrm{B}}$ plane and the axis of the 18th thruster. (rad) |
| :---: | :---: |
| t | Mean solar time. (sec) |
| $\mathrm{T}_{\mathrm{n}}$ | Thrust of the nth engine. (lb) |
| $\mathrm{T}_{\mathbf{X}_{\mathrm{b}}}, \mathrm{T}_{\mathbf{Y}_{\mathrm{b}}}, \mathrm{T}_{\mathrm{Z}_{\mathrm{b}}}$ | The magnitudes of the projections of the total thrust vector on the $B$-frame $X, Y, Z$ axes. (lb) |
| $\mathrm{u}_{\mathrm{h}}$ | The projection of the vehicle's velocity vector on the Hframe $\mathbf{X}$ axis. (ft/sec) |
| ${ }^{u}{ }_{R}$ | The magnitude of the projection of $\mathrm{V}_{\mathrm{R}}$ on the B -frame X axis. (ft/sec) |
| $\mathrm{V}_{\mathrm{R}}$ | The magnitude of the vehicle velocity relative to the rotating atmosphere. (ft/sec) |
| $\mathbf{v}_{\mathbf{R}}$ | The magnitude of the projection of $\mathrm{V}_{\mathrm{R}}$ on the B -frame Y axis. (ft/sec) |
| ${ }^{\mathbf{w}}$ R | The magnitude of the projection of $\mathrm{V}_{\mathrm{R}}$ on the B -frame Z axis. (ft/sec) |
| $\left(\mathrm{X}_{\mathrm{I}}\right)_{\mathrm{CM}},{ }^{\left(\mathrm{Y}_{\mathrm{I}}\right)_{\mathrm{CM}},\left(\mathrm{Z}_{\mathrm{I}}\right)_{\mathrm{CM}}}$ | $\mathrm{I}_{\mathrm{E}}$-frame or $\mathrm{I}_{\mathrm{M}}$-frame coordinates of CM position. These quantities represent $\mathrm{I}_{\mathrm{E}}$-frame coordinates during earth orbital computation and $\mathrm{I}_{\mathbf{M}}$-frame coordinates during lunar phase computation. <br> (ft) |
|  | $\mathrm{I}_{\mathrm{E}}$-frame or $\mathrm{I}_{\mathrm{M}}$-frame coordinates of CM position relative to the LEM. (ft) |
| ${ }^{\left(\mathrm{X}_{\mathrm{I}}\right)} \mathrm{V}^{\prime},{ }^{\left(\mathrm{Y}_{\mathrm{I}}\right)_{\mathrm{V}},}{ }^{\left(\mathrm{Z}_{\mathrm{I}}\right)_{V}}$ | $\mathrm{I}_{\mathrm{E}}$-frame or $\mathrm{I}_{\mathrm{M}^{\text {-frame }}}$ coordinates of LEM position. These quantities represent $I_{E}$-frame coordinates during earth orbital computation and $\mathrm{I}_{\mathrm{M}}$-frame coordinates during lunar phase computation. (ft) |
| $\left(\mathrm{X}_{\mathrm{I}_{\mathrm{E}}}\right)_{\mathrm{M}^{\prime}},\left(\mathrm{Y}_{\mathrm{I}_{\mathrm{E}}}\right)_{\mathrm{M}^{\prime}},\left(\mathrm{Z}_{\mathrm{I}_{\mathrm{E}}}\right)_{\mathrm{M}}$ | $\mathrm{I}_{\mathrm{E}}$-frame coordinates of the moon's position. (ft) |
| $\left(\mathrm{X}_{\mathrm{I}_{E}}\right)_{S},\left(\mathrm{Y}_{\mathrm{I}_{\mathrm{E}}{ }_{S}}\right)^{\prime}\left(\mathrm{Z}_{\mathrm{I}_{\mathrm{E}}}\right)_{S}$ | $\mathrm{I}_{\mathrm{E}}$-frame coordinates of the sun's position. (ft) |
| $\left(\mathrm{x}_{\mathrm{I}_{\mathrm{M}_{\mathrm{E}}}}\right),\left(\mathrm{Y}_{\mathrm{I}_{\mathrm{M}_{\mathrm{E}}}}\right),\left(\mathrm{Z}_{\mathrm{I}_{\mathrm{M}_{\mathrm{E}}}}\right)$ | $\mathrm{I}_{\mathrm{M}}$-frame coordinates of the earth's position. (ft) |
|  | $\mathrm{I}_{\mathrm{M}^{\text {-frame }} \text { coordinates of the sun's position. (ft) }}$ |
| $\ddot{X}_{e} \backslash, \ddot{Y}_{e} \backslash, \ddot{Z}_{e} \backslash$ | E-frame differential acceleration components. (ft/sec ${ }^{2}$ ) |
|  | $\mathrm{I}_{\mathrm{E}}$-frame components of the differential gravitational acceleration components due to the sun and the moon. (ft/sec ${ }^{2}$ ) |
| $\left.\ddot{( }_{I_{M}}^{\prime}{ }_{S, E}, \ddot{( }_{I_{M}}{ }_{S, E}, \ddot{( }_{I_{M}}\right)_{S, E}$ | $\mathrm{I}_{\mathbf{M}}$-frame components of the differential gravitational acceleration components due to the sun and the earth. ( $\mathrm{ft} / \mathrm{sec}^{2}$ ) |

NOTE: 1. A dot placed above a quantity indicates the first time derivative of that quantity.
2. Two dots placed above a quantity indicates the second time derivative of that quantity.
3. The subscript $t=t_{0}$ means the value of the quantity at the start of computation.
4. The following subscripts are to be read:

| CM | Command Module |
| :--- | :--- |
| E | Earth or E-frame depending on the manner it is used. |
| G | Gravitational |
| LEM | Lunar Excursion Module |
| M | Moon |
| R | Relative |
| S | Sun |
| V | Vehicle |



## 2. 2 COMMAND MODULE CONTROL EQUATIONS (FIGURE 19a)

| $\mathrm{a}_{11}, \mathrm{a}_{12}, \mathrm{a}_{13}$ |
| :---: |
| $\mathrm{a}_{21}, \mathrm{a}_{22}, \mathrm{a}_{23}$ |
| $\mathrm{a}_{31}, \mathrm{a}_{32}, \mathrm{a}_{33}$ |
| $\alpha_{11}, \alpha_{12}, \alpha_{13}$ |
| $\alpha_{21}, \alpha_{22}, \alpha_{23}$ |
| $\alpha_{31}, \alpha_{32}, \alpha_{33}$ |
| $\beta_{11}, \beta_{12}, \beta_{13}$ |
| $\beta_{21}, \beta_{22}, \beta_{23}$ |
| $\beta_{31}, \beta_{32}, \beta_{33}$ |
| $\delta_{11}, \delta_{12}, \delta_{13}$ |
| $\delta_{21}, \delta_{22},{ }^{\delta}{ }_{23}$ |
| $\delta_{31}, \delta_{32}, \delta_{33}$ |
| $e_{1}, e_{2}, e_{3}, e_{4}$ |
| $\begin{aligned} & \left(e_{1}\right)_{C},{ }^{\left(e_{2}\right)} C^{\prime},{ }^{\left(e_{3}\right)_{C},}{ }^{\left(e_{4}\right)} C \\ & \Delta \dot{e}_{1}, \Delta e_{2}, \Delta e_{3}, \Delta e_{4} \end{aligned}$ |

The magnitudes of the projections of a unit vector along the LEM B-frame X axis on the $\mathrm{I}_{\mathrm{E}}$-frame or $\mathrm{I}_{\mathrm{M}}$-frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes.

The magnitudes of the projections of a unit vector along the LEM B-frame $Y$ axis on the $\mathrm{I}_{\mathrm{E}}$-frame or $\mathrm{I}_{\mathrm{M}}$-frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes.

The magnitudes of the projections of a unit vector along the LEM B-frame $Z$ axis on the $\mathrm{I}_{\mathrm{E}}$-frame or $\mathrm{I}_{\mathrm{M}}$-frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes.

The magnitudes of the projections of a unit vector along the commanded B-frame X axis on the H -frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes.

The magnitudes of the projections of a unit vector along the commanded B-frame Y axis on the H -frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes.

The magnitudes of the projections of a unit vector along the commanded B-frame Z axis on the H-frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes.

The magnitudes of the projections of a unit vector along the CM E-frame $X$ axis on the $I_{E}$-frame or $\mathrm{I}_{\mathrm{M}}$-frame X , $\mathrm{Y}, \mathrm{Z}$ axes.

The magnitudes of the projections of a unit vector along the CM E-frame $Y$ axis on the $\mathrm{I}_{\mathrm{E}}$-frame or $\mathrm{I}_{\mathrm{M}}$-frame X , $\mathrm{Y}, \mathrm{Z}$ axes.

The magnitudes of the projections of a unit vector along the CM E-frame Z axis on the $\mathrm{I}_{\mathrm{E}}$-frame or $\mathrm{I}_{\mathrm{M}}$-frame X , $\mathrm{Y}, \mathrm{Z}$ axes.

The magnitudes of the projections of a unit vector along the CM H-frame X axis on the CM B-frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes.

The magnitudes of the projections of a unit vector along the CM H-frame Y axis on the CM B-frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes.

The magnitudes of the projections of a unit vector along the CM H-frame Z axis on the CM B-frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes.

LEM I-frame to B -frame quaternion parameter notation. (See WADC Technical Report 58-17, "On the Use of Quaternions in Simulation of Rigid-Body Motion" by Alfred C. Robinson.)

Commanded LEM I-frame to B-frame quaternions.
Incremental changes in the LEM quaternion rates due to a difference between the commanded quaternions and the actual quaternions. $\left(\mathrm{sec}^{-1}\right)$

| $\gamma_{11}, \gamma_{12}, \gamma_{13}$ | The magnitudes of the projections of a unit vector along the CM B-frame $X$ axis on the $I_{E}$-frame or $I_{M}$-frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes. |
| :---: | :---: |
| $\gamma_{21}, \gamma_{22}, \gamma_{23}$ | The magnitudes of the projections of a unit vector along the CM B-frame $Y$ axis on the $I_{E}$-frame or $\mathrm{I}_{\mathrm{M}}$-frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes. |
| $\gamma_{31}, \gamma_{32}, \gamma_{33}$ | The magnitudes of the projections of a unit vector along the CM B-frame $Z$ axis on the $I_{E}$-frame or $I_{M}$-frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes. |
| $\gamma_{11}, \ldots, \gamma_{33}$ | The time rate of change of $\gamma_{11}, \ldots, \gamma_{33} \cdot\left(\sec ^{-1}\right)$ |
| $\left(\gamma_{11}\right)_{\mathbf{c}},\left(\gamma_{12}\right)_{\mathbf{c}},\left(\gamma_{13}\right)_{\mathbf{c}}$ | The magnitudes of the projections of a unit vector along the commanded CM B-frame $X$ axis on the $I_{E}$-frame or $\mathrm{I}_{\mathrm{M}^{-}}$frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes. |
| $\left.\left(\gamma_{21}\right)_{\mathbf{c}},\left(\gamma_{22}\right)_{\mathbf{c}}, \gamma_{23}\right)_{\mathbf{c}}$ | The magnitudes of the projections of a unit vector along the commanded CM B-frame $Y$ axis on the $I_{E}$-frame or $\mathrm{I}_{\mathrm{M}^{-f r a m e ~} \mathrm{X}, \mathrm{Y}, \mathrm{Z} \text { axes. }}$ |
| $\left.\left.\left(\gamma_{31}\right)_{\mathbf{c}}, \gamma_{32}\right)_{\mathbf{c}}, \gamma_{33}\right)_{\mathbf{c}}$ | The magnitudes of the projections of a unit vector along the commanded CM B-frame Z axis on the $\mathrm{I}_{\mathrm{E}}$-frame or $\mathrm{I}_{\mathrm{M}^{-}}$frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes. |
| $\mathrm{k}_{11}, \mathrm{k}_{12}, \mathrm{k}_{13}$ | The magnitudes of the projections of a unit vector along the CM B-frame X axis on the LEM B-frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes. |
| $\mathrm{k}_{21}, \mathrm{k}_{22}, \mathrm{k}_{23}$ | The magnitudes of the projections of a unit vector along the CM B-frame Y axis on the LEM B-frame X, Y, Z axes. |
| $\mathrm{k}_{31}, \mathrm{k}_{32}, \mathrm{k}_{33}$ | The magnitudes of the projections of a unit vector along the CM B-frame Z axis on the LEM B-frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes. |
| $\mathrm{K}_{1}, \mathrm{~K}_{2}$ | Gain constants. ( $\mathrm{sec}^{-1}$ ) |
| $\mathrm{L}_{\mathrm{CM}}$ | The latitude of the CM measured with respect to the $\mathrm{J}^{\prime}$-frame. (rad) |
| ${ }^{\lambda} \mathrm{CM}$ | The longitude of the CM measured with respect to the J'-frame. (rad) |
| $\psi_{c}, \theta_{c}, \phi_{c}$ | Commanded B-frame to H -frame Euler angles. These angles are generated by rotating the B-frame away from the $H$-frame through the angles $\psi_{c}, \theta_{c}$, and $\phi_{c}$. The first rotation, through $\psi_{c}$, is about the B-frame Z axis. The second rotation, thr ${ }^{\prime}$ ugh $\theta$, is about the $B$-frame Y axis. The third rotation, thfough $\phi_{c}$, is about the B-frame X axis. (rad) |
| $\left(\psi_{\mathrm{h}}\right)^{\text {CM }}$ | The heading angle of the CM H-frame. This is the angle measured from the CM E-frame X axis to the CM H-frame X axis. (rad) |
| $\left.\left(\mathrm{T}_{\mathrm{X}_{\mathrm{b}}}\right)_{C M},\left(\mathrm{~T}_{\mathrm{Y}_{\mathrm{b}}}\right)_{C M},{ }^{( } \mathrm{T}_{\mathrm{X}_{\mathrm{b}}}\right)_{C M}$ | The magnitudes of the projections of the instructor-controlled commanded thrust vector on the CM B-frame $\mathrm{X}, \mathrm{Y}$, and Z axes. |



$$
\zeta_{11}, \zeta_{12}, \zeta_{13}
$$

$$
\zeta_{21}, \zeta_{22}, \zeta_{23}
$$

$$
\zeta_{31}, \zeta_{32}, \zeta_{33}
$$

controlled commanded thrust vector on the CM H-frame $\mathrm{X}, \mathrm{Y}$ and Z axes. (lb)

The magnitudes of the projections of a unit vector along the CM H-frame $X$ axis on the $I_{E}$-frame or $I_{M}$-frame $\mathrm{X}, \mathrm{Y}$, and Z axes.

The magnitudes of the projections of a unit vector along the CM H-frame Y axis on the $\mathrm{I}_{\mathrm{E}}$-frame or $\mathrm{I}_{\mathrm{M}}$-frame $\mathrm{X}, \mathrm{Y}$, and Z axes.

The magnitudes of the projections of a unit vector along the $\mathrm{CM} H$-frame Z axis on the $\mathrm{I}_{\mathrm{E}}$-frame or $\mathrm{I}_{\mathrm{M}}$-frame $\mathrm{X}, \mathrm{Y}$, and Z axes.


| $A_{j_{b}}, A_{X_{b}}, A_{Y_{b}}, A_{Z_{b}}$ |
| :---: |
| B* |
| $\mathrm{I}_{\mathrm{j}_{\mathrm{FB}}}$ |
| $\mathrm{I}_{\mathrm{XX}}, \mathrm{I}_{\mathrm{YY}}, \mathrm{I}_{\mathrm{ZZ}}$ |
| $\mathrm{I}_{\mathrm{XY}}, \mathrm{I}_{\mathrm{XZ}}, \mathrm{I}_{\mathrm{YZ}}$ |
| $\left(\mathrm{I}_{\mathrm{O}_{\mathrm{jFB}}}\right){ }_{\text {AS }}$ |
| $\left(\mathrm{I}_{\mathrm{FFB}^{\prime}}\right) \mathrm{C} / \mathrm{SM}$ |
| $\left(\mathrm{I}_{\mathrm{O}_{\mathrm{jFB}}}\right){ }_{\text {DS }}$ |
| $\left(\Delta \mathrm{I}_{\mathrm{j}_{\mathrm{FB}}}\right)_{\mathrm{FC}}$ |
| $\left(\Delta \mathrm{I}_{\mathrm{jFB}}\right)_{\text {GOT }}$ |
| $\left(\Delta \mathrm{I}_{\mathrm{j}_{\mathrm{FB}}}\right)_{\mathrm{HT}}$ |
| $\left(\Delta \mathrm{I}_{\mathrm{j}_{\mathrm{FB}}}\right) \mathrm{HT}(\mathrm{RCS})$ |
| $\left(\Delta \mathrm{I}_{\mathrm{jFB}}\right){ }_{\mathrm{LG}}$ |
| $\left(\Delta_{\mathrm{j}}^{\mathrm{FB}}\right.$ ) ${ }_{\text {LHT }}$ |
| $\left(\Delta \mathrm{I}_{\mathrm{j}_{\mathrm{FB}}}\right)_{\mathrm{LOX}}$ |
| $\left(\Delta \mathrm{I}_{\mathrm{j}}{ }^{\prime}\right)$ |
| $\left(\Delta \mathrm{I}_{\mathrm{j}}{ }^{\prime}\right)_{\mathrm{PAE}}$ |
| $\left(\Delta \mathrm{I}_{\mathrm{jFB}}\right){ }_{\text {PDE }}$ |
| $\left(\Delta \mathrm{I}_{\mathrm{jFB}}\right)^{\text {PRCS }}$ |

Body axes components of the distance vector measured from the origin of the body axis to the origin of the fixed body axes along the $\mathrm{X}, \mathrm{Y}$, and Z body axes. (ft)

Boolean term.
Moments of inertia of the complete vehicle about the $\mathrm{X}, \mathrm{Y}$, and Z fixed body axes. (slug-ft ${ }^{2}$ )

Moments of inertia of the complete vehicle about the $\mathbf{X}, \mathbf{Y}$, and Z body axes. (slug- $\mathrm{ft}^{2}$ )

Products of inertia of the complete vehicle about the body axes in the XY, XZ, and YZ planes. (slug-ft ${ }^{2}$ )

Fixed body moments of inertia of the empty ascent stage. (slug-ft ${ }^{2}$ )

Fixed body moments of inertia. of the Command Service Module. (slug- $\mathrm{ft}^{2}$ )

Fixed body moments of inertia of the empty descent stage. (slug- $\mathrm{ft}^{2}$ )

Incremental moments of inertia. of the fuel in the fuel cell about the fixed body axes. (slug- $\mathrm{ft}^{2}$ )

Incremental moments of inertia of the gaseous oxygen in the gaseous oxygen tank, about the fixed body axes. (slug- $\mathrm{ft}^{2}$ )

Incremental moments of inertia of the helium in the helium tank about the fixed body axes. (slug- $\mathrm{ft}^{2}$ )

Incremental moments of inertia of the Reaction Control System helium in the helium tank about the fixed body axes. (slug-ft ${ }^{2}$ )

Incremental moments of inertia of the landing gear about the fixed body axes. (slug-ft ${ }^{2}$ )

Incremental moments of inertia of the líquid hydrogen in the liquid hydrogen tank about the fixed body axes. (slug-ft ${ }^{2}$ )

Incremental moments of inertia of the liquid oxygen in the liquid oxygen tank about the fixed body axes. (slug-ft ${ }^{2}$ )

Incremental moments of inertia of the oxygen in the oxygen tank about the fixed body axes. (slug-ft ${ }^{2}$ )

Incremental moments of inertia of the ascent engine propellant about the fixed body axes. (slug-ft ${ }^{2}$ )

Incremental moments of inertia of the descent engine propellant about the fixed body axes. (slug-ft ${ }^{2}$ )

Incremental moments of inertia of the reaction control system propellant about the fixed body axes. (slug-ft ${ }^{2}$ )

| $\left(\Delta \mathrm{I}_{\mathrm{j}_{\mathrm{FB}}}\right)$ | Incremental moments of inertia of the water in the water tank about the fixed body axes. (slug- $\mathrm{ft}^{2}$ ) |
| :---: | :---: |
| j | Indices representing $\mathrm{X}, \mathrm{Y}$, or Z axes. |
| m | Total vehicle mass. (slugs) |
| $\mathrm{m}_{\mathrm{OAS}}$ | Mass of the empty ascent stage. (slugs) |
| $\mathrm{m}_{\mathrm{C} / \mathrm{SM}}$ | Mass of the Command Service Module. (slugs) |
| $\mathrm{m}_{\mathrm{ODS}}$ | Mass of the empty descent stage. (slugs) |
| $\mathrm{m}_{\mathrm{FC}}$ | Mass of the fuel in the fuel cell. (slugs) |
| $\mathrm{m}_{\text {GOT }}$ | Mass of the gaseous oxygen in the gaseous oxygen tank. (slugs) |
| $\mathrm{m}_{\mathrm{HT}}$ | Mass of the helium in the helium tank. (slugs) |
| $\mathrm{m}_{\mathrm{HT}(\mathrm{RCS})}$ | Mass of the reaction control system helium in the helium tank (slugs) |
| $\mathrm{m}_{\text {LHT }}$ | Mass of the liquid hydrogen in the liquid hydrogen tank. (slugs) |
| $\mathrm{m}_{\text {LOX }}$ | Mass of the liquid oxygen in the liquid oxygen tanks. (slugs) |
| $\mathrm{m}_{\mathrm{CT}}$ | Mass of the oxygen in the oxygen tank. (slugs) |
| $\mathrm{m}^{\text {PAE }}$ | Propellant mass of the ascent engine. (slugs) |
| $\mathrm{m}^{\text {PDE }}$ | Propellant mass of the descent engine. (slugs) |
| $\mathrm{m}_{\text {PRCS }}$ | Propellant mass of the reaction control system. (slugs) |
| $\mathrm{m}_{\text {WT }}$ | Mass of the water in the water tank. (slugs) |
| $\left(\mathrm{mA}_{\mathrm{O}_{\mathrm{jFB}}}\right)_{\mathrm{AS}}$ | Incremental moment of the empty ascent stage about the fixed body axes. (slug-ft) |
| $\left(\mathrm{mA}_{\mathrm{j}_{\mathrm{FB}}}\right)$ CISM | Incremental moment of the command service module about the fixed body axes. (slug-ft) |
| $\left(\mathrm{mA}_{\mathrm{O}_{\mathrm{j}_{\mathrm{FB}}}}\right)$ | Incremental moment of the empty descent stage about the fixed body axes. (slug-ft) |
| $\left(\mathrm{mA}_{\mathrm{j}_{\mathrm{FB}}}\right)_{\mathrm{FC}}$ | Incremental moment of the fuel in the fuel cell about the fixed body axes. (slug-ft) |
| $\left(\mathrm{mA}_{\mathrm{j}_{\mathrm{FB}}}\right)_{\mathrm{GOT}}$ | Incremental moment of the gaseous oxygen in the gaseous oxygen tank about the fixed body axes. (slug-ft) |
| $\left(\mathrm{mA}_{\mathrm{j}_{\mathrm{FB}}}\right)_{\mathrm{HT}}$ | Incremental moment of the helium in the helium tank about the fixed body axes. (slug-ft) |
| $\left(\mathrm{mA}_{\mathrm{j}_{\mathrm{FB}}}\right) \text { HT(RCS) }$ | Incremental moment of the reaction control system helium in the helium tank about the fixed body axes. (slug-ft) |
| $\left(\mathrm{mA}_{\mathrm{j}_{\mathrm{FB}}}\right)_{\mathrm{LHT}}$ | Incremental moment of the liquid hydrogen in the liquid hydrogen tank about the fixed body axes. (slug-ft) |

$\left(m A_{j_{F B}}\right)$
$\left(m A_{j_{F B}}\right)$
$\left(m A_{j_{F B}}\right){ }_{\text {PAE }}$
$\left(m A_{j_{F B}}\right)_{\text {PDE }}$
$\left(m A_{j_{F B}}\right)$
$\left(m A_{j_{F B}}\right)$

Incremental moment of the liquid oxygen in the liquid oxygen tank about the fixed body axes. (slug-ft)

Incremental moment of the oxygen in the oxygen tank about the fixed body axes. (slug-ft)

Incremental moment of the ascent engine propellant about the fixed body axes. (slug-ft)

Incremental moment of the descent engine propellant about the fixed body axes. (slug-ft)

Incremental moment of the reaction control system proabout the fixed body axes. (slug-ft)

Incremental moment of the water in the water tank about the fixed body axes. (slug-ft)

| (1) VEHICLE MASS |  | (3) CENTER OF GRAVITY LOCATION |
| :---: | :---: | :---: |
| $\begin{aligned} \mathrm{m}= & \mathrm{mo}_{\mathrm{AS}}+\mathrm{m}_{\mathrm{PRCS}}+\mathrm{m}_{\mathrm{PAE}}+\mathrm{m}_{\mathrm{LHT}}+\mathrm{m}_{\mathrm{GOT}}+\mathrm{m}_{\mathrm{LOX}} \\ & +\mathrm{m}_{\mathrm{HT}}+\mathrm{m}_{\mathrm{HT}(\mathrm{RCS})}+\mathrm{B}_{1}^{*}\left[\mathrm{mo}_{\mathrm{DS}}+\mathrm{m}_{\mathrm{PDE}}+\mathrm{m}_{\mathrm{FC}}\right. \\ & \left.+\mathrm{m}_{\mathrm{WT}}+\mathrm{m}_{\mathrm{HT}}+\mathrm{m}_{\mathrm{OT}}\right]+\mathrm{B}_{2}^{*} \mathrm{~m}_{\mathrm{C} / \mathrm{SM}} \end{aligned}$ | TO INTEGRATED operation EQUATIONS | $\begin{aligned} \mathrm{Aj}_{\mathrm{b}}= & -\frac{1}{\mathrm{~m}}\left\{(\mathrm{mAoj} \mathrm{FB})_{\mathrm{AS}}+\left(\mathrm{mAj}_{\mathrm{FB}}\right)_{\mathrm{PRCS}}+\left(\mathrm{mAj}_{\mathrm{FB}}\right)_{\mathrm{PAE}}+\left(\mathrm{mAj} \mathrm{FB}_{\mathrm{LHT}}\right)_{\mathrm{LHT}}\right. \\ & \left.+\left(\mathrm{mAj}_{\mathrm{FB}}\right)_{\mathrm{GOT}}+\left(\mathrm{mAj}_{\mathrm{FB}}\right)_{\mathrm{LOX}}+\left(\mathrm{mAj}_{\mathrm{FB}}\right)_{\mathrm{HT}}+\left(\mathrm{mAj}_{\mathrm{FB}}\right)_{\mathrm{HT}(\mathrm{RCS})}\right) \end{aligned}$ |
|  |  | $+\mathrm{B}_{1}^{*}\left[(\mathrm{mAoj} \mathrm{FB})_{\mathrm{DS}}+(\mathrm{mAj} \mathrm{FB})_{\mathrm{PDE}}+(\mathrm{mAj} \mathrm{FB})_{\mathrm{FC}}+(\mathrm{mAj} \mathrm{FB})_{\mathrm{WT}}\right.$ |
|  |  | $\left.\left.+\left(\mathrm{mAj}_{\mathrm{FB}}\right)_{\mathrm{HT}}+(\mathrm{mAj} \mathrm{FB})_{\mathrm{OT}}\right]+\mathrm{B}_{2}^{*}(\mathrm{mAj} \mathrm{FB})_{\mathrm{C} / \mathrm{SM}}\right\}$ |

## (2) FIXED BODY INERTIAS

$\mathrm{Ij}_{\mathrm{FB}}=\left(\mathrm{Ioj}_{\mathrm{FB}}\right)_{\mathrm{AS}}+(\Delta \mathrm{Ij} \mathrm{FB})_{\mathrm{PRCS}}+\left(\Delta \mathrm{Ij}_{\mathrm{FB}}\right)_{\mathrm{PAE}}+(\Delta \mathrm{Ij} \mathrm{FB})_{\mathrm{LHT}}+(\Delta \mathrm{Ij} \mathrm{FB})_{\mathrm{GOT}}$
$+\left(\Delta \mathrm{Ij}_{\mathrm{FB}}\right)_{\mathrm{LOX}}+\left(\Delta \mathrm{Ij} \mathrm{FB}_{\mathrm{HT}}\right)_{\mathrm{HT}}+(\Delta \mathrm{Ij} \mathrm{FB})_{\mathrm{HT}(\mathrm{RCS})}+\mathrm{B}_{1}^{*}\left[\mathrm{Ioj}_{\mathrm{FB}}\right)_{\mathrm{DS}}$
$+(\Delta \mathrm{Ij} \mathrm{FB})_{\mathrm{PDE}}+(\Delta \mathrm{Ij} \mathrm{FB})_{\mathrm{FC}}+(\Delta \mathrm{Ij} \mathrm{FB})_{\mathrm{WT}}+(\Delta \mathrm{IjFB})_{\mathrm{HT}}+(\Delta \mathrm{IjFB})_{\mathrm{OT}}$
$\left.+\left(\Delta \mathrm{Ij}_{\mathrm{FB}}\right)_{\mathrm{LG}}\right]+\mathrm{B}_{2}^{*}\left(\mathrm{Ij}_{\mathrm{FB}}\right)_{\mathrm{C}} / \mathrm{SM}$


| $\mathrm{a}_{11}, \mathrm{a}_{12}, \mathrm{a}_{13}$ |
| :---: |
| $\mathrm{a}_{21}, \mathrm{a}_{22}, \mathrm{a}_{23}$ |
| $a_{31}, a_{32}, a_{33}$ |
| $\mathrm{AZ}_{\mathrm{CM} / \mathrm{L}}, \mathrm{EL}_{\mathrm{CM} / \mathrm{L}}$ |
| $\mathrm{AZ}_{\mathrm{E} / \mathrm{L}}, \mathrm{EL}_{\mathrm{E} / \mathrm{L}}$ |
| $\mathrm{AZ}_{\mathrm{M} / \mathrm{L}}, \mathrm{EL}_{\mathrm{M} / \mathrm{L}}$ |
| $\mathrm{AZ}_{\mathrm{S} / \mathrm{L}}, \mathrm{EL}_{\mathrm{S} / \mathrm{L}}$ |
| $\mathrm{b}_{11}, \mathrm{~b}_{12}, \mathrm{~b}_{13}$ |
| $\mathrm{b}_{21}, \mathrm{~b}_{22}, \mathrm{~b}_{23}$ |
| $\mathrm{b}_{31}, \mathrm{~b}_{32}, \mathrm{~b}_{33}$ |
| $\mathrm{B}_{\mathrm{M}}$ |
| $\mathrm{c}_{11}, \mathrm{c}_{12}, \mathrm{c}_{13}$ |
| $\mathrm{c}_{21}, \mathrm{c}_{22}, \mathrm{c}_{23}$ |
| $\mathrm{c}_{31}, \mathrm{c}_{32}, \mathrm{c}_{33}$ |
| $\left(\mathrm{C}_{11}\right)_{\mathrm{AMS}},\left(\mathrm{C}_{12}\right)_{\mathrm{AMS}}{ }^{\left(\mathrm{C}_{13}\right)_{\mathrm{AMS}}}$ |
|  |

The magnitudes of the projections of a unit vector along the LEM B-frame X axis on the $\mathrm{I}_{\mathrm{E}}$-frame or $\mathrm{I}_{\mathrm{M}}$-frame $\mathrm{X}, \mathrm{Y}$, Z axes.

The magnitudes of the projections of a unit vector along the LEM B-frame $Y$ axis on the $I_{E}$-frame or $\mathrm{I}_{\mathrm{M}}$-frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes.

The magnitudes of the projections of a unit vector along the LEM B-frame $Z$ axis on the $\mathrm{I}_{\mathrm{E}}$-frame or $\mathrm{I}_{\mathrm{M}}$-frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes.

Relative azimuth and elevation angles of CM with respect to the LEM B-frame Z axis. (rad)

Relative azimuth and elevation angles of the earth with respect to the LEM B-frame Z axis. (rad)

Relative azimuth and elevation angles of the moon with respect to the LEM B-frame Z axis. (rad)

Relative azimuth and elevation angles of the sun with respect to the LEM B-frame Z axis. (rad)

The magnitudes of the projections of a unit vector along the $\mathrm{I}_{\mathrm{E}}$-frame or $\mathrm{I}_{\mathrm{M}}$-frame X axis on the LEM E-frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes.

The magnitudes of the projections of a unit vector along the $\mathrm{I}_{\mathrm{E}}$-frame or $\mathrm{I}_{\mathrm{M}}$-frame Y axis on the LEM E-frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes.

The magnitudes of the projections of a unit vector along the $\mathrm{I}_{\mathrm{E}}$-frame or $\mathrm{I}_{\mathrm{M}}$-frame Z axis on the LEM E-frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes.

A Boolean term which is equal to one for lunar phase simulation.

The magnitudes of the projections of a unit vector along the LEM B-frame X axis on the LEM E-frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes.

The magnitudes of the projections of a unit vector along the LEM B-frame Y axis on the LEM E-frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes.

The magnitudes of the projections of a unit vector along the LEM B-frame Z axis on the LEM E-frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes.

The magnitudes of the projections of a unit vector along the CM B-frame axis on the $\mathrm{I}_{\mathrm{E}}$-frame or $\mathrm{I}_{\mathrm{M}}$-frame $\mathrm{X}, \mathrm{Y}$, Z axes.

The magnitudes of the projections of a unit vector along the CM B-frame axis on the $\mathrm{I}_{\mathrm{E}}$-frame or $\mathrm{I}_{\mathrm{M}}$-frame $\mathrm{X}, \mathrm{Y}$, Z axes.

| $\left(\mathrm{C}_{31}\right)_{\text {AMS }},\left(\mathrm{C}_{32}\right)_{\text {AMS }},{ }^{\left(\mathrm{C}_{33}\right)}{ }_{\text {AMS }}$ | The magnitudes of the projections of a unit vector along the CM B-frame axis on the $\mathrm{I}_{\mathrm{E}}$-frame or $\mathrm{I}_{\mathrm{M}^{-f r a m e}} \mathrm{X}, \mathrm{Y}$, Z axes. |
| :---: | :---: |
| $D_{L}^{\prime}$ | Distance across a selected orbit. The distance, measured from $D_{\lambda}^{\dot{\lambda}}$, perpendicular to the trace of a selected orbit on the surface of the moon. (ft) |
| $D_{\lambda}^{\prime}$ | Distance along a selected orbit. The distance along the trace of a selected orbit on the surface of the moon. (ft) |
| $\mathrm{f}_{11}, \mathrm{f}_{12}, \mathrm{f}_{13}$ | The magnitudes of the projections of a unit vector along the ecliptic-frame $X$ axis on the $I_{E}$-frame or $\mathrm{I}_{\mathrm{M}}$-frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes. |
| $\mathrm{f}_{21}, \mathrm{f}_{22}, \mathrm{f}_{23}$ | The magnitudes of the projections of a unit vector along the ecliptic-frame $Y$ axis on the $\mathrm{I}_{\mathrm{E}}$-frame or $\mathrm{I}_{\mathrm{M}}$-frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes. |
| $\mathrm{f}_{31}, \mathrm{f}_{32}, \mathrm{f}_{33}$ | The magnitudes of the projections of a unit vector along the ecliptic-frame Z axis on the $\mathrm{I}_{\mathrm{E}}$-frame or $\mathrm{I}_{\mathrm{M}}$-frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes. |
| h | LEM altitude above the earth's or moon's surface measured along the radius vector. (ft) |
| $\mathrm{h}_{11}, \mathrm{~h}_{12}, \mathrm{~h}_{13}$ | The magnitudes of the projections of a unit vector along the $\mathrm{J}_{\mathrm{R}}{ }^{- \text {fframe }} \mathrm{X}$ axis on the LEM H-frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes. |
| $\mathrm{h}_{21}, \mathrm{~h}_{22}, \mathrm{~h}_{23}$ | The magnitudes of the projections of a unit vector along the $\mathrm{J}_{\mathrm{R}}^{\top}$-frame Y axis on the LEM H -frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes. |
| $\mathrm{h}_{31}, \mathrm{~h}_{32}, \mathrm{~h}_{33}$ | The magnitudes of the projections of a unit vector along the $J_{R}^{\top}$-frame $Z$ axis on the LEM H-frame $X, Y, Z$ axes. |
| $\mathrm{k}_{11}, \mathrm{k}_{12}, \mathrm{k}_{13}$ | The magnitudes of the projections of a unit vector along the CM B-frame X axis on the LEM B-frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes. |
| $k_{21}, k_{22}, k_{23}$ | The magnitudes of the projections of a unit vector along the CM B-frame $Y$ axis on the LEM B-frame X, Y, Z axes. |
| $\mathrm{k}_{31}, \mathrm{k}_{32}, \mathrm{k}_{33}$ | The magnitudes of the projections of a unit vector along the CM B-frame $Z$ axis on the LEM B-frame X, Y, Z axes. |
| $\mathrm{K}_{1}-\mathrm{K}_{8}$ | Constants which depend on the inclination and the longitude of the ascending mode of a given orbit selection. |
| $\mathrm{K}_{9}-\mathrm{K}_{16}$ | Constants which depend on the orientation of the moon relative to the sun. |
| 1.0.8. | The distance along the Z body axis to the surface of the moon. (ft) |
| L | The angle of latitude with respect to the $\mathrm{J}^{\prime}$-frame. (rad) |
| L' | Latitude referenced to the great circle defined by the intersection of a selected orbit and a theoretical moon of constant radius. (rad) |



Latitude referenced to the lunar great circle which contains the moon-sun line. (rad)

Longitude referenced to the great circle defined by the intersection of a selected orbit and a theoretical moon of constant radius. (rad)

Longitude referenced to the lunar great circle which contains the moon-sun line. Measured from the right ascension of the sun on the lunar surface. (rad)

The longitude of an arbitrary point on the surface of the earth. (rad)

The longitude of an arbitrary point on the surface of the moon. (rad)

Longitude measured with respect to the earth's or moon's surface. (rad)

The magnitude of the rotational velocity of the earth. (rad/sec)

The magnitude of the rotational velocity of the moon. (rad/sec)

The magnitudes of the projections of a unit vector along the $\mathrm{J}_{\mathrm{R}}$-frame X axis on the LEM H-frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes.

The magnitudes of the projections of a unit vector along the $\mathrm{J}_{\mathrm{R}}^{\prime \prime}$-frame Y axis on the LEM H-frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes.

The magnitudes of the projections of a unit vector along the $J_{R}^{\prime \prime}$-frame $Z$ axis on the LEM H-frame X, Y, $Z$ axes.

The heading angle of the H-frame. This is the angle the H -frame X axis makes with the E-frame X axis. (rad)

The magnitudes of the projections of a unit vector along the ecliptic-frame $\mathbf{X}$ axis on the B -frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes.

The magnitudes of the projections of a unit vector along the ecliptic-frame Y axis on the B-frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes.

The magnitudes of the projections of a unit vector along the ecliptic-frame Z axis on the B -frame $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes.

The magnitude of the radius of the vehicle as measured in the $I_{\mathrm{E}}$-frame or $\mathrm{I}_{\mathrm{M}}$-frame. This quantity is measured in the $I_{E}$-frame during earth orbital computation and in the $\mathrm{I}_{\mathrm{M}}$-frame during lunar phase computation. (ft)

The projection of the LEM's radius on a plane perpendicular to the moon-sun line. (ft)

Absolute range of CM from LEM. (ft)
The constant radius of a theoretical moon. (ft)
${ }^{\theta} \mathrm{B} / \mathrm{E}, \phi_{\mathrm{B} / \mathrm{E}}, \psi_{\mathrm{B} / \mathrm{E}}$
${ }^{\theta} \mathrm{CM} / \mathrm{L}, \phi_{\mathrm{CM}} / \mathrm{L}, \psi_{\mathrm{CM} / \mathrm{L}}$
${ }^{\theta} \mathrm{E} / \mathrm{H}, \phi_{\mathrm{E} / \mathrm{H}}, \psi_{\mathrm{E} / \mathrm{H}}$
${ }^{\theta} E / M,{ }^{\phi}{ }_{\mathrm{E} / \mathrm{M}}, \psi_{\mathrm{E} / \mathrm{M}}$
$\theta_{M / E},{ }^{\phi_{M / E}}, \psi_{M / E}$
${ }^{\mathbf{M} / \mathrm{H}}, \phi_{\mathrm{M} / \mathrm{H}}, \psi_{\mathrm{M} / \mathrm{H}}$
${ }^{\theta} \mathbf{S}^{\prime},{ }^{\prime} \phi_{\mathrm{S} / \mathrm{L}}, \psi_{\mathrm{S} / \mathrm{L}}$
$\mathrm{X}_{\mathrm{CM} / \mathrm{L}}, \mathrm{Y}_{\mathrm{CM} / \mathrm{L}}, \mathrm{Z}_{\mathrm{CM} / \mathrm{L}}$
$\mathrm{X}_{\mathrm{I}_{\mathrm{CM} / \mathrm{L}}}, \mathrm{Y}_{\mathrm{I}_{\mathrm{CM} / \mathrm{L}}}, \mathrm{Z}_{\mathrm{IM} / \mathrm{L}}$

$\left(\mathrm{X}_{\mathrm{I}_{\mathrm{E}}}\right)_{\mathrm{M}},{ }^{\left(\mathrm{Y}_{\mathrm{I}_{\mathrm{E}}}\right)}{ }_{\mathrm{M}},{ }^{\left(\mathrm{Z}_{\mathrm{I}_{\mathrm{E}}}\right)_{\mathrm{M}}}$
$\left(\mathrm{X}_{\mathrm{I}_{\mathrm{E}}}\right),\left(\mathrm{Y}_{\mathrm{I}}\right)_{\mathrm{E}_{\mathrm{S}}},{ }^{\left(\mathrm{Z}_{\mathrm{I}_{\mathrm{E}}}\right)}{ }_{\mathrm{S}}$

$\mathrm{X}_{\mathrm{I}_{\mathrm{V}}}, \mathrm{Y}_{\mathrm{I}_{\mathrm{V}}}, \mathrm{Z}_{\mathrm{I}_{\mathrm{V}}}$
$X_{M / L}, Y_{M / L}, Z_{M / L}$
$\mathrm{X}_{\mathrm{S} / \mathrm{L}}, \mathrm{Y}_{\mathrm{S} / \mathrm{L}}, \mathrm{Z}_{\mathrm{S} / \mathrm{L}}$

LEM attitude with respect to the LEM E-frame.
CM attitude angles with respect to the LEM body axes. (rad)
Earth attitude angles with respect to the H-frame during earth orbital computation. (rad)

Earth attitude angles with respect to the H -frame during lunar phase computation. (rad)

Moon attitude angles with respect to the H -frame during earth orbital computation. (rad)

Moon attitude angles with respect to the H-frame during lunar phase computation. (rad)

Starfield display with respect to LEM body axis. (rad)
LEM B-frame coordinates of CM position. (ft)
$\mathrm{I}_{\mathrm{E}}$-frame or $\mathrm{I}_{\mathrm{M}}$-frame coordinates of CM position relative to the LEM. (ft)
$\mathrm{I}_{\mathrm{E}}$-frame or $\mathrm{I}_{\mathrm{M}}$-frame coordinates of the sun's position relative to the LEM. (ft)
$\mathrm{I}_{\mathrm{E}}$-frame coordinates of the moon's position. (ft)
$\mathrm{I}_{\mathrm{E}}$-frame coordinates of the sun's position.
$\mathrm{I}_{\mathrm{E}}$-frame or $\mathrm{I}_{\mathrm{M}}$-frame coordinates of LEM position. These quantities represent $\mathrm{I}_{\mathrm{E}}$-frame coordinates during earth orbital computation and $\mathrm{I}_{\mathrm{M}}$-frame coordinates during lunar phase computation. (ft)

LEM B-frame coordinates of the moon's position. (ft)
LEM B-frame coordinates of the sun's position. (ft)
lunar effects projector signals

additional signal requirements


### 4.1 VARIABLES

AREG
$\mathrm{A}_{\mathrm{REG}}^{\prime}$
${ }^{A} \mathbf{X}$

BX
${ }_{\mathrm{S}}^{\mathrm{S}}$

F
$\mathrm{F}_{\mathrm{A}}^{\prime}$
$\dot{F}_{B}^{\prime}$
$\Delta \dot{\mathrm{F}}_{\text {ASC }}$

## 下

$\mathrm{f}_{1}$ (PRESSURE RATIO)
$\mathrm{f}_{2}\left(\mathrm{~T}_{\mathrm{FUEL}}\right)$
$f_{3}$ (TOXID)
$\mathrm{f}_{4}\left(\right.$ PMAN $\left._{\text {FUEL }}\right)$
f5 (PMANOXID)
$\mathrm{f}_{6}\left[\mathrm{f}_{5} / \mathrm{f}_{4}\right]$

Effective area of the squib, the two solenoid valves, and the four pressure regulator valves, which connect the helium reservoir with the region immediately downstream of the pressure regulators, and upstream of the check valves (in ${ }^{2}$ ).

Uncorrected effective flow area (in ${ }^{2}$ ). NOTE: Further explanation of this variable is given in paragraph 3.3.1 of the technical proposal.

The symbol $A_{X}$, where $X$ is a 1 , 2 , or 3 digit numeric subscript, is an arithmetic quantity, the existence of which is implied by the corresponding Boolean quantity BX and the following relations; $\mathrm{AX}=1$ if $\mathrm{BX}_{\mathrm{X}}=1$, and $\mathrm{AX}=0$ if $\mathrm{BX}=0$. NOTE: The B's are defined in Section 4.3

See definition of AX.
Fractional sensor error, i.e., the ratio of the actual sensor error to the maximum plus or minus variation in sensor error.

Fuel quantity. (lbs.)
Summation of the fuel flow rates for the 8 reaction control jets of RCS-A. (lbs-sec ${ }^{-1}$ )

Summation of the fuel flow rates for the 8 reaction control jets of RCS-B. (lbs-sec ${ }^{-1}$ )

Incremental increase in ascent engine fuel consumption rate due to RCS operation. (lbs-sec ${ }^{-1}$ )

Thrust output of a single reaction jet if the TCA solenoid valves are open. (lbs.)

See definitions of $\stackrel{\circ}{\mathrm{M}}_{\mathrm{T}}, \stackrel{\circ}{\mathrm{M}}_{\mathrm{T}}^{\mathrm{F}}$, and $\stackrel{\circ}{\mathrm{M}}_{\mathrm{T}}^{\mathrm{O}}$.
See definition of $\rho_{\mathrm{F}}$.
See definition of $\rho_{\mathrm{O}}$.
The fuel flow rate for a single thruster if the TCA solenoid valve is open (lbs-sec ${ }^{-1}$ ). NOTE: This function will be defined for PMANFUEL in the range $0 \leq$ PMANFUEL $\leq 250$ psia.

The oxidizer flow rate for a single thruster if the TCA solenoid valve is open ( $\mathrm{lbs}-\mathrm{sec}^{-1}$ ). NOTE: This function will be defined for PMANOXID in the range $0 \leq$ PMANOXID $\leq 250$ psia.

Represents the available specific impulse as a function of the available $0 / \dot{F}$ ratio (sec). NOTE: This function will be defined over a sufficient range of $f_{5} / f_{4}$, say $C_{1} \leq f_{5} / f_{4} \leq C_{2}$, such that $f_{6}\left(C_{3}\right)$ may be assumed equal to zero if $C_{3}$ is less than $\mathrm{C}_{1}$ or greater than $\mathrm{C}_{2}$.

| $\mathrm{K}_{\mathbf{i}}$ |
| :---: |
| $\stackrel{\circ}{\text { T }}^{\text {T }}$ |
| $\stackrel{\circ}{M}_{\text {T }}^{\text {F }}$ |
| $\stackrel{\wedge}{\mathrm{M}}_{\mathrm{T}}{ }_{\mathrm{O}}$ |
| 0 |
| $\mathrm{O}_{\mathrm{A}}^{\prime}$ |
| $\dot{O}_{B}^{\prime}$ |
| $\Delta \dot{\mathrm{O}}_{\text {ASC }}$ |
| P |
| $\mathrm{P}_{\mathrm{C}}$ |
| $\Delta \mathrm{P}_{\mathrm{C}}$ |
| $\triangle \mathrm{P}_{C_{A P}}$ |
| $\Delta \mathrm{P}_{\mathrm{C}_{\text {AR }}}$ |
| $\Delta \mathrm{P}_{\mathrm{C}_{\mathrm{BP}}}$ |
| $\Delta \mathrm{P}_{\mathrm{C}_{\mathrm{BR}}}$ |
| $\mathrm{P}_{\text {CREW }}$ |

The $\mathrm{i}^{\text {th }}$ system constant. NOTE: The $\mathbf{K}$ 's are defined in Section 4.2.

Mass flow parameter based on upstream total pressure. The mass flow parameter, as applied, is a function of the ratio of pressure in the helium reservoir to regulator outlet pressure, and for helium has a range $0 \leq \mathrm{M}_{\mathrm{T}} \leq 0.21 .(\sqrt{\circ} \mathrm{R} / \mathrm{sec})$

Mass flow parameter as applied to the check valve upstream of the fuel tank, MTF $=\mathrm{f}\left(\mathrm{P}_{\mathrm{REG}} / \mathrm{P}_{\text {FUEL }}\right) .\left({ }^{\circ} \mathrm{R} / \mathrm{sec}\right)$

Mass flow parameter ąs applied to the check valve upstream of the oxidizer tank, $\mathrm{M}_{\mathrm{T}}=\mathrm{f}\left(\mathrm{P}_{\mathrm{REG}} / \mathrm{POXID}\right) .\left({ }^{\circ} \mathrm{R} / \mathrm{sec}\right)$

Oxidizer quantity. (lbs.)
Summation of the oxidizer flow rates for the 8 reaction control jets of RCS-A. (lbs-sec ${ }^{-1}$ )

Summation of the oxidizer flow rates for the 8 reaction control jets of RCS-B. (lbs-sec ${ }^{-1}$ )

Incremental increase in ascent engine oxidizer consumption rate due to RCS operation. (lbs-sec ${ }^{-1}$ )

Instructor indicator readings displayed on the RCS pressure indicators if the instructor selects to read true values. (psia)

Commanded regulator outlet pressure.(psia)
Increment in commanded regulator outlet pressure as referenced to the nominal regulator outlet pressure of 181 psia . This increment may be applied to the series regulators in either the primary or redundant branches of RCS-A or RCS-B.(psi)

Increment in command regulator pressure for the two series pressure regulators in the primary branch of RCS-A. This increment represents the difference between the actual regulator command pressure for the two series regulators and the nominal regulator command pressure of 181 psia .(psi)

Increment in command regulator pressure for the two series pressure regulators in the redundant branch of RCS-A. This increment represents the difference between the actual regulator command pressure for the two series regulators and the nominal regulator command pressure of 181 psia . (psi)
Increment in command regulator pressure for the two series pressure regulators in the primary branch of RCS-B. This increment represents the difference between the actual regulator command pressure for the two series regulators and the nominal regulator command pressure of 181 psia . (psi)

Increment in command regulator pressure for the two series pressure regulators in the redundant branch of RCS-B. This increment represents the difference between the actual regulator command pressure for the two series regulators and the nominal regulator command pressure of 181 psia.(psi)

Crew indicator readings as displayed on the RCS pressure indicators.(psia)

PFUEL $\Delta P_{\text {FUEL }}$ $\mathrm{P}_{\mathrm{He}}$ $\mathrm{P}_{\text {INST }}$
$\mathrm{P}_{\text {MAN }}{ }_{\text {FUEL }}$ PMANOXID

Poxid
$\triangle$ POXID
$P_{\text {REG }}$
$P_{\text {SEL }}$

Q
$Q_{\text {CREW }}$
QinsT
Quleak $^{\text {Le }}$

QSEL
$\rho_{\mathrm{F}}$
${ }^{\rho} \mathrm{O}$

T

Fuel tank pressure. $(\mathrm{psia})$
Fuel pressure drop from the fuel source to fuel manifold. The fuel source will be either the RCS-A fuel tank, the RCS-B fuel tank, or the ascent engine fuel tank. (psi)

Helium reservoir pressure,(psia)
Instructor indicator readings as displayed on the RCS pressure indicators.(psia)

Fuel manifold pressure.(psia)
Oxidizer manifold pressure.(psia)
Oxidizer tank pressure. (psia)
Oxidizer pressure drop from the oxidizer source to the oxidizer manifold. The oxidizer source will be either the RCS-A oxidizer tank, the RCS-B oxidizer tank, or the ascent engine oxidizer tank, dependent on the status of the main propellant shut-off valves, the crossfed valves, and the ascent engine feed valves.(psi)

Pressure regulator outlet pressure.(psia)
Instructor indicator readings displayed on the RCS pressure indicators if the instructor selects to read pressures other than the pressures dictated by the crew selector switch position.(psia)

Instructor indicator readings displayed on the RCS propellant quantity indicators if the instructor selects to read true values. (\%)

Crew indicator readings as displayed on the RCS propellant (fuel or oxidizer) quantity indicators. (\%)

Instructor indicator readings as displayed on the RCS propellant (fuel or oxidizer) quantity indicators.(\%)

Variable instructor control of propellant leakage. The instructor may apply this leakage rate to the fuel and/or oxidizer tanks of RCS-A and/or RCS-B as per the instructor Boolean inputs $\mathrm{B}_{119}$ thru $\mathrm{B}_{122}$. (lbs-sec ${ }^{-1}$ )

Instructor indicator readings displayed on the RCS propellant quantity indicators if the instructor selects to read propellant quantities other than the propellant quantities dictated by the crew selector switch position.(\%)

Fuel density (lbs-in-3) NOTE: As indicated on Figure 21 of the proposal, fuel density is assumed to be a function of fuel temperature.

Oxidizer density ( $\mathrm{lbs}^{-1 \mathrm{in}^{-3} \text { ) NOTE: As indicated on Figure } 21}$ of the proposal, oxidizer density is assumed to be a function of oxidizer temperature.

Instructor indicator readings displayed on the RCS temperature indicators if the instructor selects to read true values. $\left({ }^{\circ} \mathrm{F}\right)$

| TCREW |
| :---: |
| T FUEL |
| $\mathrm{T}_{\mathrm{He}}$ |
| TINST |
| $\mathrm{TMANFUELA}^{\text {m }}$ |
| $\mathrm{TMAN}_{\text {OXID }}{ }_{\text {B }}$ |
| TOXID |
| $\mathrm{T}_{\text {SEL }}$ |
| $\mathrm{TMAN}_{\text {FUEL }}{ }_{\text {A }}$ |
| $\mathrm{T}_{\text {MAN }^{+}}{ }_{\text {OXID }}{ }_{\text {B }}$ |
| $\delta \mathrm{t}$ |
| VHefuel |
| $\mathrm{V}_{\text {He OXID }}$ |
| $\mathrm{W}_{\mathrm{He}}$ |
| $\mathrm{W}_{\text {He FUEL }}$ |
| $\mathrm{WHe}_{\text {OXID }}$ |
| $\dot{W}_{\text {CVF }}$ |
| $\dot{W}_{\text {CVO }}$ |
| $\dot{W}_{\text {He }}^{\text {LEAK }}$ |

Environmental control temperature. $\left({ }^{\circ} \mathrm{R}\right)$ NOTE: Further explanation of this variable is given in paragraph 3.3.3 of the proposal.

Crew indicator readings as displayed on the RCS temperature indicators. $\left({ }^{\circ} \mathrm{F}\right)$

Common temperature of fuel and ullage helium in the fuel tank. $\left({ }^{\circ} \mathrm{R}\right)$

Temperature of helium in the helium reservoir. $\left({ }^{\circ} \mathrm{R}\right)$
Instructor indicator readings as displayed on the RCS temperature indicators. $\left({ }^{\circ} \mathrm{F}\right)$

Temperature of the fuel in the RCS-A fuel manifold. $\left({ }^{\circ} \mathrm{R}\right)$
Temperature of the oxidizer in the RCS-B oxidizer manifold. $\left({ }^{\circ} \mathrm{R}\right)$

Common temperature of oxidizer and ullage helium in the oxidizer tank. $\left({ }^{\circ} \mathrm{R}\right)$

Instructor indicator readings displayed on the RCS temperature indicators if the instructor selects to read temperatures other than the temperatures dictated by the crew selector switch position. ( ${ }^{\circ} \mathrm{F}$ )

Steady-state temperature of the fuel in the RCS-A fuel manifold. $\left({ }^{\circ} \mathrm{R}\right)$

Steady-state temperature of the oxidizer in the RCS-B oxidizer manifold. ( ${ }^{\circ}$ R)

The effective full open total on time for 8 thrusters as measured over the last. 20 second interval divided by .20 seconds. The manner by which this dimensionless parameter accounts for $I_{s p}$ variation in the short pulse width regime is discussed in paragraph 3.3.4 of the proposal.

Ullage volume in the fuel tank. (in-3)
Ullage volume in the oxidizer tank. (in-3)
Weight of helium in the helium reservoir.(lbs)
Helium quantity occupying the fuel tank ullage volume.(lbs)
Helium quantity occupying the oxidizer tank ullage volume. (lbs)

Helium flow rate through the check valve and into the fuel tank.(lbs-sec-1)

Helium flow rate through the check valve and into the oxidizer tank.(lbs-sec ${ }^{-1}$ )

Variable instructor control of helium leakage. The instructor may apply this leakage rate to the helium reservoir and/or the fuel and oxidizer tank ullage of either system A or B as per the instructor Boolean inputs $\mathrm{B}_{101}$ thru $\mathrm{B}_{105}$. (lbs/sec)

Summation of the helium flow rates through the primary and redundant pressure regulator branches. (lbs-sec ${ }^{-1}$ )
$\dot{\mathrm{W}}_{\mathrm{RVF}}$
$\dot{\mathrm{W}}_{\mathrm{RVO}}$
Helium flow rate out of the fuel ullage relief valve.(lbs-sec ${ }^{-1}$ )
Helium flow rate out of the oxidizer ullage relief valve. (lbs-sec ${ }^{-1}$ )

## SUBSCRIPTS:

A
Pertains to RCS-A
B
Pertains to RCS-B
ASC
Pertains to Ascent Engine
$\mathrm{H}_{\mathrm{A}}$
Crew indicator input from RCS-A
$\mathrm{II}_{\mathrm{B}}$
Crew indicator input from RCS-B

NOTE:
(1) A dot placed above a quantity indicates the first time derivative of that quantity
(2) Two dots placed above a quantity indicate the second time derivative of that quantity

### 4.2 CONSTANTS

$K_{1}$

K2
$K_{3}$
$\mathrm{K}_{4}$

K5
$\mathrm{K}_{6}$
$\mathrm{K}_{7}$

K8

Defines the range of $\Delta \mathrm{P}_{\mathrm{C}}$ in the absence of full open pressure regulator failures, i.e., if there are no regulators failed open, $-\mathrm{K}_{1} \leq \Delta \mathrm{P}_{\mathrm{C}} \leq \mathrm{K}_{1}$. (psi)

Incremental change in $\Delta \mathrm{P}_{\mathrm{C}}$ due to full open failure of the highpressure pressure-regulator valve.(psi)

Incremental change in $\Delta \mathrm{P}_{\mathrm{C}}$ due to full open failure of the lowpressure pressure-regulator valve. (psi)

Constant to be evaluated to provide acceptable transient response of regulator outlet pressure to system loading. $\left(\mathrm{sec}^{-1}\right)$

Constant to be evaluated to provide acceptable transient response of regulator outlet pressure to system loading. ( $\mathrm{sec}^{-2}$ )

Constant to be determined as a function of steady-state regulator data and the selected value of $\mathrm{K}_{5}$. $\left(\mathrm{in}^{4} \mathrm{lbs}^{-1} \mathrm{sec}^{-2}\right)$ NOTE: The ratio $\mathrm{K}_{6} / \mathrm{K}_{5}$ is determined from the steady-state regulator data as $\mathrm{K}_{6} / \mathrm{K}_{5}=-\partial \mathrm{A}_{\mathrm{REG}}^{\prime} / \partial \mathrm{P}_{\text {REG }}\left(\right.$ in $\left.^{4}{ }^{4} \mathrm{lbs}-1\right)$

Constant to be determined as a function of zero-flow steadystate regulator data and the selected value of $\mathrm{K}_{6}$. ( $\mathrm{in}^{4} \mathrm{lbs}^{-1} \mathrm{sec}^{-2}$ ) NOTE: The ratio $\mathrm{K}_{7} / \mathrm{K}_{6}$ is determined from the steady-state regulator data as $\mathrm{K}_{7} / \mathrm{K}_{6}=-\partial \mathrm{P}_{\mathrm{REG}} / \partial \mathrm{P}_{\mathrm{He}}$.

Constant to be determined in accordance with the regulator preload, such that the zero-flow steady-state value of regulator outlet pressure ( $P_{R E G}$ ) equals the regulator outlet command pressure ( $\mathrm{P}_{\mathrm{C}}$ ) at a specified value of reservoir pressure ( $\mathrm{PHe}^{\text {) }}$ ). ( $\mathrm{in}^{2} \mathrm{sec}^{-2}$ ) NOTE: The ratio $\mathrm{K}_{8} / \mathrm{K}_{7}$ is defined as $\mathrm{K}_{8} / \mathrm{K}_{7}=$ $\mathrm{P}_{\mathrm{HeS}}$ psi, where $\mathrm{P}_{\mathrm{HeS}}$ is the specified value of $\mathrm{P}_{\mathrm{He}}$ referred to above.

Effective flow area ( $\mathrm{A}_{\mathrm{REG}}$ ) if the high pressure helium squib valve is open and both series pressure regulators are failed open in a branch with an open high pressure solenoid valve. (in ${ }^{2}$ )

Ratio of the gas constant for helium to the volume of the helium reservoir tank. $\left({ }^{\circ} \mathrm{R}^{-1}-\mathrm{in}^{-2}\right)$

Compressibility factor for helium minus one, $\left(\mathrm{Z}_{\mathrm{He}}-1\right)$. Ratio of specific heats for helium minus one, $\left(\gamma_{\mathrm{He}}-1\right)$.

Ratio of $\mathbf{K}_{13}$ to the specific heat of helium at constant volume, where $\mathrm{K}_{13}^{\prime}$ represents the ratio of heat input rate of the reservoir tank $\left(\mathrm{Q}_{\mathrm{He}}\right)$ to the difference in environmental temperature and helium temperature, $K_{13}=Q_{H e} /\left[\mathrm{CV}_{\mathrm{V}}\left(\mathrm{T}_{\mathrm{C}}-\mathrm{T}_{\mathrm{He}}\right)\right] .(\mathrm{lbs} / \mathrm{sec})$

This constant is provided in the event it is necessary to adjust the temperature rate and may be considered to have a value of zero at this time.

Constant to be evaluated to provide acceptable transient response of regulator outlet pressure to system loading. ( $\mathrm{sec}-\mathrm{in}^{2}$ )

Check valve flow area when the check valve is open. (in ${ }^{2}$ )
Gas constant for helium, $\mathrm{R}_{\mathrm{He}}$ ( $\mathrm{in}-{ }^{\circ} \mathrm{R}^{-1}$ )
Ratio of relief valve flow rate to propellant tank pressure when the relief valve is open. $\left(\mathrm{in}^{2}-\mathrm{sec}^{-1}\right)$

Ratio of $\mathrm{K}^{\prime} 19$ to the specific heat of helium at constant volume, where $\mathrm{K}^{\prime} 19$ represents the ratio of heat input rate of the fuel tank (QF) to the difference in environmental temperature and fuel temperature, $\mathrm{K}_{19}=$ QF/[ $\mathrm{CV}_{\mathrm{He}}(\mathrm{TC}$ - TFUEL) $]$.
Ratio of specific heats for helium, $\left(\gamma \gamma_{\mathrm{He}}\right)$.
Multiplicative inverse of the specific heat of helium at constant volume, $\mathrm{CV}^{-1}$. $\left({ }^{\circ} \mathrm{R}-\mathrm{in}^{-1}\right)$

Ratio of specific heats for helium minus one, $\left(\gamma_{\mathrm{He}}-1\right)$.
Ratio of the fuel specific heat to the specific heat of helium at constant volume, $\left(\mathrm{C}_{\mathrm{F}} / \mathrm{C}_{\mathrm{V}_{\mathrm{He}}}\right)$.

Ratio of $K_{24}^{\prime}$ to the specific heat of helium at constant volume, where K'24 represents the ratio of heat input rate of the oxidizer tank ( $\mathrm{QO}_{\mathrm{O}}$ ) to the difference in environmental temperature and oxidizer temperature, $\mathrm{K}_{24}=$ $\mathrm{Q}_{\mathrm{O}} /\left[\mathrm{CV}_{\mathrm{He}}\left(\mathrm{T}_{\mathrm{C}}-\mathrm{T}_{\mathrm{OXID}}\right)\right]$.

Ratio of the oxidizer specific heat to the specific heat of helium at constant volume ( $\mathrm{CVO} / \mathrm{CV}_{\mathrm{He}}$ ).
Total volume of the fuel tank. (in ${ }^{3}$ )
Total volume of the oxidizer tank. (in ${ }^{3}$ )

The product of average fuel consumption rate and the ratio of mission time to real time.(lbs $-\mathrm{sec}^{-1}$ )

The product of average oxidizer consumption rate and the ratio of mission time to real time. ( $\mathrm{lbs}-\mathrm{sec}^{-1}$ )

This constant is included in the event it is necessary that the range of oxidizer leakage rates be greater than the range of fuel leakage rates. If this is not required, $\mathrm{K}_{30}=1$ and may be deleted.

The ratio $\triangle \mathrm{P}_{\text {FUEL }} / \dot{\mathrm{F}}^{\dagger}$ if the fuel flow path is from the ascent engine fuel tank to either the RCS-A or RCS-B fuel manifolds, and the cross-feed valves are closed. $\left(\mathrm{sec}-\mathrm{in}^{-2}\right)$

The ratio $\triangle \mathrm{P}_{\text {FUEL }} / \mathrm{F}^{*}$ if the fuel flow path is from RCS-A or RCS-B fuel tanks to the RCS-A or RCS-B fuel manifolds, respectively. (sec-in ${ }^{-2}$ )

The ratio $\Delta \mathrm{P}_{\text {FUEL }} / \dot{F}^{\prime}$ if the cross-feed valves are open and the fuel flow path is from the ascent engine to the common (RCS-A/RCS-B) fuel manifold. $\left(\mathrm{sec}-\mathrm{in}^{-2}\right.$ )

The ratio $\Delta P_{\text {FUEL }} / \dot{F}^{\prime}$ if the cross-feed valves are open and the fuel flow path is from either the RCS-A or RCS-B fuel tank to the common (RCS-A/RCS-B) fuel manifold.( $\mathrm{sec}-\mathrm{in}{ }^{-2}$ )
The ratio $\left[\Delta \mathrm{P}_{\mathrm{OXID}} / \dot{\mathrm{O}}^{\prime}\right] /\left[\Delta \mathrm{P}_{\text {FUEL }} / \dot{\mathrm{F}}^{\prime}\right]$.
The ratio between the rate of change of fuel temperature in the RCS-A fuel manifold to the difference between the steady-state and actual fuel manifold temperature. $\left(\mathrm{sec}^{-1}\right)$

The ratio between the rate of change of oxidizer temperature in the RCS-B oxidizer manifold to the difference between the steady-state and actual oxidizer manifold temperature.( $\mathrm{sec}^{-1}$ )

Maximum fuel leakage rate. (lbs-sec ${ }^{-1}$ )
Greatest plus or minus variation in control temperature about the nominal level of $530{ }^{\circ} \mathrm{R}$, i. e., $530-\mathrm{K}_{39} \leq \mathrm{T}_{\mathrm{C}} \leq 530+\mathrm{K}_{39}$. ( $\mathrm{R}^{\circ}$ )

That value of $P_{\text {REG }}$ below which the regulator caution warning light will be on.(psia)

That value of $P_{\text {REG }}$ above which the regulator caution warning light will be on if either of the high pressure helium solenoid valves are open.(psia)

That ratio of oxidizer to fuel quantity above which the RCS caution warning light will be on.

That ratio of oxidizer to fuel quantity below which the RCS caution warning light will be on.

Maximum plus or minus variation in sensor error for the helium reservoir pressure sensors.(psi)

Maximum plus or minus variation in sensor error for the helium reservoir temperature sensors, the fuel temperature sensors, or the oxidizer temperature sensors. $\left({ }^{\circ} \mathrm{R}\right)$

| $\mathrm{K}_{46}$ | Maximum pius or minus variation in sensor error for the fuel or oxidizer pressure sensors.(psi) |
| :---: | :---: |
| $\mathrm{K}_{47}$ | Maximum plus or minus variation in sensor error for the fuel quantity sensors.(lbs) |
| $\mathrm{K}_{48}$ | Maximum plus or minus variation in sensor error for the oxidizer quantity sensors.(lbs) |
| K49 | Conversion from ${ }^{\circ} \mathrm{R}$ to ${ }^{\circ} \mathrm{F}, \mathrm{K}_{49}=459.7 .\left(\mathrm{R}^{\circ}\right)$ |
| $\mathrm{K}_{50}$ | The ratio of 100 to the nominal fuel load of a single RCS fuel tank. (\%/lbs) |
| $\mathrm{K}_{51}$ | The ratio of 100 to the nominal oxidizer load of a single RCS oxidizer tank. (\%/lbs) |
| $\mathrm{K}_{52}$ | Minimum value of temperature shown on the RCS temperature indicators. $\left({ }^{\circ} \mathrm{F}\right)$ |
| $\mathrm{K}_{55}$ | Maximum value of helium leakage rate ( $\dot{W}_{\mathrm{He}}^{\text {LEAK }}$ ). (lbs-sec ${ }^{-1}$ ) |

### 4.3 BOOLEAN QUANTITIES

NOTES: (1) All definitions pertain to $B=1$. The words which should be substituted to denote conditions pertaining to $\mathrm{B}=0$ are shown in parentheses.
(2) To aid in identifying the Boolean quantities on Figure 21, they have been categorized as indicated below:

| Type |
| :--- |
| Computer Inputs from Crew |
| Computer Inputs from Instructor |
| Computer Outputs to Crew |
| Computer Outputs to Instructor |
| Booleans Used Internal to the Computer |

Number Range
B1 to B99 B100 to B199
B500 to B599
B600 to B699
B800 to B999

### 4.3.1 Crew Inputs

$B_{1}$

B2

B3

B4
$B_{5}$

B6

B7

High pressure helium squib valves are (are not) being commanded open.

Propellant crossfeed squib valves are (are not) being commanded open.

High pressure helium solenoid valve in the primary branch of RCS-A is (is not) commanded open.

High pressure helium solenoid valve in the primary branch of RCS-A is (is not) commanded closed.

High pressure helium solenoid valve in the redundant branch of RCS-A is (is not) commanded open.

High pressure helium solenoid valve in the redundant branch of RCS-A is (is not) commanded closed.

High pressure helium solenoid valve in the primary branch of RCS-B is (is not) commanded open.

| B8 | High pressure helium solenoid valve in the primary branch of RCS-B is (is not) commanded closed. |
| :---: | :---: |
| B9 | High pressure helium solenoid valve in the redundant branch of RCS-B is (is not) commanded open. |
| $\mathrm{B}_{10}$ | High pressure helium solenoid valve in the redundant branch of RCS-B is (is not) commanded closed. |
| $\mathrm{B}_{11}$ | Solenoid valves connecting the ascent engine propellant tanks with the RCS-A propellant manifolds are (are not) commanded open. |
| $\mathrm{B}_{12}$ | Solenoid valves connecting the ascent engine propellant tanks with the RCS-A propellant manifolds are (are not) commanded closed. |
| $\mathrm{B}_{13}$ | Solenoid valves connecting the ascent engine propellant tanks with the RCS-B propellant manifolds are (are not) commanded open. |
| B14 | Solenoid valves connecting the ascent engine propellant tanks with the RCS-B propellant manifolds are (are not) commanded closed. |
| $\mathrm{B}_{15}$ | RCS-A main propellant solenoid shut-off valves are (are not) commanded open. |
| $\mathrm{B}_{16}$ | RCS-A main propellant solenoid shut-off valves are (are not) commanded closed. |
| B17 | RCS-B main propellant solenoid shut-off valves are (are not) commanded open. |
| B18 | RCS-B main propellant solenoid shut-off valves are (are not) commanded closed. |
| B19 | TCA isolation solenoid valves for thrusters \#1 and \#3 are (are not) commanded open. |
| $\mathrm{B}_{20}$ | TCA isolation solenoid valves for thrusters \#1 and \#3 are (are not) commanded closed. |
| $\mathrm{B}_{21}$ | TCA isolation solenoid valves for thrusters \#2 and \#4 are (are not) commanded open. |
| $\mathrm{B}_{22}$ | TCA isolation solenoid valves for thrusters \#2 and \#4 are (are not) commanded closed. |
| B23 | TCA isolation solenoid valves for thrusters \#5 and \#8 are (are not) commanded open. |
| $\mathrm{B}_{24}$ | TCA isolation solenoid valves for thrusters \#5 and \#8 are (are not) commanded closed. |
| $\mathrm{B}_{25}$ | TCA isolation solenoid valves for thrusters \#6 and \#7 are (are not) commanded open. |
| B26 | TCA isolation solenoid valves for thrusters \#6 and \#7 are (are not) commanded closed. |

The helium leakage rates defined by $\mathrm{B}_{106}$ thru $\mathrm{B}_{108}$ pertain (do not pertain) to RCS-A.

The helium leakage rates defined by B106 thru B108 pertain (do not pertain) to RCS-B.

The helium leakage rates defined by $\mathrm{B}_{106}$ thru B108 pertain (do not pertain) to the helium reservoir.

The helium leakage rates defined by $\mathrm{B}_{106}$ thru $\mathrm{B}_{108}$ pertain (do not pertain) to the fuel ullage.

The helium leakage rates defined by B106 thru B108 pertain (do not pertain) to the oxidizer ullage.

An incremental helium leakage rate of $1 / 7$ th of the maximum leakage rate is (is not) present.

An incremental helium leakage rate of $2 / 7$ ths of the maximum leakage rate is (is not) present.

An incremental helium leakage rate of $4 / 7$ ths of the maximum leakage rate is (is not) present.

Pressure regulator failures denoted by B111 thru $\mathrm{B}_{118}$ pertain to RCS-B (RCS-A).

Pressure regulator failures denoted by $\mathrm{B}_{111}$ thru $\mathrm{B}_{117}$ pertain to the redundant (primary) regulator branch.

One or both regulators are (neither regulator is) failed closed.

The high-pressure pressure regulator is (is not) failed open.

The low-pressure pressure regulator is (is not) failed open.

An incremental change in regulator command pressure of $1 / 7$ th of the maximum change is (is not) present.

An incremental change in regulator command pressure of $2 / 7$ ths of the maximum change is (is not) present.

An incremental change in regulator command pressure of $4 / 7$ ths of the maximum change is (is not) present.

The incremental changes due to $\mathrm{B}_{114}$ thru $\mathrm{B}_{116}$ result in an increase (decrease) in regulator command pressure.

Any two parallel pressure regulators, i.e., one in the primary and one in the redundant branch, are (are not) failed closed.

The propellant leakage rates defined by $\mathrm{B}_{123}$ thru $\mathrm{B}_{125}$ pertain (do not pertain) to RCS-A.

The propellant leakage rates defined by B123 thru B125 pertain (do not pertain) to RCS-B.

The propellant leakage rates defined by $\mathrm{B}_{123}$ thru $\mathrm{B}_{125}$ pertain (do not pertain) to fuel leakage.

The propellant leakage rates defined by $\mathrm{B}_{123}$ thru $\mathrm{B}_{125}$ pertain (do not pertain) to oxidizer leakage.

An incremental propellant leakage rate of $1 / 7$ th of the maximum leakage rate is (is not) present.

An incremental propellant leakage rate of $2 / 7$ ths of the maximum leakage rate is (is not) present.

An incremental propellant leakage rate of $4 / 7$ ths of the maximum leakage rate is (is not) present.

The high-pressure helium solenoid valve failures defined by $\mathrm{B}_{127}$ thru $\mathrm{B}_{130}$ pertain to RCS-B (RCS-A).

The high-pressure helium solenoid valve in the primary branch is (is not) failed open.

The high-pressure helium solenoid valve in the primary branch is (is not) failed closed.

The high-pressure helium solenoid valve in the redundant branch is (is not) failed open.

The high-pressure helium solenoid valve in the redundant branch is (is not) failed closed.

The main propellant shut-off valves for RCS-A are (are not) failed closed.

The main propellant shut-off valves for RCS-B are (are not) failed closed.

The TCA propellant isolation valve failures defined by B136 thru B139 pertain to RCS-B (RCS-A).

The TCA isolation valves in quad \#1 are (are not) failed closed.

The TCA isolation valves in quad \#2 are (are not) failed closed.

The TCA isolation valves in quad \#3 are (are not) failed closed.

The TCA isolation valves in quad \#4 are (are not) failed closed.

An incremental change in environmental control temperature of $1 / 7$ th of the maximum change is (is not) present.

An incremental change in environmental control temperature of $2 / 7$ ths of the maximum change is (is not) present.

An incremental change in environmental control temperature of $4 / 7$ ths of the maximum change is (is not) present.

The incremental changes due to $\mathrm{B}_{140}$ thru $\mathrm{B}_{142}$ result in an increase (decrease) in environmental control temperature.

Sensor failures defined by $\mathrm{B}_{155}$ thru $\mathrm{B}_{159}$ pertain to RCS-B (RCS-A).

Sensor failures defined by B155 thru B159 pertain (do not pertain) to helium reservoir pressure.

Sensor failures defined by B155 thru B159 pertain (do not pertain) to helium reservoir temperature.

Sensor failures defined by B155 thru B159 pertain (do not pertain) to fuel pressure.

Sensor failures defined by $\mathrm{B}_{155}$ thru $\mathrm{B}_{159}$ pertain (do not pertain) to fuel temperature.

Sensor failures defined by B155 thru B159 pertain (do not pertain) to fuel quantity.

Sensor failures defined by B155 thru B159 pertain (do not pertain) to oxidizer pressure.

Sensor failures defined by B155 thru B159 pertain (do not pertain) to oxidizer temperature.

Sensor failures defined by $\mathrm{B}_{155}$ thru $\mathrm{B}_{159}$ pertain (do not pertain) to oxidizer quantity.

Sensor failures defined by B155 thru B159 pertain (do not pertain) to propellant manifold pressure.

Sensor failures defined by $\mathrm{B}_{155}$ thru $\mathrm{B}_{159}$ pertain (do not pertain) to propellant manifold temperature.

The applicable sensor as defined by B144 thru B154 provides (does not provide) a zero output.

An incremental error in sensor output of $1 / 7$ th of the maximum error is (is not) present.

An incremental error in sensor output of $2 / 7$ ths of the maximum error is (is not) present.

An incremental error in sensor output of $4 / 7$ ths of the maximum error is (is not) present.

The error in sensor output defined by B156 thru B158 results in sensor outputs greater (less) than the true value.

Indicator failures defined by B161 thru B172 pertain to RCS-B (RCS-A).

Pressure indicator displays (does not display) its minimum value.

Temperature indicator displays (does not display) its maximum value.

Quantity indicator remains frozen at its present value(is not failed).
The applicable talk-back indicator defined by $\mathrm{B}_{165}$ thru $\mathrm{B}_{172}$ is failed on (off).

Talk-back indicator for the high pressure helium solenoid valve in the primary branch is failed in accordance with $\mathrm{B}_{160}$ and $\mathrm{B}_{164}$ (is not failed).

Talk-back indicator for the high pressure helium solenoid valve in the redundant branch is failed in accordance with $\mathrm{B}_{160}$ and $\mathrm{B}_{164}$ (is not failed).

Talk-back indicator for the ascent engine propellant feed valves is failed in accordance with $\mathrm{B}_{160}$ and $\mathrm{B}_{164}$ (is not failed).

Talk-back indicator for the main propellant shut-off valve is failed in accordance with $\mathrm{B}_{160}$ and $\mathrm{B}_{164}$ (is not failed).

Talk-back indicator for the TCA propellant isolation valves for Quadrant No. 1 is failed in accordance with $\mathrm{B}_{160}$ and $\mathrm{B}_{164}$ (is not failed).

Talk-back indicator for the TCA propellant isolation valves for Quadrant No. 2 is failed in accordance with $\mathrm{B}_{160}$ and $\mathrm{B}_{164}$ (is not failed).

| $\mathrm{B}_{171}$ |
| :--- |
| $\mathrm{~B}_{172}$ |
| $\mathrm{~B}_{192}$ |
| $\mathrm{~B}_{193}$ |
| $\mathrm{~B}_{194}$ |
| $\mathrm{~B}_{195}$ |
| $\mathrm{~B}_{196}$ |
| $\mathrm{~B}_{197}$ |
| $\mathrm{~B}_{198}$ |
| $\mathrm{~B}_{506}$ |
| $\mathrm{~B}_{505}$ |
| $\mathrm{~B}_{509}$ |
| $\mathrm{~B}_{504}$ |
| $\mathrm{~B}_{502} 3.3$ |
| Crew Outputs |

Talk-back indicator for the TCA propellant isolation valves for Quadrant No. 3 is failed in accordance with $\mathrm{B}_{160}$ and $\mathrm{B}_{164}$ (is not failed).

Talk-back indicator for the TCA propellant isolation valves for Quadrant No. 4 is failed in accordance with $\mathrm{B}_{160}$ and $\mathrm{B}_{164}$ (is not failed).

Signal to extinguish the improper-valve-sequencing-light is (is not) present.
Signal which enables the instructor to monitor fuel quantities, when the crew is monitoring oxidizer quantities, is (is not) present.

Instructor activates (does not activate) momentary switch to display propellant manifold pressures and temperatures.

Instructor activates (does not activate) momentary switch to display oxidizer tank pressures and temperatures.

Instructor activates (does not activate) momentary switch to display fuel tank pressures and temperatures.

Instructor activates (does not activate) momentary switch to display helium reservoir pressures and temperatures.

Instructor activates (does not activate) momentary switch to display true values (no sensor or indicator failure effects) of all system display parameters.

Accelerated run signal is (is not) present.

Talk-back indicator indicates that the high pressure helium solenoid valve in the primary branch of RCS-A is open (closed).

Talk-back indicator indicates that the high pressure helium solenoid valve in the redundant branch of RCS-A is open (closed).

Talk-back indicator indicates that the high pressure helium solenoid valve in the primary branch of RCS-B is open (closed).

Talk-back indicator indicates that the high pressure helium solenoid valve in the redundant branch of RCS-B is open (closed).

Talk-back indicator indicates that both solenoid valves connecting the ascent engine propellant tanks with the RCS-A propellant manifolds are open (closed).

Talk-back indicator indicates that both solenoid valves connecting the ascent engine propellant tanks with the RCS-B propellant manifolds are open (closed).

### 4.3.4 Instructor Outputs

Talk-back indicator indicates that the high pressure helium solenoid valve in the primary branch of RCS-A is open (closed).

Talk-back indicator indicates that the high pressure helium solenoid valve in the redundant branch of RCS-A is open (closed).

Talk-back indicator indicates that the high pressure helium solenoid valve in the primary branch of RCS-B is open (closed).

Talk-back indicator indicates that the high pressure helium solenoid valve in the redundant branch of RCS-B is open (closed).

Talk-back indicator indicates that both solenoid valves connecting the ascent engine propellant tanks with the RCS-A propellant manifolds are open (closed).

Talk-back indicator indicates that both solenoid valves connecting the ascent engine propellant tanks with the RCS-B propellant manifolds are open (closed).

Talk-back indicator indicates that both RCS-A main propellant shut-off valves are open (closed).

Talk-back indicator indicates that both RCS-B main propellant shut-off valves are open (closed).

Talk-back indicator indicates that both TCA isolation valves for thrusters \#1 and \#3 are open (closed).

Talk-back indicator indicates that both TCA isolation valves for thrusters \#2 and \#4 are open (closed).

Talk-back indicator indicates that both TCA isolation valves for thrusters \#5 and \#8 are open (closed).

Talk-back indicator indicates that both TCA isolation valves for thrusters \#6 and \#7 are open (closed).

Talk-back indicator indicates that both TCA isolation valves for thrusters \#9 and \#12 are open (closed).

Talk-back indicator indicates that both TCA isolation valves for thrusters \#10 and \#11 are open (closed).

Talk-back indicator indicates that both TCA isolation valves for thrusters \#13 and \#15 are open (closed).

Talk-back indicator indicates that both TCA isolation valves for thrusters \#14 and \#16 are open (closed).

Regulator caution warning light for RCS-A is on (off).
Regulator caution warning light for RCS-B is on (off).
RCS-A FAIL caution warning light is on (off).
RCS-B FAIL caution warning light is on (off).
Improper-valve-sequencing light is on (off).
Light indicating that the crew monitor select switch is in the OFF position is on (off).

Light indicating that the crew monitor select switch is in the H position is on (off).

Light indicating that the crew monitor select switch is in the FUEL position is on (off).

Light indicating that the crew monitor select switch is in the OXID position is on (off).

Light indicating that the crew monitor select switch is in the MANIF position is on (off).

# $B_{627}$ <br> $\mathrm{B}_{628}$ 

Light indicating that the crew fuel-oxid monitor select switch is in the fuel position is on (off).

Light indicating that the crew fuel-oxid monitor select switch is in the oxidizer position is on (off).

The following quantities are defined in Figure 21 :

| Boolean Quantity | Block Number |
| :---: | :---: |
| $\mathrm{B}_{801}$ thru $\mathrm{B}_{804}$ | II-5 |
| $\mathrm{B}_{805}$ thru $\mathrm{B}_{808}$ | II-4 |
| $\mathrm{B}_{809}$ | II-12 |
| $\mathrm{B}_{810}, \mathrm{~B}_{811}$ | II-4 |
| $\mathrm{B}_{812}, \mathrm{~B}_{813}$ | II-2 |
| $\mathrm{B}_{814}$ thru $\mathrm{B}_{817}$ | II-10 |
| $\mathrm{B}_{818}$ thru $\mathrm{B}_{821}$ | II-8 |
| $\mathrm{B}_{822}$ | II-12 |
| $\mathrm{B}_{823}$ thru $\mathrm{B}_{834}$ | II-10 |
| $\mathrm{B}_{835}$ thru $\mathrm{B}_{838}$ | II-13 |
| $\mathrm{B}_{840}$ thru $\mathrm{B}_{845}$ | II-13 |
| $\mathrm{B}_{846}$ thru $\mathrm{B}_{853}$ | II-12 |
| $\mathrm{B}_{854}$ thru $\mathrm{B}_{861}$ | III-4 |
| $\mathrm{B}_{862}$ thru $\mathrm{B}_{873}$ | III-3 |
| $\mathrm{B}_{874}$ thru $\mathrm{B}_{893}$ | III-1 |
| $\mathrm{B}_{896}{ }^{\text {thru } \mathrm{B}_{901}}$ | III-2 |
| $\mathrm{B}_{902}$ | III-7 |
| $\mathrm{B}_{903}$ | II-16 |
| B904, B905 | I-3 |
| B906 thru B925 | III-1 |




Boolean quantities used in LEM RCS thrust and moment transform to AMS, equal to zero or one as determined by orientation logic.

Boolean quantities used in LEM weight and balance transform to AMS, equal to zero or one as determined by orientation logic.

LEM B-frame X, Y, Z components, respectively, of the distance vector measured from the LEM Bframe origin to the LEM FB-frame origin. LEM B-frame origin coincident with LEM center of gravity. (ft)

CSM FB-frame X, Y, Z components, respectively, of the distance vector measured from the CSM FBframe origin to the LEM center of gravity. (ft)

Magnitudes of the respective projections of a unit vector along the LEM $B$-frame $\mathbf{X}$ axis on the $\mathrm{X}, \mathrm{Y}$, Z axes of the $\mathrm{I}_{\mathrm{E}}$ or $\mathrm{I}_{\mathrm{M}}$-frame.

Magnitudes of the respective projections of a unit vector along the LEM B-frame Y axis on the $\mathrm{X}, \mathrm{Y}$, Z axes of the $\mathrm{I}_{\mathrm{E}}$ or $\mathrm{I}_{\mathrm{M}^{-f}}$ frame.

Magnitudes of the respective projections of a unit vector along the LEM B-frame Z axis on the $\mathrm{X}, \mathrm{Y}$, Z axes of the $\mathrm{I}_{\mathrm{E}}$ or $\mathrm{I}_{\mathrm{M}}$-frame.

Magnitudes of the respective projections of a unit vector along the LEM E-frame $\mathbf{X}$ axis on the $\mathrm{X}, \mathrm{Y}$, Z axes of the $\mathrm{I}_{\mathrm{E}}$ or $\mathrm{I}_{\mathrm{M}}{ }^{\text {-frame. }}$

Magnitudes of the respective projections of a unit vector along the LEM E-frame Y axis on the $\mathrm{X}, \mathrm{Y}$, Z axes of the $\mathrm{I}_{\mathrm{E}}$ or $\mathrm{I}_{\mathrm{M}^{-f r a m e}}$.

Magnitudes of the respective projections of a unit vector along the LEM E-frame $Z$ axis on the $X, Y$, Z axes of the $\mathrm{I}_{\mathrm{E}}$ or $\mathrm{I}_{\mathrm{M}^{-f}}$ frame.

Magnitudes of the respective projections of a unit vector along the I-frame X axis on the $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes of the $\mathrm{J}^{\prime}$-frame.

Magnitudes of the respective projections of a unit vector along the I-frame Y axis on the $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes of the $J$ '-frame.

Magnitudes of the respective projections of a unit vector along the I-frame Z axis on the $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes of the $J^{\prime}$-frame.

CSM quaternion parameters (See WADC Technical Report 58-17, "On the use of Quaternions in the Simulation of Rigid-Body Motion" by A. C. Robinson).


Corresponding LEM quaternion parameters with LEM attached to CSM.

Allowable deviation from -1 for $\mathrm{K}_{33}$ and $\mathrm{K}_{23}$ and from 1 for $K_{31}$ and $K_{21}$ to allow for computer roundoff, etc.

Magnitudes of the projections of the LEM's total applied force vector in the $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes of the LEM E-frame.

LEM moments of inertia about the $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes of the LEM FB-frame. (slug-ft ${ }^{2}$ )

LEM products of inertia due to a nonsymmetric mass distribution about the $\mathrm{XZ}, \mathrm{XZ}, \mathrm{XY}$ planes of the LEM FB-frame. (slug-ft ${ }^{2}$ )

LEM moments of inertia about the $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes of the CSM FB-frame. (slug-ft ${ }^{2}$ )

LEM products of inertia due to a nonsymmetric mass distribution about the $\mathrm{XZ}, \mathrm{XZ}, \mathrm{XY}$ planes of the CSM FB-frame. (slug-ft ${ }^{2}$ )

Magnitude of the projection of a unit vector along the Z axis of the LEM B or FB frames on the Z axis of the CSM B or FB-frame.

Magnitude of the projection of a unit vector along the Z axis of the LEM B or FB frames on the Y axis of the CSM B or FB-frame.

Magnitude of the projection of a unit vector along the X axis of the LEM B or FB frames on the Z axis of the CSM B or FB-frame.

Magnitude of the projection of a unit vector along the X axis of the LEM B or FB frames on the Y axis of the CSM B or FB-frame.

The angle of latitude with respect to the $\mathrm{I}_{\mathrm{E}}$-frame or the $J^{\prime}$-frame. (rad)

The LEM angle of latitude with respect to the $\mathrm{I}_{\mathrm{E}^{-}}$ frame or the J'-frame updated by IMCC data. (rad)

Absolute value of distance from origin of LEM FBframe to origin of CSM FB-frame in Orientations 1 and 2. Measured along X axis of LEM FBframe. Attachment thru upper docking tunnel. (ft)

Absolute value of distance from origin of LEM FBframe to origin of CSM FB-frame in Orientations 3 and 4. Measured along $Z$ axis of LEM FB-frame. Attachment thru forward docking tunnel. (ft)

The angle of longitude with respect to the $I_{E}$-frame or the $\mathrm{J}^{\prime}$-frame. (rad)


The angle of longitude with respect to the surface of the earth or moon. (rad)

The LEM angle of longitude with respect to the $\mathrm{I}_{E^{-f r a m e ~}}$ or the $J^{\prime}$-frame updated by IMCC data. (rad)

The LEM angle of longitude with respect to the surface of the earth or moon updated by IMCC data. (rad)

Magnitudes of the projections of the LEM RCS total moment vector about the LEM FB-frame origin on the $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes of the LEM FB-frame. (lb-ft)

Magnitudes of the projections of the LEM RCS total moment vector about the CSM FB-frame origin on the X, Y, Z axes of the CSM FB-frame. (lb-ft)

LEM mass. (slugs)
Magnitudes of the projections of the absolute rotational velocity vector of the CSM B-frame on the $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes of the CSM B-frame. ( $\mathrm{rad} / \mathrm{sec}$ )

Magnitudes of the projections of the absolute rotational velocity vector of the CSM B-frame on the $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes of the LEM B-frame. (rad/sec)

Magnitudes of the projections of the absolute rotational acceleration vector of the LEM B-frame on the $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes of the LEM B-frame. (rad/sec)

Heading angle of the LEM or CSM velocity vector. The angle between the X axes of the E and H frames. (rad)

Magnitude of the projection of the LEM or CSM velocity vector on the local radius vector. ( $\mathrm{ft} / \mathrm{sec}$ )

Distance from the center of mass of the earth or moon to the center of gravity of the LEM updated by IMCC data. (ft)

Magnitudes of the projections of the LEM RCS total thrust vector on the $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes of the LEM FB-frame. (lb)

Magnitudes of the projections of the LEM RCS total thrust vector on the $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes of the CSM FB-frame. (lb)

Magnitude of the projection of the LEM or CSM velocity vector on the XY plane of the E-frame. (ft/sec)

Magnitudes of the projections of the LEM or CSM velocity vector on the $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes of the E-frame. (ft/sec)
$\ddot{X}_{e}, \ddot{Y}_{e}, \dot{z}_{e}$
$X_{I}, Y_{I}, Z_{I}$
$\dot{\mathrm{X}}_{\mathrm{I}}, \dot{\mathrm{Y}}_{\mathrm{I}}, \dot{\mathrm{Z}}_{\mathrm{I}}$
$\ddot{x}_{I}, \ddot{\mathrm{Y}}_{\mathrm{I}}, \ddot{z}_{\mathrm{I}}$
${\left.\left(\mathrm{X}_{\mathrm{I}}\right)_{\text {CORR }},\left(\mathrm{Y}_{\mathrm{I}}\right)_{\text {CORR }},\left(\mathrm{Z}_{\mathrm{I}}\right)_{\mathrm{CORR}}\right)}$
$\left(\mathrm{X}_{\mathrm{J}}{ }^{\prime}\right)_{\text {CORR }},\left(\mathrm{Y}_{\mathrm{J}}{ }^{\prime}\right)_{\text {CORR }},\left(\mathrm{Z}_{\mathrm{J}}{ }^{\prime}\right)_{\text {CORR }}$
$\psi_{\mathrm{B} \rightarrow \mathrm{I}^{\prime}}{ }^{\theta} \mathrm{B} \rightarrow \mathrm{I}^{\prime}{ }^{\phi} \mathrm{B} \rightarrow \mathrm{I}$

Magnitudes of the projections of the LEM's total acceleration vector on the $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes of the LEM E-frame. (ft/sec ${ }^{2}$ )

Magnitudes of the projections of LEM or CSM position vector on the $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes of the $\mathrm{I}_{\mathrm{E}}$ or $\mathrm{I}_{\mathrm{M}}$-frame. (ft)

Magnitudes of the projections of the LEM or CSM velocity vector on the $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes of the $\mathrm{I}_{\mathrm{E}}$ or $\mathrm{I}_{\mathrm{M}}$-frame. (ft/sec)

Magnitudes of the projections of the LEM's total acceleration vector on the $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes of the $\mathrm{I}_{\mathrm{E}}$ or $\mathrm{I}_{\mathrm{M}}$-frame. ( $\mathrm{ft} / \mathrm{sec}^{2}$ )

Magnitudes of the projections of the LEM's position vector, updated by IMCC, on the $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes of the $\mathrm{I}_{\mathrm{E}}$ or $\mathrm{I}_{\mathrm{M}}$-frame. (ft)
Magnitudes of the projections of the LEM's position vector, updated by IMCC data, on the $\mathrm{X}, \mathrm{Y}, \mathrm{Z}$ axes of the $J^{\dagger}$-frame. (ft)

Standard Euler angles, due to yaw, pitch, and roll rotations, between LEM or CSM B-frames and the $\mathrm{I}_{\mathrm{E}}$ or $\mathrm{I}_{\mathrm{M}^{\text {-frame. }}} \quad$ (rad)

(b) AMS TO LMS TRAJECTORY DATA FLOW



aLL otrer ans renectook data used drectry as such in mas
(c) LMS TO IMCC TRAJECTORY DATA FLOW


Lem attrive accelberatons
Lem postion
$\frac{\text { LEM Postrion }}{x_{1}, x_{1} z_{1}}$


