GOODYEAR AEROSPACE

(NASA-CR-120261) USERS MANUAL: DYNAMICS OF TWO BODIES CONNECTED BY AN ELASTIC TETHER, SIX DEGREES OF FREEDOM FOREBODY AND FIVE DEGREES OF (Goodyear Aerospace Corp.)

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GOODYEAR AEROSPACE CORPORATION
AKRON 15, OHIO

USERS MANUAL
DYNAMICS OF TWO BODIES CONNECTED
By an Elastic Tether - Six Degrees of Freedom Forebody
And Five Degrees of Freedom Decelerator
(REF. NASA CONTRACT NAS8-29144 S/A1)

By
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&
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GER-16047

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ABSTRACT

One important aspect to recovering a body falling through the atmosphere, is to decelerate and stabilize it. This is usually accomplished by means of a parachute. The design of the recovery system necessitates a knowledge of the dynamics and loads during parachute deployment and inflation. In many cases, a pitch plane analysis will provide adequate information. However, if the body is in general tumbling motion, it is necessary to analyze its motion in three dimensions.

This report contains the equations of motion and a computer program for the dynamics of a six degree of freedom body joined to a five degree of freedom body by a quasilinear elastic tether. The forebody is assumed to be a completely general rigid body with six degrees of freedom; the decelerator is also assumed to be rigid, but with only five degrees of freedom (symmetric about its longitudinal axis). The tether is represented by a spring and dashpot in parallel, where the spring constant is a function of tether elongation. Lagrange's equation is used to derive the equations of motion with the Lagrange multiplier technique used to express the constraint provided by the tether. A computer program is included which provides a time history of the dynamics of both bodies and the tension in the tether.
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The following is a list of variables used in the computer program and in the derivation of the equations as discussed in this report. A brief description and associated units are included.
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<tr>
<td>A a</td>
<td>Distance along the longitudinal axis of the forebody ($X_b$) from the intersection of the body axes to the tether-forebody confluence point, positive towards the nose</td>
<td>(m)</td>
<td>ft</td>
</tr>
<tr>
<td>AA(6,4)</td>
<td>Dummy variables used to express incremental velocities of the forebody in the Runge-Kutta integration</td>
<td>(m/sec)</td>
<td>ft/sec or rad/sec</td>
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<tr>
<td>AALPDE(8)</td>
<td>An array of eight variables signifying angle-of-attack of the forebody used with damping coefficients</td>
<td></td>
<td>deg</td>
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<tr>
<td>AALPFE(16)</td>
<td>An array of sixteen variables signifying angle-of-attack of the forebody used with force coefficients</td>
<td></td>
<td>deg</td>
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<tr>
<td>AALPME(16)</td>
<td>An array of sixteen variables signifying angle-of-attack of the forebody used with moment coefficients</td>
<td></td>
<td>deg</td>
</tr>
<tr>
<td>AALPPE(8)</td>
<td>An array of eight variables signifying angles of attack of the decelerator</td>
<td></td>
<td>deg</td>
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<td>AAM(8)</td>
<td>An array of eight variables signifying Mach number of the forebody used with force and moment coefficients</td>
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<td>AAMD(8)</td>
<td>An array of eight variables signifying Mach number of the forebody used with damping coefficients</td>
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<td>AAMP(8)</td>
<td>An array of eight variables signifying Mach number of the decelerator</td>
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<tr>
<td>AERATO</td>
<td>Suspension Line AE Ratio ($AERATO = AE/AE_{Nylon}$)</td>
<td></td>
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<td>AIPHI</td>
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<td>Number of elements in PPHIE array</td>
<td></td>
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<td></td>
<td></td>
<td>(= 2 to 8)</td>
<td></td>
</tr>
<tr>
<td>AIPHID</td>
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<td>Number of elements in PPHIDE array</td>
<td></td>
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<td></td>
<td></td>
<td>(= 2 to 8)</td>
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<tr>
<td>AJALPD</td>
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<td>Number of elements in AALPDE array</td>
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<td></td>
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<td>(= 8)</td>
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<td></td>
<td></td>
<td>(= 8 or 16)</td>
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<td></td>
<td>(= 8 or 16)</td>
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<td>(= 2 to 8)</td>
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<td>(= 2 to 8)</td>
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<td>ALPE</td>
<td>$\alpha$</td>
<td>Angle-of-attack of the forebody</td>
<td>deg</td>
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<td>ALPPE</td>
<td>$\alpha_p$</td>
<td>Angle-of-attack of the decelerator</td>
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<tr>
<td>AM</td>
<td></td>
<td>Mach number of the forebody</td>
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<td>Larger ordinate of two points on the longitudinal added mass versus $D_o$ log log plot</td>
<td>kg</td>
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<tr>
<td>AMAX2</td>
<td></td>
<td>Smaller ordinate of two points on the longitudinal added mass versus $D_o$ log log plot</td>
<td>kg</td>
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<tr>
<td>AMAY1</td>
<td></td>
<td>Larger ordinate of two points on the lateral added mass versus $D_o$ log log plot</td>
<td>kg</td>
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<tr>
<td>AMAY2</td>
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<td>Small ordinate of two points on the lateral added mass versus $D_0$ log log log plot</td>
<td>kg</td>
</tr>
<tr>
<td>AMP</td>
<td></td>
<td>Mach number of the decelerator</td>
<td></td>
</tr>
<tr>
<td>AP</td>
<td>a, p</td>
<td>Distance along the longitudinal axis of the decelerator ($X_{pb}$) from the c.g. to the tether-decelerator confluence point</td>
<td>(m)</td>
</tr>
<tr>
<td>AX</td>
<td></td>
<td>Exponent of longitudinal added mass equation $(MPAL = \rho_000 * BX * DS ** AX)$</td>
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<td>Exponent of lateral added mass equation $(MPAS = \rho_000 * BY * DS ** AY)$</td>
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<td>B</td>
<td>b</td>
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<td>(m)</td>
</tr>
<tr>
<td>BB(5,4)</td>
<td></td>
<td>Dummy variables used to express incremental velocities of the decelerator in the Runge-Kutta integration</td>
<td>(m/sec)</td>
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<tr>
<td>BX</td>
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<td>Coefficient of longitudinal added mass equation $(MPAL = \rho_000 * BX * DS ** AX)$</td>
<td></td>
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<tr>
<td>BY</td>
<td></td>
<td>Coefficient of lateral added mass equation $(MPAS = \rho_000 * BY * DS ** AY)$</td>
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<tr>
<td>C</td>
<td>c</td>
<td>Distance along the vertical axis of the forebody ($Z_b$) from the intersection of the body axes to the tether-forebody confluence point, positive up</td>
<td>(m)</td>
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<td>FORTRAN</td>
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<td>CA</td>
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<td>Axial force coefficient of forebody</td>
<td></td>
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<tr>
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<td>$C_{AP}$</td>
<td>Axial force coefficient of decelerator</td>
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<td>CAA(8,16,8)</td>
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<td>A three dimensional array of variables signifying axial force coefficients of the forebody corresponding to AAM(8), AALPFE(16), and PPHIE(8)</td>
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<tr>
<td>CCAP(8,8)</td>
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<td>A two dimensional array of 64 variables signifying axial force coefficients of the decelerator with respect to angle of attack corresponding to AAMP(1) thru AAMP(8)</td>
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</tr>
<tr>
<td>CCHI</td>
<td>$C_\chi$</td>
<td>$\cos(\chi)$</td>
<td></td>
</tr>
<tr>
<td>CHID</td>
<td>$C_{\chi_p}$</td>
<td>$\cos(\chi_p)$</td>
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<td>CCLL(8,16,8)</td>
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<td>A three dimensional array of variables signifying rolling moment coefficients of the forebody corresponding to AAM(8), AALPME(16), and PPHIE(8)</td>
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<td>CCLLP(8,8,8)</td>
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<td>A three dimensional array of variables signifying roll damping coefficients of the forebody corresponding to AAMD(8), AALPDE(8), and PPHIDE(8)</td>
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<td>A three dimensional array of variables signifying pitching moment coefficients of the forebody corresponding to AAM(8), AALPME(16), and PPHIE(8)</td>
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<td>FORTRAN STANDARD</td>
<td>DESCRIPTION</td>
<td>METRIC UNITS</td>
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<td>CCLMQ(8,8,8)</td>
<td>A three dimensional array of variables signifying pitch damping coefficients of the forebody corresponding to AAMD(8), AALPDE(8), and PPHIE(8)</td>
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<td>CCLN(8,16,8)</td>
<td>A three dimensional array of variables signifying yaw moment coefficients of the forebody corresponding to AAM(8), AALPME(16), and PPHIE(8)</td>
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<td>CCLNR(8,8,8)</td>
<td>A three dimensional array of variables signifying yaw damping coefficients of the forebody corresponding to AAM(8), AALPDE(8), and PPHIE(8)</td>
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<tr>
<td>CCN(8,16,8)</td>
<td>A three dimensional array of variables signifying normal force coefficients of the forebody corresponding to AAM(8), AALPFE(16), PPHIE(8)</td>
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<td>A two dimensional array of 64 variables signifying the normal force coefficient of the decelerator with respect to angle-of-attack corresponding to AAMP(1) thru AAMP(8)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CCP(3,3) C_{pij}</td>
<td>Elements of transformation matrix from inertial coordinates to body coordinates of the decelerator</td>
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<tr>
<td>FORTRAN</td>
<td>STANDARD</td>
<td>DESCRIPTION</td>
<td>METRIC UNITS</td>
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<tr>
<td>CCRIT</td>
<td>c/cr = damping ratio :: 0.06</td>
<td>c.g.</td>
<td>Center of gravity</td>
</tr>
<tr>
<td>CCY(8,16,8)</td>
<td>A three dimensional array of variables signifying side force coefficients of the forebody corresponding to AAM(8), AALPFE(16), and PPHIE(8)</td>
<td>Drag area of decelerator</td>
<td>(m²)</td>
</tr>
<tr>
<td>CDAP</td>
<td>Drag area of decelerator</td>
<td>c.g.</td>
<td>Center of gravity</td>
</tr>
<tr>
<td>CGAM</td>
<td>C₁</td>
<td>Cos(γ)</td>
<td></td>
</tr>
<tr>
<td>CGAMP</td>
<td>C₁ₚ</td>
<td>Cos(γₚ)</td>
<td></td>
</tr>
<tr>
<td>CHIE</td>
<td>χ</td>
<td>Flight path angle of forebody in horizontal plane, measured from X axis toward Y axis</td>
<td>deg</td>
</tr>
<tr>
<td>CHIPE</td>
<td>χₚ</td>
<td>Flight path angle of decelerator in horizontal plane, measured from X axis toward Y axis</td>
<td>deg</td>
</tr>
<tr>
<td>CLL</td>
<td>Cₗ</td>
<td>Rolling moment coefficient of the forebody</td>
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<tr>
<td>CLLP</td>
<td>Cₗₚ</td>
<td>Rolling damping coefficient of the forebody</td>
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<tr>
<td>CLM</td>
<td>Cₘ</td>
<td>Pitching moment coefficient of the forebody</td>
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<tr>
<td>CLMQ</td>
<td>Cₘ₉</td>
<td>Pitch damping coefficient of the forebody</td>
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<td>CLN</td>
<td>Cₙ</td>
<td>Yawing moment coefficient of the forebody</td>
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<td>Yaw damping coefficient of the forebody</td>
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<tr>
<td>CN</td>
<td>$C_N$</td>
<td>Normal force coefficient of the forebody</td>
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<td>CNP</td>
<td>$C_{Np}$</td>
<td>Normal force coefficient of the decelerator</td>
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<td>COM(20)</td>
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<td>Input variable used to define computer simulation - up to eighty figures</td>
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<tr>
<td>CPHI</td>
<td>$C\phi$</td>
<td>$\cos (\phi)$</td>
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<td>CPHII</td>
<td>$C\phi_i$</td>
<td>$\cos (\phi_i)$</td>
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<td>CPHIPI</td>
<td>$C\phi_{pi}$</td>
<td>$\cos (\phi_{pi})$</td>
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<td>CPSI</td>
<td>$C\psi$</td>
<td>$\cos (\psi)$</td>
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<td>$C\psi_p$</td>
<td>$\cos (\psi_p)$</td>
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<tr>
<td>CS</td>
<td>$C_s$</td>
<td>Damping coefficient of tether</td>
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<td>CSIGP</td>
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<td>Cosine of one half the apex angle of the cone formed by the suspension lines</td>
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<td>$\cos (\theta)$</td>
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<td>$\cos (\theta_p)$</td>
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<td>$C_Y$</td>
<td>Side force coefficient of forebody</td>
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</tr>
<tr>
<td>D</td>
<td>d</td>
<td>Aerodynamic reference length of forebody</td>
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<td>Lu(6,6)</td>
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<td>A two dimensional array of variables signifying the coefficients of the second derivatives in the equations of motion</td>
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<td>DDP(3,3)</td>
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<td>A two dimensional array of variables signifying the coefficients of the second derivatives in the equations of motion of the decelerator</td>
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<td>DELSX</td>
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<td>Total suspension line deflection array</td>
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**METRIC UNITS** | **ENGLISH UNITS**
--- | ---
N-sec | lb-f-sec
m | ft
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<td>DELTX</td>
<td></td>
<td>Total tether line deflection array</td>
<td>m</td>
<td>ft</td>
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<tr>
<td>DLTO</td>
<td></td>
<td>Initial elongation of tether beyond unstretched length. DLTO is negative if the forebody and decelerator confluence points are closer together than LTO</td>
<td>(m)</td>
<td>ft</td>
</tr>
<tr>
<td>DLTX</td>
<td></td>
<td>Tether deflection component in array element (DLX(I)) associated with load PX(I)</td>
<td>m</td>
<td>ft</td>
</tr>
<tr>
<td>DLX</td>
<td></td>
<td>Effective spring deflection array</td>
<td>m</td>
<td>ft</td>
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<tr>
<td>DMD</td>
<td></td>
<td>Rate of change of longitudinal added mass</td>
<td>kg/sec</td>
<td>slug/sec</td>
</tr>
<tr>
<td>Dp</td>
<td>d_p</td>
<td>Aerodynamic reference length of decelerator</td>
<td>(m)</td>
<td>ft</td>
</tr>
<tr>
<td>DPR</td>
<td></td>
<td>Degrees per radian - 57.2957795</td>
<td></td>
<td></td>
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<tr>
<td>DS</td>
<td></td>
<td>Parachute diameter associated with SP</td>
<td>m</td>
<td>ft</td>
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<td>DSP</td>
<td></td>
<td>Parachute projected diameter associated with DS</td>
<td>m</td>
<td>ft</td>
</tr>
<tr>
<td>DSX1</td>
<td></td>
<td>Larger abscissa of two points on the longitudinal added mass versus $D_o$ log log plot</td>
<td>m</td>
<td>ft</td>
</tr>
<tr>
<td>DSX2</td>
<td></td>
<td>Smaller abscissa of two points on the longitudinal added mass versus $D_o$ log log plot</td>
<td>m</td>
<td>ft</td>
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<td>DSY1</td>
<td></td>
<td>Larger abscissa of two points on the lateral added mass versus $D_o$ log log plot</td>
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<td>ft</td>
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<td>DSY2</td>
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<td>Smaller abscissa of two points on the lateral added mass versus $D_0$ log log plot</td>
<td>m</td>
<td>ft</td>
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<tr>
<td>DT</td>
<td></td>
<td>Integration increment</td>
<td>sec</td>
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<tr>
<td>DTP</td>
<td></td>
<td>Number of integrations between data output</td>
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<tr>
<td>DTFL</td>
<td></td>
<td>Number of integrations between data output when $t &lt; TDTC$</td>
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<tr>
<td>DTI</td>
<td></td>
<td>Integration increment when $t &lt; TDTC$</td>
<td>sec</td>
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<tr>
<td>DTT</td>
<td></td>
<td>Estimated parachute system period/12</td>
<td>sec</td>
<td>sec</td>
</tr>
<tr>
<td>DYPR</td>
<td>$q$</td>
<td>Dynamic pressure of forebody</td>
<td>(N/m$^2$)</td>
<td>lb$_f$/ft$^2$</td>
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<tr>
<td>DYPRP</td>
<td>$q_p$</td>
<td>Dynamic pressure of decelerator</td>
<td>(N/m$^2$)</td>
<td>lb$_f$/ft$^2$</td>
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<td>EE(6)</td>
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<td>An array signifying the nonhomogeneous terms in the six equations of motion of the forebody</td>
<td>(N/m)</td>
<td>ft-lb$_f$ or (N)</td>
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<tr>
<td>EPL</td>
<td></td>
<td>Suspension line strain array</td>
<td>m/m</td>
<td>ft/ft</td>
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<tr>
<td>EPS</td>
<td></td>
<td>Number used to check for inconsistent equations in PIVERT Subroutine, $10^{-13}$</td>
<td></td>
<td></td>
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<tr>
<td>EPSI</td>
<td></td>
<td>Number used to check if $Q$ is approaching a singular point $Q = \frac{2n+1}{2}$. If $Q$ is approaching a singular point, the accelerations are kept fixed until this region is passed. EPSI = 0.0000001 freezes the accelerations if $\theta$ is within $0.2^\circ$ of a singular point.</td>
<td></td>
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<tr>
<td>EPT</td>
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<td>Tether line strain array</td>
<td>m/m</td>
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<td>ETAI</td>
<td></td>
<td>Number which controls DT if ( \theta ) is near a singular point. ( \text{ETAI} = 0.00061 ) sets ( DT = \text{DTI}/5, ) if ( \theta ) is within ( 2^\circ ) of a singularity</td>
<td>( \text{(m/sec)} )</td>
<td>ft/sec or ( \text{rad/sec} )</td>
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<td>FF5</td>
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<td>An array signifying the accelerations of the decelerator</td>
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<td>FREQP</td>
<td></td>
<td>Estimated parachute system frequency</td>
<td>( 1/\text{sec} )</td>
<td>( 1/\text{sec} )</td>
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<td>FSULT</td>
<td></td>
<td>Ultimate design factor of safety for parachute</td>
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<td>FX</td>
<td>( F_x )</td>
<td>Generalized force on forebody in ( X ) direction</td>
<td>( (\text{N}) )</td>
<td>( \text{lb}_f )</td>
</tr>
<tr>
<td>FXB</td>
<td>( F_{xb} )</td>
<td>Body force in direction of ( X_b ) due to aerodynamics</td>
<td>( (\text{N}) )</td>
<td>( \text{lb}_f )</td>
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<td>FXP</td>
<td>( F_{xp} )</td>
<td>Generalized force on decelerator in ( X ) direction</td>
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<td>( \text{lb}_f )</td>
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<td>FXPB</td>
<td>( F_{xpB} )</td>
<td>Body force in direction of ( X_{pb} )</td>
<td>( (\text{N}) )</td>
<td>( \text{lb}_f )</td>
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<td>FY</td>
<td>( F_y )</td>
<td>Generalized force on forebody in ( Y ) direction</td>
<td>( (\text{N}) )</td>
<td>( \text{lb}_f )</td>
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<td>FYB</td>
<td>( F_{yb} )</td>
<td>Body force in direction of ( Y_b ) due to aerodynamics</td>
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<td>( \text{lb}_f )</td>
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<td>FYP</td>
<td>( F_{yp} )</td>
<td>Generalized force on decelerator in ( Y ) direction</td>
<td>( (\text{N}) )</td>
<td>( \text{lb}_f )</td>
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<td>FYPB</td>
<td>( F_{ypB} )</td>
<td>Body force in direction of ( Y_{pb} )</td>
<td>( (\text{N}) )</td>
<td>( \text{lb}_f )</td>
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<td>FZ</td>
<td>( F_z )</td>
<td>Generalized force on forebody in ( Z ) direction</td>
<td>( (\text{N}) )</td>
<td>( \text{lb}_f )</td>
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<td>FZB</td>
<td>( F_{zb} )</td>
<td>Body force in direction of ( Z_b ) due to aerodynamics</td>
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<td>( \text{lb}_f )</td>
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<td>FZP</td>
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<td>Generalized force on decelerator in Z direction</td>
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<td>FZPB</td>
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<td>Body force in direction of Z</td>
<td>(N)</td>
<td>lb$_f$</td>
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<td>G</td>
<td>$g$</td>
<td>Acceleration of gravity at Z</td>
<td>(m/sec$^2$)</td>
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<td>GAME</td>
<td>$\gamma$</td>
<td>Flight path angle of forebody in vertical plane</td>
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<td>GAMPE</td>
<td>$\gamma_p$</td>
<td>Flight path angle of decelerator in vertical plane</td>
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<td>GLOAD</td>
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<td>Limit design load factor of forebody</td>
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<td>GO</td>
<td></td>
<td>Acceleration of gravity at earth's surface, 32.17</td>
<td>(m/sec$^2$)</td>
<td>ft/sec$^2$</td>
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<td>HHH</td>
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<td>Altitude below which simulation is ended</td>
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<td>ft</td>
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<td>ICXO</td>
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<td>Canopy roll moment of inertia about its C.M.</td>
<td>kg-m$^2$</td>
<td>slug-ft$^2$</td>
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<td>ICYO</td>
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<td>Canopy pitch moment of inertia about its C.M.</td>
<td>kg-m$^2$</td>
<td>slug-ft$^2$</td>
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<td>IERSW</td>
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<td>Variable signifying whether or not the equations being solved in subroutine PIVEK are consistent</td>
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<td>ILXO</td>
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<td>Parachute lines roll moment of inertia about its C.M.</td>
<td>kg-m$^2$</td>
<td>slug-ft$^2$</td>
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<td>ILYO</td>
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<td>Parachute lines pitch moment of inertia about its C.M.</td>
<td>kg-m$^2$</td>
<td>slug-ft$^2$</td>
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<tr>
<td>IXB</td>
<td>$I_{xb}$</td>
<td>Moment of inertia about X$_b$ axis</td>
<td>(kg-m$^2$)</td>
<td>slug-ft$^2$</td>
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<td>FoTRAN</td>
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<tr>
<td>IXPB</td>
<td>I&lt;sub&gt;xpb&lt;/sub&gt;</td>
<td>Apparent moment of inertia about X&lt;sub&gt;pb&lt;/sub&gt; axis</td>
<td>(kg·m&lt;sup&gt;2&lt;/sup&gt;)</td>
<td>slug-ft&lt;sup&gt;2&lt;/sup&gt;</td>
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<td>IXYB</td>
<td>I&lt;sub&gt;xyb&lt;/sub&gt;</td>
<td>Product of inertia associated with X&lt;sub&gt;b&lt;/sub&gt; and Y&lt;sub&gt;b&lt;/sub&gt; axes</td>
<td>(kg·m&lt;sup&gt;2&lt;/sup&gt;)</td>
<td>slug-ft&lt;sup&gt;2&lt;/sup&gt;</td>
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<td>I&lt;sub&gt;xzb&lt;/sub&gt;</td>
<td>Product of inertia associated with X&lt;sub&gt;b&lt;/sub&gt; and Z&lt;sub&gt;b&lt;/sub&gt; axes</td>
<td>(kg·m&lt;sup&gt;2&lt;/sup&gt;)</td>
<td>slug-ft&lt;sup&gt;2&lt;/sup&gt;</td>
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<tr>
<td>IYB</td>
<td>I&lt;sub&gt;yb&lt;/sub&gt;</td>
<td>Moment of inertia about Y&lt;sub&gt;b&lt;/sub&gt; axis</td>
<td>(kg·m&lt;sup&gt;2&lt;/sup&gt;)</td>
<td>slug-ft&lt;sup&gt;2&lt;/sup&gt;</td>
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<tr>
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<td>I&lt;sub&gt;ypb&lt;/sub&gt;</td>
<td>Apparent moment of inertia about Y&lt;sub&gt;pb&lt;/sub&gt; axis</td>
<td>(kg·m&lt;sup&gt;2&lt;/sup&gt;)</td>
<td>slug-ft&lt;sup&gt;2&lt;/sup&gt;</td>
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<tr>
<td>IYZB</td>
<td>I&lt;sub&gt;yzb&lt;/sub&gt;</td>
<td>Product of inertia associated with Y&lt;sub&gt;b&lt;/sub&gt; and Z&lt;sub&gt;b&lt;/sub&gt; axes</td>
<td>(kg·m&lt;sup&gt;2&lt;/sup&gt;)</td>
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<tr>
<td>IZB</td>
<td>I&lt;sub&gt;zb&lt;/sub&gt;</td>
<td>Moment of inertia about Z&lt;sub&gt;b&lt;/sub&gt; axis</td>
<td>(kg·m&lt;sup&gt;2&lt;/sup&gt;)</td>
<td>slug-ft&lt;sup&gt;2&lt;/sup&gt;</td>
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<td>KS</td>
<td>K&lt;sub&gt;s&lt;/sub&gt;</td>
<td>Tether spring constant</td>
<td>(N/m)</td>
<td>lb&lt;sub&gt;f&lt;/sub&gt;/ft</td>
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<tr>
<td>LS</td>
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<td>Suspension line length</td>
<td>m</td>
<td>ft</td>
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<td>LSCL</td>
<td></td>
<td>Distance along parachute centerline between the confluence point and the projected diameter plane</td>
<td>m</td>
<td>ft</td>
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<tr>
<td>LT</td>
<td>L&lt;sub&gt;T&lt;/sub&gt;</td>
<td>Tether length - distance between confluence points</td>
<td>(m)</td>
<td>ft</td>
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<tr>
<td>LTD</td>
<td>L&lt;sub&gt;T&lt;/sub&gt;</td>
<td>Time rate of change of tether length</td>
<td>(m/sec)</td>
<td>ft/sec</td>
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<td>LTO</td>
<td>L&lt;sub&gt;T0&lt;/sub&gt;</td>
<td>Unstretched tether length</td>
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<td>ft</td>
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<tr>
<td>M</td>
<td>m</td>
<td>Mass of forebody</td>
<td>(kg)</td>
<td>slugs</td>
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<tr>
<td>MP</td>
<td>m&lt;sub&gt;p&lt;/sub&gt;</td>
<td>Real mass of decelerator</td>
<td>(kg)</td>
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<td>MPAL</td>
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<td>Added mass of the decelerator along X&lt;sub&gt;pb&lt;/sub&gt; axis</td>
<td>(kg)</td>
<td>slugs</td>
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<td>MPAS</td>
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<td>Added mass of the decelerator along $Y_{pb}$ or $Z_{pb}$ axis</td>
<td>(kg)</td>
<td>slugs</td>
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<td>MPL</td>
<td>$m_{pl}$</td>
<td>Apparent longitudinal ($X_{pb}$) mass of decelerator</td>
<td>(kg)</td>
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<td>MPS</td>
<td>$m_{ps}$</td>
<td>Apparent side ($Y_{pb}$ or $Z_{pb}$) mass of decelerator</td>
<td>(kg)</td>
<td>slugs</td>
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<tr>
<td>NS</td>
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<td>Number of parachute suspension lines</td>
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<td>NT</td>
<td></td>
<td>Number of tether lines</td>
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<td>OMETRC</td>
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<td>Option variable: if OMETRC = 1, Input and Output are in the metric system. If OMETRC = 0,0 Input and Output are in the English system.</td>
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<td>OMXBE</td>
<td>$\omega_{xb}$</td>
<td>Angular velocity about $X_{b}$ axis</td>
<td>deg/sec</td>
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<tr>
<td>OMYBE</td>
<td>$\omega_{yb}$</td>
<td>Angular velocity about $Y_{b}$ axis</td>
<td>deg/sec</td>
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<tr>
<td>OMZBE</td>
<td>$\omega_{zb}$</td>
<td>Angular velocity about $Z_{b}$ axis</td>
<td>deg/sec</td>
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<tr>
<td>OPAM</td>
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<td>Option variable: if OPAM = 1., added mass of the decelerator ≠ 0; if OPAM = 0., added mass of decelerator = 0</td>
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<td>OPDA</td>
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<td>Option variable: if OPDA = 1., damping moment coefficients of the forebody are read in as arrays; if OPDA = 0, damping moment coefficients are read in as constants</td>
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<td>OPOS</td>
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<td>Option variable: if OPOS = 1., at least one of the c.g. offsets or products of inertia of the forebody ≠ 0.; if OPOS = 0., all c.g. offsets and products of inertia = 0.</td>
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<td>Option variable: if OPPOPT = 1., a plot tape can be made; if OPPOPT = 0., no plot tape is made.</td>
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<td>OPPRIN</td>
<td>Option variable: if OPPRIN = 1., all aerodynamic coefficient arrays are printed out; if OPPRIN = 0, no aerodynamic coefficient arrays are printed out</td>
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<td>OPDT</td>
<td>Option for automatic DT determination (OPDT = 1)</td>
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<td>OPSP</td>
<td>Option for automatic parachute area calculations (OPSP = 1)</td>
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<td>OPSYM</td>
<td>Option variable: if OPSYM = 1., the forebody is aerodynamically symmetric such that ( C_y = C_m = 0 ); if OPSYM = 0, the forebody is not symmetric</td>
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<td>PCTO1</td>
<td>Parachute overinflation at reefed stage 1. (percent/100)</td>
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<td>PCTO1</td>
<td>Parachute overinflation at reefed stage 1. (percent/100)</td>
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<td>PCTO2</td>
<td>Parachute overinflation at reefed stage 2. (percent/100)</td>
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<td>PCTO3</td>
<td>Parachute overinflation at reefed stage 3. (percent/100)</td>
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<td>PHIAE</td>
<td>Aerodynamic roll angle of forebody, ( 0 \leq PHIAE \leq 180^\circ )</td>
<td>deg</td>
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<td>PHIDDE</td>
<td>Angular acceleration about ( X_b ) axis</td>
<td>deg/sec^2</td>
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<td>PHIDE</td>
<td>Angular velocity about ( X_b ) axis</td>
<td>deg/sec^2</td>
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<td>$\phi_i$</td>
<td>Aerodynamic roll angle of forebody, $-180^\circ \leq \phi_i \leq 180^\circ$</td>
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<td>Angle between tether and forebody centerline</td>
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<td>Suspension line load array</td>
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<td>X&lt;sub&gt;b&lt;/sub&gt;</td>
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<td>X&lt;sub&gt;b&lt;/sub&gt; body axis velocity</td>
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<td>ft/sec</td>
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<td>Down range velocity of forebody</td>
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<td>X&lt;sub&gt;p&lt;/sub&gt;</td>
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<td>ft/sec&lt;sup&gt;2&lt;/sup&gt;</td>
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<td>X&lt;sub&gt;pb&lt;/sub&gt; body axis velocity of decelerator</td>
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### Table: Description of Variables

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<th>English Units</th>
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<td>c.g. offset along Y_b axis</td>
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<td>Y_b body axis velocity</td>
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CHAPTER I - INTRODUCTION

The system to be simulated is two rigid bodies joined by an elastic tether. The forebody may have a completely general shape and mass characteristics, and will be free to move with six degrees of freedom (three translational, three rotational). The decelerator is assumed to be symmetric in shape and mass characteristics about its longitudinal (roll) axis, and will be free to move with five degrees of freedom (three translational, two rotational). A frictionless swivel is assumed at the decelerator-tether confluence point. Thus the roll motions of the forebody will not couple with the decelerator. The tether is simulated by a spring and dashpot in parallel. Damping coefficients for tether lines are difficult to obtain; but spring constants for a tether can be found from experimental stress strain curves. Consequently; the damping coefficient is assumed constant, while the spring constant is assumed to be a function of elongation in the computer program, thereby introducing a quasilinear spring.
CHAPTER II DERIVATION OF EQUATIONS OF MOTION

SECTION 1 - COORDINATE SYSTEM

Figure 1 shows the different coordinate systems used to derive the equations of motion. $XYZ$ is an inertial orthogonal coordinate system attached to a flat non-rotating earth. $XYZ$ and $X_p Y_p Z_p$ are orthogonal axes fixed to the forebody and decelerator at "O" and "O_p" respectively. Coordinate systems $XYZ$ and $X_p Y_p Z_p$ translate with the bodies but do not rotate, always remaining parallel to corresponding inertial axes. The displacements $X, Y, Z, X_p, Y_p,$ and $Z_p$, as measured from the origin of $XYZ$, are the six translational degrees of freedom of the two bodies. The reference forebody body axes, longitudinal ($X_b$), lateral ($Y_b$), and vertical ($Z_b$), intersect at "O", the origin of the aerodynamics load system of the forebody. The reference decelerator body axes, longitudinal ($X_{pb}$), lateral ($Y_{pb}$), and vertical ($Z_{pb}$) intersect at "O_p", the c.g. of the decelerator. The variables $X, Y, Z$ are the distances from "O" to the c.g. of the forebody measured positively in the direction of the positive body axes $X_b, Y_b, Z_b$ respectively. For orientation purposes, the reader should position himself as a pilot in an airplane. In this position, $X_b$ is positive toward the nose, $Y_b$ is positive toward the left wing and $Z_b$ is positive up. $\hat{r}_1$ is the vector distance from the intersection of the longitudinal, lateral, and vertical axes of the forebody ("O") to the tether confluence point of the forebody. $\hat{r}_2$ is the vector distance from the c.g. of the decelerator ("O_p") to the tether confluence point of the decelerator; $\hat{r}_2$ lies along $X_{pb}$. 
FIGURE 1 - COORDINATE SYSTEMS
SECTION 2 - EULER ANGLE TRANSFORMATION

In order to specify the angular orientation of a body with reference to a non-rotating coordinate system \((X, Y, Z)\), three successive rotations are made as shown in Figure 2. The first rotation is in the direction, \(-OZ\), such that \(OX\) and \(OY\) are rotated through an angle \(\psi\) into \(Oa\) and \(ON\) respectively. The second rotation is in the direction, \(-ON\), such that \(Oa\) and \(OZ\) are rotated through an angle \(\theta\) into \(OX_b\) and \(Ob\) respectively. The final rotation is about \(OX_b\) such that \(ON\) and \(Ob\) are rotated through an angle \(\phi\) into \(OY_b\) and \(OZ_b\) respectively. The three angular rotations \((\psi, \theta, \phi)\) specify the orientation of the body axes \((X_b, Y_b, Z_b)\) with respect to the inertial axes \((X, Y, Z)\). Again, from a pilot's viewpoint, a positive \(\psi\) is a nose to the right yaw; a positive \(\theta\) is a nose up pitch; and a positive \(\phi\) is a right wing down roll.

The transformation matrix between the body axes and inertial axes is now found by considering one rotation at a time and then combining. The first rotation is given by:

\[
\begin{bmatrix}
Oa \\
ON \\
OZ
\end{bmatrix}
= \begin{bmatrix}
C\psi & -S\psi & 0 \\
S\psi & C\psi & 0 \\
0 & 0 & 1
\end{bmatrix}
\begin{bmatrix}
OX \\
OY \\
OZ
\end{bmatrix} \quad (1)
\]

where \(S\psi = \sin\psi\) and \(C\psi = \cos\psi\).

The second rotation is:

\[
\begin{bmatrix}
OX_b \\
ON \\
Ob
\end{bmatrix}
= \begin{bmatrix}
C\theta & 0 & S\theta \\
0 & 1 & 0 \\
-S\theta & 0 & C\theta
\end{bmatrix}
\begin{bmatrix}
Oa \\
ON \\
OZ
\end{bmatrix} \quad (2)
\]
The final rotation is:

\[
\begin{bmatrix}
O_X^b \\
O_Y^b \\
O_Z^b
\end{bmatrix} =
\begin{bmatrix}
1 & 0 & 0 \\
0 & C\phi & S\phi \\
0 & -S\phi & C\phi
\end{bmatrix}
\begin{bmatrix}
O_X^b \\
O_Y^b \\
O_Z^b
\end{bmatrix}
\]

By substituting Equation (1) into (2) and (2) into (3), the transformation matrix \([C]\) is formed:

\[
\begin{bmatrix}
O_X^b \\
O_Y^b \\
O_Z^b
\end{bmatrix} =
\begin{bmatrix}
\psi'C\theta & -S\psi'C\theta & S\theta \\
-C\psi'S\phi + S\psi'C\phi & S\psi'S\phi + C\psi'C\phi & C\theta S\phi \\
-C\psi'S\phi - S\psi'C\phi & S\psi'S\phi - C\psi'C\phi & C\theta C\phi
\end{bmatrix}
\begin{bmatrix}
O_X \\
O_Y \\
O_Z
\end{bmatrix}
\]

Since \([C]\) is a linear orthogonal (\(\sum_{i=1}^{3} C_{ij} C_{ik} = \delta_{jk}\), \(j, k = 1, 2, 3\)) transformation, its inverse is equal to its transpose. Therefore,

\[
\begin{bmatrix}
O_X \\
O_Y \\
O_Z
\end{bmatrix} =
\begin{bmatrix}
\psi'C\theta & -\psi'S\phi + S\psi'C\phi & -\psi'S\theta C\phi - S\psi'C\phi \\
-\psi'C\theta & \psi'S\phi + C\psi'C\phi & \psi'S\theta C\phi - C\psi'C\phi \\
S\theta & C\theta S\phi & C\theta C\phi
\end{bmatrix}
\begin{bmatrix}
O_X^b \\
O_Y^b \\
O_Z^b
\end{bmatrix}
\]

For the decelerator, there is no rotation about the longitudinal axis. Consequently, the transformation matrix in (4) is simplified by letting \(\phi = 0\). The result is \([C_p]\).

\[
\begin{bmatrix}
O_X_p^b \\
O_Y_p^b \\
O_Z_p^b
\end{bmatrix} =
\begin{bmatrix}
\psi_p C\theta_p & -S\psi_p C\theta_p & S\theta_p \\
S_p & C\psi_p & 0 \\
-C\psi_p S\theta_p & S\psi_p S\theta_p & C\theta_p
\end{bmatrix}
\begin{bmatrix}
O_X_p \\
O_Y_p \\
O_Z_p
\end{bmatrix}
\]
The total angular velocity of the forebody is given by:
\[ \dot{\omega} = \psi \dot{k} - \dot{\phi} \ddot{s}_1 + \dot{\phi} \dot{i}_b \]  
(7)

From the inverse of (3):
\[ \ddot{s}_1 = C\phi \dot{j}_b - S\phi \dot{k}_b \]  
(8)
\[ \ddot{s}_2 = S\phi \dot{j}_b + C\phi \dot{k}_b \]  
(9)

From the inverse of (2):
\[ \ddot{k} = S\theta \dot{i}_b + C\theta \ddot{s}_2 \]  
(10)

Substituting (8), (9), and (10) into (7):
\[ \dot{\omega} = \left[ -\dot{\psi}(S\theta) + \phi \right] \dot{i}_b + \left[ -\dot{\psi}(C\theta S\phi) - \dot{\theta}(C\phi) \right] \dot{j}_b + \left[ -\dot{\psi}(C\theta C\phi) + \dot{\theta}(S\phi) \right] \dot{k}_b \]  
(11)

The components of angular velocity for the forebody are:
\[ \omega_{xb} = -\dot{\psi}(S\theta) + \phi \]  
(12)
\[ \omega_{yb} = -\dot{\psi}(C\theta S\phi) - \dot{\theta}(C\phi) \]  
(13)
\[ \omega_{zb} = -\dot{\psi}(C\theta C\phi) + \dot{\theta}(S\phi) \]  
(14)

Likewise, for the decelerator, the angular velocities are:
\[ \omega_{xpb} = -\dot{\psi}_p(S\theta_p) \]  
(15)
\[ \omega_{ypb} = -\dot{\theta}_p \]  
(16)
\[ \omega_{zpb} = -\dot{\psi}_p(C\theta_p) \]  
(17)
SECTION 3 - KINETIC ENERGY

The kinetic energy of the system is due to the translational and rotational velocities of the forebody and the decelerator. The forebody is completely general in shape, and products of inertia and c.g. offsets will effect the kinetic energy. On the other hand, the decelerator is assumed to be symmetric about the longitudinal axis and the aerodynamic loads are referenced to the c.g. Therefore, all products of inertia and c.g. offsets are zero. The expression for kinetic energy is:

\[ T = \frac{1}{2} m (\dot{\mathbf{v}} \cdot \dot{\mathbf{v}}) + \frac{1}{2} \left[ I_{xb} \dot{\omega}^2_{xb} + I_{yb} \dot{\omega}^2_{yb} + I_{zb} \dot{\omega}^2_{zb} \right] \]

\[ - \left[ I_{yzb} \dot{\omega}^2_{zb} + I_{xzb} \dot{\omega}^2_{zb} + I_{xyb} \dot{\omega}^2_{yb} \right] \]

\[ + m \left[ \dot{x}_{b} (\dot{\omega}_{yb} \dot{y}_{zb} - \dot{\omega}_{zb} \dot{y}_{yb}) + \dot{y}_{b} (\dot{\omega}_{zb} \dot{x}_{zb} - \dot{\omega}_{xb} \dot{x}_{yb}) + \dot{z}_{b} (\dot{\omega}_{xb} \dot{y}_{yb} - \dot{\omega}_{yb} \dot{y}_{xb}) \right] \]

\[ + \frac{1}{2} m_{ps} \dot{x}^2_{pb} + \frac{1}{2} m_{ps} \dot{y}^2_{pb} + \dot{z}^2_{pb} \]

\[ + \frac{1}{2} \left[ I_{xp} \dot{\omega}^2_{xp} + I_{yp} \dot{\omega}^2_{yp} + I_{zp} \dot{\omega}^2_{zp} \right] \]  \hspace{1cm} (18)

In Equation (18), \( m_{ps} \) and \( m_{ps} \) include directional mass terms due to the air enclosed in the canopy, \( I_{xp} \), \( I_{yp} \), and \( I_{zp} \) are apparent mass moments of inertia.
SECTION 4 - POTENTIAL ENERGY

The potential energy of the system is due to the gravitational potential of both bodies and the elastic potential of the tether.

\[
V = mg(z + \bar{x}(S\theta) + \bar{y}(C\theta S\phi) + \bar{z}(C\theta C\phi)) + m_p g z_p + \frac{1}{2} K_s [L_T - L_{TO}]^2
\]  

(19)

\(L_{TO}\) is the unstretched length of the tether; and \(L_T\) is the stretched length of the tether as given by the geometry of the system. Referring to Figure 1:

\[
L_T = |\bar{r}_2 - \bar{r}_1|
\]  

(20)

\(\bar{r}_1\) and \(\bar{r}_2\) are the vectors from the inertial coordinate system \((X, Y, Z)\) to the confluence points of the forebody and decelerator respectively. For the forebody,

\[
\bar{r}_1 = a_i \bar{r}_b + b_j \bar{r}_b + c_k \bar{r}_b
\]  

(22)
a, b, and c are measured along positive body axes \(X_b\), \(Y_b\), and \(Z_b\) respectively. Using the coordinate transformation matrix (4):

\[
\bar{r}_1 = [X + a(C\psi C\theta) + b(-C\psi S\theta S\phi + S\psi C\phi) + c(-C\psi S\theta C\phi - S\psi S\phi)] \mathbf{i} + [Y + a(-S\psi C\theta) + b(S\psi S\theta S\phi + C\psi C\phi) + c(S\psi S\theta C\phi - C\psi S\phi)] \mathbf{j} + [Z + a(S\theta) + b(C\theta S\phi) + c(C\theta C\phi)] \mathbf{k}
\]  

(23)
Similarly for the decelerator:

\[ \dot{x}_2 = x_p \dot{I} + y_p \dot{J} + z_p \dot{K} + \dot{x}_2 \]  

(24)

\[ \dot{x}_2 = a_p \dot{I}_{pb} \]  

(25)

Substituting (25) into (24) and using matrix equation (6),

\[ \dot{x}_2 = [x_p + a_p (C_p \dot{C}_p)] \dot{I} + [y_p + a_p (-S_p \dot{C}_p)] \dot{J} + [z_p + a_p (S_p \dot{C}_p)] \dot{K} \]  

(26)

\[ L_T = [L_T \cdot L_T]^{1/2} \]  

(27)

\[ L_T = \left\{ \left[ x_p + a_p (C_p \dot{C}_p) - x - a(C_p \dot{C}_p) - b(-C_p S_p S_p + S_p C_p) - c(-C_p S_p C_p - S_p S_p) \right]^2 + \left[ y_p + a_p (-S_p \dot{C}_p) - y - a(-S_p \dot{C}_p) - b(S_p S_p S_p + C_p C_p) - c(S_p S_p C_p - C_p S_p) \right]^2 + \left[ z_p + a_p (S_p \dot{C}_p) - z - a(S_p \dot{C}_p) - b(C_p S_p) - c(C_p C_p) \right]^2 \right\}^{1/2} \]  

(28)

Define the variables \( \bar{A}, \bar{B}, \) and \( \bar{C} \) such that:

\[ L_T = \left\{ [\bar{A}]^2 + [\bar{B}]^2 + [\bar{C}]^2 \right\}^{1/2} \]  

(29)

Further on in the derivation it will be necessary to know

the total time derivative of \( L_T \) and the partial derivatives of \( \bar{A}, \bar{B}, \) and \( \bar{C} \) with respect to the generalized coordinates.

\[ \dot{L_T} = \frac{[\bar{A} \dot{\bar{A}} + \bar{B} \dot{\bar{B}} + \bar{C} \dot{\bar{C}}]}{L_T} \]  

(30)
\[ \mathbf{\dot{x}} = \dot{x}_p + a_p \left[ \psi (-S_p \psi C_{\theta_p}) + \dot{\theta}_p (-C_p \psi S_{\theta_p}) \right] - a \left[ \psi (-S_p \psi C_{\theta}) + \dot{\theta} (-C_p \psi S_{\theta}) \right] \]

\[ -b \left[ \psi (S_p S \theta S \phi + C_p C\phi) + \dot{\theta} (C_p C \theta \phi + S_p S \theta \phi) \right] \]

\[ -c \left[ \psi (S_p S \theta C \phi - C_p S \phi) + \dot{\theta} (C_p S \theta C \phi + S_p S \phi - C_p C \phi) \right] \]  

(31)

\[ \mathbf{\dot{\epsilon}} = \dot{\epsilon}_p + a_p \left[ \psi (-C_p \psi C_{\theta_p}) + \dot{\theta}_p (S_p \psi S_{\theta_p}) \right] - \dot{\epsilon} \left[ \psi (-C_p \psi C_{\theta}) + \dot{\theta} (S_p S \theta C_{\phi}) \right] \]

\[ -b \left[ \psi (S_p S \theta C \phi - S_p S \phi + \dot{\theta} (S_p C \theta C \phi + S_p S \theta C \phi) \right] \]

\[ -c \left[ \psi (C_p S \theta C \phi + S_p S \phi) + \dot{\theta} (S_p S \theta \phi - C_p C \phi) \right] \]  

(32)

\[ \mathbf{\dot{\zeta}} = \dot{\zeta}_p + a_p \left[ \dot{\theta}_p (C_{\theta_p}) \right] - 2 - a \left[ \dot{\theta} (C_{\theta}) \right] - b \left[ \dot{\theta} (S \theta S \phi) + \dot{\phi} (S \theta C \phi) \right] \]

\[ -c \left[ \dot{\theta} (-S \theta C \phi) + \dot{\phi} (-C \cos \phi) \right] \]  

(33)

\[ \frac{\partial \mathbf{\dot{A}}}{\partial x} = \frac{\partial \mathbf{\dot{B}}}{\partial y} = \frac{\partial \mathbf{\dot{C}}}{\partial z} = -1 \]  

(34)

\[ \frac{\partial \mathbf{\dot{A}}}{\partial x} = \frac{\partial \mathbf{\dot{B}}}{\partial y} = \frac{\partial \mathbf{\dot{C}}}{\partial z} = 1 \]  

(35)

\[ \frac{\partial \mathbf{\dot{A}}}{\partial y} = \frac{\partial \mathbf{\dot{A}}}{\partial z} = \frac{\partial \mathbf{\dot{A}}}{\partial \chi} = \frac{\partial \mathbf{\dot{A}}}{\partial \zeta} = 0 \]

\[ \frac{\partial \mathbf{\dot{B}}}{\partial x} = \frac{\partial \mathbf{\dot{B}}}{\partial z} = \frac{\partial \mathbf{\dot{B}}}{\partial \chi} = \frac{\partial \mathbf{\dot{B}}}{\partial \zeta} = 0 \]  

(36)

\[ \frac{\partial \mathbf{\dot{C}}}{\partial x} = \frac{\partial \mathbf{\dot{C}}}{\partial y} = \frac{\partial \mathbf{\dot{C}}}{\partial \chi} = \frac{\partial \mathbf{\dot{C}}}{\partial \zeta} = 0 \]  

-11-
\[
\begin{align*}
\frac{\partial A}{\partial \psi} &= a(S\psi C\theta) - b(S\psi S\theta + C\psi C\phi) - c(S\psi S\theta C\phi - C\psi S\phi) \\
\frac{\partial A}{\partial \theta} &= a(C\psi S\theta) + b(C\psi C\theta S\phi) + c(C\psi C\theta C\phi) \\
\frac{\partial A}{\partial \phi} &= b(C\psi S\theta C\phi + S\psi S\phi) - c(C\psi S\theta S\phi - S\psi C\phi) \\
\frac{\partial A}{\partial \psi_p} &= a_p(-S\psi \cdot C\theta) \\
\frac{\partial A}{\partial \theta_p} &= a_p(-C\psi \cdot S\theta) \\
\frac{\partial B}{\partial \psi} &= a(C\psi S\theta) - b(C\psi S\theta S\phi - S\psi C\phi) - c(C\psi S\theta C\phi + S\psi S\phi) \\
\frac{\partial B}{\partial \theta} &= a(-S\psi S\theta) - b(S\psi C\theta S\phi) - c(S\psi C\theta C\phi) \\
\frac{\partial B}{\partial \phi} &= -b(S\psi S\theta C\phi - C\psi S\phi) + c(S\psi S\theta S\phi + C\psi C\phi) \\
\frac{\partial B}{\partial \psi_p} &= a_p(-C\psi \cdot C\theta) \\
\frac{\partial B}{\partial \theta_p} &= a_p(S\psi \cdot S\theta) \\
\frac{\partial C}{\partial \psi} &= 0 \\
\frac{\partial C}{\partial \theta} &= a(-C\theta) + b(S\theta S\phi) + c(S\theta C\phi)
\end{align*}
\]
If the viscous damping force is proportional to the velocity of the particle at which the force acts, an expression analogous to the potential energy of a spring may be used. This function, \( F \), is known as Rayleigh's dissipation function, and is defined as:

\[
F = \frac{1}{2} \sum_{i=1}^{n} C_i \dot{q}_i^2
\]  

For this problem, Rayleigh's damping is considered only in the tether.

\[
F = \frac{1}{2} C_s L_T^2
\]

SECTION 6 - LAGRANGE'S EQUATION

The Lagrange equation for a non-conservative (aerodynamic forces) system with a holonomic (can be expressed as an algebraic expression), scleronomous (independent of time) constraint and Rayleigh's dissipation function (damping in the elastic tether) can be written as:

\[
\frac{\partial C}{\partial \dot{\phi}} = b(-C\dot{\phi}) + c(C\dot{\phi})
\]  

\[
\frac{\partial C}{\partial \psi_p} = 0
\]  

\[
\frac{\partial C}{\partial \theta_p} = a_p(C\theta_p)
\]  

(49)  

(50)  

(51)
In Equation (54), the term \( \lambda \frac{\partial \bar{g}}{\partial q_i} \) expresses the generalized force exerted by the tether on the \( i \)th degree of freedom. The constraint equation is:

\[
\bar{g} = \left( [\bar{A}]^2 + [\bar{B}]^2 + [\bar{C}]^2 \right)^{1/2} - L_T = 0
\]  

(55)

\( Q_i \) is the generalized force due to the aerodynamics.

\( \frac{\partial F}{\partial q_i} \) is the force due to damping in the tether.

The Lagrangian is equal to the total kinetic energy of the system (Equation (18)) minus the total potential energy of the system (Equation (19)). With substitutions from Equations (4), (6) and (12) to (17), the Lagrangian is:

\[
L = \frac{1}{2} m \left( \dot{x}_p^2 + \dot{y}_p^2 + \dot{z}_p^2 \right) + \frac{1}{2} m_p \left[ \dot{x}_p (C_p \dot{C}_p) + \dot{y}_p (-S_p \dot{C}_p + \dot{S}_p) + \dot{z}_p (S_p) \right]^2
\]

\[
+ \frac{1}{2} I_{ps} \left( \dot{C}_p \dot{S}_p + \dot{S}_p \dot{C}_p \right)^2 + \frac{1}{2} I_{px} \left( \dot{\psi} \dot{\psi} + \dot{\phi} \dot{\phi} \right)^2 + I_{xz} [\dot{\psi} \dot{\psi} + \dot{\phi} \dot{\phi}]^2
\]

\[
+ \frac{1}{2} I_{yb} \left( \dot{\psi} \dot{\psi} + \dot{\phi} \dot{\phi} \right)^2 + I_{xb} [\dot{\psi} \dot{\psi} + \dot{\phi} \dot{\phi}]^2
\]

\[
- \left( I_{yrb} \left( \dot{\psi} \dot{\psi} + \dot{\phi} \dot{\phi} \right) \right) I_{xb} [\dot{\psi} \dot{\psi} + \dot{\phi} \dot{\phi}]
\]

\[
+ I_{xyb} [\dot{\psi} \dot{\psi} + \dot{\phi} \dot{\phi}]
\]
\[
+ \frac{1}{2} I_{xp} \left[ -\dot{\psi}^2 (S^2 \theta) + \frac{1}{2} I_{yp} \left[ \dot{\theta}^2 + \dot{\psi}^2 (C^2 \theta) \right] \right] \\
+ m \left[ X(C\psi C\theta) + \dot{Y}(-S\psi C\theta) + \dot{Z}(S\theta) \right] \left[ \ddot{Z}(-\dot{\psi} (C\theta S \phi) - \dot{\theta} (C \phi)) - \ddot{Y}(-\dot{\psi} (C\theta C \phi) + \dot{\theta} (S \phi)) \right] \\
+ [X(-C\psi S S \phi + C\psi C \phi) + \dot{Y}(S\psi S S \phi + C\psi C \phi) + \dot{Z}(C\theta S \phi)] \left[ \ddot{X}(-\dot{\psi} (C\theta C \phi) + \dot{\theta} (S \phi)) - \ddot{Z}(-\dot{\psi} (S \theta) + \dot{\phi}) \right] \\
+ [X(-C\psi S C \phi - S \psi S \phi) + \ddot{Y}(S\psi S C \phi - C\psi S \phi) + \dot{Z}(C\theta C \phi)] \left[ \ddot{Y}(-\dot{\psi} (S \phi) + \dot{\phi}) - \ddot{X}(-\dot{\psi} (C\theta S \phi) - \dot{\theta} (C \phi)) \right] \\
- mg \{ Z + \ddot{X}(S \theta) + \ddot{Y}(C\theta S \phi) + \ddot{Z}(C\theta C \phi) \} - mgz \frac{1}{Z^3} \left[ \frac{1}{2} \frac{L_T}{L_{TO}} \right]^2
\]

Note: \( I_{yp} = I_{xp} \) due to decelerator symmetry.

**SECTION 7 - GENERAL EQUATIONS OF MOTION**

Equation (56) displays all of the generalized coordinates explicitly except those appearing \( \propto L_T \). The terms to be substituted into Equation (54) are now developed.

**X Equation**

\[
\frac{d}{dt} \left( \frac{\partial L}{\partial \dot{X}} \right) = \ddot{X}(m) + \ddot{\psi}(m[X(-S\psi C \theta) + \dddot{Y}(S\psi S C \phi + C\psi C \phi) + \dddot{Z}(S\psi S \theta C \phi - C\psi S \phi)]) \\
+ \ddot{\theta}(m[X(-C\psi S \theta) + \dddot{Y}(-C\psi C S \phi) + \dddot{Z}(-C\psi C \theta C \phi)]) \\
+ \ddot{\phi}(m[\dddot{Y}(-C\psi S C \phi - S \psi S \phi) + \dddot{Z}(C\psi S C \theta S \phi - S \psi S \phi)]) \\
+ \ddot{\psi}(m[X(2S \psi S \theta) + \dddot{Y}(2S \psi C S \phi) + \dddot{Z}(2S \psi C \theta C \phi)])
\]
\[ + \ddot{\psi} \{ m \{ \bar{Y} (2 \psi \theta \phi - 2 \psi \phi) + \bar{z} (-2 \psi \theta \phi + 2 \psi \phi) \} \} + \dot{\theta} \{ m \{ \bar{Y} (-2 \psi \theta \phi + \bar{z} (2 \psi \theta \phi) \} \} \]

\[ + \dot{\psi} \{ m \{ \bar{X} (-C \psi \theta \phi) + \bar{y} (C \psi \theta \phi - S \psi \phi) + \bar{z} (C \psi \theta \phi + S \psi \phi) \} \} \]

\[ + \dot{\theta} \{ m \{ \bar{X} (-C \psi \phi) + \bar{Y} (C \psi \theta \phi - S \psi \phi) + \bar{z} (C \psi \theta \phi + S \psi \phi) \} \} \]

\[ + \dot{\theta} \{ m \{ \bar{X} (-C \psi \phi) + \bar{Y} (C \psi \theta \phi - S \psi \phi) + \bar{z} (C \psi \theta \phi + S \psi \phi) \} \} \]

\[ + \dot{\psi} \{ m \{ \bar{X} (C \psi \theta \phi - S \psi \phi) + \bar{z} (C \psi \theta \phi + S \psi \phi) \} \} \] (57)

\[ \frac{\partial L}{\partial X} = 0 \] (58)

\[ \frac{\partial \bar{q}}{\partial X} = \frac{-A}{L_T} \] (59)

\[ \frac{\partial F}{\partial X} = 0 \] (60)

\[ \textbf{Y Equation} \]

\[ \frac{d}{dt} \left( \frac{\partial L}{\partial \dot{X}} \right) = \bar{Y} \{ m \{ \bar{X} (-C \psi \theta \phi) + \bar{Y} (C \psi \theta \phi - S \psi \phi) + \bar{z} (C \psi \theta \phi + S \psi \phi) \} \} \]

\[ + \dot{\theta} \{ m \{ \bar{X} (S \psi \theta \phi) + \bar{Y} (S \psi \theta \phi + S \psi \phi) + \bar{z} (S \psi \theta \phi + S \psi \phi) \} \} \]

\[ + \dot{\psi} \{ m \{ \bar{X} (-C \psi \theta \phi - C \psi \phi) + \bar{X} (-S \psi \theta \phi - C \psi \phi) \} \} \]

\[ + \psi \{ m \{ \bar{X} (2 \psi \theta \phi) + \bar{Y} (2 \psi \theta \phi + 2 \psi \phi) + \bar{z} (2 \psi \theta \phi + 2 \psi \phi) \} \} \]
\[ +\psi (m [\bar{Y} (2C\psi S\theta C\phi + 2S\psi S\phi) + \bar{Z} (-2C\psi S\theta S\phi + 2S\psi C\phi)]) \]
\[ +\phi (m [\bar{Y} (2S\psi C\theta C\phi) + \bar{Z} (-2S\psi C\theta S\phi)]) \]
\[ +\psi^2 (m [\bar{X} (S\psi C\theta) + \bar{Y} (-S\psi S\theta S\phi - C\psi C\phi) + \bar{Z} (-S\psi S\theta C\phi + C\psi S\phi)]) \]
\[ +\phi^2 (m [\bar{Y} (2S\psi C\theta C\phi) + \bar{Z} (-2S\psi C\theta S\phi)]) \]
\[ +\phi^2 (m [\bar{Y} (-S\psi S\theta S\phi - C\psi C\phi) + \bar{Z} (-S\psi S\theta C\phi + C\psi S\phi)]) \]

\[ \frac{\partial L}{\partial \bar{Y}} = 0 \quad (62) \]
\[ \frac{\partial q}{\partial \bar{Y}} = \frac{-\bar{H}}{L_T} \quad (63) \]
\[ \frac{\partial F}{\partial \bar{Y}} = 0 \quad (64) \]

**Z Equation**

\[ \frac{d}{dt} \left( \frac{\partial L}{\partial \bar{Z}} \right) = \dot{\bar{Z}} (m) + \phi (m [\bar{X} (C\theta C\phi) + \bar{Y} (-S\theta S\phi) + \bar{Z} (-S\theta C\phi)]) \]
\[ +\phi (m [\bar{Y} (C\theta C\phi) + \bar{Z} (-C\theta S\phi)]) \]
\[ +\phi (m [\bar{Y} (-2S\theta C\phi) + \bar{Z} (S\theta S\phi)]) \]
\[ +\phi (m [\bar{X} (-S\theta) + \bar{Y} (-C\theta S\phi) + \bar{Z} (-C\theta C\phi)]) \]
\[ +\phi (m [\bar{Y} (-C\theta S\phi) + \bar{Z} (-C\theta C\phi)]) \]

\[ \text{(65)} \]
\[
\frac{3L}{3z} = -mg \tag{66}
\]
\[
\frac{3\varphi}{3z} = -\frac{C}{L_T} \tag{67}
\]
\[
\frac{3F}{3z} = 0 \tag{68}
\]

**X_p Equation**

\[
\frac{d}{dt}(\frac{3L}{3x_p}) = x_p \left\{ m_p \left[ c^2 \psi_p c^2 \theta_p \right] + m_{ps} \left[ s^2 \psi_p + c^2 \psi_p s^2 \theta_p \right] \right\}
\]
\[
+ \dot{x}_p \left\{ [m_p - m_{ps}] \left[ -\frac{1}{2} S^2 \psi_p c^2 \theta_p \right] \right\}
\]
\[
+ \dot{z}_p \left\{ [m_p - m_{ps}] \left[ \frac{1}{2} C \psi_p s^2 \theta_p \right] \right\}
\]
\[
+ \dot{x}_p \dot{\psi}_p \left\{ [m_p - m_{ps}] \left[ -S \dot{\psi}_p c^2 \theta_p \right] \right\}
\]
\[
+ \dot{x}_p \dot{\theta}_p \left\{ [m_p - m_{ps}] \left[ -C \dot{\psi}_p s^2 \theta_p \right] \right\}
\]
\[
+ \dot{y}_p \dot{\psi}_p \left\{ [m_p - m_{ps}] \left[ -C \dot{\psi}_p c^2 \theta_p \right] \right\}
\]
\[
+ \dot{y}_p \dot{\theta}_p \left\{ [m_p - m_{ps}] \left[ \frac{1}{2} S \dot{\psi}_p s^2 \theta_p \right] \right\}
\]
\[
+ \dot{z}_p \dot{\psi}_p \left\{ [m_p - m_{ps}] \left[ -\frac{1}{2} S \dot{\psi}_p s^2 \theta_p \right] \right\}
\]
\[
+ \dot{z}_p \dot{\theta}_p \left\{ [m_p - m_{ps}] \left[ C \dot{\psi}_p c^2 \theta_p \right] \right\} \tag{69}
\]
\[
\frac{3L}{3x_p} = 0
\]

(70)

\[
\frac{3q}{3x_p} = \frac{A}{L_T}
\]

(71)

\[
\frac{3F}{3x_p} = 0
\]

(72)

\[\gamma_p \text{ ~Equation}\]

\[
\frac{d}{dt} \left( \frac{3L}{3y_p} \right) = \ddot{x}_p \left\{ \left[ m_p - m_{ps} \right] \left[ -\frac{1}{2} S_2 \psi_p C_2^2 \theta_p \right] \right\} + \dot{y}_p \left\{ m_p \left[ S_2^2 \psi_p C_2^2 \theta_p \right] + m_{ps} \left[ C_2^2 \psi_p + S_2^2 \psi_p S_2^2 \theta_p \right] \right\} + \dot{z}_p \left\{ m_p \left[ m_p - m_{ps} \right] \left[ -\frac{1}{2} S_2 \psi_p S_2 \theta_p \right] \right\} + \dot{x}_p \dot{\theta}_p \left\{ \left[ m_p - m_{ps} \right] \left[ -C_2 \psi_p C_2^2 \theta_p \right] \right\} + \dot{x}_p \dot{\theta}_p \left\{ \left[ m_p - m_{ps} \right] \left[ \frac{1}{2} S_2 \psi_p S_2 \theta_p \right] \right\} + \dot{y}_p \dot{\theta}_p \left\{ \left[ m_p - m_{ps} \right] \left[ S_2 \psi_p C_2^2 \theta_p \right] \right\} + \dot{y}_p \dot{\theta}_p \left\{ \left[ m_p - m_{ps} \right] \left[ -S_2 \psi_p S_2 \theta_p \right] \right\} + \dot{z}_p \dot{\theta}_p \left\{ \left[ m_p - m_{ps} \right] \left[ -\frac{1}{2} \psi_p S_2 \theta_p \right] \right\} + \dot{z}_p \dot{\theta}_p \left\{ \left[ m_p - m_{ps} \right] \left[ -\psi_p C_2 \theta_p \right] \right\}
\]

(73)
\[ \frac{\partial l}{\partial y_p} = 0 \quad (74) \]

\[ \frac{\partial q}{\partial y_p} = \frac{B}{L_T} \quad (75) \]

\[ \frac{\partial F}{\partial \dot{y}_p} = 0 \quad (76) \]

**Z_p Equation**

\[ \frac{d}{dt} \left( \frac{\partial L}{\partial \ddot{z}_p} \right) = \dot{x}_p \left[ m_{pl} - m_{ps} \right] \left( \frac{1}{2} C_{p_{\theta}} S_{2\theta_p} \right) \]

\[ + \dot{y}_p \left[ m_{ps} - m_{ps} \right] \left( -\frac{1}{2} S_{\psi} S_{2\theta_p} \right) \]

\[ + \ddot{z}_p \left[ m_{pl} S_{2\theta_p} \right] + m_{ps} \left[ C_{2\theta_p} \right] \]

\[ + \dot{x}_p \dot{\psi} \left[ m_{pl} - m_{ps} \right] \left( -\frac{1}{2} S_{\psi} S_{2\theta_p} \right) \]

\[ + \dot{x}_p \dot{\theta} \left[ m_{pl} - m_{ps} \right] \left[ C_{\psi} C_{2\theta_p} \right] \]

\[ + \dot{y}_p \dot{\psi} \left[ m_{pl} - m_{ps} \right] \left( -\frac{1}{2} C_{\psi} S_{2\theta_p} \right) \]

\[ + \dot{y}_p \dot{\theta} \left[ m_{pl} - m_{ps} \right] \left( -S_{\psi} C_{2\theta_p} \right) \]

\[ + \ddot{z}_p \dot{\theta} \left[ m_{pl} - m_{ps} \right] \left[ S_{2\theta_p} \right] \] \quad (77)
\[ \frac{\partial L}{\partial z_p} = -m_p g \]  
(78)

\[ \frac{\partial q}{\partial z_p} = \frac{C}{L_T} \]  
(79)

\[ \frac{\partial F}{\partial z_p} = 0 \]  
(80)

\[ \psi \quad \text{Equation} \]

\[ \frac{d}{dt} \left( \frac{\partial L}{\partial \psi} \right) = \ddot{\psi} \{ [I_{xb}(S^2) + I_{yrb}(S^2) + I_{zrb}(C^2)] (C^2) + I_{yrb}(-C^2S2\phi) + [I_{zrb}(C\phi) + I_{yrb}(S\phi)] (-S2\theta) \} \]

\[ + \ddot{\phi} \{ [(I_{yrb} - I_{zrb})(1/2S2\phi) - I_{yrb}(C2\phi)] (C\theta) + [I_{zrb}(S\phi) - I_{yrb}(C\phi)] (S\theta) \} \]

\[ + \dddot{\psi} \{ [I_{xb}(-S\theta) + [I_{zrb}(C\phi) + I_{yrb}(S\phi)] (C\theta) \} \]

\[ + \dot{\psi} \{ [m[\bar{X}(-S\psi C\phi) + \bar{Y}(S\psi S\theta S\phi + C\psi C\phi)] + \bar{Z}(S\psi S\theta C\phi - C\psi S\phi)] \} \]

\[ + \dddot{\phi} \{ [I_{yrb}(-C\phi) - I_{yrb}(S\phi) + S\psi C\phi] - \bar{X}(C\psi S\theta C\phi - S\psi S\phi)] \} \]

\[ + \ddot{\psi} \{ [I_{zrb}(S^2) - I_{zrb}(C^2) + I_{yrb}(S2\phi)] (S2\theta) - [I_{zrb}(C\phi) + I_{yrb}(S\phi)] (2C2\theta) \} \]

\[ + \ddot{\phi} \{ [I_{yrb}(1/2S2\phi) - I_{yrb}(C2\phi)] (C^2) + [I_{zrb}(S\phi) - I_{yrb}(C\phi)] (S2\theta) \} \]

\[ + \dddot{\psi} \{ [-I_{xb}, \bar{Y}(I_{yrb}(-C\phi) - I_{yrb}(S\phi)] (C2\phi) + I_{yrb}(2S2\phi)] (C\theta) \} \]
\[ + \theta^2 \left( \left( I_{yx} - I_{zb} \right) \left( -\frac{1}{2} S_2 \phi \right) + I_{yzb} (C2\phi) \right) \left( S_2 \phi \right) + I_{xz} \left( C\phi \phi \right) - I_{xyb} \left( C\phi \phi \right) \]

\[ + \phi^2 \left( I_{xyb} \left( C\phi \phi \right) - I_{xz} \left( C\phi \phi \right) \right) \]

\[ + \dot{x}_\psi \left( m \left[ -X(C\psi C\phi) - \bar{Y}(C\psi S\phi + S\psi C\phi) - \bar{Z}(C\psi S\phi + S\psi C\phi) \right] \right) \]

\[ + \dot{y}_\psi \left( m \left[ X(S\psi S\phi) + Y(S\psi C\phi) + \bar{Z}(S\psi C\phi + C\psi C\phi) \right] \right) \]

\[ + \dot{z}_\psi \left( m \left[ Y(S\psi C\phi) + \bar{Y}(C\psi C\phi) + \bar{Z}(C\psi C\phi) \right] \right) \]

\[ + \dot{\phi}_\psi \left( m \left[ -Y(-C\psi S\phi - S\psi \phi) + \bar{Z}(-C\psi S\phi + S\psi \phi) \right] \right) \]

(81)

\[ \frac{\partial L}{\partial \psi} = \dot{x}_\psi \left( m \left[ -X(C\psi C\phi) - \bar{Y}(C\psi S\phi + S\psi C\phi) - \bar{Z}(C\psi S\phi + S\psi C\phi) \right] \right) \]

\[ + \dot{x}_\psi \left( m \left[ X(S\psi S\phi) + Y(S\psi C\phi) + \bar{Z}(S\psi C\phi + C\psi C\phi) \right] \right) \]

\[ + \dot{y}_\psi \left( m \left[ Y(S\psi C\phi) + \bar{Y}(C\psi C\phi) + \bar{Z}(C\psi C\phi) \right] \right) \]

\[ + \dot{z}_\psi \left( m \left[ -Y(-C\psi S\phi - S\psi \phi) + \bar{Z}(-C\psi S\phi + S\psi \phi) \right] \right) \]

(82)

\[ \frac{\partial q}{\partial \psi} = \left( A \frac{\partial A}{\partial \psi} + B \frac{\partial B}{\partial \psi} \right) / L_T \]

(83)

\[ \frac{\partial P}{\partial \psi} = 0 \]

(84)
\[ \frac{d}{dt} \left( \frac{2L}{o} \right) = \dot{\psi}\left[ (I_{yb} - I_{zb}) \left( \frac{1}{2} S2\phi \right) - I_{yzb} (C2\phi) \right] (S\theta) - \left[ I_{xyb} (C\phi) - I_{xz} (S\phi) \right] (S\theta) \]

\[ + \ddot{\theta} \left[ I_{yb} (C2\phi) + I_{zb} (S2\phi) + I_{yzb} (S2\phi) \right] \]

\[ + \dot{\phi} \left[ I_{xyb} (C\phi) - I_{xz} (S\phi) \right] \]

\[ \ddot{x} \left[ m \left[ \dot{x} (-C\psi S\theta) + \dot{y} (-C\psi C\theta S\phi) + \dot{z} (-C\psi C\theta C\phi) \right] \right] \]

\[ + \ddot{y} \left[ m \left[ \dot{x} (S\psi S\theta) + \dot{y} (S\psi C\theta S\phi) + \dot{z} (S\psi C\theta C\phi) \right] \right] \]

\[ + \ddot{z} \left[ m \left[ \dot{x} (C\theta) + \dot{y} (-S\theta S\phi) + \dot{z} (-S\theta C\phi) \right] \right] \]

\[ + \ddot{\theta} \left[ \left( I_{yb} - I_{zb} \right) \left( \frac{1}{2} S2\phi \right) + I_{yzb} (C2\phi) \right] (S\theta) \]

\[ + \ddot{\phi} \left[ \left( I_{yb} - I_{zb} \right) (C2\phi) + I_{yzb} (C2\phi) \right] \]

\[ + \dot{\phi} \left[ I_{yb} (C2\phi) - I_{xz} (S2\phi) + I_{yzb} (2S2\phi) \right] \]

\[ + \dot{\phi} \left[ \left( I_{yb} - I_{zb} \right) (C2\phi) + I_{yzb} (C2\phi) \right] \]

\[ + \dot{\phi} \left[ \left( I_{yb} - I_{zb} \right) (C2\phi) - I_{xz} (S2\phi) + I_{yzb} (2C2\phi) \right] \]

\[ + \dot{\phi} \left[ \left( I_{yb} - I_{zb} \right) (C2\phi) - I_{xz} (S2\phi) \right] \]

\[ \dot{\phi} \left[ \left( I_{yb} - I_{zb} \right) (C2\phi) - I_{xz} (S2\phi) \right] \]

\[ + \dot{x} \left[ m \left[ \dot{x} (C\psi S\theta) + \dot{y} (S\psi C\theta S\phi) + \dot{z} (S\psi C\theta C\phi) \right] \right] \]

\[ + \dot{y} \left[ m \left[ \dot{x} (C\psi S\theta) + \dot{y} (S\psi C\theta S\phi) + \dot{z} (S\psi C\theta C\phi) \right] \right] \]

\[ + \dot{z} \left[ m \left[ \dot{x} (C\psi S\theta) + \dot{y} (S\psi C\theta S\phi) + \dot{z} (S\psi C\theta C\phi) \right] \right] \]
\[
+\dot{y} \delta \{ m [ x ( \psi C \theta ) + y ( - S \psi S S \phi ) + z ( - S \psi S C \phi ) ] \} \\
+\dot{y} \phi \{ m [ y ( S \psi C C \phi ) + z ( - S \psi C 8 \phi ) ] \} \\
+\ddot{z} \delta \{ m [- x ( \psi S ) - y ( C 8 \phi ) - z ( C 8 C \phi ) ] \} \\
+\ddot{z} \phi \{ m [ y ( - S \theta C \phi ) + z ( S \theta S \phi ) ] \} \\
\frac{\partial L}{\partial \dot{\theta}} = \dot{\psi} \{ [ I_{x b} - I_{y b} ][ S \theta S 2 \phi ] + [ - I_{x y b} ( C \phi ) + I_{x z b} ( S \theta ) ] ( C \theta ) + [ I_{y z b} ] ( S \theta C 2 \phi ) \} \\
+\dot{\phi} \{ [ I_{x b} ] ( - C \theta ) + [ I_{x z b} ( C \phi ) + I_{x y b} ( S \theta ) ] ( - S \theta ) \} \\
+\ddot{\psi} \{ [ I_{x b} ] [ S \theta S ^ 2 \phi ] - [ I_{x z b} ( S 2 \phi ) ] ( 1 / 2 ) S 2 \theta ) + [ I_{x z b} ( C \phi ) + I_{x y b} ( S \theta ) ] ( C 2 \theta ) \} \\
+\dot{\psi} \{ m [ x ( S \psi S \theta ) + y ( C \psi C 8 S \phi ) + z ( S \psi C 8 C \phi ) ] \} \\
+\dot{y} \delta \{ m [ x ( - C \psi C \theta ) + y ( C \psi S S \phi ) + z ( C \psi C 8 C \phi ) ] \} \\
+\dot{y} \phi \{ m [ y ( - C \psi C 8 C \phi ) + z ( C \psi C 8 C \phi ) ] \} \\
+\ddot{y} \delta \{ m [ x ( C \psi S \theta ) + y ( C \psi C 8 S \phi ) + z ( C \psi C 8 C \phi ) ] \} \\
+\ddot{y} \phi \{ m [ y ( C \psi C \theta ) + z ( - S \psi S S \phi ) + z ( - S \psi S C \phi ) ] \} \\
+\dot{\phi} \{ m [ y ( S \psi C C \phi ) + z ( - S \psi C 8 \phi ) ] \} \\
+\ddot{z} \delta \{ m [ x ( - S \theta ) + y ( - C 8 \phi ) + z ( - C 8 C \phi ) ] \} \\
+\ddot{z} \phi \{ m [ y ( - S \theta C \phi ) + z ( S \theta S \phi ) ] \} \\
- m g [ x ( C \theta ) + y ( - S \theta S \phi ) + z ( - S \theta C \phi ) ] \\
\]
\[
\frac{\partial q}{\partial \theta} = \left( A \frac{\partial \theta}{\partial \phi} + B \frac{\partial \phi}{\partial \phi} + C \frac{\partial \phi}{\partial \theta} \right) / L_T
\]  

(37)

\[
\frac{\partial F}{\partial \phi} = 0
\]  

(38)

\textbf{Equation}

\[
\frac{d}{dt} \left( \frac{2L}{\partial \phi} \right) = \psi \left( -x_b (\text{C}) + I_{xﺏ} (\text{COS}) + I_{xﺏ} (\text{COS}) \right) \\
+ \dot{\psi} \left( I_{xﺏ} (\text{C}) - I_{xﺏ} (\text{S}) \right) + \ddot{\phi} (x_b) \\
+ \dddot{x} \left( m \left[ \psi (\text{COS} \text{COS} - \text{COS} \text{S}) + \psi (\text{COS} \text{COS} - \text{COS} \text{S}) \right] \right) \\
+ \dddot{y} \left( m \left[ \psi (\text{COS} \text{S}) + \psi (\text{COS} \text{COS} - \text{COS} \text{S}) \right] \right) \\
+ \dddot{z} \left( m \left[ \psi (\text{COS} \text{S}) + \psi (\text{COS} \text{COS} - \text{COS} \text{S}) \right] \right) \\
+ \psi \dot{x} \left( I_{xﺏ} (\text{C}) + I_{xﺏ} (\text{S}) \right) (\text{COS}) \\
+ \psi \dot{x} \left( I_{xﺏ} (\text{C}) - I_{xﺏ} (\text{S}) \right) (\text{S}) \\
+ \psi \dot{x} \left( I_{xﺏ} (\text{C}) - I_{xﺏ} (\text{C}) \right) (\text{C}) \\
+ \psi \dot{x} \left( I_{xﺏ} (\text{C}) - I_{xﺏ} (\text{S}) \right) (\text{C}) \\
+ \psi \dot{x} \left( I_{xﺏ} (\text{C}) - I_{xﺏ} (\text{C}) \right) (\text{S}) \\
+ \psi \dot{x} \left( m \left[ \psi (\text{COS} \text{COS} - \text{COS} \text{S}) + \psi (\text{COS} \text{COS} - \text{COS} \text{S}) \right] \right) \\
+ \psi \dot{x} \left( m \left[ \psi (\text{COS} \text{COS} - \text{COS} \text{S}) + \psi (\text{COS} \text{COS} - \text{COS} \text{S}) \right] \right) \\
+ \psi \dot{x} \left( m \left[ \psi (\text{COS} \text{COS} - \text{COS} \text{S}) + \psi (\text{COS} \text{COS} - \text{COS} \text{S}) \right] \right)
\]
\[
\begin{align*}
\frac{\delta L}{\delta \phi} &= \hat{\psi} \{ \left[ (I_{y_{b}} - I_{z_{b}})(C2\phi) + I_{y_{zb}}(2S2\phi) \right] (C\theta) + [I_{xy_{b}}(S\phi) + I_{xz_{b}}(C\phi)] (S\theta) \\
&+ \hat{\phi} \{ [I_{xy_{b}}(C\phi) - I_{xz_{b}}(S\phi)] (C\theta) \} \\
&+ \hat{\phi} \{ -I_{xy_{b}}(S\phi) - I_{xz_{b}}(C\phi) \} \\
&+ \psi^{2} \{ \left[ (I_{y_{b}} - I_{z_{b}}) \left( \frac{1}{2} S2\phi \right) - I_{y_{zb}}(C2\phi) \right] (C^2\theta) + [I_{xz_{b}}(S\phi) - I_{xy_{b}}(C\phi)] \left( \frac{1}{2} S2\phi \right) \} \\
&+ \delta^{2} \{ (I_{y_{b}} - I_{z_{b}}) \left( \frac{1}{2} S2\phi \right) + I_{y_{zb}}(C2\phi) \} \\
&+ \dot{\psi} \{ m \left[ Y(S\psi S\phi - C\psi S\phi) + Z(-S\psi S\phi - C\psi C\phi) \right] \} \\
&+ \dot{\phi} \{ m \left[ Y(-C\psi C\phi) + Z(C\psi C\phi) \right] \} \\
&+ \dot{\phi} \{ m \left[ Y(C\psi S\phi - S\psi C\phi) + Z(C\psi S\phi + S\psi S\phi) \right] \} \\
&+ \dot{\psi} \{ m \left[ Y(C\psi S\phi + S\psi C\phi) + Z(-C\psi S\phi + S\psi S\phi) \right] \} \\
&+ \dot{\psi} \{ m \left[ Y(S\psi C\phi) + Z(-S\psi C\phi) \right] \} \\
&+ \dot{\phi} \{ m \left[ Y(-S\psi S\phi - C\psi C\phi) + Z(-S\psi S\phi + C\psi S\phi) \right] \}
\end{align*}
\]
\[
\frac{\partial \bar{q}}{\partial \phi} = \left( \frac{A}{\partial \phi} \frac{\partial A}{\partial \phi} + \frac{B}{\partial \phi} \frac{\partial B}{\partial \phi} + \frac{C}{\partial \phi} \frac{\partial C}{\partial \phi} \right) / L_T
\] (91)

\[
\frac{\partial F}{\partial \phi} = 0
\] (92)

\text{\underline{\psi Equation}}

\[
\frac{d}{dt} \left( \frac{\partial L}{\partial \dot{\psi}_p} \right) = \dot{\psi}_p \left( I_{xp} (S^2 \theta_p) + I_{yp} (C^2 \theta_p) \right) + \dot{\psi}_p \theta_p \left( [I_{xp} - I_{yp} \chi S2\theta_p] \right)
\] (93)

\[
\frac{\partial L}{\partial \dot{\psi}_p} = \dot{x}_p \left( \frac{[m_p - m_{ps}]}{2} \left[ -S2\theta_p \right] \right)
\] (94)
Substituting Equations (101) to (104) into (54) yields:

\[ \lambda = -\left[K_s(L_T - L_{TO}) + C_s \dot{L}_T \right] \]  

(105)

The value of \( \lambda \) in Equation (54) is now defined and is expressed in terms of the eleven generalized coordinator and their time derivatives. The eleven simultaneous, nonlinear, coupled differential equations of motion are then written as:

1. **X Equation**

\[ \dddot{X}(m) + \dddot{\psi}\left(\bar{X} C_{12} + \bar{Y} C_{22} + \bar{Z} C_{32}\right) \]

\[ + \dddot{\varphi}\left(\bar{X}(\text{C}\psi\phi) + \bar{Y}(\text{C}\psi\phi) + \bar{Z}(\text{C}\psi\phi)\right) \]

\[ + \dddot{\theta}\left(\bar{X}(\text{C}\psi\phi) + \bar{Y}(\text{C}\psi\phi) + \bar{Z}(\text{C}\psi\phi)\right) \]

\[ = \dddot{\psi}(\text{-2m}\left[\bar{X}(\text{S}\psi\phi) + \bar{Y}(\text{S}\psi\phi) + \bar{Z}(\text{S}\psi\phi)\right] + \dddot{\varphi}(\text{-2m}\left[\bar{X} C_{31} - \bar{Z} C_{21}\right]) \]
\[ + \dot{\theta} \{2m[\bar{Y}(\psi C \theta C \phi) - \bar{Z}(C \psi \theta S \phi)]\} + \dot{\psi} \{2m[\bar{X}_{C1} + \bar{Y}_{C21} + \bar{Z}_{C31}]\} + \dot{\phi} \{m[\bar{X}_{C11} + \bar{Y}_{C21} + \bar{Z}_{C31}]\} \]

\[ + \dot{\theta} \{2m[\bar{X}_{C11} + \bar{Y}(-C \psi S \theta S \phi) + \bar{Z}(-C \psi \theta C \phi)]\} + \dot{\psi} \{2m[\bar{Y}_{C21} + \bar{Z}_{C31}]\} \]

\[ + [K_S (L_T - L_{TO}) + C_S L_T] \left[ \bar{A}/L_T \right] + F_X \]

(106)

2. \textit{Y Equation}

\[ \ddot{Y}(m) + \dot{\psi} \{-m[\bar{X}_{C11} + \bar{Y}_{C21} + \bar{Z}_{C31}]\} + \dot{\phi} \{2m[\bar{Y}_{C31} + \bar{Z}_{C21}]\} \]

\[ + \dot{\theta} \{2m[\bar{X}(S \psi \theta S \phi) + \bar{Y}(C \psi S \theta S \phi) + \bar{Z}(C \psi \theta C \phi)]\} + \dot{\phi} \{2m[\bar{Y}_{C12} + \bar{Y}_{C22} + \bar{Z}_{C32}]\} \]

\[ + \dot{\phi} \{2m[\bar{X}_{C12} + \bar{Y}(S \psi S \phi) + \bar{Z}(S \psi \theta C \phi)]\} + \dot{\phi} \{2m[\bar{Y}_{C22} + \bar{Z}_{C32}]\} \]

\[ + [K_S (L_T - L_{TO}) + C_S L_T] \left[ \bar{E}/L_T \right] + F_Y \]

(107)

3. \textit{Z Equation}

\[ \ddot{Z}(m) + \dot{\psi} \{m[\bar{X}(C \theta) + \bar{Y}(-S \theta S \phi) + \bar{Z}(-S \theta C \phi)]\} + \dot{\phi} \{m[\bar{Y}_{C33} - \bar{Z}_{C23}]\} \]

\[ = \dot{\phi} \{2m[\bar{Y}(S \theta C \phi) - \bar{Z}(S \theta S \phi)]\} + \dot{\phi} \{2m[\bar{X}_{C13} + \bar{Y}_{C23} + \bar{Z}_{C33}]\} \]

\[ + \dot{\phi} \{2m[\bar{Y}_{C23} + \bar{Z}_{C33}]\} + [K_S (L_T - L_{TO}) + C_S L_T] \left[ \bar{E}/L_T \right] - mg + F_z \]

(108)
4. \( \dot{X} \) Equation

\[
\ddot{X}_p \left\{ m_p \left[ c^2 \psi_p c^2 \theta_p \right] + m_p \left[ s^2 \psi_p c^2 \theta_p \right] \right\} \\
+ \dot{Y}_p \left\{ \left[ m_p \left[ -\frac{1}{2} s^2 \psi_p c^2 \theta_p \right] \right] + \dot{Z}_p \left\{ \left[ m_p \left[ \frac{1}{2} c^2 \psi_p \right] \right] \right\} \\
= \left[ m_p \left[ \frac{1}{2} s^2 \psi_p c^2 \theta_p \right] \right] + \dot{X}_p \left\{ \left[ c^2 \psi_p c^2 \theta_p \right] \right\} + \dot{Y}_p \left\{ c^2 \psi_p c^2 \theta_p \right\} \\
+ \dot{Y}_p \left\{ \frac{1}{2} s^2 \psi_p c^2 \theta_p \right\} + \dot{Z}_p \left\{ \frac{1}{2} c^2 \psi_p \right\} + \dot{Z}_p \left\{ -c^2 \psi_p c^2 \theta_p \right\} \\
- \left[ K_s \left( L_T - L_{TO} \right) + C_s \dot{L}_T \right] \frac{\bar{A}}{L_T} + F_{xp} \tag{109}
\]

5. \( \dot{Y} \) Equation

\[
\ddot{Y}_p \left\{ m_p \left[ -\frac{1}{2} s^2 \psi_p c^2 \theta_p \right] \right\} + \dot{Y}_p \left\{ m_p \left[ s^2 \psi_p c^2 \theta_p \right] + m_p \left[ c^2 \psi_p c^2 \theta_p \right] \right\} \\
+ \dot{Z}_p \left\{ \left[ m_p \left[ -\frac{1}{2} s^2 \psi_p c^2 \theta_p \right] \right] \right\} \\
= \left[ m_p \left[ \frac{1}{2} s^2 \psi_p c^2 \theta_p \right] \right] + \dot{X}_p \left\{ \left[ c^2 \psi_p c^2 \theta_p \right] \right\} + \dot{Y}_p \left\{ -s^2 \psi_p c^2 \theta_p \right\} \\
+ \dot{Y}_p \left\{ s^2 \psi_p c^2 \theta_p \right\} + \dot{Z}_p \left\{ \frac{1}{2} c^2 \psi_p \right\} + \dot{Z}_p \left\{ s^2 \psi_p c^2 \theta_p \right\} \\
- \left[ K_s \left( L_T - L_{TO} \right) + C_s \dot{L}_T \right] \frac{\bar{B}}{L_T} + F_{yp} \tag{110}
\]
6. \( z \) Equation

\[
\ddot{y}_p \left( [m_{\rho p} - m_{ps}] [\dot{\omega}_p S \theta_p] + \dot{\gamma}_p \left( [m_{\rho p} - m_{ps}] \frac{1}{2} \dot{\psi}_p S \theta_p \right) \right) + \dot{z}_p \left( \frac{m_{\rho p}}{t_p} \right) S \theta_p + m_{ps} \left( \frac{C^2 \theta_p}{t_p} \right)
\]

\[
= \left[ m_{\rho p} - m_{ps} \right] \left( \dot{\gamma}_p \left( \frac{1}{2} S \psi_p \dot{S} \theta_p \right) \right) + \dot{x}_p \left( -C \psi_p C \dot{\theta}_p \right) + \dot{y}_p \left( \frac{1}{2} C \psi_p S \theta_p \right) + \dot{z}_p \left( S \psi_p C \dot{\theta}_p \right) + [K_S (L_T - L_{TO}) + C_s \vec{z}] \left[ \vec{C} / L_T \right] - m_g + P_{zp}
\]

(111)

7. \( \psi \) Equation

\[
\ddot{\psi} \left[ I_{xb}(S^2 \theta) + [I_{yb}(S^2 \phi) + I_{zxb}(C^2 \phi)] \right] + \dot{\psi} \left[ \left[ (I_{yb} - I_{zxb}) \left( \frac{1}{2} S2 \phi \right) - I_{zxb}(C2 \phi) \right] \right] 
\]

\[
+ \left[ I_{zxb}(C \phi) - I_{zxb}(S \phi) \right] \left( -S \theta \right) + \psi \left( \left[ \left( I_{yb} - I_{zxb} \right) \left( \frac{1}{2} S2 \phi \right) - I_{zxb}(C2 \phi) \right] \right] 
\]

\[
+ \left[ I_{zxb}(S \phi) - I_{zxb}(C \phi) \right] \left( S \theta \right) + \psi \left( \left[ \left( I_{yb} - I_{zxb} \right) \left( \frac{1}{2} S2 \phi \right) - I_{zxb}(C2 \phi) \right] \right] 
\]

\[
= \ddot{\psi} \left( [I_{xb} - I_{yb}(S^2 \phi)] - I_{zxb}(C^2 \phi) + I_{zxb}(S2 \phi) \right) \left( -S \theta \right) + \left[ I_{zxb}(C \phi) \right]
\]

\[
+ \dot{x_{yb}}(S \phi) \left( 2C \theta \right) + \psi \left( \left[ \left( I_{yb} - I_{zxb} \right)(S2 \phi) - I_{zxb}(2C \phi) \right] \right) \left( -C^2 \theta \right)
\]

\[
+ \left[ I_{zxb}(S \phi) - I_{zxb}(C \phi) \right] \left( -S \theta \right) + \psi \left( \left[ \left( I_{yb} - I_{zxb} \right)(C \phi) - I_{zxb}(S2 \phi) \right] \right) \left( S \theta \right)
\]

\[
+ \ddot{\theta} \left( \left[ \left( I_{yb} - I_{zxb} \right)(S \phi) - I_{zxb}(C \phi) \right] \right) \left( \dot{\theta} \right) - I_{zxb}(2C \phi) \left( S \theta \right) - I_{zxb}(C2 \phi) + \dot{x_{yb}}(S \phi)
\]

\[
+ \ddot{\theta} \left( \left[ (I_{yb} - I_{zxb})(S \phi) - I_{zxb}(C \phi) \right] \right) \left( \dot{\theta} \right) - I_{zxb}(2C \phi) \left( S \theta \right) - I_{zxb}(C2 \phi) + \dot{x_{yb}}(S \phi)
\]

\[
-32-
\]
8. \( \theta \) Equation

\[
\ddot{\psi} \{ (I_{yb} - I_{zb}) - I_{yb} (S2) \} - \dot{I}_{yb} (C2) \} + [I_{xyb} (C2) - I_{xyz}(S)] (S2) \}
\]

\[
\ddot{\psi} \{ I_{yb} (C2) + I_{zb} (S2) - I_{yzb} (S2) \} + \dot{\phi} \{ I_{xyb} (C2) - I_{xyz}(S) \}
\]

\[
= \ddot{\psi} \{ I_{xb} + (I_{yb} - I_{zb}) (S2) + I_{yzb} (S2) \} (S2) + [I_{xyz}(C2) + I_{xyb} (S2)] (S2)\}
\]

\[
+ \ddot{\psi} \{ (I_{yb} - I_{zb}) (S2) - I_{yzb} (2C2) \}
\]

\[
+ \psi \{ 2(I_{yb} - I_{zb} (S2)) - I_{yzb} (C2 - I_{xyz} (S2)) \} + [I_{xyz}(C2) + I_{xyb} (S2)] - mg [\bar{X}(C2) + \bar{Y}(S2) + \bar{Z} (S2)]
\]

\[
- [K_s (L_T - L_T) + I_{xyz} (S2)] \{ \bar{A} \ddot{A} + \bar{B} \ddot{B} + \bar{C} \ddot{C} \} / L_T + Q_\theta
\]

9. \( \phi \) Equation

\[
\ddot{\psi} \{ I_{yb} C_2 - \bar{Z} C_2 \} + \ddot{\psi} \{ I_{yb} C_2 - \bar{Z} C_2 \} + \ddot{\psi} \{ I_{yb} C_2 - \bar{Z} C_2 \}
\]

\[
+ \psi \{ -I_{xb} C_2 + L_T \} + I_{xyb} C_2 + I_{xyz} (C3) \} + \dot{\phi} \{ I_{xyb} (C2) - I_{xyz} (S2) \} + \ddot{\phi} \{ I_{xb} \}
\]
\[ \psi_p \{ [I_{xb} + (I_{yb} - I_{zb}) (C_2 \phi) + I_{yzb} (2S_2 \phi)] (C_\theta) + [I_{xyb} (S_\phi) + I_{xzb} (C_\phi)] (2S_\theta) \} \\
+ \psi^2 \{ [(I_{yb} - I_{zb}) (1/2) S_2 \phi) - I_{yzb} (C_2 \phi)] (C^2 \theta) + [I_{xzb} (S_\phi) - I_{xyb} (C_\phi)] (1/2) S_2 \theta \} \\
+ \psi^2 \{ (I_{yb} - I_{zb}) (-1/2) S_2 \phi + I_{yzb} (C_2 \phi) \} - mg [\bar{\nu} C_{33} - \bar{z} C_{23}] \\
- [K_s (L_T - L_{T0}) + C_s \dot{L}_T] \left[ \frac{\bar{A}}{\partial \phi} + \bar{B} \frac{\partial \bar{E}}{\partial \phi} + \bar{C} \frac{\partial \bar{C}}{\partial \phi} \right] / L_T + \psi + Q_{\psi} \] (114)

10. \( \psi_p \) Equation

\[ \dot{\psi}_p \{ I_{xp} (S^2 \phi_p^p) + I_{yp} (1/2) \} \]

\[ = \dot{\psi}_p \{ (I_{xp} - I_{yp}) (-S_2 \phi_p^p) \} + m_p \dot{z}_p - m_{ps} \{ \dot{x}_p \dot{z}_p \} \psi_p \{ -C_2 \psi_p (S^2 \phi_p^p) \} \\
+ \dot{x}_p \dot{z}_p \left[ \frac{1}{2} \right] \psi_p \{ -S_2 \phi_p (S^2 \phi_p^p) \} + \dot{y}_p \dot{z}_p \left[ \frac{1}{2} \right] \psi_p \{ -S_2 \phi_p (S^2 \phi_p^p) \} + \dot{z}_p \dot{z}_p \left[ \frac{1}{2} \right] \psi_p \{ -S_2 \phi_p (S^2 \phi_p^p) \} \\
- [K_s (L_T - L_{T0}) + C_s \dot{L}_T] \left[ \frac{\bar{A}}{\partial \phi_p} + \bar{B} \frac{\partial \bar{E}}{\partial \phi_p} + \bar{C} \frac{\partial \bar{C}}{\partial \phi_p} \right] / L_T + \psi + Q_{\psi} \] (115)

11. \( \theta_p \) Equation

\[ \dot{\theta}_p \{ I_{yp} \} \]

\[ = \dot{\theta}_p \{ (I_{xp} - I_{yp}) \left( \frac{1}{2} S_2 \phi_p^p \right) \} + [m_p \dot{z}_p - m_{ps}] \{ \dot{x}_p \dot{z}_p \} \left[ \frac{1}{2} S_2 \psi_p (S_2 \phi_p^p) \right] + \dot{x}_p \dot{z}_p \left[ \frac{1}{2} C_2 \psi_p (S_2 \phi_p^p) \right] + \dot{y}_p \dot{z}_p \left[ \frac{1}{2} C_2 \psi_p (S_2 \phi_p^p) \right] + \dot{z}_p \dot{z}_p \left[ \frac{1}{2} C_2 \psi_p (S_2 \phi_p^p) \right] \\
- [K_s (L_T - L_{T0}) + C_s \dot{L}_T] \left[ \frac{\bar{A}}{\partial \phi_p} + \bar{B} \frac{\partial \bar{E}}{\partial \phi_p} + \bar{C} \frac{\partial \bar{C}}{\partial \phi_p} \right] / L_T + \psi + Q_{\theta} \] (116)
SECTION 8 - SIMPLIFIED EQUATIONS OF MOTION

Equations (106) to (116) are for the most general situation possible, and as a result, are quite lengthy. Under some circumstances, these equations can be simplified. If this can be accomplished, a significant decrease in computer time will be realized. The first simplification occurs if the forebody's aerodynamic (body) reference axes are principal axes. In this case $\overline{\alpha} = \overline{\beta} = \overline{\gamma} = 0$ and $I_{xyb} = I_{xzb} = I_{yzb} = 0$. Equations (106), (107), (108), (112), (113), and (114) become:

\[
\ddot{x}(m) = \left[ K_s (L_T^2 - L_{TO}^2) + C_s \dot{L}_T \right] \left[ \overline{\beta}/L_T \right] + F_x
\]

\[
\ddot{y}(m) = \left[ K_s (L_T^2 - L_{TO}^2) + C_s \dot{L}_T \right] \left[ \overline{\beta}/L_T \right] + F_y
\]

\[
\ddot{z}(m) = \left[ K_s (L_T^2 - L_{TO}^2) + C_s \dot{L}_T \right] \left[ \overline{\beta}/L_T \right] - mg + F_z
\]

\[
\dot{\psi} \{ I_{xb} (s^2) + [I_{yb} (s^2) + I_{zb} (c^2)] (C^2) \} + \dot{\phi} \{ (I_{yb} - I_{zb}) (1/2) C \theta S 2 \phi \} + \dot{\psi} \{ -I_{xb} C_{13} \}
\]

\[
= \dot{\psi} \{ [I_{xb} - I_{yb} (s^2)] (C^2) \} + \dot{\phi} \{ (I_{yb} - I_{zb}) (-C^2 S 2 \phi) \}
\]

\[
+ \dot{\phi} \{ [I_{xb} - (I_{yb} - I_{zb}) (C 2 \phi)] (C 9) \} + \dot{\phi} \{ (I_{yb} - I_{zb}) (1/2) S C S 2 \phi) \}
\]

\[
- \left[ K_s (L_T^2 - L_{TO}^2) + C_s \dot{L}_T \right] \left[ \overline{\alpha} \frac{3A}{3\psi} + \overline{\beta} \frac{3B}{3\psi} \right] / L_T + Q_\psi
\]

\[
\dot{\psi} \{ (I_{yb} - I_{zb}) (1/2) C \theta S 2 \phi) \} + \dot{\phi} \{ (I_{yb} (C^2) + I_{zb} (s^2)) \}
\]

\[
= \dot{\psi} \{ [I_{xb} + (I_{yb} - I_{zb}) (C 2 \phi)] (C 9) \} + \dot{\phi} \{ (I_{yb} - I_{zb}) (S 2 \phi) \}
\]

\[
\dot{\psi} \{ [I_{xb} - (I_{yb} (s^2)) - I_{zb} (C^2)] (1/2) S 2 \phi) \}
\]
The above six equations of motion have not only been shortened, but they also have been uncoupled in the translational accelerations making them easier to solve. The second simplification involves the decelerator degrees of freedom. If the added masses of the decelerator are ignored \((m_{\text{pe}} = m_{\text{ps}} = m_\text{p})\), Equations (109), (110), (111), (115), and (116) become:

\[
\begin{align*}
\ddot{x}_p (m_\text{p}) &= -[K_s (L_T - L_{TO}) + C_s \dot{L}_T] (A/L_T) + F_{xp} \\
\ddot{y}_p (m_\text{p}) &= -[K_s (L_T - L_{TO}) + C_s \dot{L}_T] (B/L_T) + F_{yp} \\
\ddot{z}_p (m_\text{p}) &= -[K_s (L_T - L_{TO}) + C_s \dot{L}_T] (C/L_T) - m_\text{p} g + F_{zp}
\end{align*}
\]
Like the simplified equation for the forebody, the decelerator equations have also shortened. Furthermore, they have completely uncoupled in the second derivatives making numerical integration easy.
SECTION 9 - GENERALIZED FORCES - AERODYNAMICS

The nonconservative forces acting on the forebody are due to aerodynamics. The aerodynamics and the convention used in this report apply to the Space Shuttle Solid Rocket Booster (S.R.B.). If a different body is to be simulated, the aerodynamic coefficients and possibly the convention used to define them, would change.

For the S.R.B., the aerodynamics are a function of roll angle, angle-of-attack, and Mach number. The angle-of-attack is measured from the total velocity vector to the positive longitudinal axis \((X_b)\) as shown in Figure 3.

\[
\alpha = \tan^{-1}\left[ \frac{\dot{Y}_b^2 + \dot{Z}_b^2}{\dot{X}_b} \right]
\]  

(128)

The normal force coefficient, \(C_N\), is in the plane formed by the velocity vector and the longitudinal axis, and is perpendicular to the longitudinal axis \((X_b)\). The roll angle, \(\phi_i\), is then measured from the normal force coefficient to the \(Z_b\) body axis. The axial force coefficient is defined as usual, positive in the negative \(X_b\) direction. Finally, the side force coefficient is perpendicular to the \(X_b\) body axis and to the normal force, such that the directions of \(C_A', C_N, C_Y\) form a right-handed orthogonal coordinate system. Mathematically, the aerodynamics roll angle is given by:

\[
\phi_i = \tan^{-1}\left[ -\dot{Y}_b / -\dot{Z}_b \right]
\]  

(129)
FIGURE 3 - AERODYNAMIC COORDINATE SYSTEM
The positive directions of the moment coefficients are shown in Figure 3 as double arrows. Damping and coefficients are about the body axes \((X_b, Y_b, Z_b)\). Aerodynamic body axes forces are given as:

\[
F_{xb} = -q S C_A
\]

\[
F_{yb} = qS[-C_Y C \phi_i + C_N S \phi_i]
\]

\[
F_{zb} = qS[C_Y S \phi_i + C_N C \phi_i]
\]

The body axes forces are converted to inertial axis force using the elements of \([C]\), Equation 4.

\[
F_x = F_{xb} C_{11} + F_{yb} C_{21} + F_{zb} C_{31}
\]

\[
F_y = F_{xb} C_{12} + F_{yb} C_{22} + F_{zb} C_{32}
\]

\[
F_z = F_{xb} C_{13} + F_{yb} C_{23} + F_{zb} C_{33} - mg
\]

Body axes torques are:

\[
T_{xb} = qSd[C_\chi + C_{\chi p} \frac{\omega_{xb} d}{2v}]
\]

\[
T_{yb} = qSd[-C_m C \phi_i - C_n S \phi_i + C_m \frac{\omega_{yb} d}{2v}]
\]

\[
T_{zb} = qSd[C_m S \phi_i - C_n C \phi_i + C_n \frac{\omega_{zb} d}{2v}]
\]

The body axis torques are transformed to generalized torques using Equations (5) and (1) and noting sign conventions.
The aerodynamics of a decelerator (parachute) are not well known because a parachute is not a rigid body, and does not lend itself to easily obtainable test data, especially under dynamic conditions. Consequently the aerodynamics of a symmetric decelerator tend to be relatively simple due to a lack of better understanding rather than the inability to use available information. If better aerodynamic data is attainable, it is a simple matter to alter the body forces and torques appropriately.

For this report, the decelerator body forces and torques are:

\[
Q_\psi = -[T_{xb}C_{13} + T_{yb}C_{23} + T_{zb}C_{33}] 
\]

(139)

\[
Q_\theta = -T_{yl}C_\phi + T_{zb}S_\phi
\]

(140)

\[
Q_\phi = T_{xb}
\]

(141)

\[
F_{xpb} = -q_p S_p C_{Ap}
\]

(142)

\[
F_{ypb} = q_p S_p C_{NP} S_\phi^\prime i
\]

(143)

\[
F_{zpb} = q_p S_p C_{NP} C_\phi^\prime i
\]

(144)

\[
T_{ypb} = -q_p S_p d_p (C_{NP} - 0.1 \times \dot{\phi}_p D_p/V) C_\phi^\prime i
\]

(145)

\[
T_{zpb} = q_p S_p d_p (C_{NP} - 0.1 \times \dot{\phi}_p D_p/V) S_\phi^\prime i
\]

(146)

\[
\phi^\prime i = \tan^{-1}[-\dot{\psi}_{pb}/-\dot{\theta}_{pb}]
\]

(147)
The generalized forces for the decelerator are:

\[
F_{xp} = F_{xpb} C_{p11} + F_{ypb} C_{p21} + F_{zpb} C_{p31}
\]

(148)

\[
F_{yp} = F_{xpb} C_{p12} + F_{ypb} C_{p22} + F_{zpb} C_{p32}
\]

(149)

\[
F_{zp} = F_{xpb} C_{p13} + F_{zpb} C_{p33} - m_p g
\]

(150)

\[
Q_{\psi p} = -T_{zpb} C_{p33}
\]

(151)

\[
Q_{\theta p} = -T_{ypb}
\]

(152)
CHAPTER III  COMPUTER PROGRAM

SECTION 1 - FEATURES OF THE COMPUTER PROGRAM

The computer program contains the following features.

1. The program has many options which simplify the input of data or decrease the program run time. Use of the options are contained in the listing of the program as comment cards. These options are:

   a. Options are included which change the dimensions of the aerodynamic coefficient arrays as dictated by input requirements.

   b. An option is provided (OPDT = 1.0) which automatically determines the magnitude of the integration time interval, DT.

   c. An option is provided (OPSP = 1.0) which calculates the parachute drag area (SP) time history. If this option is not used the drag area versus time is input into the program in the form of look-up arrays.

   d. An option for including longitudinal and lateral added air mass effects on the parachute (OPAM = 1.0) is included in the program.

   e. A provision is made to use simplified equations of motion (OPOS = 0.0) to reduce run time, if all the forebody products of inertia and center of mass offsets are equal to zero.

   f. An option (OPPLOT = 1.0) for making a plot tape is available.

   g. English or metric systems may be used for data input and output by equating OMETRC to 0.0 or 1.0 respectively.

2. All aerodynamic coefficients are read into the program as functions of angle of attack, roll angle, and mach number in the form of three dimensional look-up arrays.
3. The initial start conditions for the forebody and aft body are completely general.

4. The stacking of design cases is possible.

5. The attachment location of the tether to the forebody is completely general.

6. The tether load and the angle it makes with the centerline of the forebody are program outputs.

7. All load and trajectory data are output at pre-selected times.

8. Termination of a design case occurs at a predetermined time or altitude.

9. The program calculates the effective system spring constant.

10. The program calculates the parachute physical properties as the parachute inflates as a function of time.

11. The parachute may have three stages of reefing, if the automatic drag area versus time option is chosen.

12. As the parachute inflates, the drag area versus time follows a second degree curve \((y = ax^2)\).
SECTION 2 - INPUT

Except for the variable COM, all inputs are read in under the format statement 8F10.0. COM is an 80 column header card. All of the following variables are defined in the nomenclature.

<table>
<thead>
<tr>
<th>INPUT ITEM</th>
<th>VARIABLE</th>
<th>NUMBER OF CARDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>a)</td>
<td>AIPHI, AIPHID, AJALPF, AJALPM, AKAM, AKAMD, OPSYM, OPDA</td>
<td>1 card</td>
</tr>
<tr>
<td>b)</td>
<td>PPHIE</td>
<td>1 card</td>
</tr>
<tr>
<td>c)</td>
<td>AALPFE</td>
<td>1 or 2 cards</td>
</tr>
<tr>
<td>d)</td>
<td>AALPME</td>
<td>1 or 2 cards</td>
</tr>
<tr>
<td>e)</td>
<td>AAM</td>
<td>1 card</td>
</tr>
<tr>
<td>f)</td>
<td>CCA</td>
<td>4 to 128 cards</td>
</tr>
<tr>
<td>g)</td>
<td>CCN</td>
<td>4 to 128 cards</td>
</tr>
<tr>
<td>h)</td>
<td>CCLM</td>
<td>4 to 128 cards</td>
</tr>
<tr>
<td>i)</td>
<td>CCY</td>
<td>0 or 4 to 128 cards</td>
</tr>
<tr>
<td>j)</td>
<td>CCLL</td>
<td>0 or 4 to 128 cards</td>
</tr>
<tr>
<td>k)</td>
<td>CCLN</td>
<td>0 or 4 to 128 cards</td>
</tr>
<tr>
<td>l)</td>
<td>CLLP, CLMQ, CLNR</td>
<td>0 or 1 card</td>
</tr>
<tr>
<td>m)</td>
<td>PPHIDE</td>
<td>0 or 1 card</td>
</tr>
<tr>
<td>n)</td>
<td>AALPDE</td>
<td>0 or 1 card</td>
</tr>
<tr>
<td>o)</td>
<td>AAMD</td>
<td>0 or 1 card</td>
</tr>
<tr>
<td>p)</td>
<td>CCLLP</td>
<td>0 or 4 to 64 cards</td>
</tr>
<tr>
<td>q)</td>
<td>CCLMQ</td>
<td>0 or 4 to 64 cards</td>
</tr>
<tr>
<td>r)</td>
<td>CCLNR</td>
<td>0 or 4 to 64 cards</td>
</tr>
<tr>
<td>s)</td>
<td>AALPPE</td>
<td>1 card</td>
</tr>
<tr>
<td>t)</td>
<td>AAMP</td>
<td>1 card</td>
</tr>
<tr>
<td>u)</td>
<td>CCAP</td>
<td>2 to 8 cards</td>
</tr>
<tr>
<td>v)</td>
<td>CCNP</td>
<td>2 to 8 cards</td>
</tr>
<tr>
<td>w)</td>
<td>CCMP</td>
<td>2 to 8 cards</td>
</tr>
</tbody>
</table>
The values of the variables read in input item "a" determine, in part, the sizes of the aerodynamic arrays. The axial and moment coefficients have the option of using either eight or sixteen angles-of-attack (one or two cards). If, for example, five or eleven angles-of-attack are needed, one or two cards are needed respectively. The roll and Mach number arrays may vary from two to eight. As an example consider the array CCA where the value of $C_A$ depends on five roll angles ($\phi_i$), eleven angles-of-attack ($\alpha_i$) and seven Mach numbers (AM). The array PPHIE would be read in on one card containing five distinct roll angles, the last three fields of ten digits would be blanks. The array AALPFE would be read in on two cards. The first card would contain eight distinct angles-of-attack, and the second card would contain three distinct angles-of-attack and five blank fields of ten digits. The array AAM would be read in on one card containing seven distinct Mach numbers and one blank field of ten digits. The first element in each of the above arrays should start at zero and increase numerically until $C_A$ highest

<table>
<thead>
<tr>
<th>INPUT ITEM</th>
<th>VARIABLE</th>
<th>NUMBER OF CARDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>x)</td>
<td>PS, PT, EPL, EPT</td>
<td>1 card</td>
</tr>
<tr>
<td>y)</td>
<td>X, Y, X, V, GAME, CHIE, EPSI, ETAI</td>
<td>1 card</td>
</tr>
<tr>
<td>z)</td>
<td>WT, IXB, IYB, IZB, IXYB, IXYB, IYZB</td>
<td>1 card</td>
</tr>
<tr>
<td>aa)</td>
<td>S, D, XBAR, YBAR, ZBAR, OPPRIN, OPPLT, OPOS</td>
<td>1 card</td>
</tr>
<tr>
<td>bb)</td>
<td>PSIE, THEE, PHIE, OMXBE, OMYBE, OMZBE</td>
<td>1 card</td>
</tr>
<tr>
<td>cc)</td>
<td>A, B, C, OPAM, OMETRC</td>
<td>1 card</td>
</tr>
<tr>
<td>dd)</td>
<td>PSIPE, THEPE, PSIPDE, THEPDE, VP, GAMPE, CHIPE</td>
<td>1 card</td>
</tr>
<tr>
<td>ee)</td>
<td>LS, LTO, DLTO, NS, NT, DP, CCRIT</td>
<td>1 card</td>
</tr>
<tr>
<td>ff)</td>
<td>AMAX1, AMAX2, DSX1, DSX2, AMAY1, AMAY2, DSY1, DSY2</td>
<td>1 card</td>
</tr>
<tr>
<td>gg)</td>
<td>WTC, WTL, OPSP, OPDT</td>
<td>1 card</td>
</tr>
<tr>
<td>hh)</td>
<td>TRO, TR1, TR2, TR3</td>
<td>1 card</td>
</tr>
<tr>
<td>jj)</td>
<td>SPRO, SPR1, SPR2, SPR3, PCTO1, PCTO2, PCTO3, POROS</td>
<td>1 card</td>
</tr>
<tr>
<td>kk)</td>
<td>TTIP, SSP</td>
<td>4 cards</td>
</tr>
<tr>
<td>ll)</td>
<td>GLOAD, FSULT, AERATO, TO, DTP1, TTT, HHH</td>
<td>1 card</td>
</tr>
<tr>
<td>mm)</td>
<td>DT1, TO, DTP1, TTT, HHH</td>
<td>1 card</td>
</tr>
<tr>
<td>nn)</td>
<td>COM</td>
<td>1 card</td>
</tr>
</tbody>
</table>
possible value expected to be encountered is specified. In this particular example, the array size used will be CCA(5, 16, 7). The proper read sequence is to first read two cards containing the values of $C_A$ at eleven angle-of-attack, the initial roll angle (zero) and the initial Mach number (zero). These cards are followed by two cards containing values of $C_A$ at eleven angles-of-attack, the second roll angle and the initial Mach number. This is continued for five roll angles at the initial Mach number. After these ten cards, the same procedure is followed for the second Mach number, and the third, etc. up to seven sets of ten cards.

All the aerodynamic coefficient arrays are read similarly. However, notice that the angle-of-attack array associated with the moment coefficients is different than that associated with the force coefficients. Also, the damping moment coefficient arrays (input items "p", "q", and "r") may not be read in at all, depending on the value of OPDA. Instead, input item "1" can be used if the damping coefficients are constant. Finally, the damping coefficients correspond to the arrays read in input items "m", "n", and "o".

Figure 4 helps to clarify the meaning of the input parameters associated with the added air mass on the parachute (Ref. Input Item ff).

![Figure 4. Input Parameters for Parachute Added Air Mass](image-url)
Figure 5 helps to clarify the meaning of the parameters associated with OPSO = 1.0 which directs the program to calculate the parachute area time history as time advances (Reference Input Items hh and jj).

Figure 5. Parameters for Program Calculated Parachute Drag Area Time History
SECTION 3 - OUTPUT

All output variables are defined in the nomenclature. Before beginning the simulation, the following variables, specifying the characteristics of the rigid body and initial parameters, are printed out.

Line 1. COM
Line 2. IXB, IXYB, XBAR, S, CLIP, OPPRN, OPSYM, AIPHI, AIPHID, DT1 EPSI
Line 3. IYB, IXZB, YBAR, D, CLMQ, OPPLOT, OPDA, AJALPF, AJALPM, AJALPD, TTT, ETA1
Line 4. IZB, IYZB, ZBAR, WT, CLNR, OPPO, OMETRC, AKAM, AKAMD, HHH

If CLLP, CLMQ, and CLNR are constants for the simulation, their values are printed out in the appropriate place. If the damping coefficients are found from interpolation of three dimensional arrays, CLLP, CLMQ, and CLNR are set equal to zero for this printout only. Several variables dealing with the decelerator are then printed out.

Line 5. A, LTO, LS, AMAX1, AMAX2, AMAY1, AMAY2, AP, GLOAD, FREQP, OPAM, PCTO1
Line 6. B, NT, NS, DSK1, DSK2, DSY1, DSY2, CHIPE, FSULT, POROS, OPDT, PCTO2
Line 7. C, DLTO, DP, WTC, WTL, WTP, CCRIT, VP, AERATO, TO OPSO, PCTO3
Line 8. TRO, TR1, TR2, TR3, SPRO, SPR1, SPR2, SPR3

The parachute suspension line load and strain arrays are printed out next on Lines 9 and 10.

Line 9. PS(1)
Line 10. EPL(1)

The tether line load and strain arrays are printed out next on Lines 11 and 12.

Line 11. PT(1)
Line 12. EPT(1)
The parachute inflation time history array and drag area array are printed out next. If the option (OPSP = 1.0) the arrays are set equal to zero because they are not known before initial time TO.

Line 13. TTIP(I)
Line 14. SSP(I)

The computer program then checks the option variable OPPRIN. If OPPRIN = 1., all the aerodynamic data is listed as follows:

PPHIE(I)
AALPFE(J)
AALPME(J)
AAM(K)
CCA(I,J,K)
CCN(I,J,K)
CCLM(I,J,K)

If OPSYM = 0., the following aerodynamic data is listed

CCY(I,J,K)
CCLL(I,J,K)
CCLN(I,J,K)

In the above aerodynamic coefficient arrays, AALPFE(J) is associated with CCA, CCN, and CCY; AALPME(J) is associated with CCLM, CCLL, and CCLN.

If OPDA = 1., the damping aerodynamics is listed.

PPHIDE(I)
AALPDE(J)
AAMD(K)
CCLLP(I,J,K)
CCLMQ(I,J,K)
CCLNR(I,J,K)
The aerodynamic arrays associated with the decelerator then follow.

AALPPE(I)
AAMP(I)
CCAP(I)
CCNP(I)
CCMP(I)

After the listing of the input data, the computer program begins numerically integrating. At $T = T_o$ and at predetermined time increments, the following data is printed out.

Line 1. $T$, $X$, $XD$, $XDD$, $FX$, $CA$, $V$, $TENS$, $XP$, $XPD$, $XPDD$, $FXP$, $CDAP$, $CMP$
Line 2. $TXB$, $Y$, $YD$, $YDD$, $FY$, $CN$, $AM$, $LT$, $YP$, $YPD$, $YPDD$, $FYP$, $CNP$, $AMP$
Line 3. $TYB$, $Z$, $ZD$, $ZDD$, $FZ$, $CY$, $DYPR$, $TPD$, $ZP$, $ZPD$, $ZPDD$, $FZP$, $TYPB$, $DYPRP$
Line 4. $TZB$, $PSIE$, $PSIDE$, $PSIDDE$, $QPSI$, $CLN$, $ALPE$, $OMXBE$, $PSIPE$, $PSIPDE$, $PSPDDE$, $QPSIP$, $TZPB$, $ALPPE$
Line 5. GAME, THEE, THEDE, THEDDE, QTHE, CLM, PHIIE, OMYBE, THEPE, THEPDE, THPDDE, QTHEP, TPDXB, GAMPE
Line 6. CHIE, PHIE, PHIDE, PHIDDE, QPHI, CLL, PHIAE, OMZBE, KS, CLLP, CLMQ, CLNR, TYPRDB, PULAN
Line 7. MPAL, MPAS, DMD, QMAXPB, IXPB, IYPB, SPD, SP, SPRU, SPRL, TINT, TNINY, TFI, XPBDE

When the simulation reaches HHH or TTT, the computer will write out "RUN ENDED BY CONSTRAINTS". It will then attempt to read in more data cards, to initialize for another simulation, starting with input item "y". If there are no data cards available, the program will CALL EXIT.
For the most general type rigid body, there are six second order differential equations, coupled in the acceleration terms. These six equations can be written as:

\[
\sum_{i=1}^{6} D_{ij} \ddot{U}_i = v_j \quad j = 1,2, \ldots, 6
\]  

(153)

and solved simultaneously using the PIVERT subroutine. PIVERT uses Gauss elimination with complete pivoting to obtain the largest diagonal elements. After solving for the accelerations \( \ddot{U}_i \) in equation (153), the results are numerically integrated using Runge-Kutta, fourth order techniques.

If the forebody has the properties that \( \bar{X} = \bar{Y} = \bar{Z} = I_{xyb} = I_{xzb} = I_{yzb} = 0 \), the equations of motion greatly simplify for the forebody. In the case of integrating the Euler angles, three equations remain coupled in the acceleration terms, and are separated using PIVERT. The three translational accelerations are already in a suitable form to integrate immediately. A simpler situation occurs if the added masses of the decelerator are neglected. All five equations of motion are uncoupled in the second derivative and are easily integrated by 4th order Runge-Kutta.
SECTION 5 - PLOTTING ROUTINE

If OPLOP = 1., eleven variables are saved in arrays. At the end of the simulation, any or all of these variables are plotted by calling PLTRAJ and setting the appropriate arguments. PLTRAJ was originally written for use on a CALCOMP 563 plotter and 750 tape drive. It has been modified for use at M.S.F.C. where a SC 4020 plotter is the preferred plotter. The original PLTRAJ will plot up to 4 variables versus time on one graph for each call to PLTRAJ. The modified PLTRAJ for the SC 4020 plotter plots only one variable versus time per plot; therefore four plots will be made instead of one for each call to PLTRAJ. Two hundred data points are plotted on each graph per variable.
SECTION 6 - ENGLISH TO METRIC CONVERSION

The computer program operates in either English or Metric units. The program input and output is in English units unless the option parameter, OMETRC, is set equal to 1. If OMETRC = 1, the input and output is in the Metric System. A conversion table from English to Metric is given below for commonly used engineering parameters.

### ENGLISH TO METRIC CONVERSION

**REFERENCE NASA SP 7012**

*EXACT*

<table>
<thead>
<tr>
<th>ENGLISH</th>
<th>METRIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>FORCE</td>
<td>(LB) X 4.4482216152605* = (1) NEWTON N</td>
</tr>
<tr>
<td>LENGTH</td>
<td>(FT) X 0.30480090 * = (1) METER m</td>
</tr>
<tr>
<td>MASS</td>
<td>(SLUG) X 14.5939029 = (1) KILOGRAM kg</td>
</tr>
<tr>
<td>SPEED</td>
<td>(FT/SEC) X 0.3048 = (1) METERS SEC m/sec</td>
</tr>
<tr>
<td>PRESSURE</td>
<td>(LB/FT²) X 47.880258 = (1) NEWTON/METER² N/m²</td>
</tr>
<tr>
<td>volume</td>
<td>(FT³) X 0.028316846592* = METERS³ m³</td>
</tr>
<tr>
<td>AREA</td>
<td>(FT²) X 0.09290304* = METERS² m²</td>
</tr>
<tr>
<td>ACCELERATION</td>
<td>(FT/SEC²) X 0.3048* = METER/SEC² m/sec²</td>
</tr>
<tr>
<td>INERTIA</td>
<td>(SLUG-FT²) X 1.355817948 = KILOGRAM-METER² kg-m²</td>
</tr>
<tr>
<td>TORQUE</td>
<td>(FT-LB) X 1.355817948 = METER - NEWTON m-N</td>
</tr>
<tr>
<td>DENSITY</td>
<td>(SLUG/FT³) X 515.379 = KILOGRAM/METER³ kg/m³</td>
</tr>
<tr>
<td>viscosity</td>
<td>(SLUG/FT-SEC) X 47.880258 = NEWTON SEC/METER² (N·sec)/m²</td>
</tr>
<tr>
<td>SPRING CONSTANT</td>
<td>(LB/FT) X 14.59390293 = NEWTON/METER N/m</td>
</tr>
</tbody>
</table>

* Exact Numbers - No round offs
SECTION 7 - CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are made for use of the 6+3 D.O.F. computer program.

1. The (6+5) DOF loads assessment computer program should be used primarily to analyze the loads induced on a wobbling or spinning body when the body is stabilized by the deployment of a drogue parachute.

2. After the body has been stabilized by the drogue, further parachute deployments (main chutes) should be analyzed using the planer (3+3) DOF computer program. The (3+3) program should be used because of the following reasons:
   a. The (3+3) program is faster and easier to use than the (6+5) program.
   b. Terminal descent with the forebody pitch angle equal to ±90° presents no mathematical solution problem using the (3+3) DOF program.

3. It should be noted here that the (6+5) DOF program has a mathematical singularity point at a forebody pitch angle of ±90°. To permit passage through this point the six forebody accelerations are frozen at their last value when the pitch angle is in the region of $89.8° < \theta < 90.2°$. This reduces some error in the translational coordinates and attitude of the forebody, but it has been shown to be small for normal velocity passes through this point. A time count (TNINY) for the time spent in this region is a program output.

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CHAPTER IV - PROGRAM LISTING AND SAMPLE COMPUTER RUN

The following program listing is for the Univac 1108 at M.S.F.C. and adapted from the IBM 360 listing used by Goodyear Aerospace Corporation.

The sample problem, SRB Stabilization by 54' Drogue Parachute, represents the deployment of a 54' drogue from a SRB which is wobbling and flying broadside to the wind vector. The trajectory of the SRB is nearly vertical. The drogue is starting to inflate and is stretched out normal to the SRB centerline. The drogue has one stage of reefing (0.82 of full open area).

Some of the more important initial conditions are given in the table below.

<table>
<thead>
<tr>
<th>Attitude</th>
<th>Ft</th>
<th>19,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity</td>
<td>Ft/Sec</td>
<td>553.</td>
</tr>
<tr>
<td>Angle of Attack</td>
<td>Deg.</td>
<td>90.</td>
</tr>
<tr>
<td>Flight Path Angle</td>
<td>Deg.</td>
<td>85.</td>
</tr>
<tr>
<td>Body Axis Rates</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pitch</td>
<td>Deg/Sec</td>
<td>- 1.0</td>
</tr>
<tr>
<td>Yaw</td>
<td>Deg/Sec</td>
<td>0.0</td>
</tr>
<tr>
<td>Roll</td>
<td>Deg/Sec</td>
<td>0.0</td>
</tr>
</tbody>
</table>

The output from the sample problem starts on Page 57, and selected portions of the trajectory are found starting on page 107.
0010  86   JALPD=AJALPO
0014  87   KAM=KAM
0018  88   KAM=KAM
0022  89   READI[N]:1{PPH][E]:1,I,J,1,PHI1
0026  90   READI[N]:1{ALDPF:J,J,1,JALPF1
0030  91   READI[N]:1{ALPHJ,1,J,1,JALPH1
0034  92   READI[N]:1{AM(K):K=1,KAM1
0038  93   READI[N]:1{CCLP1{J,K,J,1,JALPD;1,1,PHI1;1,1,KAM1
0042  94   READI[N]:1{ICLNR1{J,K,J,1,JALPD;1,1,PHI1;1,1,KAM1
0046  95   READI[N]:1{ICLMJ,1,J,K,J,1,JALPD;1,1,PHI1;1,1,KAM1
0050  96   diagnostic the test for equality between non-integers may not be meaningful.
0054  97   IF OP=1.0/2.0 GOTO 98
0058  98   CONTINUE
0062  99   XOR=1 TO PRINT OUT AERO DYNAMIC COEFFICIENTS
0068 103   XOR=0 TO NOT PRINT OUT AERO DYNAMIC COEFFICIENTS
0072 104   OPPLOT=1 TO MAKE PLOT TAPe
0076 105   OPPLOT=0 TO NOT MAKE PLOT TAPe
0080 106   OPOS=1. IF ONE PRODUCT OF INERTIA OR C.G. OFFSET NOT = 0.
0084 107   OPOS=0. IF ALL PRODUCTS OF INERTIA AND C.G. OFFSETS = 0.
0088 108   OPAH=1. IF ADDED MASS OF PARACHUTE NOT EQUAL 0.
0092 109   OPAH=0. IF ADDED MASS OF PARACHUTE EQUAL 0.
0096 110   OPD=1. PROGRAM CALCULATES AN ESTIMATE FOR DT
0098 111   OPD=0.0 IF DT IS NOT INTO PROGRAM
0100 112   ODSF=1. PROGRAM CALCULATES PARACHUTE DRAG AREA (SP)
0102 113   ODSF=0.0 5SP(14).TTP1(14) ARAYS ARE READ INTO PROGRAM
0104 114   OMETR=1. IF METRIC UNITS ARE USED
0105 115   OMETR=0.0 IF ENGLISH UNITS ARE USED
CRR, W

**CRR, W**

CRR, W

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193.                      60 DTT=.04735*SQRT((LS*WTP)/(GLOAD*RT*PSL*AT+RATO))
194.                      FREQ=10/142+*DXT)
195.                      YY= DTT
196.                      I=0
197.                      IF(NN.GE.1) GO TO 62
198.                      I=1+1
199.                      YY=YY+10
200.                      GO TO 61
201.                      DTT=NN/10+1
202.                      62 CONTINUE
203.                      GN=32+17
204.                      RHO0=002378
205.                      RHO9=092436.
206.                      DIAGNOStie THE TEST FOR EQUaLITY BETWEEN NON-INTZeJERS MAY NOT BE MEANINGFUL.
207.                      IF(IN地位E,EE,1+) GO TO 140
208.                      GO TO 141
209.                      140 R=6373977.
210.                      PHIO=1.22857
211.                      GO=1901460
212.                      DPR=.572957795
213.                      M=NT/GO
214.                      MP=WTP/GO
215.                      MTCM=WTC/32+17
216.                      RTM=WTL/32+17
217.                      LSCLO=SQRT((LS*LS+10160*DP*DP))
218.                      AP=(MTC/(1.1595*DP*LSCLO+5*LSCLO+WTL)/MTC+WTL)
219.                      AX=(ALOG1(MAX1)-ALOG1(MAX2))/(ALOG1(DS1)-ALOG1(DS2))
220.                      BX=MAX1/(DS1+AX)
221.                      AX=(ALOG1(MAX1)-ALOG1(MAX2))/(ALOG1(DS1)-ALOG1(DS2))
222.                      BX=MAX1/(DS1+AX)
223.                      PY=MAX1/(DS1+AX)
224.                      AX=MAX1/(DS1+AX)
225.                      BX=MAX1/(DS1+AX)
226.                      PY=MAX1/(DS1+AX)
227.                      AX=MAX1/(DS1+AX)
228.                      BX=MAX1/(DS1+AX)
229.                      PY=MAX1/(DS1+AX)
230.                      AX=MAX1/(DS1+AX)
231.                      BX=MAX1/(DS1+AX)
232.                      PY=MAX1/(DS1+AX)
233.                      AX=MAX1/(DS1+AX)
234.                      BX=MAX1/(DS1+AX)
235.                      PY=MAX1/(DS1+AX)
236.                      AX=MAX1/(DS1+AX)
237.                      BX=MAX1/(DS1+AX)
238.                      PY=MAX1/(DS1+AX)
239.                      AX=MAX1/(DS1+AX)
240.                      BX=MAX1/(DS1+AX)
241.                      PY=MAX1/(DS1+AX)
242.                      AX=MAX1/(DS1+AX)
243.                      BX=MAX1/(DS1+AX)
244.                      PY=MAX1/(DS1+AX)
245.                      AX=MAX1/(DS1+AX)
246.                      BX=MAX1/(DS1+AX)
247.                      AX=MAX1/(DS1+AX)
248.                      BX=MAX1/(DS1+AX)
249.                      PY=MAX1/(DS1+AX)
250.                      AX=MAX1/(DS1+AX)
251.                      BX=MAX1/(DS1+AX)
252.                      PY=MAX1/(DS1+AX)
253.                      AX=MAX1/(DS1+AX)
254.                      BX=MAX1/(DS1+AX)
255.                      PY=MAX1/(DS1+AX)
DO 91 K=1,KAM
  WRITE(IOUT,20)
  FORMAT///,//,92X,CN (MACH COEF, ARRAY(IPHI,JALPF,KAM))/
  WRITE(IOUT,17) AM(K)
  DO 91 K=1,IPHI
  WRITE(IOUT,24)
  FORMAT///,//,92X,CCNY(I,J,K),J=1,JALPF)
  DO 91 K=1,KAM
  WRITE(IOUT,17) AM(K)
  DO 91 K=1,IPHI
  WRITE(IOUT,24)
  FORMAT///,//,92X,CCNY(I,J,K),J=1,JALPF)
  DO 91 K=1,KAM
  WRITE(IOUT,17) AM(K)
  DO 91 K=1,IPHI
  WRITE(IOUT,24)
  FORMAT///,//,92X,CCNY(I,J,K),J=1,JALPF)
  DO 91 K=1,KAM
  WRITE(IOUT,17) AM(K)
  DO 91 K=1,IPHI
  WRITE(IOUT,24)
  FORMAT///,//,92X,CCNY(I,J,K),J=1,JALPF)
  DO 91 K=1,KAM
  WRITE(IOUT,17) AM(K)
  DO 91 K=1,IPHI
  WRITE(IOUT,24)
  FORMAT///,//,92X,CCNY(I,J,K),J=1,JALPF)
  DO 91 K=1,KAM
  WRITE(IOUT,17) AM(K)
  DO 91 K=1,IPHI
  WRITE(IOUT,24)
  FORMAT///,//,92X,CCNY(I,J,K),J=1,JALPF)
  DO 91 K=1,KAM
  WRITE(IOUT,17) AM(K)
  DO 91 K=1,IPHI
  WRITE(IOUT,24)
  FORMAT///,//,92X,CCNY(I,J,K),J=1,JALPF)
  DO 91 K=1,KAM
  WRITE(IOUT,17) AM(K)
  DO 91 K=1,IPHI
  WRITE(IOUT,24)
  FORMAT///,//,92X,CCNY(I,J,K),J=1,JALPF)
  DO 91 K=1,KAM
  WRITE(IOUT,17) AM(K)
  DO 91 K=1,IPHI
  WRITE(IOUT,24)
  FORMAT///,//,92X,CCNY(I,J,K),J=1,JALPF)
  DO 91 K=1,KAM
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  DO 91 K=1,IPHI
  WRITE(IOUT,24)
  FORMAT///,//,92X,CCNY(I,J,K),J=1,JALPF)
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  WRITE(IOUT,24)
  FORMAT///,//,92X,CCNY(I,J,K),J=1,JALPF)
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  DO 91 K=1,IPHI
  WRITE(IOUT,24)
  FORMAT///,//,92X,CCNY(I,J,K),J=1,JALPF)
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  FORMAT///,//,92X,CCNY(I,J,K),J=1,JALPF)
  DO 91 K=1,KAM
  WRITE(IOUT,17) AM(K)
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  WRITE(IOUT,24)
  FORMAT///,//,92X,CCNY(I,J,K),J=1,JALPF)
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  WRITE(IOUT,24)
  FORMAT///,//,92X,CCNY(I,J,K),J=1,JALPF)
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  WRITE(IOUT,24)
  FORMAT///,//,92X,CCNY(I,J,K),J=1,JALPF)
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  DO 91 K=1,IPHI
  WRITE(IOUT,24)
  FORMAT///,//,92X,CCNY(I,J,K),J=1,JALPF)
  DO 91 K=1,KAM
  WRITE(IOUT,17) AM(K)
  DO 91 K=1,IPHI
  WRITE(IOUT,24)
  FORMAT///,//,92X,CCNY(I,J,K),J=1,JALPF)
  DO 91 K=1,KAM
  WRITE(IOUT,17) AM(K)
  DO 91 K=1,IPHI
  WRITE(IOUT,24)
  FORMAT///,//,92X,CCNY(I,J,K),J=1,JALPF)
  DO 91 K=1,KAM
  WRITE(IOUT,17) AM(K)
  DO 91 K=1,IPHI
  WRITE(IOUT,24)
  FORMAT///,//,92X,CCNY(I,J,K),J=1,JALPF)
  DO 91 K=1,KAM
  WRITE(IOUT,17) AM(K)
  DO 91 K=1,IPHI
  WRITE(IOUT,24)
  FORMAT///,//,92X,CCNY(I,J,K),J=1,JALPF)
  DO 91 K=1,KAM
  WRITE(IOUT,17) AM(K)
  DO 91 K=1,IPHI
  WRITE(IOUT,24)
  FORMAT///,//,92X,CCNY(I,J,K),J=1,JALPF)
  DO 91 K=1,KAM
  WRITE(IOUT,17) AM(K)
  DO 91 K=1,IPHI
  WRITE(IOUT,24)
  FORMAT///,//,92X,CCNY(I,J,K),J=1,JALPF)
  DO 91 K=1,KAM
  WRITE(IOUT,17) AM(K)
  DO 91 K=1,IPHI
  WRITE(IOUT,24)
  FORMAT///,//,92X,CCNY(I,J,K),J=1,JALPF)
  DO 91 K=1,KAM
  WRITE(IOUT,17) AM(K)
  DO 91 K=1,IPHI
  WRITE(IOUT,24)
  FORMAT///,//,92X,CCNY(I,J,K),J=1,JALPF)
  DO 91 K=1,KAM
  WRITE(IOUT,17) AM(K)
  DO 91 K=1,IPHI
  WRITE(IOUT,24)
  FORMAT///,//,92X,CCNY(I,J,K),J=1,JALPF)
  DO 91 K=1,KAM
  WRITE(IOUT,17) AM(K)
  DO 91 K=1,IPHI
  WRITE(IOUT,24)
  FORMAT///,//,92X,CCNY(I,J,K),J=1,JALPF)
  DO 91 K=1,KAM
  WRITE(IOUT,17) AM(K)
  DO 91 K=1,IPHI
  WRITE(IOUT,24)
  FORMAT///,//,92X,CCNY(I,J,K),J=1,JALPF)
  DO 91 K=1,KAM
  WRITE(IOUT,17) AM(K)
  DO 91 K=1,IPHI
  WRITE(IOUT,24)
  FORMAT///,//,92X,CCNY(I,J,K),J=1,JALPF)
  DO 91 K=1,KAM
  WRITE(IOUT,17) AM(K)
  DO 91 K=1,IPHI
  WRITE(IOUT,24)
  FORMAT///,//,92X,CCNY(I,J,K),J=1,JALPF)
  DO 91 K=1,KAM
  WRITE(IOUT,17) AM(K)
  DO 91 K=1,IPHI
  WRITE(IOUT,24)
  FORMAT///,//,92X,CCNY(I,J,K),J=1,JALPF)
33 FORMAT(///,30X,CLNG (PITCH DAMPING HOM. COEF. ARRAY(IPHI,JALPD,K
1AMD))///)
1454 WRITE(OUT,17) AMD(K)
1455 DO 49 I=1,IPHI
1456 49 WRITE(OUT,34)(CLNG(1,J,K),J=1,JALPD)
1457 DO 49 K=1,KAMO
1458 WRITE(OUT,32)
1461 32 FORMAT(///,30X,CLNG (YAR DAMPING HOM. COEF. ARRAY(IPHI,JALPD,KAM
1 AMD))///)
1462 WRITE(OUT,17) AMD(K)
1463 DO 49 I=1,IPHI
1464 49 WRITE(OUT,34)(CLNG(1,J,K),J=1,JALPD)
1465 WRITE(OUT,66)
1466 FORMAT(///,///,30X,AE DYNAMICS OF PARACHUTE///)
1467 WRITE(OUT,47) AALPPE, AAMP, CCAP, CCNP, CCHP
1468 47 FORMAT(///,///,20X,ANGLE OF ATTACK ARRAY (AALPPE(8))///,10X,8F10.3///)
1469 DO 42 I=1,8
1470 AZX(I,MACH NUMBER ARRAY(AAMP(8)))///,10X,8F10.3///
1471 ICX(I,AXIAL COEFF. ARRAY (CCAP(8)))///,6(10X,8F10.3///)
1472 CCX(I,NORMAL COEFF. ARRAY (CCNP(8)))///,6(10X,8F10.3///)
1473 CCHX(I,PITCH HOM. COEF. ARRAY (CCHP(8)))///,6(10X,8F10.3///)
1474 CONTINUE
1475 WRITE(OUT,50)
1476 IF(2+L+H M) CONSTR=0.
1477 IF(TG+TTT) CONSTR=1.
1478 IF(JJJEQ.1) GO TO 101
1479 DTPC=DTPC+1.
1480 IF(DTPCLT=OTP) GO 0 110
1481 JJJ=JJJ+1.
1482 DTPC=0.
1483 IF(JJJEQ.6) GO TO 101
1484 WRITE(OUT,50)
1485 JJ=1.
1486 CALL SUBR
1487 PSIE=PSIE+DPR
1488 THEE=THEE+DPR
1489 PHIE=PHIE+DPR
1490 PSIE=PSIE+DPR
1491 THEE=THEE+DPR
1492 PSIDE=PSIDE+DPR
1493 THEDE=THEDE+DPR
1494 PHIDE=PHIDE+DPR
1495 PSIPDE=PSIPDE+DPR
1496 THEPDE=THEPDE+DPR
1497 PSIDDE=PSIDDE+DPR
1498 THEEDDE=THEEDDE+DPR
1499 PMIDE=PMIDE+DPR
1500 XMDE=XMDE+DPR
1501 YDDE=YDDE+DPR
1502 ZDDE=ZDDE+DPR
1503 PSpodde=PSpode+DPR
1504 Tmpode=TMPODE+DPR
1505 Zspode=ZSPODE+DPR
1506 Xpdeo=XPDDE+DPR
1507 Ypdeo=YPDDE+DPR
1508 Zpdeo=ZPDDE+DPR
SPECIFY VARIABLES FOR LOT TAPE

DIAGNOSTIC THE TEST FOR EQUALITY BETWEEN NON-INTEGERs MAY NOT BE MEANINGFUL.

IF (OPPLOT.EQ.0) GO TO 110

IF (CONSTR.LT.1) GO TO 116
C C RUNGE KUTTA INTEGRATION (4TH ORDER)

103 DO 79 J=1,9

*DIAGNOSTIC  THE TEST FOR EQUALITY BETWEEN NON-INTEGERS MAY NOT BE MEANINGFUL.
 IF (J.EQ.0.AND.DTPC.EQ.0.0) GO TO 77

CALL SUBR

DO 75 J=1,6

DO 76 I=1,5

76 BB(J,J)=FF(J)DT

GO TO (71,72,73,74) J

71 PSI=PSI+.S*PSIDT

THE=THE+.S*THEDT

PHI=PHI+.S*PHIDT

X=X+.S*XD

Z=Z+.S*ZDT

XPP=XP+.S*XPDDT

YP=YP+.S*YDPDT

ZP=ZP+.S*ZPDDT

PSID=PSD+.S*AA(1:1)

THEID = TD+.S*AA(2:1)

PHIID = TD+.S*AA(3:1)

XDD=.X+.S*AA(4:1)

YDD=.Y+.S*AA(5:1)

ZDD=.Z+.S*AA(6:1)

XPPD=XP+.S*BB(1:1)

THPPD=THP+.S*BB(2:1)

XPDD=XP+.S*BB(3:1)

YPDD=YP+.S*BB(4:1)

ZPDD=ZP+.S*BB(5:1)

GO TO 79

72 FSI=PSI+.S*.25*AA(1:1)

THE=THE+.S*.25*AA(2:1)

PHI=PHI+.S*.25*AA(3:1)

X=X+.S*.25*AA(4:1)

Y=Y+.S*.25*AA(5:1)

Z=Z+.S*.25*AA(6:1)

PSIP=PSIP+.S*.25*BB(1:1)

THE1 = THE+.S*.25*BB(2:1)

XP1=X+.S*BB(3:1)

YP=YP+.S*BB(4:1)

ZP=ZP+.S*BB(5:1)

79 CONTINUE
CALCULATE TRANSFORMATION MATRICES

++C++
CC(1,1)=CPS1*CTHE
CC(1,2)=SPS1*CTHE
CC(1,3)=CTHE
++C++
CC(2,1)=C15253*SPS1*CTHE
CC(2,2)=C15253*CTHE*SPH1
CC(2,3)=CTHE*SPH1
++C++
CC(3,1)=C15253*SPS1*CTHE
CC(3,2)=C15253*CTHE*SPH1
CC(3,3)=CTHE*SPH1
++C++
CCP(1,1)=CPS1*CTHE
CCP(1,2)=SPS1*CTHE
++C++
CCP(1,2)=CPS1
CCP(2,2)=CPS1
CCP(3,2)=CPS1
++C++
CCP(1,3)=STHE
CCP(2,3)=STHE
CCP(3,3)=STHE
++C++
G=GO*RE/(Z*RL)**2
*DIAGNOSTIC THE TEST FOR EQUALITY BETWEEN NON-INTEGERS MAY NOT BE MEANINGFUL*
++C++
IF(DIOMETRIC.EQ.1.) GO TO 10
++C++
CALL DENSHIZ,PR,RHO,VS)
++C++
GO TO 11
++C++
CALL DENSIZ,PR,RHO,VS)
++C++
GO TO 11
++C++
VSQR1(SNL(1D*2+TD*2+ZD*2))
++C++
VP=SNGL(APD*2+TPD*2+ZPD*2))
++C++
AM=VP/VS
++C++
AMP=VP/VS
++C++
DYPR=SSRHO*VP/2
++C++
DYPRP=SSRHO*VP/2
++C++
ZBD=XC+CC(1,1)+YD+CC(1,2)+ZD+CC(1,3)
++C++
YBD=XC+CC(2,1)+YD+CC(2,2)+ZD+CC(2,3)
++C++
ZBD=XC+CC(3,1)+YD+CC(3,2)+ZD+CC(3,3)
"DIAGNOSTIC  THE TEST FOR EQUALITY BETWEEN NON-INTEGER MAY NOT BE MEANINGFUL."

"FORMAT(/,2X,"TERMINATION REQUESTED BY PROGRAN",TRU="IX,FIG.,4"

"1,2X,*GIVES NEGATIVE TIME ON REEDED STAGE")"
0824 213* 194 WRITE(3,196) TRU
0827 214* STOP
0830 215* 200 CONTINUE
0831 216* IF(1.1ABS(STME) .LT.,EPS) TINITY=THINT+DT
0833 217* DS = SWRT(1+27.224*SPI)
0836 218* DSP = .6383*DS
0835 219* LSCL = SQR(LS*LS+25*DSP*DSP)
0836 220* CSIGP = LSCL/LS
0837 221* RHOD = RHOD/1000
0840 222* MPAL = RHOD0+0.6*DS+AX
0841 223* MPAS = RHOD0+0.5*DS+AY
0842 224* DMD = RHOD0+AX*EPS*DS(1/SQR(T3+1459*SPI)*DS+(AX=1)
0843 225* GMAPB = DMD*EPSDR
0844 226* 200 DIAGNOSTIC THE TEST FOR EQUALITY BETWEEN NON-INTEGERS MAY NOT BE MEANINGFUL.
0844 227* IF(GPAMEEQ+.C) GO TO 102
0846 227* GO TO 104
0847 228* MPAL = 0.0
0848 229* MPAS = 0.0
0851 230* 104 CONTINUE
0852 231* MPL=MPAL+MP
0853 232* MPS=MPAS+MP
0854 233* MLHMP=MLH-MPS
0855 234* ICYO = ION67*TRCM+P*DSP
0856 235* ICXO = .625*ICYO
0857 236* ILYO = W1LM+1*8333*LS*LS+G125*DSP*DSP)
0858 237* ILYO = ILYO+1*25*DSP+DSP
0859 238* [YPB = [ICYO + ILYO]*MLH*(AP+.5*LS*CSIGP)*.2*(MPAS+TRCM)
0860 239* 1 (.25*DSP+LS*CSIGP)*APP+2
0862 240* [YPB = ICKO + ILYO
0863 241* [XNPB = [XPB + IYPB
0864 242* 110 IF([MAPLE+AMP(1)]=0) GO TO 111
0865 243* [=+1
0867 244* GO TO 110
0867 245* 11 AMP=AMP+AMP(1)-1)/AMP(1)=AMP(1)
0867 246* AMP=AMP
0867 247* 210 IF([ALPPE]+ALPPE(1)) GO TO 211
0867 248* [J=1
0867 249* J=1+1
0869 250* J=2
0870 251* 211 ALPPE=ALPPE(J+1)/ALPPE(J)+ALPPE(1)
0872 252* CLAP=ICAP(1,J+1)-ICAP(1,J+1)
0873 253* ICAP(1,J+1)+ICAP(1,J+1)
0874 254* [2CAP(1,J+1)]*ALPPE
0875 255* CHMP=CCMP(1,J+1)-CCMP(1,J+1)
0876 256* ICMP(1,J+1)+ICMP(1,J+1)
0877 257* [2CMOP(1,J+1)]*ALPPE
0878 258* CHMP=CCMP(1,J+1)-CCMP(1,J+1)
0879 259* ICMP(1,J+1)+ICMP(1,J+1)
0880 260* [2CMOP(1,J+1)]*ALPPE
0881 261* CHMP=CHMP+CHMP*AP+DP
0882 262* CHP=CHP+CHM*AP
0883 263* [SHP=CPH+1*PHPI]
0884 264* [SHP=1*PHPI]
0885 265* VPR=SGRT(YBD**2/BD**2)
0887 267* IF (VPRB) 213:2,219
0890 267* 213 PII = 0.
GO TO 215
214 PHI1 = ATAN2(-YD, -XD)
215 CONTINUE
216 PHI1=PHI1+DFR
217 IF(PHI1.0) PHI1=PHI1
218 THE ABOVE STATEMENT SHOULD BECOME A COMMENT CARD IF THERE IS NO
219 AERODYNAMIC PLANE OF SYMMETRY
220 C
221 C AERODYNAMICS
222 C
223 K=2
500 IF(AH.0) GO TO 501
K=K+1
GO TO 500
501 AHS=(AH=AHH(K-1))/(AAM(K)-AAM(K-1))
502 J=2
503 IF(ALPE.0) (ALPE.AAPF(J)=GO TO 601
504 J=J+1
GO TO 600
505 AALPFE=(ALPE.AALPFE(J=1))/(AALPFE(J)-AALPFE(J-1))
506 I=2
507 IF(PHI1.0) PHI1(PHI1(I)=GO TO 701
508 I=I+1
GO TO 700
509 PHI1=(PHI1(PHI1(I)=GO TO 701
510 JJ=JJ+1
511 GO TO 700
512 AALPMSL=(ALPE-AALPME(JJ-1))/(AALPME(JJ)-AALPME(JJ-1))
513 C
514 THE FIFTH, SIXTH, AND SEVENTH ARGUMENTS OF SUBROUTINE 'INTERP'
515 C MUST AGREE WITH THE DIMENSIONS OF THE FIRST ARGUMENT
516 CALL INTERP(CCA, AHS, ALPFSL, PHISL, 8, 10, J, K, CF)
517 CA=CF
518 CALL INTERP(CCA, AHS, ALPFSL, PHISL, 8, 10, J, K, CF)
519 CH=CF
520 CALL INTERP(CCA, AHS, ALPFSL, PHISL, 8, 10, J, K, CF)
521 CLM=CF
522 #DIAGNOSTIC# THE TEST FOR EQUALITY BETWEEN NON-INTEGERS MAY NOT BE MEANINGFUL.
523 IF(OPSYPH.0) GO TO 98
524 CALL INTERP(CCF, AHS, ALPFSL, PHISL, 8, 10, J, K, CF)
525 CY=CF
526 CALL INTERP(CCF, AHS, ALPFSL, PHISL, 8, 10, J, K, CF)
527 CCL=CF
528 CALL INTERP(CCF, AHS, ALPFSL, PHISL, 8, 10, J, K, CF)
529 CLO=CF
530 GO TO 99
531 #DIAGNOSTIC# THE TEST FOR EQUALITY BETWEEN NON-INTEGERS MAY NOT BE MEANINGFUL.
IF(OPDA=EQ.1) GO TO 97
GO TO 94
97 J=2
800 IF(ALPE LE AALPDE(J)) GO TO 801
J=J+1
GO TO 800
801 ALPSL=(ALPE-AALPDE(J-1))/(AALPDE(J)-AALPDE(J-1))
K=2
900 IF IAM LE AAND(K)) GO TO 901
K=K+1
GO TO 900
901 AMSL=IAM-AAND(K-1))/(AAND(K)-AAND(K-1))
I=2
300 IF(PHIAE LE PPHIDE(I)) GO TO 301
I=I+1
GO TO 300
301 PHISL=(PHIAE-PPHIDE(I))/(PPHIDE(I)-PPHIDE(I-1))
CALL INTERP(CLLP;AMS;ALPSL;PHISL;6,8,61,J,K,CF)
CLLP=CF
CALL INTERP(CLMG;AMS;ALPSL;PHISL;6,8,61,J,K,CF)
CLMG=CF
CALL INTERP(CCLR;AMS;ALPSL;PHISL;6,8,61,J,K,CF)
CLNR=CF
906 SPHII=SIN(PHII)
CPHII=COS(PHII)
C CALCULATE GENERALIZED FORCES
FRR=DPYPR+SA
FTB=DPYPR+S(CN*PHII+CY*CPHII)
FZB=DPYPR+S(CN*CPHII+CY*PHII)
0MB=PHII-PSIDCC11,3)
OMY=THEDCPHII-PSIDCC2,3)
OMZ=THEDCPHII-PSIDCC3,3)
TB=DPYPR+S*ICL+CLLP*OMX+V/((Z+V))
TY=DPYPR+S*ICL+CLMG*OMY+V/((Z+V))
TZ=DPYPR+S*ICL+CLNRUMZ+V/((Z+V))
FXPB=-DPYPR+SP*CAP=MAXPB
FYPB=DPYPR+SP*CAP=PHII
FZPB=DPYPR+SP*CAP=CPHII
THPB=DPYPR+SP*DP*(CMP+I*THEPD+DP/VPI*CPHII
THPB=DPYPR+SP*DP*(CMPI*THEPD+DP/VPI*CPHII
BVAR=TP+AP*CCP11,2)-HCACCC11,11-BCC11,11+CCL11,11)
CBAR=ZP+AP*CCP11,3)-HCACCC11,31-BCC11,31-CCL11,31)
ABAR=RPD+AP*PSIDCCP11,2)+THEPD*CCP11,11)-AD*PSID)
ICCI1,2)=THEDC11,2)=PSIDCC11,2)+PHIDC11,11)=THEDC11,2)
2AC=PSIDCC11,2))-100CC11,2)+THEDC11,23)
BARD=YPD+AP*IPDCCP11,2)+THEPD*CC11,11)-TD*AP*PSID)
ICCI1,1)=THEDCC11,1)+PSIDCC11,3)+PHIDC11,3)+THEDC11,3)
2AC=PSIDCC11,3)+PHIDC11,3)+THEDC11,3)
CBAR=ZPD+AP*THEPD*CMID=ZD*THEDECMID=THEDE52S3*PHID)
ICCI1,3)=CMIDTHEDE52S3*PHIDCC11,3)
LT=SORT(BAR=2;BAR=2;BAR=2)
LTD=BAR=BAR=BAR=BAR=BAR=BAR=BAR=BAR=BAR)/LT
DLT=LT-LTQ
*DIAGNOSTIC* THE TEST FOR EQUALITY BETWEEN NON-INTEGERS MAY NOT BE MEANINGFUL.

IF(POS*EQ.,1,G) GO TO 40

C EQUATIONS OF MOTION FOR SIMPLE FOREBODY

IF(1.-ABS(STHE))/LT,EPS1) GO TO 43

DD(1,1)=XZ+THE2*(16*SPH2+12*CPH2)+THE2

DD(1,2)=THE1+5*SPH2

DD(2,1)=DD(1,2)

DD(2,2)=4*CPH2+12*SPH2

DD(3,1)=DD(1,3)

DD(3,2)=DD(2,3)

DD(3,3)=XZ

EE11=PSDD*(12*SPH2+12*CPH2)*(-4*SPH2)*THE1

EE21=THE2*SPH2+12*CPH2)*THE3

EE22=TPD*(12*SPH2+12*CPH2)*THE3

CALL PIVERT(DD,EE,3,6,1,EPS,IESR)

IF(IESR,IEQ) GO TO 43

IF(1.0,EQ.) GO TO 43

STOP

C EQUATIONS OF MOTION FOR GENERAL FOREBODY

IF(1.-ABS(STHE))/LT,EPS1) GO TO 43

DD(1,1)=THE2*(16*SPH2+12*CPH2)+THE2

DD(1,2)=THE1+5*SPH2

DD(2,1)=DD(1,2)

DD(2,2)=4*CPH2+12*SPH2

DD(3,1)=DD(1,3)

DD(3,2)=DD(2,3)

DD(3,3)=XZ

EE11=PSDD*(12*SPH2+12*CPH2)*(-4*SPH2)*THE1

EE21=THE2*SPH2+12*CPH2)*THE3

EE22=TPD*(12*SPH2+12*CPH2)*THE3

CALL PIVERT(DD,EE,3,6,1,EPS,IESR)

IF(IESR,IEQ) GO TO 43

STOP

C EQUATIONS OF MOTION FOR GENERAL FOREBODY

IF(1.-ABS(STHE))/LT,EPS1) GO TO 43

DD(1,1)=THE2*(16*SPH2+12*CPH2)+THE2

DD(1,2)=THE1+5*SPH2

DD(2,1)=DD(1,2)

DD(2,2)=4*CPH2+12*SPH2

DD(3,1)=DD(1,3)

DD(3,2)=DD(2,3)

DD(3,3)=XZ

EE11=PSDD*(12*SPH2+12*CPH2)*(-4*SPH2)*THE1

EE21=THE2*SPH2+12*CPH2)*THE3

EE22=TPD*(12*SPH2+12*CPH2)*THE3

CALL PIVERT(DD,EE,3,6,1,EPS,IESR)

IF(IESR,IEQ) GO TO 43

STOP
DD(2, 5) = He(1XBAR = S1S2 = YBAR = S1C53 = ZBAR = S1C23)
DD(2, 6) = He(1XBAR = CTHE = YBAR = S2S3 - ZBAR = S2C3)
DD(3, 1) = DD(1, 3)
DD(3, 2) = DD(2, 3)
DD(3, 3) = 1X8
DD(3, 4) = He(YBAR = C3, 1) = ZBAR = C2(2, 1)
DD(3, 5) = He(YBAR = C3, 2) = ZBAR = C2(2, 1)
DD(3, 6) = He(YBAR = C3, 3) = ZBAR = C2(2, 1)
DD(4, 1) = DD(1, 4)
DD(4, 2) = DD(2, 4)
DD(4, 3) = DD(3, 4)
DD(4, 4) = DD(1, 5)
DD(4, 5) = DD(2, 5)
DD(4, 6) = DD(3, 6)
DD(5, 1) = DD(1, 5)
DD(5, 2) = DD(2, 5)
DD(5, 3) = DD(3, 5)
DD(5, 4) = DD(4, 5)
DD(5, 5) = DD(5, 6)
DD(5, 6) = DD(6, 5)
DD(6, 1) = DD(1, 6)
DD(6, 2) = DD(2, 6)
DD(6, 3) = DD(3, 6)
DD(6, 4) = DD(4, 6)
DD(6, 5) = DD(5, 6)
DD(6, 6) = DD(6, 6)

EE(1) = PSTD(1 + S21HE) + (1XBAR = YBAR + S1PHI = 1ZBAR + S2PHI)
EE(2) = C3THE + (1XBAR = YBAR + S1PHI) + PSTD(1 - C3THE) + (1XBAR = YBAR + S2PHI)
EE(3) = PSTD(1 - C3THE) + (1XBAR = YBAR + S1PHI) + PSTD(1 - C3THE) + (1XBAR = YBAR + S2PHI)
EE(4) = PSTD(1 - C3THE) + (1XBAR = YBAR + S1PHI) + PSTD(1 - C3THE) + (1XBAR = YBAR + S2PHI)
EE(5) = PSTD(1 - C3THE) + (1XBAR = YBAR + S1PHI) + PSTD(1 - C3THE) + (1XBAR = YBAR + S2PHI)
EE(6) = PSTD(1 - C3THE) + (1XBAR = YBAR + S1PHI) + PSTD(1 - C3THE) + (1XBAR = YBAR + S2PHI)

CALL PRINT (DD, EE, 1, 1, EPS, 123111)
IF (ER15 = 0) GO TO 41
WRITE (OUT, 51) ER15
STOP
DIAGNOSTIC THE TEST FOR EQUALITY BETWEEN NON-INTERGERS MAY NOT BE MEANINGFUL.
IF (OPAR.EQ.1) GO TO 41
GO TO 42
CALL PIVERT(DOP,EFP,3,3,1,EPS,IERBS)
IF(IERSB,NE.0) WRITE(OUT,62)
IF(IERSB,NE.0) STOP
52 FORMAT(///52-"INCONSISTENT EQUATIONS ON PARACHUTE",//20A,"IERBS=",)
12)
FF(3)=EFP(1)
FF(4)=EFP(2)
FF(5)=EFP(3)
RETURN
END

END OF COMPIATION!  II DIAGNOSTICS.
SUBROUTINE PLRAJ ENTRY POINT 000172

STORAGE USED CODE(1) 000233 DATA(2) 000161 BLANK COMMON(2) 000000

EXTERNAL REFERENCES (BLOCK, NAME)

0003 IDENT
0004 QUID3Y
0005 NERR3S

STORAGE ASSIGNMENT (BLOCK, TYPE, RELATIVE LOCATION, NAME)

0001 000013 ISOL 0001 000154 S5OL 0001 000154 900L 0000 R 000000 ADANY 0000 N 000044 FLDA
0000 R 000042 FLDY 0000 000142 INJPS 0000 L 000137 ISYM 0000 L 000136 ITIME 0000 N 000044 LABELS

PC0000 DIAGNOSTIC THE NAME BUFF APPEARS IN A DIMENSION OR TYPE STATEMENT BUT IS NEVER REFERENCED.
PC0101 1* C
PC0101 2* C
PC0101 3* C
PC0101 4* C
PC0101 5* C
PC0101 6* C
PC0101 7* C
PC0101 8* C
PC0101 9* C
PC0101 10* C
PC0101 11* C
PC0101 12* C
PC0101 13* C
PC0101 14* C
PC0101 15* C
PC0101 16* C
PC0101 17* C
PC0101 18* C
PC0101 19* C
PC0101 20* C
PC0101 21* C
PC0101 22* C
PC0101 23* C
PC0101 24* C
PC0101 25* C
PC0101 26* C
PC0101 27* C
PC0101 28* C
PC0101 29* C
PC0101 30* C

SUBROUTINE PLRAJ(X,Y1,Y2,Y3,Y4,N,H,M,X1,M,R,ADANY,FLDA)

X IS THE ARRAY CONTAINING THE ABSCISSA VALUES

Y1,Y2,Y3,Y4 ARE THE ARRAYS CONTAINING THE ORDI NATE VALUES FOR THE

FOUR POSSIBLE ORDI NATE AXES CORRESPONDING TO X

Y1 IS THE RIGHT MOST AXIS

N IS THE NUMBER OF POINTS PER ARRAY

IX SPECIFIES THE TITLE OF THE ABSCISSA AXIS

IF IX=10 , THE TITLE IS "TIME"

N1,Y1,Y2,Y3,Y4 SPECIFY THE TITLES OF THE FOUR ORDI NATE AXES RESPECTIVELY

IF ONLY ONE ORDI NATE IS DESIRED , SET 1Y2=1Y3=1Y4=0

IF ONLY TWO ORDI NATES ARE DESIRED , SET 1Y3=1Y4=0

IF ONLY THREE ORDI NATES ARE DESIRED , SET 1Y4=0

HDR IS AN ALPHABERIC ARRAY USED AS A TITLE TO THE PLOT

ALL SCALING IS AUTOMATIC
*DIAGNOSTIC*  THE LIST CONTAINS AN ILLEGAL ITEM.
*DIAGNOSTIC*  A LIST IN THE ABOVE STATEMENT IS TOO LONG.
SUBROUTINE INTERP ENTRY POINT $Q0113$

STORAGE USED: CODE(1) $Q001251$ DATA(0) $Q000171$ BLANK COMMON(2) $Q00000$

EXTERNAL REFERENCES (BLOCK, NAME)

$Q003$ HERR39

STORAGE ASSIGNMENT (BLOCK, TYPE, RELATIVE LOCATION, NAME)

$Q0000$ R $Q000000$ CF1 $Q0000$ R $Q000001$ CF2 $Q0000$ $Q00002$ INUPS

SUBROUTINE INTERP(CCF, AMSL, ALPSL, PHISL, I, JJ, KK, J, J, K, CF1)

THREE DIMENSIONAL LINEAR INTERPOLATION TO FIND AERO. COEFF.

DIMENSION CCF(I, J, K)

CF1 = CCF(I, J, K) + CCF(I, J, K - 1) * PHISL + CCF(I, J, K) * PHISL
     + CCF(I, J, K) * PHISL + CCF(I, J, K) * ALPSL

CF2 = CCF(I, J, K - 1) + CCF(I, J, K) * PHISL + CCF(I, K, I) + CCF(I, K, I)
     + CCF(I, K, I) + CCF(I, K, I) * ALPSL

RETURN

END

END OF COMPILATION, NO DIAGNOSTICS.
SUBROUTINE PIVERT
ENTRY POINT 005490

STORAGE USED: CODE(1) 007051 DATA(1) 001111 BLANK COMMON(2) 000000

EXTERNAL REFERENCES (BLOCK, NAME)
0003 NERR39

STORAGE ASSIGNMENT (BLOCK, TYPE, RELATIVE LOCATION, NAME)

SUBROUTINE PIVERT(A, R, M, ND, N, EPS, IER)

TO SOLVE A GENERAL SYSTEM OF SIMULTANEOUS LINEAR EQUATIONS. GELG 70
COMPLETE PIVOTING. GELG 470

DESCRIPTION OF PARAMETERS

A = THE M BY M COEFFICIENT MATRIX. (DESTROYED) GELG 150
R = THE M BY N MATRIX OF RIGHT HAND SIDES. (DESTROYED) GELG 130
M = THE NUMBER OF EQUATIONS IN THE SYSTEM. GELG 140
N = THE NUMBER OF RIGHT HAND SIDE VECTORS. GELG 170
ND = THE DIMENSION OF A GELG 180
EPS = AN INPUT CONSTANT WHICH IS USED AS RELATIVE GELG 190
TOLERANCE FOR TEST ON LOSS OF SIGNIFICANCE. GELG 190
IER = RESULTING ERROR PARAMETER CODED AS FOLLOWS GELG 20U
IERR = NO ERROR,
IERR = 1 = NO RESULT BECAUSE OF M LESS THAN 1 OR GELG 21U
PIVOT ELEMENT AT ANY ELIMINATION STEP GELG 220
IERR = 2 = EQUAL TO 0, GELG 230
IERR = 3 = WARNING DUE TO POSSIBLE LOSS OF SIGNIFICANCE INDICATED AT ELIMINATION STEP K+1, GELG 250
WHERE PIVOT ELEMENT WAS LESS THAN ON GELG 270
IERR = 4 = EQUAL TO THE INTERNAL TOLERANCE EPS TIMES ABSOLUTELY GREATEST ELEMENT OF MATRIX A, GELG 280
IERR = 7 = GELG 290
IERR = 8 = GELG 300
IERR = 9 = GELG 310

REMARKS
THIS IS A MODIFICATION OF GEL6 (FROM IBM-SSP)

INPUT MATRICES A AND A ARE ASSUMED TO BE STORED COLUMNWISE

THE PROCEDURE GIVES RESULTS IF THE NUMBER OF EQUATIONS M IS

GREATER THAN 0 AND PIVOT ELEMENTS AT ALL ELIMINATION STEPS

ARE DIFFERENT FROM 0, HOWEVER WARNING IER = K - IF GIVEN -

INDICATES POSSIBLE LOSS OF SIGNIFICANCE IN CASE OF A WELL

SCALED MATRIX A AND APPROPRIATE TOLERANCE EPS, IER = K MAY BE

INTERPRETED THAT MATRIX A HAS THE RANK K, NO WARNING IS

GIVEN IN CASE M = 1,

DIMENSION A(M,M), I(M), K(M)

DOUBLE PRECISION A, R, EPS, ZERO, ONE, PIV, PIV1, TB, TOL

DATA ZERO, ONE, 0.0, 0.0,

IF(IM1230.230.10

SEARCH FOR GREATEST ELEMENT IN MATRIX A

IF IER = 0

PIV = ZERO

DO 30 L1 = 1, M

DO 30 L2 = 1, M

TB = DABS(A(L1,L2))

IF (TB = PIV) 30, 0, 20

PIV = TB

11 = L1

12 = L2

30 CONTINUE

TOL = EPS*PIV

A(I,J) IS PIVOT ELEMENT, PIV CONTAINS THE ABSOLUTE VALUE OF A(I,J)

START ELIMINATION LOOP

DO 70 K = 1, M

TEST ON SINGULARITY

IF (PIV) .LT. 1230.230.10

IF (IER) .LT. 70, 60, 70

60 IER = 0

70 PIV = ONE/A(I,J)

I = I - K

J = J - K

I*K IS ROW-INDEX, J*K COLUMN-INDEX OF PIVOT ELEMENT

PIVROW REDUCTION AND ROW INTERCHANGE IN RIGHT HAND SIDE R

DO 80 L1 = 1, M

80 R(K,L1) = TB

COLUMN INTERCHANGE IN MATRIX A

90 CONTINUE
PC171  94*  IF(J)120,170,100
PC174  85*  100 CONTINUE
PC175  86*  DO 110 L=K,N
PC200  87*      TB = A(L,K)
PC201  88*      A(L,K) = A(L,12)
PC202  89*  110 A(L,12) = TB
PC207  90*  C  ROW INTERCHANGE AND PIVOT ROW REDUCTION IN MATRIX A
PC209  91* 120 DO 130 L=K,N
PC207  92*      TB = PIVI*A(I1,L)
PC210  93*      A(I1,L) = A(K,L)
PC211  94*  130 A(K,L) = TB
PC211  95*  C  SAVE COLUMN INTERCHANGE INFORMATION
PC213  96*      A(K,K) = J
PC213  97*  C  ELEMENT REDUCTION AND NEXT PIVOT SEARCH
PC214  98* 100 PIV = ZERO
PC215  99*  101*  K1 = K
PC216 102*  DO 160 I=K1,N
PC221 103*      PIVI = -A(I,I)
PC222 104*  DO 150 L=K1,N
PC225 105*      A(I1,L) = A(I1,L) + PIVI*A(K,L)
PC226 106*      TB = DABS(A(I1,L))
PC227 107*  IF(TB = PIV)150,150,140
PC232 108* 140 PIV = TB
PC233 109*      I1 = I
PC234 110*      I2 = L
PC235 111*  150 CONTINUE
PC237 112*  DO 160 L=1,N
PC242 113* 160 R(I1,L) = R(I1,L) + PIVI*R(K,L)
PC249 114*  170 CONTINUE
PC249 115*  C  END OF ELIMINATION LOOP
PC249 116*  C  BACK SUBSTITUTION AND BACK INTERCHANGE
PC249 117*  180 IF(M)230,220,190
PC252 118*  190 CONTINUE
PC253 119*  DO 210 J=1,M
PC254 120*  121*      I1 = M-J + 1
PC257 122*  DO 210 J=1,N
PC260 123*      L = A(I1,J) + TB
PC263 124*      TB = R(I1,J)
PC264 125*  130 I1 = I1 + 1
PC264 126*  DO 200 K=I1+1,N
PC267 127*  200 TB = TB + A(I1,K)*R(K,J)
PC270 128*  210 R(I1,L,J) = TB
PC273 130*  220 RETURN
PC273 131*  C  C  ERROR RETURN
PC274 132*  GEL61620
PC274 133*  GEL61620
PC300 135*  RETURN
PC301 136*  END

END OF Compilation:  NO DIAGNOSTICS.
SUBROUTINE DENS

ENTRY POINT 000194

STORAGE USED
CODE(1) 000121 DATA(1) 00011 BLANK COMMON(2) 00000

EXTERNAL REFERENCES (BLOCK, NAME)
0003 EXP
0004 XPR
0005 SQRT
0006 HERR8

STORAGE ASSIGNMENT (BLOCK, TYPE, RELATIVE LOCATION, NAME)

0010 1 SUBROUTINE DENS(Z, P, RHO, CS)
0010 2 DOUBLE PRECISION Z
0010 3
0010 4 DIMENSION HB(22), PG(22), TB(22), A(22), B(22)
0010 5
0010 6 DATA M8/0.34,99,239.464,798,109,34,88,15,198,98,170,43,47/
0010 7
0010 8 1 2001.13,2.25,18.35,2.9,153.4,323,0,75,35,473,59,3,440,39,39
0010 9 2 4907,1,94,5,124,4,14,532,5,86,652,6,4,7282,3,91,33,984,7,5
0010 10 3 123,4,19.4,152,799,9,179,726,9,25,6,776,6/
0010 11
0010 12 DATA M/S/2.11,0.217,0.72,0.792,2,114,35,0,5,1,1,28,8,52,2,31,2,941
0010 13 1 23225,12,365,3,173,2,247,8,18,1,03,933,492,4,04,0,4,129,53,
0010 14 2 000153,599,6,00052,64,0,6,6407,660,0,000071,5671,6
0010 15 3 000005,32,4,72,0,00035,198,19,0,080,1,1,57,1,393,14,978,5,6
0010 16 4 0,1764,97,71,22,84,17,4,7,72,545,63,6,8,245,12,684,6/8
0010 17
0010 18 DATA TB/28,15,2,216,65,228,65,2,270,65,252,65,21,8,65,2,10,65,
0010 19 1 280,65,2,65,45,940,65,11,1C,65,127,6,130,65,15,6,65,130,65,
0010 20 2 2160,65,2,42,45,2,590,45,2,70,6,65/
0010 21
0010 22 DATA A/1.6775,586,5,5,0,1,406877,5,5,3725,679,5,5,0,1
0010 23 1 2252,355,5,4,8255,681,5,5,52,1,14,6,5,7475,723,5,6,5
0010 24 2 0,124,120,4,17,628,0,6,4,479,1,97,5,5,2884,637,5,5
0010 25 3 18635,746,5,5,120,11,72,5,6,5,63,1,974,6,0,116347,6,0
0010 26 4 92089,498,6,255989,9,6,2,157235,5,6/6
0010 27
0010 28 DATA B/7,2555,0,4,4063,13,2,9,34,1,632,2,12,2,17,11,9,13973,67,9
0010 29 1 17,814,127,6,5,0,8,5,746113,5,1,110522,6,6,6,127901
0010 30 2 3,2671,673,4,1,63795,6,2,17,9,6,4,3,246,979,6,4,615949
0010 31 3 19,933899,7,8732,15,9,7,30703,7,1,1427,17,32198
0010 32 4 2,9,255,62,133/
0010 33
0010 34 C
0010 35 H = 2085553, EQ = 7/(2085553), EQ + Z
0010 36 D0 1 = 2, 2
0010 37 IF(H=NB1),12,11
30 CONTINUE
31 I = 23
32 2 I = I + 1
33 DM = M - MB(I)
34 TEMP = 1.0 + A(I)*DM
35 T = TO(I) + TEMP
36 IF(A(I))3,4,3
37 6 TEMP = EXP(B(I)*DM)
38 GO TO 4
39 3 TEMP = TEMPE+B(I)
40 4 P = PB(I)*TEMP
41 RHO = 0.3236619E-3*P/T
42 CS = 65.770322E0+5*SRT(T)
43 RETURN
44 END

END OF COMPILE
NO DIAGNOSTICS.
SUBROUTINE DENS91 (Z, P, RH0, CS1)

DOUBLE PRECISION Z, P, RH0, CS1

DIMENSION H(22), P(22), H(22), T(22), A(22), B(22)

DATA H/0.33393239,65616.798,109998,8815419998,17040367,
1 200131232591863529153403230c2753575355938490439,
2 480781095120616593215486056046728293919989475,
3 1234619415279991798786624687766/

DATA PR/21612174726792114345051812885223162944,
1 12322512380321730217028180034334820062412953,
2 +00015359986+000052466007++00001057158200007715701,
3 +000058324672+00003619613000145917100343908764,
4 +81176667E7++22884717E7+77250893AL0+24891244E8/

DATA TR/28315122665422645270452524652160464616204666,
1 24045346657401651101651210651130651550651806066,
2 16065292045259045270466/

DATA A/-68755855E5-50/+4046775E5+373251695-50+,
1 -22523554E5-50-4825481E5-50+52414995E5-74757236E5-5,
2 +1212076E4-172828E4494419974L5-20885317E5-,
3 +163574655+12041725E5-65314775E4+61163475E4-,
4 +42098419E4+25260889E4*2*15723153E4-4/

DATA B/5.25588444043102E4-34+1632212-1220119+38473667E4-9,
1 170814278954804-57641135E4-11105522664127901,
2 -3276176316397095217174993-324597994+6156999,
3 -630336618733159703703911462717025198,
4 2*25542133/

C

Z = Z1+3.29049

H = 2085543180E0+2/120AE0531.80 + Z)
END OF COMPIILATION: NO DIAGNOSTICS.
### parachute with 6 D.O.F. by an elastic tether

#### 50-Ft. drogue deployment

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<thead>
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<th>IXB</th>
<th>IYB</th>
<th>XBAR</th>
<th>S</th>
<th>CLLP</th>
<th>OPPRIN</th>
<th>OPDSM</th>
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#### parachute suspension line load and strain arrays

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<th>EPL(16)</th>
</tr>
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<td>2000.00</td>
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<tr>
<td>6000.00</td>
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#### tether line load and strain arrays

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<tr>
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<td>0.1100</td>
</tr>
<tr>
<td>0.1200</td>
<td>0.1200</td>
</tr>
</tbody>
</table>

#### parachute inflation time history array, TITP

| 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

#### parachute aerodynamic ref. area array, Ssp

| 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
### Trajectory of a Rigid Body with 6 D.O.F. Connected to a Rigid Parachute with 5 D.O.F. by an Elastic Tether

**54-FT. Drogue Deployment**

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<th>YBAR</th>
<th>ZBAR</th>
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<th>CLHR</th>
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<th>OMPTRC</th>
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**Parachute Suspension Line Load and Strain Arrays**

### Parachute Suspension Line Load and Strain Arrays

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<th>TP(L)</th>
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**Tether Line Load and Strain Arrays**

### Tether Line Load and Strain Arrays

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<th>TP(L)</th>
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**Parachute Inflation Time History Array, TIP**

### Parachute Inflation Time History Array, TIP

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**Parachute Aerodynamic Ref. Area Array, SSP**

### Parachute Aerodynamic Ref. Area Array, SSP

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### Aerodynamic Coefficients of Forebody

**PphiE (Roll Angle-Degrees)**

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**Alpfe (Angle of Attack-Degrees)**

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**C(a) (Axial Coef. Array @ Pphi, Alpfe, Kanh)**

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For Mach No. 1.200:

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For Mach No. 1.940:

\( CT (\text{LATERAL COEF. ARRAY}([PHI],[I],[J],K,K)) \)

For Mach No. 0.000:

\( CLL (\text{ROLL NAT. COEF. ARRAY}([PHI],[I],[J],K,K)) \)

For Mach No. 0.900:

\( CLL (\text{ROLL NAT. COEF. ARRAY}([PHI],[I],[J],K,K)) \)
REFERENCES


