PROPOSAL FOR LEM MISSION SIMULATOR Solar 9 Hickory volume II technical EROPRIETARY. addendum: glossary of symbols TRACTING TO STRAT TRAINING EQUIPALENT

LINK GROUP-SYSTEMS DIVISION O GENERAL PRECISION, INC.

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addendum: glossary of symbols

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FOREWORD

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 (EQUATION REFERENCE FRAMES)

The LMS axis systems, all right-handed orthogonal triads, are defined as follows:

I-frame

I_F-frame

 I_{M} -frame

E-frame

B-frame

FB-frame

H-frame

J'-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 Z_{I_E} axis is directed toward the north pole. The orientation of the X_{I_E} , Y_{I_E} , and Z_{I_E} axes is fixed with respect to the "fixed" stars.

The origin of the I_M -frame is at the center of mass of the moon. The X_{I_M} , Y_{I_M} , and Z_{I_M} axes are defined to be parallel to the X_{I_E} , Y_{I_E} , and Z_{I_E} axes.

The origin of the E-frame is at the center of mass of the spacecraft. The X_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 X_E and Y_E axes lie in a plane which is perpendicular to the radius vector, with positive X_E directed toward the north and positive Y_E directed toward the east. By virtue of the directions assigned to X_E and Y_E , positive Z_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. X_B and Z_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_{FB} , Y_{FB} , and Z_{FB} and is parallel to the body frame.

The origin of the H-frame is at the vehicle's center of gravity. The X_H and Y_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 Z_H is directed toward the center of the earth or moon along the vehicle's radius vector.

The J'-frame is coincident with the I_E -frame during earth orbital computation. During computation of vehicle motion in the lunar phase the J'-frame is referenced to the equatorial plane of the moon. The origin of the J'-frame is at the center of mass of the moon. The X and Y J'-frame axes lie in the moon's equatorial plane. The Z J'-frame axis is positive out the north pole of the moon. The orientation of the J'-frame is fixed with respect to the fixed stars.

J_R-frame

J_R-frame

Ecliptic-frame

The J_R^{\dagger} -frame differs from the J'-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 $J_R^{''}$ -frame is defined in a complimentary fashion to the $J_R^{''}$ -frame. The $J_R^{''}$ -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. LMS EQUATIONS OF MOTION (LEM AND CSM)

2.1 SYMBOLS ASSOCIATED WITH FIGURE 19

^a 11, ^a 12, ^a 13	The magnitudes of the projections of a unit vector along the LEM B-frame X axis on the I_E -frame or I_M -frame X, Y, Z axes.
a ₂₁ , a ₂₂ , a ₂₃	The magnitudes of the projections of a unit vector along the LEM B-frame Y axis on the $\rm I_E$ -frame or $\rm I_M$ -frame X, Y, Z axes.
a ₃₁ , a ₃₂ , a ₃₃	The magnitudes of the projections of a unit vector along the LEM B-frame Z axis on the $I_{\rm E}$ -frame or $I_{\rm M}$ -frame X, Y, Z axes.
A _{X_b} , A _{Y_b} , A _{Z_b}	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)
^b ₁₁ , ^b ₁₂ , ^b ₁₃	The magnitudes of the projections of a unit vector along the $I_{\rm E}\mbox{-}{\rm frame}$ or $I_{\rm M}\mbox{-}{\rm frame}$ X axis on the LEM E-frame X, Y, Z axes.
^b 21, ^b 22, ^b 23	The magnitudes of the projections of a unit vector along the $I_{\rm E}\mbox{-}{\rm frame}$ or $I_{\rm M}\mbox{-}{\rm frame}$ Y axis on the LEM E-frame X, Y, Z axes.
b ₃₁ , b ₃₂ , b ₃₃	The magnitudes of the projections of a unit vector along the ${\bf I}_{\rm E}{\rm -frame}$ or ${\bf I}_{\rm M}{\rm -frame}~{\rm Z}$ axis on the LEM E-frame axes.
^c ₁₁ , ^c ₁₂ , ^c ₁₃	The magnitudes of the projections of a unit vector along the LEM B-frame X axis on the LEM E-frame X, Y, Z axes.
^c ₂₁ , ^c ₂₂ , ^c ₂₃	The magnitudes of the projections of a unit vector along the LEM B-frame Y axis on the LEM E-frame X, Y, Z axes.
^c ₃₁ , ^c ₃₂ , ^c ₃₃	The magnitudes of the projections of a unit vector along the LEM B-frame Z axis on the LEM E-frame X, Y, Z axes.
c _D	Orbital drag coefficient.
$(C_1)_{18}^{}, (C_2)_{18}^{}, (C_3)_{18}^{}$	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 X, Y, Z axes of the LEM FB-frame. (ft)
d_{11}, d_{12}, d_{13}	The magnitudes of the projections of a unit vector along the ${\rm I}_E\text{-}{\rm frame}$ or ${\rm I}_M\text{-}{\rm frame}$ X axis on the J'-frame X, Y, Z axes.
d_{21}, d_{22}, d_{23}	The magnitudes of the projections of a unit vector along the $I_{\rm E}\mbox{-}{\rm frame}$ or $I_{\rm M}\mbox{-}{\rm frame}$ Y axis on the J'-frame X, Y, Z axes.
$d_{31}^{}, d_{32}^{}, d_{33}^{}$	The magnitudes of the projections of a unit vector along the $I_{E}\mbox{-}frame$ or $I_{M}\mbox{-}frame$ Z axis on the J'-frame X, Y, Z axes.
D_{X_b} , D_{Y_b} , D_{Z_b}	The magnitudes of the projections of the orbital drag force on the B-frame X, Y, Z axes. (lb)
D_{X_h} , D_{Y_h} , D_{Z_h}	The magnitudes of the projections of the orbital drag force on the H-frame X, Y, Z axes. (lb)

$(D_1)_{17}^{}, (D_2)_{17}^{}, (D_3)_{17}^{}$	Effective moment arms of the ascent thruster with respect to the LEM B-frame X, Y, 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 (See WADC Technical Report 58-17, "On the use of Qua in Simulation of Rigid-Body Motion," by Alfred C. Robi			
e 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 X, Y, Z axes.		
e ₂₁ , e ₂₂ , e ₂₃	The magnitudes of the projections of a unit vector along the J'-frame Y axis on the LEM E-frame X, Y, 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 X, Y, Z axes.		
$\mathbf{F}\mathbf{x}_{\mathbf{b}}^{\mathbf{'}}, \mathbf{F}\mathbf{Y}_{\mathbf{b}}^{\mathbf{'}}, \mathbf{F}\mathbf{Z}_{\mathbf{b}}^{\mathbf{'}}$	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)		
F _{Xe} , F _{Ye} , F _{Ze}	The magnitudes of the projections of the total applied force vector on the E-frame X, Y, Z axes. (lb)		
$F_{X_h}, F_{Y_h}, F_{Z_h}$	The magnitudes of the projections of the total applied force vector on the H-frame X, Y, Z axes. (lb)		
$G_{X_e}, G_{Y_e}, G_{Z_e}$	The magnitudes of the projections of the gravitational force vector on the E-frame X, Y, Z axes. (lb)		
$G_{X_e'}$, $G_{Y_e'}$, $G_{Z_e'}$	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)		
$\mathbf{G}_{\mathbf{X}_{\mathbf{h}}^{\mathbf{'}}}, \mathbf{G}_{\mathbf{Y}_{\mathbf{h}}^{\mathbf{'}}}, \mathbf{G}_{\mathbf{Z}_{\mathbf{h}}^{\mathbf{'}}}$	The magnitudes of the projections of the force vector which includes the gravitational effects of the earth, moon, and sun on the H-frame X, Y, Z axes. (lb)		
h	Vehicle altitude above the earth's or moon's surface measured along the radius vector. (ft)		
IXX	Moment of inertia about the B-frame X axis. $(slug-ft^2)$		
I _{YY}	Moment of inertia about the B-frame Y axis. $(slug-ft^2)$		
IZZ	Moment of inertia about the B-frame Z axis. (slug-ft ²)		
I _{XY}	Product of inertia due to nonsymmetric mass distribution with respect to XZ B-frame plane. (slug-ft ²)		
I _{XZ}	Product of inertia due to nonsymmetric mass distribution with respect to the XY B-frame plane. $(slug-ft^2)$		
I _{YZ}	Product of inertia due to nonsymmetric mass distribution with respect to the XZ B-frame plane. $(slug-ft^2)$		
к ²	The universal gravitational constant. $(lb-ft^2/slug^2)$		
$(K_1)_{17}, (K_2)_{17}, (K_3)_{17}$	The direction cosines of the line of action of the ascent thruster with respect to the LEM B-frame X, Y, 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 J^{\dagger} -frame. (rad)		
λ μ γ γ γ	The angle of longitude with respect to the J'-frame. (rad)		
^λ R	Longitude measured with respect to the earth's or moon's surface. (rad)		
m	Vehicle mass. (slugs)		
^m 11, ^m 12, ^m 13	The magnitudes of the projections of a unit vector along the J'-frame X axis on the CM X, Y, Z E-frame axes.		
^m 21, ^m 22, ^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.		
m ₃₁ , m ₃₂ , m ₃₃	The magnitudes of the projections of a unit vector along the J^* -frame X axis on the CM X, Y, Z E-frame axes.		
$\mathbf{M_{X_b}}, \ \mathbf{M_{Y_b}}, \ \mathbf{M_{Z_b}}$	The magnitudes of the projections of the total applied moment vector on the B-frame X, Y, Z axes. $(ft-lb)$		
ⁿ 11, ⁿ 12, ⁿ 13	The magnitudes of the projections of a unit vector along the I_E -frame or I_M -frame X axis on the X, Y, Z CM E-frame axes.		
ⁿ 21, ⁿ 22, ⁿ 23	The magnitudes of the projections of a unit vector along the ${\rm I}_E\text{-}{\rm frame}$ or ${\rm I}_M\text{-}{\rm frame}$ Y axis on the X, Y, Z CM E-frame axes.		
ⁿ 31, ⁿ 32, ⁿ 33	The magnitudes of the projections of a unit vector along the I_E -frame or I_M -frame X axis on the X, Y, Z CM E-frame axes.		
ω_{e}	The magnitude of the rotational velocity of the earth. (rad/sec)		
$\omega_{\rm m}$	The magnitude of the rotational velocity of the moon. $({\tt rad}/{\tt sec})$		
p _b	The magnitude of the projection of the absolute rotational velocity vector of the B-frame on the B-frame X axis. (rad/sec)		
Ψ _B /I', ^θ _B /I, ^φ _B /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 $\psi_{B/I}$, is about the position the B-frame Z axis has when the B-frame is parallel to the I-frame. The second rotation, through $\theta_{B/I}$, is about the position the B-frame Y axis assumes as a result of the first rotation. The third rotation, through $\phi_{B/I}$, is about the position the B-frame X axis assumes as a result of the second rotation. (rad)		
$\psi_{\mathbf{h}}$	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. (lb/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 I_E -frame or I_M -frame. This quantity is measured in the I_E -frame during earth orbital computation and in the I_M -frame during lunar phase computation. (ft)

^rCM^{, r}CM

r

^rCM/E

^rCM/M

- ^rEM
- rs

 $\mathbf{r}_{\mathbf{V}}, \mathbf{r}_{\mathbf{V}}$

 $\mathbf{r}'_{\mathbf{S}}$

^rve

^rVM

^rCM/L

 $\mathbf{r}_{\mathbf{b}}$

ρ S

σ_θ

The reference area for the orbital drag coefficient. (ft^2)

The angle between the $X_B - Y_B$ plane and the axis of the 18th thruster. (rad)

The magnitude of the radius of the CM as measured in the I_E -frame. This quantity is of interest during lunar phase computation and, hence, must be differentiated from r_{CM} , which is the magnitude of the radius of the CM as measured

in the IM-frame during lunar phase computation. (ft)

The magnitude of the radius of the CM as measured in the

quantity during lunar phase computation. (ft)

I-frame. r_{CM} denotes the value of this quantity during earth orbital computation, and r_{CM} denotes the value of this

The magnitude of the radius of the CM as measured in the I_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 I_M -frame during earth orbital computation. (ft)

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

The magnitude of the radius of the sun as measured in the $I_{\rm E}$ -frame. (ft)

The magnitude of the radius of the sun as measured in the $I_{\mbox{\scriptsize M}}\mbox{-}{\rm frame.}$ (ft)

The magnitude of the radius of the LEM as measured in the I-frame. \mathbf{r}'_V denotes the value of this quantity during earth orbital computation, and \mathbf{r}'_V denotes the value of this quantity during lunar phase computation. (ft)

The magnitude of the radius of the LEM as measured in the I_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 I_M -frame during lunar phase computation. (ft)

The magnitude of the radius of the LEM as measured in the I_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)

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Atmospheric density. $(slug/ft^3)$

σ_{ψ}	The angle between the $X_{\rm B}\text{-}Z_{\rm B}$ plane and the axis of the 18th thruster. (rad)
t	Mean solar time. (sec)
T _n	Thrust of the nth engine. (lb)
$T_{X_b}, T_{Y_b}, T_{Z_b}$	The magnitudes of the projections of the total thrust vector on the B-frame X, Y, Z axes. (lb)
u _h	The projection of the vehicle's velocity vector on the H-frame X axis. (ft/sec)
^u R	The magnitude of the projection of \boldsymbol{V}_{R} on the B-frame X axis. (ft/sec)
v _R	The magnitude of the vehicle velocity relative to the rotating atmosphere. (ft/sec)
^v R	The magnitude of the projection of \boldsymbol{V}_{R} on the B-frame Y axis. (ft/sec)
^w R	The magnitude of the projection of \boldsymbol{V}_{R} on the B-frame Z axis. (ft/sec)
$(\mathbf{x}_{\mathbf{I}})_{\mathbf{CM}}, (\mathbf{Y}_{\mathbf{I}})_{\mathbf{CM}}, (\mathbf{z}_{\mathbf{I}})_{\mathbf{CM}}$	${\rm I}_E\text{-}{\rm frame} \text{ or } {\rm I}_M\text{-}{\rm frame} \text{ coordinates of CM position. These quantities represent } {\rm I}_E\text{-}{\rm frame} \text{ coordinates during earth orbital computation and } {\rm I}_M\text{-}{\rm frame} \text{ coordinates during lunar phase computation. (ft)}$
${}^{(X_{I})}{}_{CM/L}, {}^{(Y_{I})}{}_{CM/L}, {}^{(Z_{I})}{}_{CM/L}$	$\mathbf{I_E}\text{-frame} \text{ or } \mathbf{I_M}\text{-frame} \text{ coordinates} \text{ of CM position relative} to the LEM. (ft)$
$(\mathbf{X}_{I})_{V}$, $(\mathbf{Y}_{I})_{V}$, $(\mathbf{Z}_{I})_{V}$	I_E -frame or I_M -frame coordinates of LEM position. These quantities represent I_E -frame coordinates during earth orbital computation and I_M -frame coordinates during lunar phase computation. (ft)
$(X_{I_E})_M, (Y_{I_E})_M, (Z_{I_E})_M$	I_{E} -frame coordinates of the moon's position. (ft)
$(\mathbf{X_{I_E}})_{S}$, $(\mathbf{Y_{I_E}})_{S}$, $(\mathbf{Z_{I_E}})_{S}$	$I_{E}^{-frame \ coordinates \ of \ the \ sun's \ position.}$ (ft)
$(\mathbf{X}_{\mathbf{I}_{\mathbf{M}}})_{\mathbf{E}}, (\mathbf{Y}_{\mathbf{I}_{\mathbf{M}}})_{\mathbf{E}}, (\mathbf{Z}_{\mathbf{I}_{\mathbf{M}}})_{\mathbf{E}}$	I_{M} -frame coordinates of the earth's position. (ft)
$(x_{I_M})_S, (Y_{I_M})_S, (Z_{I_M})_S$	I_{M} -frame coordinates of the sun's position. (ft)
x _e ∖, y _e ∖, z _e ∖	E-frame differential acceleration components. (ft/sec 2)
$\ddot{\mathbf{x}}_{\mathbf{I}_{\mathbf{M}}}$, $\ddot{\mathbf{x}}_{\mathbf{I}_{\mathbf{M}}}$, $\ddot{\mathbf{x}}_{\mathbf{I}_{\mathbf{M}}}$, $\mathbf{x}_{\mathbf{S}, \mathbf{E}}$, $\ddot{\mathbf{z}}_{\mathbf{I}_{\mathbf{M}}}$, $\mathbf{x}_{\mathbf{S}, \mathbf{E}}$	$I_{\rm E}\mbox{-}{\rm frame\ components\ of\ the\ differential\ gravitational\ acceleration\ components\ due\ to\ the\ sun\ and\ the\ moon.\ (ft/sec^2)$
$\ddot{\mathbf{x}}_{\mathbf{I}\mathbf{M}}$, $\mathbf{x}_{\mathbf{I}\mathbf{M}}$, $\mathbf{x}_{$	${\rm I}_M\mbox{-}{\rm frame\ components\ of\ the\ differential\ gravitational\ acceleration\ components\ due\ to\ the\ sun\ and\ the\ earth.\ (ft/sec^2)$

- 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:

СМ	Command Module			
Е	Earth or E-frame depending on the manner it is used.			
G	Gravitational			
LEM	Lunar Excursion Module			
М	Moon			
R	Relative			
S	Sun			
v	Vehicle			



2.2 COMMAND MODULE CONTROL EQUATIONS (FIGURE 19a)

a ₁₁ , a ₁₂ , a ₁₃	The magnitudes of the projections of a unit vector along the LEM B-frame X axis on the $I_{\rm E}\mbox{-}frame$ or $I_{\rm M}\mbox{-}frame$ X, Y, Z axes.
a ₂₁ , a ₂₂ , a ₂₃	The magnitudes of the projections of a unit vector along the LEM B-frame Y axis on the I_E -frame or I_M -frame X, Y, Z axes.
a ₃₁ , a ₃₂ , a ₃₃	The magnitudes of the projections of a unit vector along the LEM B-frame Z axis on the I_E -frame or I_M -frame X, Y, Z axes.
^{<i>a</i>} ₁₁ , <i>^a</i> ₁₂ , <i>^a</i> ₁₃	The magnitudes of the projections of a unit vector along the commanded B-frame X axis on the H-frame X, Y, Z axes.
α ₂₁ , α ₂₂ , α ₂₃	The magnitudes of the projections of a unit vector along the commanded B-frame Y axis on the H-frame X, Y, Z axes.
α ₃₁ , α ₃₂ , α ₃₃	The magnitudes of the projections of a unit vector along the commanded B-frame Z axis on the H-frame X, Y, Z axes.
β ₁₁ , β ₁₂ , β ₁₃	The magnitudes of the projections of a unit vector along the CM E-frame X axis on the I_E -frame or I_M -frame X, Y, Z axes.
β ₂₁ , β ₂₂ , β ₂₃	The magnitudes of the projections of a unit vector along the CM E-frame Y axis on the I_E -frame or I_M -frame X, Y, Z axes.
β ₃₁ , β ₃₂ , β ₃₃	The magnitudes of the projections of a unit vector along the CM E-frame Z axis on the $\rm I_E$ -frame or $\rm I_M$ -frame X, Y, Z axes.
δ ₁₁ , δ ₁₂ , δ ₁₃	The magnitudes of the projections of a unit vector along the CM H-frame X axis on the CM B-frame X, Y, Z axes.
δ ₂₁ , δ ₂₂ , δ ₂₃	The magnitudes of the projections of a unit vector along the CM H-frame Y axis on the CM B-frame X, Y, Z axes.
δ ₃₁ , δ ₃₂ , δ ₃₃	The magnitudes of the projections of a unit vector along the CM H-frame Z axis on the CM B-frame X, Y, Z axes.
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.)
$(e_1)_{C}, (e_2)_{C}, (e_3)_{C}, (e_4)_{C}$	Commanded LEM I-frame to B-frame quaternions.
$\triangle e_1, \triangle e_2, \triangle e_3, \triangle e_4$	Incremental changes in the LEM quaternion rates due to a difference between the commanded quaternions and the actual quaternions. (\sec^{-1})

$\gamma_{11}, \gamma_{12}, \gamma_{13}$	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 X, Y, Z axes.
γ ₂₁ , γ ₂₂ , γ ₂₃	The magnitudes of the projections of a unit vector along the CM B-frame Y axis on the I_E -frame or I_M -frame X, Y, Z axes.
γ ₃₁ , γ ₃₂ , γ 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 X, Y, Z axes.
$\dot{\gamma}_{11}, \ldots, \dot{\gamma}_{33}$	The time rate of change of $\gamma_{11}^{}, \dots, \gamma_{33}^{}$. (sec ⁻¹)
$(\gamma_{11})_{c}, (\gamma_{12})_{c}, (\gamma_{13})_{c}$	The magnitudes of the projections of a unit vector along the commanded CM B-frame X axis on the I_E -frame or I_M - frame X, Y, Z axes.
$(\gamma_{21})_{c}, (\gamma_{22})_{c}, (\gamma_{23})_{c}$	The magnitudes of the projections of a unit vector along the commanded CM B-frame Y axis on the I_E -frame or I_M -frame X, Y, Z axes.
$(\gamma_{31})_{c}, (\gamma_{32})_{c}, (\gamma_{33})_{c}$	The magnitudes of the projections of a unit vector along the commanded CM B-frame Z axis on the I_E -frame or I_M - frame X, Y, Z axes.
^k 11, ^k 12, ^k 13	The magnitudes of the projections of a unit vector along the CM B-frame X axis on the LEM B-frame X, Y, 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.
^k 31, ^k 32, ^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.
к ₁ , к ₂	Gain constants. (sec ⁻¹)
L _{CM}	The latitude of the CM measured with respect to the J' -frame. (rad)
^λ 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 ψ_c , θ_c , and ϕ_c . The first rotation, through ψ_c , is about the B-frame Z axis. The second rotation, through θ_c , is about the B-frame Y axis. The third rotation, through ϕ_c , is about the B-frame X axis. (rad)
$(\psi_h)_{CM}$	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)
$(T_{X_b})_{CM}$, $(T_{Y_b})_{CM}$, $(T_{X_b})_{CM}$	The magnitudes of the projections of the instructor-con- trolled commanded thrust vector on the CM B-frame X, Y, and Z axes.

ey,

*

 $(T_{X_h})_{CM}$, $(T_{Y_h})_{CM}$, $(T_{Z_h})_{CM}$ The magnitudes of the projections of the instructor-controlled commanded thrust vector on the CM H-frame X, Y and Z axes. (lb)

^ζ₁₁, ^ζ₁₂, ^ζ₁₃

^ζ21^{, ζ}22^{, ζ}23

^ζ₃₁, ^ζ₃₂, ^ζ₃₃

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

The magnitudes of the projections of a unit vector along the CM H-frame Y axis on the I_E -frame or I_M -frame X, Y, and Z axes.

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



Figure 19a Command Module Control Equations

2.3 WEIGHT AND BALANCE EQUATIONS (FIGURE 19b)

A_{j_b} , A_{x_b} , A_{y_b} , A_{Z_b}	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 X, Y, and Z body axes. (ft)		
B*	Boolean term.		
I _j FB	Moments of inertia of the complete vehicle about the X, Y, and Z fixed body axes. $(slug-ft^2)$		
I_{XX} , I_{YY} , I_{ZZ}	Moments of inertial of the complete vehicle about the X, Y, and Z body axes. $(slug-ft^2)$		
I_{XY} , I_{XZ} , I_{YZ}	Products of inertia of the complete vehicle about the body axes in the XY, XZ, and YZ planes. $(slug-ft^2)$		
(I _{ojFB}) _{AS}	Fixed body moments of inertial of the empty ascent stage. (slug-ft ²)		
(I _{jFB}) C/SM	Fixed body moments of inertial of the Command Service Module. (slug-ft ²)		
(I ₀) j _{FB} DS	Fixed body moments of inertia of the empty descent stage. $(slug-ft^2)$		
(△I _{jFB}) _{FC}	Incremental moments of inertia. of the fuel in the fuel cell about the fixed body axes. (slug-ft ²)		
(△I _{jFB}) _{GOT}	Incremental moments of inertial of the gaseous oxygen in the gaseous oxygen tank, about the fixed body axes. $(slug-ft^2)$		
($\Delta I_{j_{FB}})_{HT}$	Incremental moments of inertial of the helium in the helium tank about the fixed body axes. $(slug-ft^2)$		
$(\Delta I_{jFB})_{HT(RCS)}$	Incremental moments of inertia of the Reaction Control System helium in the helium tank about the fixed body axes. (slug-ft ²)		
$(\Delta I_{jFB})_{LG}$	Incremental moments of inertia of the landing gear about the fixed body axes. (slug-ft ²)		
(AI _{jFB}) _{LHT}	Incremental moments of inertia of the liquid hydrogen in the liquid hydrogen tank about the fixed body axes. (slug-ft ²)		
$(\Delta I_{j_{FB}})_{LOX}$	Incremental moments of inertia of the liquid oxygen in the liquid oxygen tank about the fixed body axes. $(slug-ft^2)$		
($\Delta I_{j_{FB}})_{OT}$	Incremental moments of inertia of the oxygen in the oxygen tank about the fixed body axes. $(slug-ft^2)$		
(⁽] _{jfb}) _{PAE}	Incremental moments of inertia of the ascent engine propellant about the fixed body axes. $(slug-ft^2)$		
$(\Delta I_{jFB})_{PDE}$	Incremental moments of inertia of the descent engine propellant about the fixed body axes. $(slug-ft^2)$		
(AI _{jfb}) prcs	Incremental moments of inertia of the reaction control system propellant about the fixed body axes. $(slug-ft^2)$		

(△I _{jFB}) WT	Incremental moments of inertia of the water in the water tank about the fixed body axes. $(slug-ft^2)$
j i konstantij	Indices representing X, Y, or Z axes.
m	Total vehicle mass. (slugs)
^m oas	Mass of the empty ascent stage. (slugs)
^m C/SM	Mass of the Command Service Module. (slugs)
^m o _{DS}	Mass of the empty descent stage. (slugs)
^m FC	Mass of the fuel in the fuel cell. (slugs)
^m GOT	Mass of the gaseous oxygen in the gaseous oxygen tank. (slugs)
m _{HT}	Mass of the helium in the helium tank. (slugs)
^m HT(RCS)	Mass of the reaction control system helium in the helium tank (slugs)
^m LHT	Mass of the liquid hydrogen in the liquid hydrogen tank. (slugs)
^m LOX	Mass of the liquid oxygen in the liquid oxygen tanks. (slugs)
^m CT	Mass of the oxygen in the oxygen tank. (slugs)
^m PAE	Propellant mass of the ascent engine. (slugs)
^m PDE	Propellant mass of the descent engine. (slugs)
^m PRCS	Propellant mass of the reaction control system. (slugs)
^m WT	Mass of the water in the water tank. (slugs)
$(mA_{oj_{FB}})$ AS	Incremental moment of the empty ascent stage about the fixed body axes. (slug-ft)
$(^{mA}j_{FB})$ CISM	Incremental moment of the command service module about the fixed body axes. (slug-ft)
(mA _{ojFB}) DS	Incremental moment of the empty descent stage about the fixed body axes. (slug-ft)
(mA _{jFB}) _{FC}	Incremental moment of the fuel in the fuel cell about the fixed body axes. (slug-ft)
(mA _{j_{FB}}) _{GOT}	Incremental moment of the gaseous oxygen in the gaseous oxygen tank about the fixed body axes. (slug-ft)
(mA _{jFB}) _{HT}	Incremental moment of the helium in the helium tank about the fixed body axes. (slug-ft)
(mA _j) ^j FB HT(RCS)	Incremental moment of the reaction control system helium in the helium tank about the fixed body axes. (slug-ft)
(mA _{jFB}) LHT	Incremental moment of the liquid hydrogen in the liquid hydrogen tank about the fixed body axes. (slug-ft)

(mA_{jFB}) LOX

(mA_{jFB}) ot

(mA_{jFB}) PAE

 $(mA_{j_{FB}})_{PDE}$

(mA_{jFB}) prcs

 $({^{mA}j}_{FB})_{WT}$

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)



Figure 19b Weight and Balance Computations

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3.	LMS	VISUAL	DISPLAY	SYSTEM	EQUATIONS

^a 11, ^a 12, ^a 13	The magnitudes of the projections of a unit vector along the LEM B-frame X axis on the I_E -frame or I_M -frame X, Y, Z axes.
a ₂₁ , a ₂₂ , a ₂₃	The magnitudes of the projections of a unit vector along the LEM B-frame Y axis on the I_E -frame or I_M -frame X, Y, Z axes.
a ₃₁ , a ₃₂ , a ₃₃	The magnitudes of the projections of a unit vector along the LEM B-frame Z axis on the $I_{\rm E}\mbox{-}{\rm frame}$ or $I_{\rm M}\mbox{-}{\rm frame}$ X, Y, Z axes.
$^{\rm AZ}$ CM/L, $^{\rm EL}$ CM/L	Relative azimuth and elevation angles of CM with respect to the LEM B-frame Z axis. (rad) $\left(rad \right)$
$AZ_{E/L}$, $EL_{E/L}$	Relative azimuth and elevation angles of the earth with respect to the LEM B-frame Z axis. (rad)
AZ _{M/L} , EL _{M/L}	Relative azimuth and elevation angles of the moon with respect to the LEM B-frame Z axis. (rad)
$^{\rm AZ}S/L$, $^{\rm EL}S/L$	Relative azimuth and elevation angles of the sun with respect to the LEM B-frame Z axis. (rad)
^b 11 ^{, b} 12 ^{, b} 13	The magnitudes of the projections of a unit vector along the I_E -frame or I_M -frame X axis on the LEM E-frame X, Y, Z axes.
^b 21, ^b 22, ^b 23	The magnitudes of the projections of a unit vector along the I_E -frame or I_M -frame Y axis on the LEM E-frame X, Y, Z axes.
^b ₃₁ , ^b ₃₂ , ^b ₃₃	The magnitudes of the projections of a unit vector along the I_E -frame or I_M -frame Z axis on the LEM E-frame X, Y, Z axes.
^B M	A Boolean term which is equal to one for lunar phase simulation.
c ₁₁ , c ₁₂ , c ₁₃	The magnitudes of the projections of a unit vector along the LEM B-frame X axis on the LEM E-frame X, Y, Z axes.
^c ₂₁ , ^c ₂₂ , ^c ₂₃	The magnitudes of the projections of a unit vector along the LEM B-frame Y axis on the LEM E-frame X, Y, Z axes.
c ₃₁ , c ₃₂ , c ₃₃	The magnitudes of the projections of a unit vector along the LEM B-frame Z axis on the LEM E-frame X, Y, Z axes.
$(C_{11})_{AMS}, (C_{12})_{AMS}, (C_{13})_{AMS}$	The magnitudes of the projections of a unit vector along the CM B-frame axis on the $I_{\rm E}$ -frame or $I_{\rm M}$ -frame X, Y, Z axes.
$(C_{21})_{AMS}, (C_{22})_{AMS}, (C_{23})_{AMS}$	The magnitudes of the projections of a unit vector along the CM B-frame axis on the I_E -frame or I_M -frame X, Y, Z axes.

$(C_{31})_{AMS}, (C_{32})_{AMS}, (C_{33})_{AMS}$	The magnitudes of the projections of a unit vector along the CM B-frame axis on the $\rm I_E$ -frame or $\rm I_M$ -frame X, Y, Z axes.
DL	Distance across a selected orbit. The distance, measured from D'_{λ} , perpendicular to the trace of a selected orbit on the surface of the moon. (ft)
D^{*}_{λ}	Distance along a selected orbit. The distance along the trace of a selected orbit on the surface of the moon. (ft)
f ₁₁ , f ₁₂ , f ₁₃	The magnitudes of the projections of a unit vector along the ecliptic-frame X axis on the $I_{\rm E}\mbox{-}{\rm frame}$ or $I_{\rm M}\mbox{-}{\rm frame}$ X, Y, Z axes.
f ₂₁ , f ₂₂ , f ₂₃	The magnitudes of the projections of a unit vector along the ecliptic-frame Y axis on the ${\rm I}_E$ -frame or ${\rm I}_M$ -frame X, Y, Z axes.
f31, f ₃₂ , f ₃₃	The magnitudes of the projections of a unit vector along the ecliptic-frame Z axis on the $I_{\rm E}\mbox{-}{\rm frame}$ or $I_{\rm M}\mbox{-}{\rm frame}$ X, Y, Z axes.
h	LEM altitude above the earth's or moon's surface measured along the radius vector. (ft)
h ₁₁ , h ₁₂ , h ₁₃	The magnitudes of the projections of a unit vector along the J_R^{\dagger} -frame X axis on the LEM H-frame X, Y, Z axes.
h ₂₁ , h ₂₂ , h ₂₃	The magnitudes of the projections of a unit vector along the J'_R -frame Y axis on the LEM H-frame X, Y, Z axes.
h ₃₁ , h ₃₂ , h ₃₃	The magnitudes of the projections of a unit vector along the J_R^i -frame Z axis on the LEM H-frame X, Y, Z axes.
^k 11, ^k 12, ^k 13	The magnitudes of the projections of a unit vector along the CM B-frame X axis on the LEM B-frame X, Y, 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.
k ₃₁ , k ₃₂ , 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.
к ₁ -к ₈	Constants which depend on the inclination and the longitude of the ascending mode of a given orbit selection.
к ₉ -к 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)
Ĺ	The angle of latitude with respect to the J^{\dagger} -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)

L" 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) ^λE The longitude of an arbitrary point on the surface of the earth. (rad) The longitude of an arbitrary point on the surface of the ^λM moon. (rad) Longitude measured with respect to the earth's or moon's λR surface. (rad) The magnitude of the rotational velocity of the earth. w (rad/sec)ω_m The magnitude of the rotational velocity of the moon. (rad/sec)p₁₁, p₁₂, p₁₃ The magnitudes of the projections of a unit vector along the $J_{\mathbf{R}}^{\mu}$ -frame X axis on the LEM H-frame X, Y, Z axes. The magnitudes of the projections of a unit vector along p21, p22, p23 the J''_R -frame Y axis on the LEM H-frame X, Y, Z axes. The magnitudes of the projections of a unit vector along p₃₁, p₃₂, p₃₃ the J_R -frame Z axis on the LEM H-frame X, Y, Z axes. The heading angle of the H-frame. This is the angle the $\psi_{\mathbf{h}}$ H-frame X axis makes with the E-frame X axis. (rad) q11, q12, q13 The magnitudes of the projections of a unit vector along the ecliptic-frame X axis on the B-frame X, Y, Z axes. q₂₁, q₂₂, q₂₃ The magnitudes of the projections of a unit vector along the ecliptic-frame Y axis on the B-frame X, Y, Z axes. q₃₁, q₃₂, q₃₃ The magnitudes of the projections of a unit vector along the ecliptic-frame Z axis on the B-frame X, Y, Z axes. The magnitude of the radius of the vehicle as measured in the I_E -frame or I_M -frame. This quantity is measured in the IE-frame during earth orbital computation and in the I_{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)

20

rp

r

λ1

λ"

R_{CM/L}

R_m

$^{\theta}$ B/E, $^{\phi}$ B/E, $^{\psi}$ B/E	LEM attitude with respect to the LEM E-frame.
$^{\theta}$ CM/L, $^{\phi}$ CM/L, $^{\psi}$ CM/L	CM attitude angles with respect to the LEM body axes. (rad)
$^{\theta}$ E/H, $^{\phi}$ E/H, $^{\psi}$ E/H	Earth attitude angles with respect to the H-frame during earth orbital computation. (rad)
$\theta_{\rm E/M}, \phi_{\rm E/M}, \psi_{\rm E/M}$	Earth attitude angles with respect to the H-frame during lunar phase computation. (rad)
$\theta_{M/E}, \phi_{M/E}, \psi_{M/E}$	Moon attitude angles with respect to the H-frame during earth orbital computation. (rad)
$\theta_{M/H}, \phi_{M/H}, \psi_{M/H}$	Moon attitude angles with respect to the H-frame during lunar phase computation. (rad)
$^{\theta}$ S/L, $^{\phi}$ S/L, $^{\psi}$ S/L	Starfield display with respect to LEM body axis. (rad)
X _{CM/L} , Y _{CM/L} , Z _{CM/L}	LEM B-frame coordinates of CM position. (ft)
$x_{I_{CM/L}}$, $y_{I_{CM/L}}$, $z_{I_{CM/L}}$	$I_{\rm E}\mbox{-}{\rm frame}~{\rm or}~I_{\rm M}\mbox{-}{\rm frame}~{\rm coordinates}~{\rm of}~{\rm CM}~{\rm position}~{\rm relative}$ to the LEM. (ft)
$(x_{I})_{S/L}, (y_{I})_{S/L}, (z_{I})_{S/L}$	$I_{\rm E}\mbox{-}{\rm frame}$ or $I_{\rm M}\mbox{-}{\rm frame}$ coordinates of the sun's position relative to the LEM. (ft)
$(\mathbf{X_{I_E}})_{\mathbf{M}}, \ (\mathbf{Y_{I_E}})_{\mathbf{M}}, \ (\mathbf{Z_{I_E}})_{\mathbf{M}}$	I_E -frame coordinates of the moon's position. (ft)
$(\mathbf{X}_{\mathbf{I}_{\mathbf{E}}})_{\mathbf{S}}, \ (\mathbf{Y}_{\mathbf{I}_{\mathbf{E}}})_{\mathbf{S}}, \ (\mathbf{Z}_{\mathbf{I}_{\mathbf{E}}})_{\mathbf{S}}$	I_E -frame coordinates of the sun's position. (ft)
$(\mathbf{X}_{I_M})_{S}^{}, \ (\mathbf{Y}_{I_M})_{S}^{}, \ (\mathbf{Z}_{I_M})_{S}^{}$	I_M -frame coordinates of the sun's position. (ft)
$x_{I_V}, y_{I_V}, z_{I_V}$	I_E -frame or I_M -frame coordinates of LEM position. These quantities represent I_E -frame coordinates during earth orbital computation and I_M -frame coordinates during lunar phase computation. (ft)
$x_{M/L}, y_{M/L}, z_{M/L}$	LEM B-frame coordinates of the moon's position. (ft)

 $x_{S/L}$, $y_{S/L}$, $z_{S/L}$

LEM B-frame coordinates of the sun's position. (ft)

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Figure 20 LMS Visual Display System Equations

4. LMS REACTION CONTROL SYSTEM EQUATIONS

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4.1 VARIABLES	
A _{REG}	Effective area of the squib, the two solenoid values, and the four pressure regulator values, which connect the helium reservoir with the region immediately downstream of the pressure regulators, and upstream of the check values (in^2) .
A'REG	Uncorrected effective flow area (in ²). NOTE: Further explanation of this variable is given in paragraph $3.3.1$ of the technical proposal.
AX	The symbol A_X , where X is a 1, 2, or 3 digit numeric sub- script, is an arithmetic quantity, the existence of which is implied by the corresponding Boolean quantity B_X and the following relations; $A_X = 1$ if $B_X = 1$, and $A_X = 0$ if $B_X = 0$. NOTE: The B's are defined in Section 4.3
BX	See definition of AX.
٤S	Fractional sensor error, i.e., the ratio of the actual sensor error to the maximum plus or minus variation in sensor error.
F	Fuel quantity.(lbs.)
f'A	Summation of the fuel flow rates for the 8 reaction control jets of $RCS-A$. (lbs-sec ⁻¹)
́г 'в	Summation of the fuel flow rates for the 8 reaction control jets of RCS-B. (lbs-sec ⁻¹)
▲FASC	Incremental increase in ascent engine fuel consumption rate due to RCS operation. (lbs-sec ^{-1})
Ħ	Thrust output of a single reaction jet if the TCA solenoid valves are open. (lbs.)
f ₁ (PRESSURE RATIO)	See definitions of \mathring{M}_{T} , \mathring{M}_{T}_{F} , and \mathring{M}_{T}_{O} .
f ₂ (T _{FUEL})	See definition of $\rho_{\mathbf{F}}$.
f ₃ (T _{OXID})	See definition of ρ_{O} .
f4 (P _{MANFUEL})	The fuel flow rate for a single thruster if the TCA solenoid value is open (lbs-sec ⁻¹). NOTE: This function will be defined for $P_{MANFUEL}$ in the range $0 \le P_{MANFUEL} \le 250$ psia.
f5 (P _{MANOXID})	The oxidizer flow rate for a single thruster if the TCA solenoid value is open (lbs-sec ⁻¹). NOTE: This function will be defined for PMAN _{OXID} in the range $0 \leq PMAN_{OXID} \leq 250$ psia.
f6 [f5/f4]	Represents the available specific impulse as a function of the available \dot{O}/\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 (C3) may be assumed equal to zero if C3 is less than C1 or greater than C2.

Ki	The i th system constant. NOTE: The K's are defined in Section 4.2.
м _т	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 $0 \le M_T \le 0.21$. ($\sqrt{\ ^{\circ}R}/\text{sec}$)
$\mathring{\mathbf{M}}_{\mathbf{T}_{\mathbf{F}}}$	Mass flow parameter as applied to the check valve upstream of the fuel tank, $M_{TF} = f (P_{REG}/P_{FUEL}). (\sqrt{R/Sec})$
м _{то}	Mass flow parameter as applied to the check value upstream of the oxidizer tank, $M_{TO} = f (P_{REG}/P_{OXID}) (\sqrt{R}/sec)$
0	Oxidizer quantity. (lbs.)
Ö'A	Summation of the oxidizer flow rates for the 8 reaction control jets of RCS-A. (lbs-sec ^{-1})
Ċ'в	Summation of the oxidizer flow rates for the 8 reaction control jets of RCS-B. (lbs-sec ^{-1})
∆Ö _{ASC}	Incremental increase in ascent engine oxidizer consumption rate due to RCS operation. (lbs-sec ^{-1})
P	Instructor indicator readings displayed on the RCS pressure indicators if the instructor selects to read true values. (psia)
PC	Commanded regulator outlet pressure.(psia)
ΔP _C	Increment in commanded regulator outlet pressure as refer- enced 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)
ΔP _{CAP}	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 regu- lator command pressure for the two series regulators and the nominal regulator command pressure of 181 psia.(psi)
∆P _{CAR}	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 regu- lator command pressure for the two series regulators and the nominal regulator command pressure of 181 psia. (psi)
∆₽ _{CBP}	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 regu- lator command pressure for the two series regulators and the nominal regulator command pressure of 181 psia. (psi)
Δ₽ _{CBR}	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 regu- lator command pressure for the two series regulators and the nominal regulator command pressure of 181 psia.(psi)
PCREW	Crew indicator readings as displayed on the RCS pressure indicators.(psia)

PFUEL	Fuel tank pressure.(psia)
ΔP _{FUEL}	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)
P _{He}	Helium reservoir pressure.(psia)
P _{INST}	Instructor indicator readings as displayed on the RCS pressure indicators.(psia)
PMANFUEL	Fuel manifold pressure.(psia)
PMANOXID	Oxidizer manifold pressure.(psia)
POXID	Oxidizer tank pressure. (psia)
ΔP _{OXID}	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)
P _{REG}	Pressure regulator outlet pressure.(psia)
PSEL	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)
Q	Instructor indicator readings displayed on the RCS propellant quantity indicators if the instructor selects to read true values. (%)
Q _{CREW}	Crew indicator readings as displayed on the RCS propellant (fuel or oxidizer) quantity indicators. (%)
QINST	Instructor indicator readings as displayed on the RCS pro- pellant (fuel or oxidizer) quantity indicators.(%)
Q LEAK	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 B_{119} thru B_{122} . (lbs-sec ⁻¹)
QSEL	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.(%)
ρ _F	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.
ρο	Oxidizer density (lbs-in ⁻³) NOTE: As indicated on Figure 21 of the proposal, oxidizer density is assumed to be a function of oxidizer temperature.
Т	Instructor indicator readings displayed on the RCS temperature indicators if the instructor selects to read true values. (°F)

T _C	Environmental control temperature.($^{\circ}$ R) NOTE: Further explanation of this variable is given in paragraph 3.3.3 of the proposal.
TCREW	Crew indicator readings as displayed on the RCS temperature indicators.(°F) \mathbf{F}
TFUEL	Common temperature of fuel and ullage helium in the fuel $tank.(^{\circ}R)$
T_{He}	Temperature of helium in the helium reservoir.(°R)
TINST	Instructor indicator readings as displayed on the RCS tem- perature indicators.(°F)
TMANFUELA	Temperature of the fuel in the RCS-A fuel manifold.(°R)
T _{MANOXID} B	Temperature of the oxidizer in the RCS-B oxidizer manifold.(°R)
TOXID	Common temperature of oxidizer and ullage helium in the oxidizer tank.($^{\circ}$ R)
T _{SEL}	Instructor indicator readings displayed on the RCS tem- perature indicators if the instructor selects to read tem- peratures other than the temperatures dictated by the crew selector switch position.($^{\circ}$ F)
TMANFUELA	Steady-state temperature of the fuel in the RCS-A fuel manifold.(°R)
T'MANOXIDB	Steady-state temperature of the oxidizer in the RCS-B oxidizer manifold.(°R)
δt	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_{sp} variation in the short pulse width regime is discussed in paragraph 3.3.4 of the proposal.
VHeFUEL	Ullage volume in the fuel tank. $(in-3)$
v _{HeOXID}	Ullage volume in the oxidizer tank. (in-3)
w _{He}	Weight of helium in the helium reservoir.(lbs)
WHeFUEL	Helium quantity occupying the fuel tank ullage volume.(lbs)
WHeOXID	Helium quantity occupying the oxidizer tank ullage volume. (lbs)
Ŵ _{CVF}	Helium flow rate through the check value and into the fuel $tank.(lbs-sec-1)$
Ŵcvo	Helium flow rate through the check value and into the oxidizer tank. (lbs-sec ⁻¹)
w _{HeLEAK}	Variable instructor control of helium leakage. The in- structor 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 B_{101} thru B_{105} . (lbs/sec)

\dot{w}_{REG}	Summation of the helium flow rates through the primary
	and redundant pressure regulator branches. $(lbs-sec^{-1})$
Ŵ _{RVF}	Helium flow rate out of the fuel ullage relief valve.(lbs-sec ⁻¹)
₩ _{RVO}	Helium flow rate out of the oxidizer ullage relief value. $(lbs-sec^{-1})$
SUBSCRIPTS:	
Α	Pertains to RCS-A
В	Pertains to RCS-B
ASC	Pertains to Ascent Engine
ΠA	Crew indicator input from RCS-A
ПB	Crew indicator input from RCS-B
 (2) Two dots placed 4.2 CONSTANTS K1 	above a quantity indicate the second time derivative of that quantity Defines the range of ΔP_C in the absence of full open pressure
-	regulator failures, i.e., if there are no regulators failed open, $-K_1 \le \Delta P_C \le K_1$. (psi)
K2	Incremental change in ΔP_C due to full open failure of the high- pressure pressure-regulator valve.(psi)
K ₃	Incremental change in ΔPC due to full open failure of the low- pressure pressure-regulator value. (psi)
K4	Constant to be evaluated to provide acceptable transient response of regulator outlet pressure to system loading. (sec ^{-1})
K5	Constant to be evaluated to provide acceptable transient response of regulator outlet pressure to system loading. (sec-2)
K ₆	Constant to be determined as a function of steady-state regulator data and the selected value of K_5 . (in ⁴ lbs ⁻¹ sec ⁻²) NOTE: The ratio K_6/K_5 is determined from the steady-state regulator data as $K_6/K_5 = -\partial A'_{REG}/\partial P_{REG}$. (in ⁴ lbs ⁻¹)
K7	Constant to be determined as a function of zero-flow steady- state regulator data and the selected value of K6. (in ⁴ lbs ⁻¹ sec ⁻² NOTE: The ratio K_7/K_6 is determined from the steady-state regulator data as $K_7/K_6 = -\partial P_{REG}/\partial P_{He}$.

K8

Constant to be determined in accordance with the regulator preload, such that the zero-flow steady-state value of regulator outlet pressure (P_{REG}) equals the regulator outlet command pressure (P_C) at a specified value of reservoir pressure (P_{He}). (in² sec⁻²) NOTE: The ratio K₈/K₇ is defined as K₈/K₇ = P_{HeS} psi, where P_{HeS} is the specified value of P_{He} referred to above.

K9	Effective flow area (A_{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)
к ₁₀	Ratio of the gas constant for helium to the volume of the helium reservoir tank. ($^{\circ}R^{-1}$ -in ⁻²)
K ₁₁	Compressibility factor for helium minus one, $(Z_{He}-1)$.
K ₁₂	Ratio of specific heats for helium minus one, (\mathcal{V}_{He} -1).
K ₁₃	Ratio of K'_{13} to the specific heat of helium at constant volume, where K'_{13} represents the ratio of heat input rate of the reservoir tank (Q_{He}) to the difference in environmental temperature and helium temperature, $K_{13} = Q_{He}/[C_V (T_C - T_{He})]$. (lbs/sec)
К ₁₄	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.
К ₁₅	Constant to be evaluated to provide acceptable transient response of regulator outlet pressure to system loading. (sec-in ²)
К ₁₆	Check valve flow area when the check valve is open. (in^2)
к ₁₇	Gas constant for helium, R_{He} .(in- $^{\circ}R^{-1}$)
к ₁₈	Ratio of relief value flow rate to propellant tank pressure when the relief value is open. $(in^2 - sec^{-1})$
к ₁₉	Ratio of K'_{19} to the specific heat of helium at constant volume, where K'_{19} represents the ratio of heat input rate of the fuel tank (QF) to the difference in environ- mental temperature and fuel temperature, $K_{19} =$ QF/[CV _{He} (TC - TFUEL)].
K ₂₀	Ratio of specific heats for helium, ($\ell_{\rm He}$).
K ₂₁	Multiplicative inverse of the specific heat of helium at constant volume, CV^{-1} . (°R- in ⁻¹)
K ₂₂	Ratio of specific heats for helium minus one, ($ec{J}_{ ext{He}}$ -1).
к ₂₃	Ratio of the fuel specific heat to the specific heat of helium at constant volume, (CV_F/CV_{He}) .
K ₂₄	Ratio of K'24 to the specific heat of helium at constant volume, where K'24 represents the ratio of heat input rate of the oxidizer tank (Q _O) to the difference in environmental temperature and oxidizer temperature, K24 = $Q_O / [CV_{He} (T_C - T_{OXID})]$.
к ₂₅	Ratio of the oxidizer specific heat to the specific heat of helium at constant volume (Cv_O/Cv_{He}).
K ₂₆	Total volume of the fuel tank.(in ³)
K27	Total volume of the oxidizer tank. (in^3)

K28	The product of average fuel consumption rate and the ratio of mission time to real time. ($lbs-sec^{-1}$)
K ₂₉	The product of average oxidizer consumption rate and the ratio of mission time to real time. ($lbs-sec^{-1}$)
K ₃₀	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, $K_{30} = 1$ and may be deleted.
к ₃₁	The ratio $\Delta PFUEL/\dot{F}$ 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 values are closed. (sec-in ⁻²)
K ₃₂	The ratio $\Delta P_{FUEL}/\dot{F}$ 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)
K ₃₃	The ratio $\Delta P_{FUEL}/F'$ if the cross-feed values are open and the fuel flow path is from the ascent engine to the common (RCS-A/RCS-B) fuel manifold.(sec-in ⁻²)
K ₃₄	The ratio $\Delta P_{FUEL}/\dot{F}$ if the cross-feed values 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.(sec-in ⁻²)
к ₃₅	The ratio $[\Delta P_{OXID} / \dot{O'}] / [\Delta P_{FUEL} / \dot{F'}].$
к ₃₆	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. (\sec^{-1})
K37	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.(sec-1)
к ₃₈	Maximum fuel leakage rate.(lbs-sec ⁻¹)
К39	Greatest plus or minus variation in control temperature about the nominal level of 530 °R, i.e., $530-K_{39} \le T_C \le 530+K_{39}.(R^3)$
к ₄₀	That value of P_{REG} below which the regulator caution warning light will be on.(psia)
K ₄₁	That value of P_{REG} above which the regulator caution warning light will be on if either of the high pressure helium solenoid values are open.(psia)
K ₄₂	That ratio of oxidizer to fuel quantity above which the RCS caution warning light will be on.
K ₄₃	That ratio of oxidizer to fuel quantity below which the RCS caution warning light will be on.
K ₄₄	Maximum plus or minus variation in sensor error for the helium reservoir pressure sensors.(psi)
K ₄₅	Maximum plus or minus variation in sensor error for the helium reservoir temperature sensors, the fuel temperature sensors, or the oxidizer temperature sensors.(°R)

K46		Maximum plus or minus variation in sensor error for the fuel or oxidizer pressure sensors.(psi)
K47		Maximum plus or minus variation in sensor error for the fuel quantity sensors.(lbs)
K48	a N	Maximum plus or minus variation in sensor error for the oxidizer quantity sensors.(lbs)
к ₄₉		Conversion from $^{\circ}R$ to $^{\circ}F$, K49 = 459.7.(R $^{\circ}$)
K 50		The ratio of 100 to the nominal fuel load of a single RCS fuel tank.($\%/lbs$)
к ₅₁		The ratio of 100 to the nominal oxidizer load of a single RCS oxidizer tank.(%/lbs)
K52		Minimum value of temperature shown on the RCS temper ature indicators.(°F)
к ₅₅		Maximum value of helium leakage rate (\dot{W}_{He}_{LEAK}). (lbs-sec ⁻¹)
4.3 BOOL	EAN QUANTITIES	
NOTES: (1) All definitions pertain conditions pertaining t	to $B = 1$. The words which should be substituted to denote to $B = 0$ are shown in parentheses.
(2) To aid in identifying the categorized as indicat	he Boolean quantities on Figure 21, they have been ed below:
	Type	Number Range
	Computer Inputs from Computer Inputs from Computer Outputs to C Computer Outputs to In Booleans Used Interna	CrewB1 to B99InstructorB100 to B199SrewB500 to B599InstructorB600 to B6991 to the ComputerB800 to B999
4.3.1 Crew	v Inputs	

B ₁	High pressure helium squib valves are (are not) being commanded open.
B2	Propellant crossfeed squib valves are (are not) being commanded open.
B ₃	High pressure helium solenoid valve in the primary branch of RCS-A is (is not) commanded open.
B4	High pressure helium solenoid valve in the primary branch of RCS-A is (is not) commanded closed.
B ₅	High pressure helium solenoid valve in the redundant branch of RCS-A is (is not) commanded open.
B ₆	High pressure helium solenoid valve in the redundant branch of RCS-A is (is not) commanded closed.
B7	High pressure helium solenoid valve in the primary branch of RCS-B is (is not) commanded open.

B ₈	High pressure helium solenoid valve in the primary branch of RCS-B is (is not) commanded closed.
Bg	High pressure helium solenoid valve in the redundant branch of RCS-B is (is not) commanded open.
B ₁₀	High pressure helium solenoid valve in the redundant branch of RCS-B is (is not) commanded closed.
B ₁₁	Solenoid valves connecting the ascent engine propellant tanks with the RCS-A propellant manifolds are (are not) commanded open.
B ₁₂	Solenoid valves connecting the ascent engine propellant tanks with the RCS-A propellant manifolds are (are not) commanded closed.
B ₁₃	Solenoid valves connecting the ascent engine propellant tanks with the RCS-B propellant manifolds are (are not) commanded open.
B ₁₄	Solenoid valves connecting the ascent engine propellant tanks with the RCS-B propellant manifolds are (are not) commanded closed.
B ₁₅	RCS-A main propellant solenoid shut-off valves are (are not) commanded open.
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.
B ₁₈	RCS-B main propellant solenoid shut-off valves are (are not) commanded closed.
B ₁₉	TCA isolation solenoid valves for thrusters #1 and #3 are (are not) commanded open.
B ₂₀	TCA isolation solenoid valves for thrusters #1 and #3 are (are not) commanded closed.
B ₂₁	TCA isolation solenoid valves for thrusters #2 and #4 are (are not) commanded open.
B ₂₂	TCA isolation solenoid valves for thrusters #2 and #4 are (are not) commanded closed.
B ₂₃	TCA isolation solenoid valves for thrusters #5 and #8 are (are not) commanded open.
B ₂₄	TCA isolation solenoid valves for thrusters #5 and #8 are (are not) commanded closed.
B ₂₅	TCA isolation solenoid valves for thrusters #6 and #7 are (are not) commanded open.
B ₂₆	TCA isolation solenoid valves for thrusters #6 and #7 are (are not) commanded closed

	B27	TCA isolation solenoid valves for thrusters $#9$ and $#12$ are (are not) commanded open.
	B ₂₈	TCA isolation solenoid values for thrusters $#9$ and $#12$ are (are not) commanded closed.
	B ₂₉	TCA isolation solenoid valves for thrusters #10 and #11 are (are not) commanded open.
	B ₃₀	TCA isolation solenoid valves for thrusters #10 and #11 are (are not) commanded closed.
	B ₃₁	TCA isolation solenoid values for thrusters $#13$ and $#15$ are (are not) commanded open.
	B ₃₂	TCA isolation solenoid valves for thrusters #13 and #15 are (are not) commanded closed.
	B ₃₃	TCA isolation solenoid valves for thrusters #14 and #16 are (are not) commanded open.
	B ₃₄	TCA isolation solenoid valves for thrusters #14 and #16 are (are not) commanded closed.
141	B38	Temperature-pressure monitor select switch is (is not) in "H" or "helium" position.
	B39	Temperature-pressure monitor select switch is (is not) in the "FUEL" position.
	B ₄₀	Temperature-pressure monitor select switch is (is not) in the "OXID" position.
	B ₄₁	Temperature-pressure monitor select switch is (is not) in the "MANIF" position.
	B ₄₂	Fuel-Ox monitor switch is in the Fuel (Oxidizer) position.
	4.3.2 Instructor Inputs	
	B ₁₀₁	The helium leakage rates defined by B_{106} thru B_{108} pertain (do not pertain) to RCS-A.
	B ₁₀₂	The helium leakage rates defined by B_{106} thru B_{108} pertain (do not pertain) to RCS-B.
	B ₁₀₃	The helium leakage rates defined by B_{106} thru B_{108} pertain (do not pertain) to the helium reservoir.
	B ₁₀₄	The helium leakage rates defined by B_{106} thru B_{108} pertain (do not pertain) to the fuel ullage.
	B ₁₀₅	The helium leakage rates defined by B_{106} thru B_{108} pertain (do not pertain) to the oxidizer ullage.
	B ₁₀₆	An incremental helium leakage rate of $1/7$ th of the maximum leakage rate is (is not) present.
	B ₁₀₇	An incremental helium leakage rate of $2/7$ ths of the maximum leakage rate is (is not) present.

	B ₁₀₈	An incremental helium leakage rate of 4/7ths of the maxi- mum leakage rate is (is not) present.
	B109	Pressure regulator failures denoted by B_{111} thru B_{118} pertain to RCS-B (RCS-A).
	B ₁₁₀	Pressure regulator failures denoted by B_{111} thru B_{117} pertain to the redundant (primary) regulator branch.
	B ₁₁₁	One or both regulators are (neither regulator is) failed closed.
	B ₁₁₂	The high-pressure pressure regulator is (is not) failed open.
	B ₁₁₃	The low-pressure pressure regulator is (is not) failed open.
	B ₁₁₄	An incremental change in regulator command pressure of $1/7$ th of the maximum change is (is not) present.
2.99 19	B ₁₁₅	An incremental change in regulator command pressure of $2/7$ ths of the maximum change is (is not) present.
	B ₁₁₆	An incremental change in regulator command pressure of $4/7$ ths of the maximum change is (is not) present.
	B ₁₁₇	The incremental changes due to B_{114} thru B_{116} result in an increase (decrease) in regulator command pressure.
÷	B ₁₁₈	Any two parallel pressure regulators, i.e., one in the primary and one in the redundant branch, are (are not) failed closed.
	B ₁₁₉	The propellant leakage rates defined by B_{123} thru B_{125} pertain (do not pertain) to RCS-A.
	B ₁₂₀	The propellant leakage rates defined by B123 thru B125 pertain (do not pertain) to RCS-B.
	B ₁₂₁	The propellant leakage rates defined by B_{123} thru B_{125} pertain (do not pertain) to fuel leakage.
	B ₁₂₂	The propellant leakage rates defined by B_{123} thru B_{125} pertain (do not pertain) to oxidizer leakage.
	B ₁₂₃	An incremental propellant leakage rate of 1/7th of the maximum leakage rate is (is not) present.
	B ₁₂₄	An incremental propellant leakage rate of 2/7ths of the maximum leakage rate is (is not) present.
	B ₁₂₅	An incremental propellant leakage rate of 4/7ths of the maximum leakage rate is (is not) present.
	B ₁₂₆	The high-pressure helium solenoid value failures defined by B_{127} thru B_{130} pertain to RCS-B (RCS-A).
	B ₁₂₇	The high-pressure helium solenoid valve in the primary branch is (is not) failed open.
	B ₁₂₈	The high-pressure helium solenoid valve in the primary branch is (is not) failed closed.

B ₁₂₉	The high-pressure helium solenoid valve in the redundant branch is (is not) failed open.
B ₁₃₀	The high-pressure helium solenoid valve in the redundant branch is (is not) failed closed.
B ₁₃₁	The main propellant shut-off valves for RCS-A are (are not) failed closed.
B ₁₃₂	The main propellant shut-off valves for RCS-B are (are not) failed closed.
B ₁₃₅	The TCA propellant isolation value failures defined by B136 thru B139 pertain to RCS-B (RCS-A).
B ₁₃₆	The TCA isolation valves in quad #1 are (are not) failed closed.
B ₁₃₇	The TCA isolation valves in quad #2 are (are not) failed closed.
B ₁₃₈	The TCA isolation valves in quad #3 are (are not) failed closed.
B ₁₃₉	The TCA isolation valves in quad #4 are (are not) failed closed.
B ₁₄₀	An incremental change in environmental control tempera- ture of $1/7$ th of the maximum change is (is not) present.
B ₁₄₁	An incremental change in environmental control tempera- ture of $2/7$ ths of the maximum change is (is not) present.
B ₁₄₂	An incremental change in environmental control tempera- ture of $4/7$ ths of the maximum change is (is not) present.
B ₁₄₃	The incremental changes due to B_{140} thru B_{142} result in an increase (decrease) in environmental control temperature.
B ₁₄₄	Sensor failures defined by B_{155} thru B_{159} pertain to RCS-B (RCS-A).
B ₁₄₅	Sensor failures defined by B155 thru B159 pertain (do not pertain) to helium reservoir pressure.
B ₁₄₆	Sensor failures defined by B_{155} thru B_{159} pertain (do not pertain) to helium reservoir temperature.
B ₁₄₇	Sensor failures defined by B_{155} thru B_{159} pertain (do not pertain) to fuel pressure.
B ₁₄₈	Sensor failures defined by B_{155} thru B_{159} pertain (do not pertain) to fuel temperature.
B ₁₄₉	Sensor failures defined by B155 thru B159 pertain (do not pertain) to fuel quantity.
B ₁₅₀	Sensor failures defined by B155 thru B159 pertain (do not pertain) to oxidizer pressure.
B ₁₅₁	Sensor failures defined by B155 thru B159 pertain (do not pertain) to oxidizer temperature.

B ₁₅₂	Sensor failures defined by B_{155} thru B_{159} pertain (do not pertain) to oxidizer quantity.
B ₁₅₃	Sensor failures defined by B_{155} thru B_{159} pertain (do not pertain) to propellant manifold pressure.
B ₁₅₄	Sensor failures defined by B_{155} thru B_{159} pertain (do not pertain) to propellant manifold temperature.
B ₁₅₅	The applicable sensor as defined by B_{144} thru B_{154} provides (does not provide) a zero output.
B ₁₅₆	An incremental error in sensor output of $1/7$ th of the maxi- mum error is (is not) present.
B ₁₅₇	An incremental error in sensor output of $2/7$ ths of the maximum error is (is not) present.
B158	An incremental error in sensor output of 4/7ths of the maxi- mum error is (is not) present.
B ₁₅₉	The error in sensor output defined by B_{156} thru B_{158} results in sensor outputs greater (less) than the true value.
B160	Indicator failures defined by B_{161} thru B_{172} pertain to RCS-B (RCS-A).
B ₁₆₁	Pressure indicator displays (does not display) its minimum value.
^B 162	Temperature indicator displays (does not display) its maximum value.
B ₁₆₃	Quantity indicator remains frozen at its present value(is not failed).
B ₁₆₄	The applicable talk-back indicator defined by B_{165} thru B_{172} is failed on (off).
B ₁₆₅	Talk-back indicator for the high pressure helium solenoid valve in the primary branch is failed in accordance with B_{160} and B_{164} (is not failed).
B ₁₆₆	Talk-back indicator for the high pressure helium solenoid valve in the redundant branch is failed in accordance with B_{160} and B_{164} (is not failed).
B ₁₆₇	Talk-back indicator for the ascent engine propellant feed valves is failed in accordance with B_{160} and B_{164} (is not failed).
B ₁₆₈	Talk-back indicator for the main propellant shut-off valve is failed in accordance with B_{160} and B_{164} (is not failed).
B ₁₆₉	Talk-back indicator for the TCA propellant isolation values for Quadrant No. 1 is failed in accordance with B_{160} and B_{164} (is not failed).
B ₁₇₀	Talk-back indicator for the TCA propellant isolation values for Quadrant No. 2 is failed in accordance with B_{160} and B_{164} (is not failed).

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B ₁₇₁	Talk-back indicator for the TCA propellant isolation valves for Quadrant No. 3 is failed in accordance with B_{160} and B_{164} (is not failed).
^B 172	Talk-back indicator for the TCA propellant isolation valves for Quadrant No. 4 is failed in accordance with B_{160} and B_{164} (is not failed).
B ₁₉₂	Signal to extinguish the improper-valve-sequencing-light is (is not) present.
B ₁₉₃	Signal which enables the instructor to monitor fuel quanti- ties, when the crew is monitoring oxidizer quantities, is (is not) present.
^B 194	Instructor activates (does not activate) momentary switch to display propellant manifold pressures and temperatures.
B ₁₉₅	Instructor activates (does not activate) momentary switch to display oxidizer tank pressures and temperatures.
^B 196	Instructor activates (does not activate) momentary switch to display fuel tank pressures and temperatures.
B ₁₉₇	Instructor activates (does not activate) momentary switch to display helium reservoir pressures and temperatures.
B ₁₉₈	Instructor activates (does not activate) momentary switch to display true values (no sensor or indicator failure effects) of all system display parameters.
B ₁₉₉	Accelerated run signal is (is not) present.
4.3.3 Crew Outputs	
B ₅₀₁	Talk-back indicator indicates that the high pressure helium solenoid valve in the primary branch of RCS-A is open (closed).
B ₅₀₂	Talk-back indicator indicates that the high pressure helium solenoid valve in the redundant branch of RCS-A is open (closed).
B ₅₀₃	Talk-back indicator indicates that the high pressure helium solenoid valve in the primary branch of RCS-B is open (closed).
B ₅₀₄	Talk-back indicator indicates that the high pressure helium solenoid valve in the redundant branch of RCS-B is open (closed).
B ₅₀₅	Talk-back indicator indicates that both solenoid valves connecting the ascent engine propellant tanks with the RCS-A propellant manifolds are open (closed).
B ₅₀₆	Talk-back indicator indicates that both solenoid valves connecting the ascent engine propellant tanks with the RCS-B propellant manifolds are open (closed)

B ₅₀₇		Talk-back indicator indicates that both RCS-A main pro- pellant shut-off valves are open (closed).
B ₅₀₈		Talk-back indicator indicates that both RCS-B main pro- pellant shut-off valves are open (closed).
в ₅₀₉		Talk-back indicator indicates that both TCA isolation valves for thrusters #1 and #3 are open (closed).
B ₅₁₀		Talk-back indicator indicates that both TCA isolation valves for thrusters #2 and #4 are open (closed).
B ₅₁₁		Talk-back indicator indicates that both TCA isolation valves for thrusters #5 and #8 are open (closed).
B ₅₁₂		Talk-back indicator indicates that both TCA isolation valves for thrusters #6 and #7 are open (closed).
в ₅₁₃		Talk-back indicator indicates that both TCA isolation valves for thrusters #9 and #12 are open (closed).
B ₅₁₄		Talk-back indicator indicates that both TCA isolation valves for thrusters #10 and #11 are open (closed).
^B 515		Talk-back indicator indicates that both TCA isolation valves for thrusters #13 and #15 are open (closed).
в ₅₁₆		Talk-back indicator indicates that both TCA isolation valves for thrusters #14 and #16 are open (closed).
B ₅₁₇		Regulator caution warning light for RCS-A is on (off).
B ₅₁₈		Regulator caution warning light for RCS-B is on (off).
B ₅₁₉		RCS-A FAIL caution warning light is on (off).
B ₅₂₀		RCS-B FAIL caution warning light is on (off).
A 3 A	Instructor Outputs	
1.0.1	Instructor Outputs	
^B 601		Talk-back indicator indicates that the high pressure helium solenoid valve in the primary branch of RCS-A is open (closed).
^B 602		Talk-back indicator indicates that the high pressure helium solenoid valve in the redundant branch of RCS-A is open (closed).
B ₆₀₃		Talk-back indicator indicates that the high pressure helium solenoid valve in the primary branch of RCS-B is open (closed).
B ₆₀₄		Talk-back indicator indicates that the high pressure

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

B ₆₀₅	Talk-back indicator indicates that both solenoid valves connecting the ascent engine propellant tanks with the RCS-A propellant manifolds are open (closed).
B ₆₀₆	Talk-back indicator indicates that both solenoid valves connecting the ascent engine propellant tanks with the RCS-B propellant manifolds are open (closed).
B ₆₀₇	Talk-back indicator indicates that both RCS-A main pro- pellant shut-off valves are open (closed).
B ₆₀₈	Talk-back indicator indicates that both RCS-B main pro- pellant shut-off valves are open (closed).
B ₆₀₉	Talk-back indicator indicates that both TCA isolation valves for thrusters #1 and #3 are open (closed).
B ₆₁₀	Talk-back indicator indicates that both TCA isolation values for thrusters $#2$ and $#4$ are open (closed).
B ₆₁₁	Talk-back indicator indicates that both TCA isolation valves for thrusters #5 and #8 are open (closed).
B ₆₁₂	Talk-back indicator indicates that both TCA isolation valves for thrusters #6 and #7 are open (closed).
B ₆₁₃	Talk-back indicator indicates that both TCA isolation valves for thrusters #9 and #12 are open (closed).
B ₆₁₄	Talk-back indicator indicates that both TCA isolation valves for thrusters #10 and #11 are open (closed).
B ₆₁₅	Talk-back indicator indicates that both TCA isolation valves for thrusters #13 and #15 are open (closed).
B ₆₁₆	Talk-back indicator indicates that both TCA isolation valves for thrusters #14 and #16 are open (closed).
B ₆₁₇	Regulator caution warning light for RCS-A is on (off).
B ₆₁₈	Regulator caution warning light for RCS-B is on (off).
B ₆₁₉	RCS-A FAIL caution warning light is on (off).
^B 620	RCS-B FAIL caution warning light is on (off).
B ₆₂₁	Improper-valve-sequencing light is on (off).
B ₆₂₂	Light indicating that the crew monitor select switch is in the OFF position is on (off).
B ₆₂₃	Light indicating that the crew monitor select switch is in the H position is on (off).
B ₆₂₄	Light indicating that the crew monitor select switch is in the FUEL position is on (off).
B ₆₂₅	Light indicating that the crew monitor select switch is in the OXID position is on (off).
^B 626	Light indicating that the crew monitor select switch is in the MANIF position is on (off).

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

В₆₂₈

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
B ₈₀₁ thru B ₈₀₄	II-5
B ₈₀₅ thru B ₈₀₈	II-4
B ₈₀₉	II-12
B ₈₁₀ , B ₈₁₁	II-4
^B 812, ^B 813	II-2
B ₈₁₄ thru B ₈₁₇	II-10
B ₈₁₈ thru B ₈₂₁	II-8
B ₈₂₂	II-12
B ₈₂₃ thru B ₈₃₄	II-10
B ₈₃₅ thru B ₈₃₈	П-13
B ₈₄₀ thru B ₈₄₅	II-13
B ₈₄₆ thru B ₈₅₃	II-12
B ₈₅₄ thru B ₈₆₁	III-4
B ₈₆₂ thru B ₈₇₃	III-3
B ₈₇₄ thru B ₈₉₃	III-1
B ₈₉₆ thru B ₉₀₁	III-2
B ₉₀₂	III-7
в ₉₀₃	II-16
B ₉₀₄ , B ₉₀₅	I-3
B906 thru B925	III-1

В₆₂₇

SECTION I - INPUTS

	CREW INPUTS-(I-1)
B ₁	(RCS pressurize)
B ₂	(Cross-feed valve command)
B ₃ thru B ₁₀	(High pressure helium solenoid valves, "open-close" commands)
B ₁₁ thru B ₁₄	(Ascent propellant feed solenoid valves, "open-close" commands)
B ₁₅ thru B ₁₈	(Main propellant S/O solenoid valves, "open-close" commands)
B_{19} thru B_{34}	(TCA isolation solenoid valves, "open-close" commands)
B_{38} thru B_{41}	(Selector switch position, H-FUEL-OXID-MANIF)
BAD	(Propellant [fuel or oxid] display selection)

INSTRUCTOR INPUTS-(I-2)

HELIUM RESERVOIR-(II-

PRESSURE-PSIA

MIU	
B ₁₀₁ thru B ₁₀₈	(Helium leakage rates for helium storage tanks, fuel tanks, and oxidizer tanks) $% \left(\left({{{\mathbf{x}}_{i}}} \right) \right)$
B109 thru B118	(Pressure regulator)
B ₁₁₉ thru B ₁₂₅	(Fuel and oxidizer leakage rates)
B126 thru B130	(High pressure helium solenoid valves)
B ₁₃₁ , B ₁₃₂	(Main propellant shut-off solenoid valves)
B ₁₃₅ thru B ₁₃₉	(TCA propellant isolation solenoid valves)
B ₁₄₀ thru B ₁₄₃	(Environmental temperature control)
B144 thru B159	(Pressure, temperature, and quantity sensors)
B ₁₆₀ thru B ₁₇₂	(Pressure, temperature, quantity, and talk-back indicators
SWITCH (MOME	NTARY)
B ₁₉₂	(Improper-valve-sequencing light extinguish)
B193	(Alternate fuel-oxid quantity select)
B ₁₉₄ thru B ₁₉₇	(Helium tanks-fuel tanks-oxidizer tanks-manifold select)
B ₁₉₈	(True value select)
SWITCH	
B ₁₉₉	(Accelerated run select)

S&C SIMULATION $\delta t_A, \ \delta t_B$ (Thruster operating time over the last 1/2 seconds) ASCENT ENGINE SIMULATION P FUELASC' P OXIDASC (Ascent propellant tank pressures) TEUELUSC' TOXIDASC (Ascent propellant tank temperature)			SUBSYSTEM INPUTS-(I-3)			
 δt_A, δt_B (Thruster operating time over the last 1/2 seconds) ASCENT ENGINE SIMULATION ^PFUELASC', ^POXIDASC (Ascent propellant tank pressures) ^TFUELUSC', ^TOXID (Ascent propellant tank temperature) 	S&C SIMULA	TION				
ASCENT ENGINE SIMULATION PFUELASC, POXIDASC (Ascent propellant tank pressures) TFUELASC, TOXIDASC (Ascent propellant tank temperature)	ot A, ot B (Th	t_A , δt_B (Thruster operating time over the last 1/2 seconds)				
P _{FUELASC} ' P _{OXID_{ASC}} (Ascent propellant tank pressures)	ASCENT EN	TINE SIMIL	ATION			
^P FUELASC' POXIDASC (Ascent propellant tank pressures)	ASCENT EN	SINE SIMUL				
TEILEL	PFUELASC'	POXIDASC	(Ascent propellant tank pressures)			
	T _{FUEL}	TOXID	(Ascent propellant tank temperature)			
	P . B		(Propellant deplete)			

(i) Each Boolean quantity B_x implies the existence of a Boolean quantity Bx, where: $B_X^* = 1$, if $B_X = 0$; and $B_X^* = 0$, if $B_X = 1$. (ii) Each Boolean quantity B_x implies the existence of an Arithmetic quantity A_, where: $A_x = 1$, if $B_x = 1$; and $A_x = 0$; if $B_x = 0$. (iii) The subscripts "n" and "n-1" refer respectively to the

"anticipated" and "stored" value of the subscripted variable.

NOTE:

 $P_{He_{A}} = \{ [K_{10} W_{He_{A}} T_{He_{A}}]^{-1} - K_{11} \}^{-1}$ WHeA, B THEA, B K12 THEA WHEA + K13 (TC - THEA $P_{He_B} = \{ [K_{10} W_{He_B} T_{He_B}]^{-1} - K_{11} \}^{-1}$ W_{HeA} + K₁₄ TEMPERATURE-°R K₁₂ T_{HeB} W_{HeB} + K₁₃ (T_C - T_{HeB}) (I-2) B101 B102 B103 $T_{He_{A_{n}}} = T_{He_{A_{n-1}}} + (.50) \dot{T}_{He_{A}}$ (2/sec WHen + K14 $T_{He_{B_n}} = T_{He_{B_{n-1}}} + (.50) T_{He_B}$ HELIUM QUANTITY RATE-LBS/SEC (2/sec (II-11) WHerEAK' TC W_{HeA} = - W_{REGA} - A₁₀₁ A₁₀₃ A₈₁₂ W_{HeLEAK} HELIUM QUANTITY-LBS $W_{He_{A_{n}}} = W_{He_{A_{n-1}}} + (.10) W_{He_{A}}$ - W_{REGB} - A₁₀₂ A₁₀₃ A₈₁₃ W_{He_{LE}} P_{HeA,B} T_{HeA,B} W_{HeA,B} $W_{He_{B_n}} = W_{He_{B_{n-1}}} + (.10) W_{He_B}$ LEAKAGE RATE CUTOFF DISCRET $0 \text{ if } P_{\text{He}_{A}} \leq 0$ $\begin{vmatrix} B_{812} = \\ 1 \text{ if } P_{\text{He}_{A}} > 0 \end{vmatrix}$ 0 if P_{He_B} ≤ 0 B₈₁₃ = 1 if P_{HeB} > 0 CHECK VALVE FLOW RATES-LBS/SEC-(II-7) W_{CVFA} = K₁₆ P_{REGA} M_{TFA} / $\sqrt{T_{HeA}}$ $W_{CVF_B} = K_{16} P_{REG_B} M_{T_{F_B}} / \sqrt{T_{He_B}}$ WREGA, B II-6 REGULATOR OUTLET PRESSURE-PSIA-(II-6 $W_{CVO_A} = K_{16} P_{REG_A} M_{TO_A} / \sqrt{T_{He_A}}$ PREGA, B $\mathbf{P}_{\text{REG}_{A_n}} = \mathbf{P}_{\text{REG}_{A_n}} + \mathbf{K}_{15} \left[\mathbf{W}_{\text{REG}_{A}} - \mathbf{W}_{\text{CVF}_{A}} - \mathbf{W}_{\text{CVO}_{A}} \right]$ $W_{CVO_B} = K_{16} P_{REG_B} M_{TO_B} / \sqrt{T_{He_B}}$ $P_{\text{REG}_{B_n}} = P_{\text{REG}_{B_{n-1}}} + K_{15} [W_{\text{REG}_{B}} - W_{\text{CVF}_{B}} - W_{\text{CVO}_{B}}]$ WCVFA, B WCVOA, B √ °R/sec $M_{T_F} = f_1 (P_{REG}/P_{FUEL})$ √R/sec $M_{T_O} = f_1 (P_{REG}/P_{OXID})$ I-8 RELIEF VALVE FLOW RATES-(II-8) $0 \leq M_T \leq 0.21$ PFUELA, B FLOW RATES-LBS/SEC WRVFA = A818 K18 PFUELA POXID $\stackrel{P_{FUEL_{A,B}}}{\longrightarrow} \stackrel{P_{OXID_{A,B}}}{\longrightarrow} \stackrel{W_{RVF_{B}}}{\longrightarrow} = A_{820} K_{18} P_{FUEL_{B}}$ PROPELLANT TANK-(II-9) PRESSURE-PSIA WRVOA = A819 K18 POXIDA K17 WHeFUELA TFUELA W_{RVOB} = A₈₂₁ K₁₈ P_{OXID_B} PFUELA VHeFUELA K₁₇ W_{He_{FUELB}} T_{FUEL} 1 if $P_{FUEL_A} \ge 250 PSIA$ PFUELB V_{He}FUEL_B B818 = 0 if P_{FUELA} < 250 PSIA K₁₇ W_{HeOXIDA} TOXID 1 if $P_{OXID_A} \ge 250 PSIA$ POXIDA V HeOXIDA 0 if POXIDA < 250 PSIA K₁₇ W_{HeOXIDB} TOXID_B 1 if $P_{FUEL_B} \ge 250 PSIA$ POXIDB 0 if P_{FUELB} < 250 PSIA TEMPERATURE-°R + (. 50) T_{FUELA} (2/sec) 1 if $P_{OXID_B} \ge 250 PSIA$ TFUELA = TFUELA + (.50) T_{FUELB} (2/sec) 0 if POXID_D < 250 PSIA TFUELB = TFUELB WRVFA, B + (.50) T_{OXIDA} (2/sec) $T_{OXID_{A_n}} = T_{OXID_{A_{n-1}}}$ $T_{OXID_{B_n}} = T_{OXID_{B_{n-1}}} + (.50) T_{OXID_B}$ (2/sec) WRVOA. B п-10 PROPELLANT TANK RATES-(II-10) ULLAGE QUANTIPY-LBS TEMPERATURE RATES-°R/SEC + (.10) W_{HeFUELA} (10/sec WHeFUELAn-1 WHeFUELA $T_{FUEL_{A}} = \{ K_{19} (T_{C} - T_{FUEL_{A}}) + K_{20} W_{CVF_{A}} T_{He_{A}} + (K_{21} F_{A} P_{FUEL_{A}} / \rho_{F_{A}}) W_{CVO_{A}, B} \}$ + (.10) W_{He_{FUELB}} (10/sec) - $T_{FUEL_A} [W_{CVF_A} + K_{22} W_{RVF_A}] / \{W_{He_{FUEL_A}} + K_{23} F_A\}$ W_{He}_{FUELB} = W_{He}_{FUELBn-1} + (.10) W_{He}OXID_A (10/sec) $T_{FUEL_{B}} = \{K_{19} (T_{C} - T_{FUEL_{B}}) + K_{20} W_{CVF_{B}} T_{He_{B}} + (K_{21} F_{B} P_{FUEL_{B}} / \rho_{F_{B}})$ W_{HeOXIDA} = W_{HeOXIDAn-1} + $T_{FUEL_{B}} [W_{CVF_{B}} + K_{22} W_{RVF_{B}}] / \{W_{He_{FUEL_{B}}} + K_{23} F_{B}\}$ + (.10) W_{Heoxid}P (10/sec) (II-10) W_{HeOXIDB} = W_{HeOXIDB} $(\mathbf{II}-9) \qquad T_{OXID_A} = \{K_{24} (T_C - T_{OXID_A}) + K_{20} W_{CVO_A} T_{He_A} + (K_{21} O_A P_{OXID_A}/\rho_{O_A})\}$ ULLAGE VOLUME-IN³ $V_{\text{He}_{\text{FUEL}_{A}}} = K_{26} - (F_A/\rho_{F_A})$ $T_{OXID_{A}} [W_{CVO_{A}} + K_{22} W_{RVO_{A}}] / \{W_{He_{OXID_{A}}} + K_{25} O_{A}\}$ $V_{\text{He}_{\text{FUEL}_{B}}} = K_{26} - (F_{B}/\rho_{F_{B}})$ $T_{OXID_B} = \{K_{24} (T_C - T_{OXID_B}) + K_{20} W_{CVO_B} T_{He_B} + (K_{21} O_B P_{OXID_B} / \rho_{O_B})\}$ $v_{\rm He_{OXID_A}} = \kappa_{27} - (O_A / \rho_{O_A})$ - $\tilde{\mathbf{T}}_{\text{OXID}_{B}} [\tilde{\mathbf{W}}_{\text{CVO}_{B}} + \tilde{\mathbf{K}_{22}} | \tilde{\mathbf{W}}_{\text{RVO}_{B}}]] / \{ \mathbf{W}_{\text{He}_{\text{OXID}_{B}}} + \tilde{\mathbf{K}}_{25} | \mathbf{o}_{B} \}$ $v_{\text{He}_{OXID_B}} = \kappa_{27} - (O_B / \rho_{O_B})$ LLAGE RATES-LBS/SEC PROPELLANT QUANTITY-LBS W_{He_{FUELA} = W_{CVFA} - W_{RVFA} - A₁₀₁ A₁₀₄ A₈₁₄ W_{He_{LFAK}}} $F_{A_n} = F_{A_{n-1}} + (.50) F_A$ (2/sec) $F_{B_n} = F_{B_{n-1}} + (.50) F_B$ (2/sec) UELD = W_{CVFB} - W_{RVFB} - A₁₀₂ A₁₀₄ A₈₁₆ W_{He}LEAK $O_{A_n} = O_{A_{n-1}} + (.50) O_A$ (2/sec) = W_{CVOA} - W_{RVOA} - A₁₀₁ A₁₀₅ A₈₁₅ W_{He} $O_{B_n} = O_{B_{n-1}} + (.50) O_B$ (2/sec) FA, FB, OA, OB $W_{He_{OXID_{R}}} = W_{CVO_{B}} - W_{RVO_{B}} - A_{102} A_{105} A_{817} W_{He_{LEAK}}$ PROPELLANT DENSITY-LBS/IN3 $\rho_{\mathbf{F}_{\mathbf{A}}} = \mathbf{f}_2 (\mathbf{T}_{\mathbf{FUEL}_{\mathbf{A}}})$ PROPELLANT RATES-LBS/SEC $\mathbf{F}_{A} = - \mathbf{A}_{823}^{*} \left\{ \mathbf{A}_{199}^{*} \left[\mathbf{A}_{852} \, \mathbf{A}_{827} \left(\mathbf{F}_{A}^{'} + \mathbf{A}_{822} \, \mathbf{F}_{B}^{'} \right) + \mathbf{A}_{119} \, \mathbf{A}_{121} \, \mathbf{Q}_{LEAK} \right] + \mathbf{A}_{199} \, \mathbf{K}_{28} \right\}$ $\rho_{FB} = f_2 (T_{FUELB})$ $\mathbf{F}_{B} = -\mathbf{A}_{825}^{*} \{\mathbf{A}_{199}^{*} [\mathbf{A}_{853} \mathbf{A}_{829} (\mathbf{F}_{B}^{'} + \mathbf{A}_{822} \mathbf{F}_{A}^{'}) + \mathbf{A}_{120} \mathbf{A}_{121} \mathbf{Q}_{LEAK}] + \mathbf{A}_{199} \mathbf{K}_{28} \}$ $\rho_{O_A} = f_3 (T_{OXID_A})$ $\dot{O}_{A} = -A_{824}^{*} \{A_{199}^{*} [A_{852} A_{828} (\dot{O}_{A} + A_{822} \dot{O}_{B}) + A_{119} A_{122} K_{30} Q_{LEAK}] + A_{199} K_{29}$ $\rho_{O_B} = f_3 (T_{OXID_B})$ B101, B102, B104, B105 $\dot{O}_{B} = -A_{826}^{*} \{A_{199}^{*} [A_{853} A_{830} (\dot{O}_{B}^{*} + A_{822} O_{A}^{*}) + A_{120} A_{122} K_{30} Q_{LEAK}] + A_{199} K_{29} \}$ B119 THRU B122 (I-2) B199 LOGIC 0 if $P_{FUEL_A} \leq 5 psia$ 1 if P_{FUELA} > 5 psia 0 if $P_{OXID_A} \leq 5$ psia 1 if POXID_A > 5 psia 0 if P_{FUELB} = 5 psia 1 if $P_{FUEL_B} > 5$ psia 0 if $P_{OXID_B} \leq 5$ psia $B_{817} = 1$ if $P_{OXID_B} > 5$ psia $1 \text{ if } \mathbf{F}_{\mathbf{A}} \leq 0$ $B_{823} = 0$ if $F_A > 0$ $| 1 \text{ if } O_A \leq 0$ $B_{824} = 0$ if $O_A > 0$ 1 if $F_B \leq 0$ $B_{825} = 0$ if $F_B > 0$ $B_{826} = \begin{cases} 1 \text{ if } O_B \leq 0 \\ 0 \text{ if } O_B > 0 \end{cases}$ $B_{827_n} = B_{827_{n-1}} + B_{831}$ FA, B OA, B $B_{828_n} = B_{828_{n-1}} + B_{832}$ $B_{829_n} = B_{829_{n-1}} + B_{833}$ $B_{830_n} = B_{830_{n-1}} + B_{834}$ 1 if $P_{FUEL_A} \ge 150 \text{ psia}$ $B_{831} = \begin{cases} 0 & \text{if } P_{FUEL_A} < 150 & \text{psia} \end{cases}$ $B_{832} = \begin{cases} 1 & \text{if } P_{OXID_A} \ge 150 \text{ psia} \\ 0 & \text{if } P_{OXID_A} < 150 \text{ psia} \end{cases}$ $1 \text{ if } P_{\text{FUEL}_{B}} \ge 150 \text{ psia}$ $B_{833} = 0$ if $P_{FUEL_B} < 150$ psia $B_{834} = \begin{cases} 1 \text{ if } P_{OXID_B} \geq 150 \text{ psia} \\ 0 \text{ if } P_{OXID_B} < 150 \text{ psia} \end{cases}$

HELIUM RESERVOIR RATES-(II-2)

TEMPERATURE RATE-°R/SEC

TRAJECTORY DATA FLOW, LMS INTEGRATED OPERATION

5.

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 X axis on the X, Y, Z axes of the I_E or I_M -frame.

Magnitudes of the respective projections of a unit vector along the LEM B-frame Y axis on the X, Y, Z axes of the I_E or I_M -frame.

Magnitudes of the respective projections of a unit vector along the LEM B-frame Z axis on the X, Y, Z axes of the I_E or I_M -frame.

Magnitudes of the respective projections of a unit vector along the LEM E-frame X axis on the X, Y, Z axes of the I_E or I_M -frame.

Magnitudes of the respective projections of a unit vector along the LEM E-frame Y axis on the X, Y, Z axes of the I_E or I_M -frame.

Magnitudes of the respective projections of a unit vector along the LEM E-frame Z axis on the X, Y, Z axes of the I_E or I_M -frame.

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

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

Magnitudes of the respective projections of a unit vector along the I-frame Z axis on the X, Y, Z axes of the J'-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).

^{e1}, ^{e2}, ^{e3}, ^{e4} Corresponding LEM quaternion parameters with LEM attached to CSM. ξ Allowable deviation from -1 for K_{33} and K_{23} and from 1 for K_{31} and K_{21} to allow for computer roundoff, etc. F_{Xe}, F_Y, F_{Ze} Magnitudes of the projections of the LEM's total applied force vector in the X, Y, Z axes of the LEM E-frame. IXX_{FB1}, I_{YY_{FB1}}, I_{ZZ_{FB}L} LEM moments of inertia about the X, Y, Z axes of the LEM FB-frame. $(slug-ft^2)$ IXYFBL, IYZFBL, IXZFBL LEM products of inertia due to a nonsymmetric mass distribution about the XZ, XZ, XY planes of the LEM FB-frame. $(slug-ft^2)$ ^IXX_{FBCSM}, ^IYY_{FBCSM}, ^IZZ_{FBCSM} LEM moments of inertia about the X, Y, Z axes of the CSM FB-frame. $(slug-ft^2)$ I_{XY_{FBCSM}}, I_{YZ_{FBCSM}}, I_{XZ_{FB}CSM} LEM products of inertia due to a nonsymmetric mass distribution about the XZ, XZ, XY planes of the CSM FB-frame. $(slug-ft^2)$ к₃₃ 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. K23 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. к₃₁ 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. к₂₁ 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. L The angle of latitude with respect to the I_E -frame or the J'-frame. (rad) LCORR The LEM angle of latitude with respect to the I_E frame or the J'-frame updated by IMCC data. (rad) ^{1}x 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 FB-frame. Attachment thru upper docking tunnel. (ft) ^{1}z 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) λ

The angle of longitude with respect to the I_E -frame or the J'-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 I_{F} -frame or the J'-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 X, Y, 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 X, Y, Z axes of the CSM B-frame. (rad/sec)

Magnitudes of the projections of the absolute rotational velocity vector of the CSM B-frame on the X, Y, 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 X, Y, 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. (ft/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 X, Y, Z axes of the LEM FB-frame. (lb)

Magnitudes of the projections of the LEM RCS total thrust vector on the X, Y, 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 X, Y, Z axes of the E-frame. (ft/sec)

 $^{\lambda}$ CORR

 $^{\lambda}R$

^{`R}CORR

M_{XFBLEM}, M_{YFBLEM}, M_{ZFBLEM}

M_{XFB}_{CSM}, M_{YFB}_{CSM}, M_{ZFB}_{CSM}

m_I or m

^pbCSM' ^qbCSM' ^rbCSM

^p_b, ^q_b, ^r_b_L

p_p, q_B, r_B

 $\psi_{\mathbf{H}}$

ŕ

rCORR

T_{X_{FBLEM}}, T_{Y_{FBLEM}}, T_{Z_{FB}LEM}

^TX_{FBCSM}, ^TY_{FBCSM}, ^TZ_{FB}CSM

^uH

ue, ve, we

 $\ddot{\mathbf{x}}_{e}, \ \ddot{\mathbf{y}}_{e}, \ \ddot{\mathbf{z}}_{e}$ $\mathbf{x}_{I}, \ \mathbf{y}_{I}, \ \mathbf{z}_{I}$ $\dot{\mathbf{x}}_{I}, \ \dot{\mathbf{y}}_{I}, \ \dot{\mathbf{z}}_{I}$ \vdots $\ddot{\mathbf{x}}_{I}, \ \ddot{\mathbf{y}}_{I}, \ \ddot{\mathbf{z}}_{I}$

 $(X_{I})_{CORR}, (Y_{I})_{CORR}, (Z_{I})_{CORR}$

 $(X_J')_{CORR}, (Y_J')_{CORR}, (Z_J')_{CORR}$

 $\psi_{B \rightarrow I}$, $\theta_{B \rightarrow I}$, $\phi_{B \rightarrow I}$

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

Magnitudes of the projections of LEM or CSM position vector on the X, Y, Z axes of the I_E or I_M -frame. (ft)

Magnitudes of the projections of the LEM or CSM velocity vector on the X, Y, Z axes of the I_E or I_M -frame. (ft/sec)

Magnitudes of the projections of the LEM's total acceleration vector on the X, Y, Z axes of the I_E or I_M -frame. (ft/sec²)

Magnitudes of the projections of the LEM's position vector, updated by IMCC, on the X, Y, Z axes of the I_E or I_M -frame. (ft)

Magnitudes of the projections of the LEM's position vector, updated by IMCC data, on the X, Y, Z axes of the J'-frame. (ft)

Standard Euler angles, due to yaw, pitch, and roll rotations, between LEM or CSM B-frames and the I_E or I_M -frame. (rad)

(b) AMS TO LMS TRAJECTORY DATA FLOW

 \mathbf{F}_{y_e}

Fze

LEM ATTITUDE ACCELERATIONS

 $\ddot{\mathbf{Y}}_{\mathbf{e}} = \frac{\mathbf{F}_{\mathbf{y}_{\mathbf{e}}}}{m}$

pB, qB, rB DIRECTLY AVAILABLE IN LMS

Ÿe

ze

 $\ddot{Y}_{I} = X_{e} b_{21} + Y_{e} b_{22} + Z_{e} b_{23}$

 $\ddot{Z}_{I} = \ddot{X}_{e} b_{31} + \ddot{Y}_{e} b_{32} + \ddot{Z}_{e} b_{33}$

- TO IMCC

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 $e_{4L} = \frac{1}{2} \left[-e_{1CSM} + e_{2CSM} + e_{3CSM} + e_{4CSM} \right]$

dpL

rbL

e1L

e2L

e3L

