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Aerospace Nuclear Safety Program

USERS MANUAL FOR THE 3DOF TRAJECTORY COMPUTER PROGRAM

by L. L. PERINI

THE JOHNS HOPKINS UNIVERSITY • APPLIED PHYSICS LABORATORY

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COMPUTER PROGRAM**

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FOREWORD

The work reported herein was conducted by the Aeronautics Division of the Applied Physics Laboratory for the Atomic Energy Commission Safety Branch, Space Nuclear Systems Office. Activities of the Aeronautics Division are under the general supervision of Dr. William H. Avery. The Project Engineer for the Aerospace Nuclear Safety Program is James C. Hagan.

ABSTRACT

This report documents the three-degree of freedom (3DOF) reentry trajectory computer code employed in the Atomic Energy Commission Aerospace Nuclear Safety Program at the Applied Physics Laboratory. The code is written in Fortran and is operational on the IBM 360/91. A sample input deck setup is illustrated.

SUMMARY

The three degree of freedom Fortran computer code employed in the Atomic Energy Commission Aerospace Nuclear Safety Program at the Applied Physics Laboratory is documented herein. The basic trajectory equations are derived and the basic environmental parameters necessary for further detailed thermal studies are defined. The capability of calculating skip type trajectories is included as an option.

The input variables are described and a sample input deck is shown. The computer code is relatively small and efficient, resulting in low computer costs. The program has been in use at APL for over a year and the results have been compared to other calculations performed at other organizations with excellent agreement. The code is operational on the IBM 360/91 and is a modification of a program developed by the Lockheed Missile and Space Corporation.

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I. INTRODUCTION

This report documents the modifications and additions made to the three-degree of freedom (3DOF) reentry trajectory computer code for the Atomic Energy Commission (AEC) Aerospace Nuclear Safety program. The 3DOF code was originally received by the Applied Physics Laboratory (APL) from Lockheed Missiles and Space Company.¹ The code was modified for use on the IBM 360/91 and two versions developed,² RAV3D and WEA3D, in conjunction with projects at APL. The development of this third version entitled 3DOF has resulted in major modifications, additions and deletions in order to satisfy the computational requirements of the AEC Aerospace Nuclear Safety program.

The 1962 atmospheric model was changed from a tabular to a hydrostatic model employing lapse rates. A subroutine previously developed was utilized. In order to correctly simulate low angle-orbital speed reentries it was necessary to add an elliptical earth model and the corresponding gravity potential and to employ double precision arithmetic. In the process of completing these latter modifications, errors were found in the basic equations of motion. The input and output formats were extensively changed. Calculations of stagnation point convective and radiative heating rates to a one-foot spherical body were added along with computations of the total pressure. These latter parameters are punched on cards and utilized as inputs to the one dimensional ablation program (CMA)³ and the multidimensional Standard Heat Transfer Program (SHTP)⁴ for further detailed thermal studies.

The capability of calculating 'skip' type reentries was incorporated by assuming the Keplerian equations of motion (i.e., no drag) are applicable above an input value of altitude.

A parameter indicating the stagnation point recession rate for a graphitic body is evaluated and is based on the assumption of a diffusion limited boundary layer analysis.

II. EQUATIONS OF MOTION

In this section are presented the equations used in the computer code for the trajectory and heating variables.

The geocentric spherical rotating coordinate system, shown in Fig. 1, is utilized. From Fig. 1 we have,

$$\vec{r} = r \vec{e}_r \quad (1)$$

$$\omega = (\dot{\theta} + \omega_e) \cos \theta \vec{e}_r - (\dot{\theta} + \omega_e) \sin \theta \vec{e}_\theta^* + \dot{\phi} \vec{e}_\phi \quad (2)$$

The rate of change of the unit vectors are

$$\left. \begin{aligned} \dot{\vec{e}}_r &= \vec{\omega} \times \vec{e}_r \\ \dot{\vec{e}}_\theta^* &= \vec{\omega} \times \vec{e}_\theta^* \\ \dot{\vec{e}}_\phi &= \vec{\omega} \times \vec{e}_\phi \end{aligned} \right\} \quad (3)$$

The velocity and acceleration vectors are

$$\bar{V} = \dot{\bar{r}} = \dot{r} \bar{e}_r + r \dot{\theta} \bar{e}_\theta^* + r(\dot{\theta} + \omega_e) \sin \theta \bar{e}_\phi \quad (4)$$

and

$$\bar{a} = \dot{\bar{V}} = \dot{V}'_r \bar{e}_r + V'_r \dot{\bar{e}}_r + \dot{V}'_\theta \bar{e}_\theta^* + V'_\theta \dot{\bar{e}}_\theta^* + \dot{V}'_\phi \bar{e}_\phi + V'_\phi \dot{\bar{e}}_\phi \quad (5)$$

where

$$\left. \begin{aligned} V'_r &= \dot{r} \\ V'_\theta &= r \dot{\theta} \\ V'_\phi &= r (\dot{\theta} + \omega_e) \sin \theta \end{aligned} \right\} \quad (6)$$

The equations of motion utilized in the 3DOF program are based on a slightly modified version of the above coordinate system in that the positive direction of $\bar{e}_\theta$ is reversed to that utilized above (shown dotted in Fig. 1). The resulting inertial velocity and acceleration components are,

$$\left. \begin{aligned} V'_r &= \dot{r} \\ V'_\theta &= - r \dot{\theta} \\ V'_\phi &= r (\dot{\theta} + \omega_e) \sin \theta \end{aligned} \right\} \quad (7)$$

$$\left. \begin{aligned} a_r &= \dot{V}'_r - (V'_\theta)^2/r - (V'_\phi)^2/r \\ a_\theta &= \dot{V}'_\theta + V'_r V'_\theta/r + (V'_\phi)^2/(r \tan \theta) \\ a_\phi &= \dot{V}'_\phi + V'_r V'_\phi/r - V'_\theta V'_\phi/(r \tan \theta) \end{aligned} \right\} \quad (8)$$

Converting from inertial to relative coordinates

$$V_{\emptyset} = V'_{\emptyset} - r \omega_e \sin \theta \quad (9)$$

and utilizing Newton's law $\bar{F} = m \cdot \bar{a}$ we then have

$$\left. \begin{aligned} V_r &= \dot{r} \\ V_{\theta} &= -r \dot{\theta} \\ V_{\emptyset} &= r \dot{\emptyset} \sin \theta \\ \dot{V}_r &= F_r/m + V_{\theta}^2/r + V_{\emptyset}^2/r + 2 V_{\emptyset} \omega_e \sin \theta - r \omega_e^2 \sin^2 \theta \\ \dot{V}_{\theta} &= F_{\theta}/m - V_r V_{\emptyset}/r - V_{\emptyset}^2/(r \tan \theta) - 2 V_{\emptyset} \omega_e \cos \theta - r \omega_e^2 \sin \theta \cos \theta \\ \dot{V}_{\emptyset} &= F_{\emptyset}/m - V_r V_{\theta}/r + V_{\theta} V_{\emptyset}/(r \tan \theta) - 2 \omega_e (V_r \sin \theta - V_{\theta} \cos \theta) \end{aligned} \right\} \quad (10)$$

The total relative velocity is given by

$$v = (V_r^2 + V_{\theta}^2 + V_{\emptyset}^2)^{1/2} \quad (11)$$

The initial conditions are specified by t_o , γ_o , A_o , λ_o , L_o , h_o and V_o from which we have

$$\left. \begin{aligned} \theta_o &= 90 - \lambda_o \\ \emptyset_o &= L_o \\ r_o &= h_o + R_e \\ (V_r)_o &= V_o \sin \gamma_o \\ (V_{\theta})_o &= V_o \cos \gamma_o \cos A_o \\ (V_{\emptyset})_o &= V_o \cos \gamma_o \sin A_o \end{aligned} \right\} \quad (12)$$

The initial conditions can be input in either relative or inertial coordinates. If the inputs are in inertial coordinates the relative values are computed from⁵

$$V = V' [1 + C^2 - 2C \cos \gamma' \sin A']^{1/2} \quad (13)$$

$$\gamma = \sin^{-1} (V' \sin \gamma' / V) \quad (14)$$

$$A = \tan^{-1} [(\sin A' - C/\cos \gamma')/\cos A'] \quad (15)$$

where

$$C = r \omega_e \cos \lambda / V'$$

The flight path angle and azimuth are given by

$$\gamma = \tan^{-1} \left(V_r / \sqrt{V_\theta^2 + V_\phi^2} \right) \quad (16)$$

$$A = \tan^{-1} (V_\phi / V_\theta) \quad (17)$$

The force components $\bar{F}$ consist of two sets of forces, aerodynamic forces $\bar{F}_A$ and gravity forces $\bar{F}_g$. The aerodynamic forces are specified by values of C_D , C_L/C_D (drag and lift are axial and normal, respectively, to the velocity vector) and C_Y/C_D (represents a yaw force normal to the L-D plane). A number of options are available in specifying C_D . Tabular values as a function of either h or M_∞ can be input and these will be defined in Section V. An analytic relation for C_D can also be selected based on a semi-empirical method of Matting⁶ that provides a definition of C_D from the free molecular flow regime to the continuum flow regime,

$$C_D = C_{D_c} \left\{ 1 + \left(C_{D_{FMF}} - C_{D_c} \right) \text{EXP} \left[-7.32 \times 10^6 R g_{SL} \rho_\infty (1 + E_D) \right] \right\} \quad (18)$$

where C_{D_c} and $C_{D_{FMF}}$ are, respectively, the continuum and free molecular flow values of the drag coefficient. R is the nose radius in feet and E_D is an empirical input variable whereby the user can modify the form of the relationship based on experimental data as discussed in Ref. 6. The lift/drag and yaw/drag ratios are input constants. The drag, lift and yaw forces are then given by

$$A_D = C_D q_\infty A_{ref} \quad (19)$$

$$A_L = A_D (C_L/C_D) \quad (20)$$

$$A_Y = A_D (C_Y/C_D) \quad (21)$$

The three aerodynamic force components are then

$$\vec{F}_A = F_{Ar} \vec{e}_r + F_{A\theta} \vec{e}_\theta + F_{A\phi} \vec{e}_\phi$$

where, referring to Fig. 2

$$\left. \begin{aligned} F_{Ar} &= -A_D \sin \gamma + A_L \cos \gamma \\ F_{A\theta} &= -A_D \cos \gamma \cos A - A_L \sin \gamma \cos A - A_Y \sin A \\ F_{A\phi} &= -A_D \cos \gamma \sin A - A_L \sin \gamma \sin A + A_Y \cos A \end{aligned} \right\} \quad (22)$$

Two earth models are available in the 3DOF code, a spherical or elliptical representation. For the spherical assumption gravity acts along $\vec{e}_r$ and is simply given by

$$g_r = g_{SL} (R_e/r)^2 \quad (23)$$

where

$$R_e = 20.898908 \times 10^6 \text{ feet}$$

$$g_{SL} = 32.174 \text{ ft/sec}^2$$

$$r = R_e + h$$

For the ellipsoidal earth model the gravity potential function in spherical harmonics⁷ up to the second harmonic is assumed,

$$U(r, \lambda) = \mu/r + \epsilon \mu (1 - 3 \sin^2 \lambda)/(3r^3) \quad (24)$$

where we have used,

$$\mu = 1.40762913 \times 10^{16} \text{ ft}^3/\text{sec}^2$$

$$\epsilon = 7.148788887 \times 10^{11} \text{ ft}^2$$

The gravity components are given by

$$m \bar{F}_g = - \frac{\partial U}{\partial r} \bar{e}_r - \frac{1}{r} \frac{\partial U}{\partial \lambda} \bar{e}_\theta = g_r \bar{e}_r + g_\theta \bar{e}_\theta \quad (25)$$

or

$$\left. \begin{aligned} g_r &= - \mu/r^2 - \mu \epsilon (1 - 3 \sin^2 \lambda)/r^4 \\ g_\theta &= - 2 \mu \epsilon \sin \lambda \cos \lambda / r^4 \end{aligned} \right\} \quad (26)$$

The earth's radius is now a function of the geocentric latitude, λ ,

$$\left. \begin{aligned} R_e(\lambda) &= R_{eq}/(1 - e_3 \sin^2 \lambda)^{1/2} \\ e_3 &= 1 - (R_{eq}/R_p)^2 \end{aligned} \right\} \quad (27)$$

where

$$R_{eq} = \text{equatorial radius} = 20.92554 \times 10^6 \text{ ft}$$

$$R_p = \text{polar radius} = 20.855107 \times 10^6 \text{ ft}$$

For the accurate determination of aerodynamic forces the geodetic altitude h_g is required and for range calculations values of the geodetic latitude λ_g are required. A sketch of the relationship between the geodetic values and the geocentric values is shown in Fig. 3. Based on the approximations outlined in Ref. 8, values of $h-h_g$ and $\lambda-\lambda_g$ were evaluated as a function of h and λ . Maximum deviations of $h-h_g \simeq 0$ to 5 meters occurred at $\lambda = 45^\circ$ in the region of interest, $h < 500$ km. The differences are small and the correction was therefore not made. Similarly a maximum deviation of $\lambda-\lambda_g = -0.19^\circ$ resulted at $\lambda = 45^\circ$ and for $h < 500$ km. As accurate range calculations are not of primary concern for the AEC safety studies, this correction was also not incorporated.

The equations are numerically integrated by the Runge-Kutta method with a variable time step selected from

$$\Delta t = 0.01 (V + 2000) / \sqrt{\dot{V}_r^2 + \dot{V}_\phi^2 + \dot{V}_\theta^2} \quad (28)$$

subject to maximum and minimum constraints specified by input variables.*

The following integrations are performed,

* Maximum and minimum values of 1.0 and 0.1 seconds are currently employed.

$$\left. \begin{aligned}
 V_r(t_{i+1}) &= V_r(t_i) + \int_{\Delta t} \dot{V}_r dt \\
 V_\theta(t_{i+1}) &= V_\theta(t_i) + \int_{\Delta t} \dot{V}_\theta dt \\
 V_\phi(t_{i+1}) &= V_\phi(t_i) + \int_{\Delta t} \dot{V}_\phi dt \\
 r(t_{i+1}) &= r(t_i) + \int_{\Delta t} \dot{r} dt \\
 \theta(t_{i+1}) &= \theta(t_i) - \int_{\Delta t} (V_\theta/r) dt \\
 \phi(t_{i+1}) &= \phi(t_i) + \int_{\Delta t} V_\phi/(r \sin \theta) dt
 \end{aligned} \right\} \quad (29)$$

III. ENVIRONMENTAL PARAMETERS

The evaluation of environmental reentry parameters for a particular trajectory is the primary output of the computer code, and described below are the correlations, equations and methods employed in the 3DOF computer code in defining the various output parameters.

Mach Number

$$M = V/a_\infty \quad (30)$$

where a_∞ is the free stream speed of sound, ft/sec, based on the 1962 standard atmosphere.⁹

Total Enthalpy

$$h_{T_S} = C_p(T_\infty - T_{ref}) + V^2/(2 g_{SL}J), \text{ Btu/lb} \quad (31)$$

where

$$C_p = 0.24 \text{ Btu/(lb-}^\circ\text{R)}, \quad T_{ref} = 536.69^\circ\text{R}$$

and $2gJ = 50062.7 \text{ (ft}^2\text{/sec}^2\text{)/(Btu/lb)}.$

Reynolds Number

$$R_N = \rho_\infty V D_{ref} / \mu_\infty \quad (32)$$

where μ_∞ is evaluated from Sutherland's viscosity relationship for air with T_∞ (see Eq. 44 below).

Knudsen Number

$$K_N = M_\infty / \sqrt{R_N} \quad (33)$$

where the boundary layer thickness is employed as the characteristic dimension.

Ballistic Coefficient

$$C_D = W / (C_D A_{ref}) \quad , \quad \text{lb/ft}^2 \quad (34)$$

Dynamic Pressure

$$q_\infty = \rho_\infty V^2 / 2 \quad , \quad \text{lb/ft}^2 \quad (35)$$

Range^{*}

$$R = R_O + [(-D_r \cos A_O + C_r \sin A_O)^2 + (D_r \sin A_O + C_r \cos A_O)^2]^{1/2} \quad , \quad \text{N.M.} \quad (36)$$

where

$$D_r = (\theta - \theta_O) R_e / 6080.0, \text{ N.M.}$$

$$C_r = (\theta - \theta_O) R_e \sin \theta_O / 6080.0, \text{ N.M.}$$

Total Pressure

The total pressure behind a normal shock, P_{T_S} , is evaluated in the hypersonic regime ($M_\infty > 5$) from the hypersonic approximation,

*The equation for range assumes a spherical earth and, in addition, is valid for short ranges only. It is planned to employ the appropriate representation in the near future.

$$P_{T_S} = 2q_\infty = \gamma_2 P_\infty M_\infty^2 / 2116.224, \text{ atm} \quad (37)$$

Comparison to equilibrium normal shock solutions¹⁰ has resulted in a value of $\gamma_2 = 1.35$ as yielding the best results. In the supersonic regime ($1 < M_\infty \leq 5$) the perfect gas Mach functions¹¹ are employed

$$P_{T_S} = \frac{P_\infty}{2116.224} \left(\frac{\gamma_1 + 1}{2} M_\infty^2 \right)^{\frac{\gamma_1}{\gamma_1 - 1}} \left(\frac{\gamma_1 + 1}{2\gamma_1 M_\infty^2 - \gamma_1 + 1} \right)^{\frac{1}{\gamma_1 - 1}}, \text{ atm} \quad (38)$$

where γ_1 is a mean value based on empirical curve fits to the NBS¹² air tables,

$$\gamma_1 = (1.4 + \gamma)/2$$

where

$$\gamma = 1.4 \text{ for } T_{T_S} \leq 500^\circ\text{R}$$

$$\gamma = \frac{3.3 + T_{T_S}/2750}{2.3 + T_{T_S}/2750} \text{ for } 550 < T_{T_S} < 3300^\circ\text{R}$$

$$\gamma = 1.286 \text{ for } T_{T_S} \geq 3300^\circ\text{R}$$

$$T_{T_S} = T_\infty \left(1 + \frac{\gamma_1 - 1}{2} M_\infty^2 \right), \text{ } ^\circ\text{R}$$

In the subsonic regime ($M_\infty \leq 1$),

$$P_{T_S} = \frac{P_\infty}{2116.224} \left(1 + \frac{\gamma - 1}{2} M_\infty^2 \right)^{\frac{\gamma}{\gamma - 1}}, \text{ atm} \quad (39)$$

where $\gamma = 1.4$.

Hypersonic ($M_\infty > 6$) Laminar Convective Heating Rate

The empirical correlation of Detra, Kemp and Riddell is utilized¹³ for the stagnation point, one-foot sphere value. The correlation, for a cold wall, is given by

$$\dot{q}_c = \frac{17600}{\sqrt{R}} \left(\frac{\rho_\infty}{\rho_{SL}} \right)^{1/2} \left(\frac{V}{\tilde{V}_s} \right)^{3.15}, \text{ Btu/(ft}^2\text{-sec)} \quad (40)$$

where ρ_{SL} is the sea level density ($2.3768 \times 10^{-3} \text{ lb-sec}^2/\text{ft}^4$) and $\tilde{V}_s$ is a reference speed, satellite speed (26000 ft/sec).

Subsonic-Supersonic ($M_\infty \leq 6$) Laminar Convective Heating Rate

Below $M_\infty = 6$ the stagnation point, one foot sphere value is determined from the Sibulkin¹⁴ relationship represented by,*

$$\dot{q}_c = \frac{0.945}{\sqrt{R}} h_{TS} (\rho_s \mu_s \beta_s V/2)^{1/2}, \text{ Btu/(ft}^2\text{-sec)} \quad (41)$$

where ρ_s is the density behind a normal shock evaluated from the Rankine-Hugoniot relations,

$$\left. \begin{aligned} P_2 &= 2 P_\infty \left(\gamma M_\infty^2 - \frac{\gamma-1}{2} \right) / (\gamma+1), \text{ lb/ft}^2 \\ M_2 &= \left[\frac{1 + (\gamma-1)M_\infty^2/2}{\gamma M_\infty^2 - (\gamma-1)/2} \right]^{1/2} \end{aligned} \right\} \quad (42)$$

*The stagnation temperatures below $M_\infty = 6$ are relatively low ($< 5000^\circ\text{R}$) and dissociation is small. Air is therefore treated as a calorically perfect gas.

$$\left. \begin{aligned} T_s &= T_\infty \left[1 + (\gamma-1) M_\infty^2/2 \right], \text{ } ^\circ\text{R} \\ P_s &= P_2 \left[1 + (\gamma-1) M_2^2/2 \right]^{\frac{\gamma}{\gamma-1}}, \text{ lb/ft}^2 \\ \rho_s &= P_s / (R_g T_s g_{SL}), \text{ lb-sec}^2/\text{ft}^4 \end{aligned} \right\} \quad (43)$$

where $R_g = 53.3 \text{ (ft-lb)/(lb-} ^\circ\text{R)}$. A value of $\gamma = 1.2$ is employed in order to provide a smooth transition to the hypersonic correlation, Eq. 41, at $M_\infty = 6$. In the subsonic and low supersonic range Eq. 41 is relatively insensitive to the value of γ . The viscosity μ_s is evaluated from the Sutherland¹² relation

$$\mu_s = 9.898 \times 10^{-7} \left(\frac{T_s}{1.8} \right)^{3/2} / (110.4 + T_s/1.8), \text{ lb/(ft-sec)} \quad (44)$$

with T_s in $^\circ\text{R}$. Below $M_\infty = 1$ Eq. 43 is used to evaluate P_s with $P_2 = P_\infty$ and $M_2 = M_\infty$. The stagnation point velocity gradient β_s below $M_\infty = 4.98$ is given by,

$$\begin{aligned} \beta_s = \frac{D}{V} \left(\frac{dU_e}{dx} \right)_{s=0} &= 2.74041 - 0.7121196 M_\infty \\ &- 0.125607 M_\infty^2 + 0.0978086 M_\infty^3 - 0.01148119 M_\infty^4 \end{aligned} \quad (45)$$

and represents a least squares fit to experimental data¹⁵ based on a perfect gas test of a spherical body. Above $M_\infty = 4.98$ the hypersonic modified Newtonian value for a sphere of $\beta_s = 1.1$ is utilized.

Free Molecular Flow Stagnation Point Heating Rate

In the free molecular flow regime the convective stagnation point heating rate is represented by

$$\dot{q}_{\text{FMF}} = \rho_{\infty} V^3 / (2J) , \text{ Btu}/(\text{ft}^2\text{-sec}) \quad (46)$$

where a unit accommodation coefficient has been assumed.

Stagnation Point Radiative Heat Transfer

For the radiative heat flux, theoretical calculations based on a computer code developed by Callis¹⁶ are utilized based on $R = 1$ foot. The results are based on inviscid, equilibrium stagnation point shock layer with non-gray emission and absorption of radiation. An eight step absorption model for air developed by Olstad¹⁷ is employed. Two of the steps in the eight step model have been modified at APL based on comparisons to more exact calculations from NASA Langley.¹⁸

Tabular values of $\dot{q}_{\text{rad}}$ as a function of V and h are incorporated in the 3DOF computer code and shown in Table I. Logarithmic interpolation is employed for values not listed in Table I.

Diffusion Limited Recession Rate

As an indicator of total recession, the recession of a graphitic material in the diffusion limited regime is evaluated throughout the trajectory. For carbon-air the mass loss rate is given by¹⁹

$$\dot{m}_D = 0.1725 (\rho_e U_e C_h), (\text{lb}/\text{ft}^2\text{-sec}) \quad (47)$$

where

$$\rho_e U_e C_h = \dot{q}/h_{T_s}, \text{ lb}/(\text{ft}^2\text{-sec}) \quad (48)$$

and $\dot{q}$ is evaluated from Matting's bridging relationship between the continuum and free molecular flow regimes,⁶

$$\dot{q} = f \dot{q}_c \left(1 - e^{-\frac{\dot{q}_{FMF}}{f \dot{q}_c}} \right), \text{ Btu}/(\text{ft}^2\text{-sec}) \quad (49)$$

and f is an input parameter used to modify the one foot spherical heating rate to a different geometry and/or nose radii and to account for blowing effects. The total mass loss is then

$$W_D = \int \dot{m}_D dt, \text{ lb}/\text{ft}^2 \quad (50)$$

and the recession is given by

$$S = 12 W_D / \rho_{\text{grap}}, \text{ inches} \quad (51)$$

It should be noted that the above analysis will, in general, result in a lower bound to a more realistic analysis incorporating effects of sublimation and erosion for steep reentries. In the case of skip type trajectories, to be discussed in Section IV, the above analysis will result in higher mass loss rates than a more realistic analysis.

IV. SKIP TRAJECTORIES

One of the design trajectories for the safety studies is a multiple skip reentry. The skip trajectories result when the velocity

is sufficiently high, greater than satellite circular speed, and the flight path angle sufficiently small, such that the body is not captured on a re-entry from 400 Kft (or some other specified arbitrary h) but rather escapes temporarily on a Kepler orbit and returns later for a subsequent reentry. On each skip energy is dissipated during the atmospheric portion of flight (near perigee) and the body will eventually be captured. The capability of calculating skip trajectories in an approximate manner has been incorporated in the program. The major assumption employed is that the atmosphere is assumed to be negligible above a prespecified height and that the drag-free vacuum Keplerian equations are valid resulting in the use of simplified algebraic relations for the orbital equations of motion. This procedure provides a great reduction in computer costs and for thermal studies is sufficiently accurate. In essence the reentry conditions (h_0, V_0, γ_0) for each skip is equivalent to the exit conditions for the previous skip (h_e, V_e, γ_e) except that the sign of γ is reversed ($\gamma_0 = -\gamma_e$). The calculations incorporated in the program are directed toward evaluating the orbital parameters and in calculating latitude, longitude and azimuth. The majority of the equations employed are taken from Ref. 20. The eccentricity e of the orbit is evaluated from the inertial atmospheric exit condition V'_e, r_e and γ'_e

$$e = \left[1 + (v_e^2 - 2) v_e^2 \cos^2 \gamma'_e \right]^{1/2} \quad (52)$$

where

$$v_e = V'_e / V_s \quad (53)$$

$$V_s = \sqrt{g_r r_e} \frac{R_e}{r_e} \quad (54)$$

The orbit perigee and apogee are then

$$r_p = r_e v_e^2 \cos^2 \gamma_e' / (1 + e) \quad (55)$$

$$r_a = r_e v_e^2 \cos^2 \gamma_e' / (1 - e) \quad (56)$$

The anomaly Ψ_e is found from ($\Psi = 0$ at perigee)

$$\Psi_e = \cos^{-1} \left[(v_e^2 \cos^2 \gamma_e' - 1) / e \right] \quad (57)$$

where the semi-major axis is,

$$a = (r_p + r_a) / 2 \quad (58)$$

The anomaly at reentry is

$$\Psi_o = 360 - \Psi_e \quad (59)$$

The flight time from $\Psi = 0$ is

$$t(\Psi) = \frac{a^{3/2}}{\sqrt{g_{SL}} R} \left[2 \tan^{-1} \left(\sqrt{\frac{1-e}{1+e}} \tan \frac{\Psi}{2} \right) - \frac{e \sqrt{1-e^2} \sin \Psi}{1 + e \cos \Psi} \right] \quad (60)$$

so that the flight time from Ψ_e to Ψ_o is

$$\Delta t = t_e(\Psi_e) - t_o(\Psi_o) \quad (61)$$

The time for a complete revolution is given by Eq. 60 with $\Psi = 360^\circ$ and

$$t = 2\pi a^{3/2} / (\sqrt{g_{SL}} R) \quad (62)$$

The inclination of the orbit plane to the equator can be found from the inertial azimuth A'_e and the inertial geocentric latitude λ'_e

$$i = \cos^{-1} (\cos \lambda'_e \sin A'_e) \quad (63)$$

The reentry latitude is given by

$$\lambda_o = \sin^{-1} (\sin \tilde{\Psi}_o \sin i) \quad (64)$$

where $\tilde{\Psi}_o$ is the reentry central angle measured from the line of nodes (i.e., the intersection of the orbit plane and the equator)

$$\tilde{\Psi}_o = \Psi_o - \Psi_e + \tilde{\Psi}_e \quad (65)$$

$$\Psi_e = \sin^{-1} (\sin \lambda'_e / \sin i) \quad (66)$$

The reentry inertial azimuth is given by

$$A'_o = \sin^{-1} (\cos i / \cos \lambda'_o) \quad (67)$$

The reentry longitude measured from the line of nodes is

$$\tilde{L}_o = \sin^{-1} (\cos \lambda_o \sin A_o) \quad (68)$$

and the initial inertial true longitude is

$$L'_o = \tilde{L}_o + L'_e - \omega_e (t_e - t_o) \quad (69)$$

V. COMPUTER PROGRAM

The program is written in Fortran and is operational on the IBM 360/91. A listing of the source code is tabulated in Appendix I.

Six subroutines are employed by the main program:

ATM _____	The 1962 standard atmosphere ²¹
AZMUTH _____	A function subroutine that determines the azimuth, A, from the velocity components
CALC _____	Performs calculations and table look-ups to evaluate the aerodynamic forces
KEPLER _____	Used during skip trajectories. Orbit parameters are evaluated and reentry conditions are evaluated
ØUTPT _____	Prints the output at the specified time point
PIF1 _____	A function subroutine that performs linear interpolation

Shown in Appendix II is a sample program setup along with the job control cards required to execute the program that currently resides on a 'BHP' library at the Applied Physics Laboratory.* A number of options with respect to program control are available to the user through input parameters. A description of the input variables and their formats follow.

The first card in the input deck is a title card that is printed at the top of each page of output. Information describing and/or identifying the run is punched on this card in columns 1 to 68. The title card is followed by a block of 'namelist' data called INPUT. The signal to the program that this data follows is &INPUT punched anywhere on the next card

* Contact the author as to the current library indexes in the event the program is desired to be used.

following the title card. The following variables are included in the data block.

HØ	Initial altitude, geocentric, ft
VI	Initial inertial velocity, ft/sec
GAMI	Initial inertial flight path angle, degrees
AZI	Initial inertial azimuth, degrees
VREL	Initial relative velocity, ft
GAMREL	Initial relative flight path angle, degrees
AZREL	Initial relative azimuth, degrees
IRI	If = 0 use inertial values, VI, GAMI and AZI If ≠ 0 use relative values VREL, GAMREL and AZREL
TØ	Initial value of time, sec
XLAT	Initial latitude, deg
XLØNG	Initial longitude, deg
WØ	Initial weight (see also TFIL), lb
RANGEØ	Initial value of range, n.m.
RØTØPT	If = 0 use non-rotating earth model If ≠ 0 use rotating earth model
IØBL	If ≠ 0 use ellipsoidal earth model If = 0 use spherical earth model
JAERØ	If = 0 use same aerodynamics as last run If ≠ 0 read new aerodynamic values
LAERØ	If = +1. Read and use $C_D = F(M)$ If = 0. Use bridging relationship for C_D , Eq. 18 If = -1. Read and use $C_D = F(h)$

CDC Continuum flow drag coefficient used in bridging relationship, Eq. 18

CDFM Free molecular flow drag coefficient used in bridging relationship, Eq. 18

RNØSE Nose radius, ft, used in bridging relationship, Eq. 18

ED Empirical constant used to modify bridging relationship, Eq. 18, equal to 0 for a sphere

SKINFR If > 0.0 read and print skin friction coefficient $C_f = f(h,v)$ table. The skin friction coefficient is added to C_D

DWT If > 0.0 read and print weight loss = $f(h)$ table

TFIL If > 0.0 use WFIL and CAFIL values listed below for weight and C_A factors

WFIL Vehicle weight if $t < \text{TFIL}$. W_0 used for vehicle weight when $t > \text{TFIL}$

CAFIL Multiplying factor for C_D if $t < \text{TFIL}$

SWMCH If > 0.0 read $C_D = f(M)$ table and use when $M < \text{SWMCH}$

SWALT If > 0.0 read $C_D = f(M)$ table and use when $h < \text{SWALT}$

RLD1 Lift to drag ratio from t_0 to $M_\infty = 1$

RLD2 Lift to drag ratio for $M_\infty < 1$

RYD1 Yaw to drag ratio from t_0 to $M_\infty = 1$

RYD2 Yaw to drag ratio for $M_\infty < 1$

HCØ Lower altitude limit, ft, of calculations

HØUT Upper altitude limit, ft, of calculations. If $h > \text{HØUT}$ and $\text{NPASS} > 0$ then skip trajectories are done

SREF Reference area used for drag and lift calculations, ft^2

DREF Reference length used in Reynolds number

RHØG Graphite density used in diffusion limited mass loss calculation, lb/ft^3 , Eq. 51

FACTOR Factor, f , used to modify the one-foot spherical heating rate for the diffusion limited mass loss calculations, Eq. 49

LKASE Number of cases to be run

NØUT Number of time steps between printouts

IPUNCH If $\neq 0$ punched cards are output at each time point printed

NPASS Number of skips allowed

NPØUT Print output control. Print each NPØUT skip trajectory. If IPUNCH $\neq 0$ also punches cards at this time

DTMAX Maximum allowable time step, sec

DTMIN Minimum allowable time step, sec

To signify the end of the INPUT data block the characters '&END' are punched on a card. The above data block variables are essentially unformatted, i.e., the order is immaterial and the variables are separated by commas and can appear anywhere on the card. An example is illustrated in Appendix II. Any variables not specified in the input either take on the initialized value in the program for the first case run or retain the value specified in the previous case. Following the namelist variables the various tables, controlled by JAERØ, IAERØ, SWMCH, SWALT, SKINFR, and DWT, are read in the following order.

1. If $IAER\emptyset < 0$ and $JAER\emptyset \neq 0$ then read and print $C_A = f(h)$
table or
If $IAER\emptyset > 0$ and $JAER\emptyset \neq 0$ then read and print $C_A = f(M_\infty)$
table or
If $IAER\emptyset = 0$ then do not read tables in this section.
2. If $SWMCH > 0$ or $SWALT > 0$ then read and print $C_A = f(M_\infty)$
table to be used when $M_\infty < SWMCH$ or $h < SWALT$.
3. If $SKINFR > 0$ then read and print $C_f = f(h, V)$ table.
4. If $DWT > 0$ then read and print weight loss factor,
 $\frac{W}{W_o} = f(h)$ table.

The formats for all the above tables are the same. On the first card the number of points in the table is punched (format I3 right adjusted). For the C_f table two integers are punched (format 2I3), the length of the h table first and the V table length second. On the next card follows the list of independent variables, six per card (format 6G12.8). For the C_f tables the list of h's are first followed by the list of V's commencing on a new card. This is then followed, starting on a new card, by the dependent variables (e.g., C_A , C_f , weight loss) with the same format as the independent variables. For the C_f tables the sequence of the values of C_f are $C_f(h_1, V_1)$, $C_f(h_2, V_1)$, ----- $C_f(h_n, V_1)$, $C_f(h_1, V_2)$, $C_f(h_2, V_2)$, ----- $C_f(h_n, V_i)$. The independent variables must be in ascending order. The maximum number of points for the C_f table is 25 values of h and 10 values of V. All the other tables have a maximum dimension of 100.

If IPUNCH = 0 in the INPUT data block, punched card output is obtained. At each time step printed (controlled by NOUT) a card is punched with the following variables on each card: t sec, h_{TS} Btu/lb, $\dot{q}_{rad}$ Btu/(ft²-sec), $\dot{q}_c$ Btu/(ft²-sec), $\dot{q}_{FMF}$ Btu/(ft²-sec), P_{TS} atm, h Kft, and V ft/sec. The card format is (1X, F9.2, F10.1, 3F10.2, F10.5, F6.1, F7.0).

VI. CONCLUSIONS

The 3DOF computer code documented herein is well suited to the requirements of the Nuclear Safety Program; generating basic heating and trajectory data at a small cost. An orbital decay trajectory with $t \sim 1800$ sec flight time can be generated at a cost of $\sim 50\phi$. The input requirements have been kept simple. The program is relatively small totaling ~ 900 cards allowing the addition of other options and capabilities, as they become necessary, in a relatively simple fashion.

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NOMENCLATURE

a	= Acceleration, ft/sec^2 , also semi-major axis of Keplerian orbit, ft, also sound speed, ft/sec
A	= Azimuth, degrees
A_D	= Drag force, lb
A_{ref}	= Reference area, ft^2
A_L	= Lift force, lb
A_Y	= Yaw force, lb
C	= See Eq. 13
C_D	= Drag coefficient
C_{D_C}	= Continuum value of C_D
$C_{D_{\text{FMF}}}$	= Free molecular flow value of C_D
C_f	= Skin friction coefficient
C_L	= Lift coefficient
C_p	= Specific heat at constant pressure $0.24 \text{ Btu/lb-}^\circ\text{R}$)
C_r	= See Eq. 36
C_Y	= Yaw coefficient
D	= Diameter, ft
D_r	= See Eq. 36
D_{ref}	= Reference diameter used in Reynolds number, ft
e	= Eccentricity of Keplerian orbit, also unit vectors
e_3	= See Eq. 27
E_D	= Constant in drag bridging relationship, Eq. 18
f	= Factor to modify heating rate in mass loss expression, Eq. 49

F	= Force, lb
F_{Ai}	= Aerodynamic forces, $i = r, \theta, \phi$
F_{g_i}	= Gravity forces, $i = r, \theta$
g	= Acceleration of gravity, ft/sec^2
h	= Altitude, ft
h_T	= Total enthalpy, Btu/lb, Eq. 31
i	= Orbit inclination
J	= Joule's constant, 778.172 ft-lb/Btu
K_N	= Knudsen number, Eq. 33
L	= Longitude, degrees
$\tilde{L}$	= Longitude measured from line of nodes, degrees
m	= Mass, $\text{lb-sec}^2/\text{ft}$
$\dot{m}_D$	= Mass loss rate, Eq. 47
M	= Mach number, Eq. 30
P	= Pressure, lb/ft^2
P_T	= Total pressure, lb/ft^2
q	= Dynamic pressure, lb/ft^2 , Eq. 35
$\dot{q}$	= Heat flux, $\text{Btu}/(\text{ft}^2\text{-sec})$
$\dot{q}_c$	= Convective continuum heat flux, $\text{Btu}/(\text{ft}^2\text{-sec})$
$\dot{q}_{\text{rad}}$	= Radiative heat flux, $\text{Btu}/(\text{ft}^2\text{-sec})$
$\dot{q}_{\text{FMF}}$	= Free molecular flow heat flux, $\text{Btu}/(\text{ft}^2\text{-sec})$
r	= Radius from earth's center to point mass, ft
r_a	= Apogee of Keplerian orbit, ft, Eq. 55
r_p	= Perigee of Keplerian orbit, ft, Eq. 56

R_{eq}	= Equatorial earth radius, 20.92554×10^6 ft
R_e	= Earth radius, 20.898908×10^6 ft for spherical earth, Eq. 27 for oblate earth
R_g	= Gas constant for air, 53.3 ft-lb/(lb-°R)
R_p	= Polar earth radius, 20.855107×10^6 ft
R_N	= Reynolds number, Eq. 32
R	= Nose radius, ft
S	= Recession, inches, Eq. 51
t	= Time, sec
T_{ref}	= Reference temperature used in h_{T_S} , 536.69°R
T	= Temperature, °R
T_T	= Total temperature, °R
U	= Gravity potential function, Eq. 24
V	= Velocity, ft/sec
V_s	= Circular velocity, ft/sec, Eq. 54
$\tilde{V}_s$	= Reference satellite velocity, 26000 ft/sec
W	= Weight, lb
W_D	= Total ablation mass loss per unit area, lb/ft ² , Eq. 50
β	= Ballistic coefficient, lb/ft ² , Eq. 34
β_s	= Stagnation point velocity gradient parameter, Eq. 45
γ	= Flight path angle, degrees, also ratio of specific heats
γ_1, γ_2	= Ratio of specific heats
ϵ	= Constant in gravity potential, $7.148788887 \times 10^{11}$ ft ²
θ	= Angle between z axis and $\vec{r}$, degrees

λ	= Latitude, degrees
μ	= Viscosity, lb/(ft ² -sec) also gravitational constant for the earth, $1.40762913 \times 10^{16}$ ft ³ /sec ²
v	= Velocity ratio, Eq. 53
ρ	= Density, lb-sec ² /ft ³
$\rho_e U_e C_h$	= Enthalpy based heat transfer coefficient, lb/(ft ² -sec), Eq. 48
ρ_{grap}	= Graphite density, lb/ft ³
$\emptyset$	= Longitude, degrees
Ψ	= Orbital central angle measured from perigee
$\tilde{\Psi}$	= Orbital central angle measured from line of nodes
ω	= Rotational rate
ω_e	= Earth rotational rate, 7.2921151×10^{-5} radians/sec

Superscripts

$(\dot{})$	= Total derivative with respect to time
$()'$	= Inertial values
$(\bar{})$	= Vectors

Subscripts

$()_0$	= Trajectory initial conditions
$()_e$	= Trajectory exit conditions for skip calculations
$()_\infty$	= Free stream conditions
$()_s$	= Stagnation conditions
$()_2$	= Conditions behind a normal shock
$()_g$	= Geodetic values
$()_{\text{SL}}$	= Sea level conditions

$()_r$ = Component in r direction

$()_\emptyset$ = Component in $\emptyset$ direction

$()_\theta$ = Component in θ direction

Table I. Stagnation Point Radiative Flux Heating Rates, Btu/(ft²-sec)

U _∞ Velocity ft/sec	Z, Altitude, Kft							
	75	100	150	200	225	250	275	300
26000	2300*	335*	5.5*	.150*	.02*	.002*	.0002*	.00004*
28000	5176.0	761.3	14.2	.453	.078	.010	.00088	.0002
30000	11611	1877	43.4	1.71	.323	.047	.0043	.0009
32000	26249	5676	219.1	12.11	2.66	.442	.046	.011
34000	52807	14794	792.3	58.6	14.3	2.46	.195	.028
36000	86000*	27609	1780.0	154.1	33.9	5.08	.432	.068
38000	160000*	50000*	3261.0	276.0	62.6	10.0	.903	.154
40000	260000*	74000*	5389.0	448	107	18.0	1.70	.314
42000	340000*	100000*	7772	675	169	29.4	2.86	.563
44000	440000*	130000*	10533	954	245	43.7	4.32	.907
46000	525000*	160000*	13564	1276	335	60.2	6.02	1.353

*Callis computer code failed to give a solution. Values are based on extrapolations.

Fig. 1 COORDINATE SYSTEM

Fig. 2 AERODYNAMIC FORCE COMPONENTS

Fig. 3 RELATIONSHIP BETWEEN GEOCENTRIC (λ, h) AND GEODETIC (λ_g, h_g) LATITUDE AND ALTITUDE

APPENDIX I LISTING OF 3DOF COMPUTER CODE

```

C *****
BLOCK DATA
DOUBLE PRECISION Y
COMMON /ATMOT/ Z(22),TME(22),R(21),PB(22),C1,C2,C3,
1 C7,C8,ZM,RO,GM,GAM,RST,GO,PO,WO,GO1
COMMON/RADI/TQR(12,8),TALR(8),TVER(12),LTV,LTZ
COMMON/FLOT/X(71)
COMMON/FIXED/I(22)
COMMON/DPRES/Y(14)
COMMON/TBLS/W(1085)
C 24000 26000 28000 30000 32000 34000 36000 38000
C 40000 42000 44000 46000
DATA TQR/
1 1000.0,2300.0,5176.0,11611.0,26249.0,52807.0,86000.0,160000.0,
* 260000.0,340000.0,440000.0,525000.0,
2 160.0,335.0,761.0,1877.0,5676.0,14794.0,27609.0,50000.0,
* 74000.0,100000.0,130000.0,160000.0,
3 2.2,5.5,14.2,43.4,219.1,792.3,1780.0,3261.0,
* 5389.0,7772.0,10533.0,13564.0,
4 .05,.150,.453,1.71,12.1,58.6,154.0,276.0,
* 448.0,675.0,954.0,1276.0,
5 .004,.020,.078,.323,2.66,14.3,33.9,62.6,
* 107.0,169.0,245.0,335.0,
6 .0004,.002,.010,.047,.44,2.5,5.1,10.0,
* 18.0,29.4,43.7,60.2,
7 .00004,.0002,.00088,.0043,.046,.195,.432,.903,
* 1.70,2.86,4.32,6.02,
8 .000008,.00004,.00020,.0009,.011,.028,.068,.154,
* .314,.563,.907,1.353 /
DATA TALR /75000.0,100000.0,150000.0,200000.0,225000.0,
1 250000.0,275000.0,300000.0 /
2 TVER /24000.0,26000.0,28000.0,30000.0,32000.0,34000.0,
3 36000.0,38000.0,40000.0,42000.0,44000.0,46000.0/
4 LTV/12,LTZ/8/
5,X/71*0.0/I/22*0/Y/14*0/W/1085*0.0/
DATA Z/ 0.,11019.,20063.,32162.,47350.,52429.,
1 61591.,79994.,90000.,100000.,110000.,120000.,150000.,
2 160000.,170000.,190000.,230000.,300000.,400000.,500000.,
3 600000.,700000. /
4 TMB/ 288.15,216.65,216.65,228.65,270.65,270.65,
5 252.65,180.65,180.65,210.65,260.65,360.65,960.65,
6 1110.65,1210.65,1350.65,1550.65,1830.65,2160.65,2420.65,
7 2590.65,2700.65 /
DATA R / -6.5,0.0,1.0,2.8,0.0,-2.0,-4.0,0.0,3.0,5.0,
9 10.0,20.0,15.0,10.0,7.0,5.0,4.0,3.3,2.6,1.7,1.1 /
DATA PB/ 1.00000E+00,2.23361E-01,5.40328E-02,8.56663E-03,
21.09455E-03,5.82289E-04,1.79718E-04,1.02410E-05,1.62230E-06,
32.96810E-07,7.25820E-08,2.48870E-08,4.99550E-09,3.64600E-09,
42.75610E-09,1.66320E-09,6.86940E-10,1.85920E-10,3.97770E-11,

```

```

51.08140E-11,3.40513E-12,1.17620E-12 /,C8/3.28084514/ 50
6 ,C1/0.3048/,C2/1.00E+03/,C3/1.8/,GO1/32.174/,C7/1.00E-08/ 51
7 ,ZM/9.00E+05/,RO/6.375605E+06/,GM/3.9862216E+14/,GAM/1.4/ 52
8 ,RST/8.31432/,GO/9.80665/,PO/2.11622E+03/,WO/28.9644/ 53
END 54
C***** 55
C MAIN PROGRAM 56
C 3D POINT MASS TRAJECTORY PROGRAM KGN JULY 69 57
C MODIFIED FOR AEC SAFETY ANALYSIS LLP 1972 58
C 59
COMMON/DPRES/RE,H(5),AZR,GAMR,WE,T,GR,AD,AL,AY 60
COMMON/FLOT /THETO,PHIO,THETAX,PHIX,GO,MASS,RAD,RHO,WTMULT, 61
1 TOLD,VAIR,MACH,QBAR,REY,CD,CA,HJACK,V SOUND,TEMP,WO,SREF, 62
2 TFIL,WFIL,CAFIL,SKINFR,DWT, QC,QR,QDC,QDR,AZO,TO, 63
3 PRS,MOLW,CASE(17),QDFM,QFM,CDC,CDFM,RNOSE,ED,HOUT,GAMI,VI, 64
4 AZI,XLAT,XLONG,DIFMD ,RANGE,RANGE0,HTS,RLD,RECS,DREF,RYD 65
COMMON/FIXED/I,NWT,NALT,NVEL,JACK,NMACH,LNKT1,KOUT,NHCHK, 66
1 NOUT,KJACK,IAERO,NCD,NMAC,ISWH,IOUT,IPASS,NPASS,IPUNCH,JDATE(3) 67
COMMON/TBLS/ DLWT(100),WALT(100),CATBL(100),ALTTBL(25), 68
1 CASFTB(25,10),TBLMAC(100),VELTBL(10),CDTBL(100),ALTBL(100), 69
2 CDMTBL(100),TBLMA(100) 70
COMMON/RADI/TQR(12,8),TALR(8),TVER(12),LTV,LTZ 71
NAMELIST/INPUT/ HO ,VI ,GAMI ,TO ,HCO ,XLAT , 72
1 XLONG ,AZREL ,WO ,SREF ,DREF ,IAERO ,NOUT ,LKASE , 73
2 ROTOPT,TFIL ,WFIL ,CAFIL ,SKINFR, 74
2 DWT ,CDC ,CDFM ,RNOSE, ED, 75
3 VREL ,GAMREL , IRI ,SWMCH , AZI ,HOUT ,IOBL ,NPASS, 76
4 DTMAX, DTMIN,JAERO,RANGE0,IPUNCH, SWALT,FACTOR,RHOG 77
5 ,NPOUT,RLD1,RLD2,RYD1,RYD2 78
DOUBLE PRECISION RE,H,AZR,GAMR,WE,T,GR,GT,VR(5),VTH(5),VPH(5), 79
1 VRD(5),VTHD(5),VPHD(5),XL,DT2,DT,THETA(5),PHI(5),HO,XMU,EPS, 80
2 REQ,RPO,RROP,HREX(5),R(5),HRE,AD,AL,AY ,WEC,WES,COSG,SING 81
REAL MACH,MASS,MRAT,MOLW 82
DO 128 I = 1,LTV 83
DO 128 J = 1,LTZ 84
128 TQR(I,J) =ALOG(TQR(I,J)) 85
NKASE=1 86
CALL IDATE(JDATE) 87
C INITIALIZE NAMELIST VARIABLES 88
RLD1=0.0 89
RLD2=0.0 90
RYD1=0.0 91
RYD2=0.0 92
HO = 400000.0 93
VI = 25711.6 94
HCO = 115.0 95
AZREL = 0.0 96
WO = 1.0 97
SREF = 1.0 98
DREF = 1.0 99

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IAERO = -1	100
NOUT = 10	101
LKASE = 1	102
ROTOPT = 0.0	103
CDC = 1.50	104
CDFM = 2.0	105
VREL = VI	106
GAMREL = GAMI	107
IRI = 0	108
SWALT = 0.0	109
SWMCH = 0.0	110
AZI = AZREL	111
HOUT = 450000.0	112
IOBL = 0	113
RNOSE = 0.50	114
DTMAX = 1.0	115
DTMIN=0.01	116
JAERO = 1	117
FACTOR = 1.26	118
RHOG = 1.75	119
NPOUT = 1	120
C	121
10 JACK=1	122
KJACK=1	123
I=5	124
IPOUT = 0	125
NHCHEK=1	126
RAD=57.29578	127
RE=20898908.0	128
GO=32.174	129
XMU = 1.40762913E+16	130
EPS = 7.148788887E+11	131
REQ = 20.92554E+6	132
RPO = 20.855107E+6	133
RROP = (REQ/RPO)**2 - 1.0	134
WE=0.0	135
MACH=0.0	136
ISWH = 0	137
QC = 0.0	138
QR = 0.0	139
QFM = 0.0	140
RECS = 0.0	141
DIFMDL = 0.0	142
QDFM = 0.0	143
QDC = 0.0	144
QDR = 0.0	145
IOUT = 0	146
HJACK=0.0	147
WTMULT=1.0	148
LNKT1=50	149

	IPASS = 0	150
C	READ TITLE CARD	151
	READ (5,425) CASE	152
	READ (5, INPUT)	153
	RLD = RLD1	154
	RYD = RYD1	155
	HCOX = HCO	156
	KOUT=NOUT	157
C	IF JAERO = 0 USE LAST AERO TABLE	158
	IF (JAERO.EQ.0) GO TO 53	159
	WRITE (6,450) CASE,JDATE	160
	WRITE (6,485)	161
C	IF IAERO = 0 USE BRIDGING EQUATION IN CALC	162
	IF (IAERO) 51,50,45	163
C	AERO TABLE CA = F(ALT) IAERO = -1	164
51	READ (5,435) NCD	165
	READ (5,440) (ALTBL(L), L=1,NCD)	166
	READ (5,440) (CDTBL(L), L=1,NCD)	167
	WRITE (6,40)	168
	WRITE (6,41) ((CDTBL(L), ALTBL(L)), L=1,NCD)	169
	GO TO 50	170
C	AERO TABLE CA = F(MACH) IAERO = +1	171
45	READ (5,435) NMACH	172
	READ (5,440) (TBLMAC(L), L=1,NMACH)	173
	READ (5,440) ((CATBL(L), L=1,NMACH))	174
	WRITE (6,46) NMACH	175
	WRITE (6,47) (TBLMAC(L), L=1,NMACH)	176
	WRITE (6,47) (CATBL(L), L=1,NMACH)	177
C	LOW MACH NO AERO TABLE CA = F(MACH) SWMCH >= 0.0 OR SWALT >= 0.0	178
50	IF ((SWMCH.LE.0.0) .AND. (SWALT.LE.0.0)) GO TO 53	179
	READ (5,435) NMAC	180
	READ (5,440) (TBLMA(L), L=1,NMAC)	181
	READ (5,440) (CDMTBL(L), L=1,NMAC)	182
	WRITE (6,491) SWMCH, SWALT	183
	WRITE (6,41) ((CDMTBL(L), TBLMA(L)), L=1,NMAC)	184
C	SKIN FRICTION - F(H,V)	185
53	IF (SKINFR.LE.0.0) GO TO 110	186
	READ (5,435) NALT,NVEL	187
	READ (5,440) (ALTTBL(K), K=1,NALT)	188
	READ (5,440) (VELTBL(J), J=1,NVEL)	189
	READ (5,440) ((CASFTB(K,J), K=1,NALT), J=1,NVEL)	190
	WRITE (6,46) NALT,NVEL	191
	WRITE (6,56) (ALTTBL(K), K=1,NALT)	192
	WRITE (6,56) (VELTBL(J), J=1,NVEL)	193
	DO 57 J=1,NVEL	194
57	WRITE (6,58) (CASFTB(K,J), K=1,NALT)	195
C	WEIGHT LOSS - ALTITUDE	196
110	IF (DWT.LE.0.0) GO TO 240	197
	READ (5,435) NWT	198
	READ (5,440) (WALT(I), I=1,NWT)	199

	READ (5,440) (DLWT(I),I=1,NWT)	200
	WRITE (6,120)	201
	WRITE (6,125)	202
	WRITE (6,495) (WALT(I),I=1,NWT)	203
	WRITE (6,130)	204
	WRITE (6,490) (DLWT(I),I=1,NWT)	205
C	ROTATING EARTH OPTION	206
240	I = 5	207
	RECSL = RECS	208
	QDFMLS = QDFM	209
	QDCLS = QDC	210
	QDRLS = QDR	211
	IF (ROTOPT.NE.0) WE = 0.7292115E-4	212
	IF (IOBL.EQ.0) GO TO 603	213
	RE = REQ/(DSQRT(1.0+RROP* SIN(XLAT/RAD)**2))	214
	HRE = HO + RE	215
	GR = XMU*(1.0 + EPS*(1.0 - 3.0*SIN(XLAT/RAD)**2)/HRE**2)/HRE**2	216
	GO TO 604	217
603	HRE = HO + RE	218
	GR = GO*(RE/HRE)**2	219
604	VCIRC = DSQRT(GR*HRE)	220
	IF (IRI.EQ.0) GO TO 43	221
	VO = VREL	222
	GAMO = GAMREL	223
	AZO = AZREL	224
	XL = XLAT/RAD	225
	C1 = HRE*WE*DCOS(XL)/VREL	226
	VI = VREL*SQRT(1.0+C1**2+2.0*COS(GAMREL/RAD)*SIN(AZREL/RAD)*C1)	227
	GAMI = ARSIN(VREL*SIN(GAMREL/RAD)/VI)*RAD	228
	C2 = DCOS(AZR/RAD)	229
	C3 = 1.0E12	230
	IF (ABS(AZREL-90.0).GE.0.0001) C3=TAN(AZREL/RAD)	231
	AZI = ATAN(C3+C1/COS(GAMREL/RAD)/C2)*RAD	232
	GO TO 44	233
43	C1 = HRE*WE*COS(XLAT/RAD)/VI	234
	VO = VI*SQRT(1.0 + C1**2 - 2.0*COS(GAMI/RAD)*SIN(AZI/RAD)*C1)	235
	GAMO = VI*SIN(GAMI/RAD)/VO	236
	GAMO = ARSIN(GAMO)*RAD	237
	AZO = SIN(AZI/RAD)-C1/COS(GAMI/RAD)	238
	AZB = COS(AZI/RAD)	239
	AZO = ATAN2(AZO,AZB)*RAD	240
44	IF(IPOUT.EQ.0) GO TO 131	241
	IF (IPOUT.NE.1) GO TO 132	242
131	IPOUT = 1	243
C	WRITE INITIAL CONDITIONS-----	244
	WRITE(6,450) CASE,JDATE	245
	WRITE (6,475)	246
	IPP1 = IPASS + 1	247
	IF (NPASS.GT.0) WRITE(6,476) IPP1	248
	WRITE(6,492) VO ,VI,GAMO ,GAMI,AZO , AZI,TO , WO,	249

1	HO, XLAT, XLONG, SREF, DREF, RLD1, RLD2, RYD1, RYD2, FACTOR, RHOG	250
	WRITE(6,486)	251
	WRITE(6,487) VCIRC	252
	IF (IOBL.EQ.1) WRITE(6,493) RPO,REQ	253
	IF (IOBL.EQ.0) WRITE(6,494) RE	254
	IF (ROTOPT.NE.0.0) WRITE(6,499) WE	255
	IF (ROTOPT.EQ.0.0) WRITE(6,496)	256
	WRITE(6,497) NOUT,DTMAX,DTMIN,HCO,HOUT	257
	IF (IAERO.EQ.0) WRITE(6,498) CDC,ED,CDFM,RNOSE	258
	WRITE(6,127)	259
C	VARIABLE SETUP	260
132	GAMR=GAMO/RAD	261
	AZR=AZO/RAD	262
	MASS=WO/GO	263
	THETA(5)=(90.0-XLAT)/RAD	264
	PHI(5)=XLONG/RAD	265
	H(5)=HO	266
	HREX(5) = HO + RE	267
	T=TO	268
	TLAST=TO	269
	THETO=THETA(5)	270
	PHIO=XLONG/RAD	271
C	INITIAL VELOCITY COMPONENTS	272
	VR(5)=VO*DSIN(GAMR)	273
	VTH(5)=VO*DCOS(GAMR)*DCOS(AZR)	274
	VPH(5)=VO*DCOS(GAMR)*DSIN(AZR)	275
C	INTEGRATION LOOP	276
	GO TO 265	277
255	DT2=DT	278
260	I=I+1	279
	VR(I) = VR(1) + VRD(I-1)*DT2	280
	VTH(I) = VTH(1) + VTHD(I-1)*DT2	281
	VPH(I) = VPH(1) + VPHD(I-1)*DT2	282
	HREX(I) = HREX(1) + VR(I-1)*DT2	283
	THETA(I) = THETA(1) - VTH(I-1)*DT2/HREX(I-1)	284
	PHI(I) = PHI(1) + VPH(I-1)*DT2/HREX(I-1)/DSIN(THETA(I-1))	285
265	VTOT= DSQRT(VR(I)**2 + VTH(I)**2 + VPH(I)**2)	286
	IF (IOBL.EQ.0) GO TO 600	287
	XL = 1.5707963 - THETA(I)	288
	RE = REQ/DSQRT(1.0+RROP*DSIN(XL)**2)	289
	HRE = HREX(I)	290
	IF (NHCHK.NE.2) H(I) = HRE-RE	291
	GR= XMU*(1.0 + EPS*(1.0 -3.0*DSIN(XL)**2)/HRE**2)/HRE**2	292
	GT = 2.0*XMU*EPS*DSIN(XL)*DCOS(XL)/HRE**4	293
	GO TO 601	294
600	HRE = HREX(I)	295
	H(I) = HRE - RE	296
	GR = GO*(RE/HRE)**2	297
	GT = 0.0	298
601	CONTINUE	299

VAIR = VTOT	300
GAMR = DATAN(VR(I)/DSQRT(VTH(I)**2 + VPH(I)**2))	301
X1 = VPH(I)	302
X2 = VTH(I)	303
X3 = AZMUTH(X1,X2)	304
AZR = X3	305
C 1962 ATMOSPHERIC PROPERITIES	306
HHHH = H(I)	307
CALL ATM(HHHH,PRS,TEMP,MOLW,VSOUND,RHO)	308
CALL CALC	309
IF (NHCHEK.EQ.2) GO TO 320	310
C EQUATIONS OF MOTION IN SPHERICAL COORDINATES	311
WEC = WE*DCOS(THETA(I))	312
WES = WE*DSIN(THETA(I))	313
HRT = HRE*DTAN(THETA(I))	314
COSG = DCOS(GAMR)	315
SING = DSIN(GAMR)	316
VRD(I) = (VTH(I)**2 + VPH(I)**2)/HRE - AD*SING - GR	317
2 + 2.0*VPH(I)*WES + HRE*WES*WES + AL*COSG	318
VTHD(I) = -VPH(I)**2/HRT - AD*COSG*DCOS(AZR) - VR(I)*VTH(I)/HRE	319
1 -2.0*VPH(I)*WEC - HRE*WES*WEC - AL*SING*DCOS(AZR) - GT	320
2 -AY*DSIN(AZR)	321
VPHD(I) = (VTH(I)*VPH(I))/HRT - VR(I)*VPH(I)/HRE	322
1 -AD*COSG*DSIN(AZR) + 2.0*(VTH(I)*WEC - VR(I)*WES)	323
2 -AL*SING*DSIN(AZR) + AY*DCOS(AZR)	324
GO TO (260,260,255,270,315),I	325
270 VR(5)=VR(1)+DT*(VRD(1)+2.0*(VRD(2)+VRD(3))+VRD(4))/6.0	326
VTH(5)=VTH(1)+DT*(VTHD(1)+2.0*(VTHD(2)+VTHD(3))+VTHD(4))/6.0	327
VPH(5)=VPH(1)+DT*(VPHD(1)+2.0*(VPHD(2)+VPHD(3))+VPHD(4))/6.0	328
THETA(5)=THETA(1)-DT*(VTH(1)/(HREX(1))+2.0*(VTH(2)/(HREX(2))+	329
1VTH(3)/(HREX(3)))+VTH(4)/(HREX(4)))/6.0	330
PHI(5)=PHI(1)+DT*(VPH(1)/((HREX(1))*DSIN(THETA(1)))	331
1+2.0*(VPH(2)/((HREX(2))*DSIN(THETA(2)))+VPH(3)/((HREX(3))*DSIN(	332
2THETA(3)))+VPH(4)/((HREX(4))*DSIN(THETA(4))))/6.0	333
HREX(5) = HREX(1) + DT*(VR(1)+2.0*(VR(2)+VR(3))+VR(4))/6.0	334
IF(IOBL.NE.0) RE=REQ/DSQRT(1.0+RROP*DSIN(1.5707963-THETA(5))**2)	335
H(5) = HREX(5) - RE	336
IF (IOUT.EQ.1) GO TO 272	337
IF(H(5).LT.HOUT) GO TO 271	338
HCO = HOUT	339
IOUT = 1	340
272 DELH = HCO-H(5)	341
GO TO 273	342
271 DELH=H(5)-HCO	343
273 IF (ABS(DELH).LE.5.0) GO TO 285	344
IF (DELH) 280,285,290	345
280 DT=DT*(H(1)-HCO)/(H(1)-H(5))	346
DT2=DT/2.0	347
HRE=H(1)+RE	348
I=1	349

	GO TO 260	350
285	NHCHEK=2	351
	H(5)=HCO	352
	T=T+DT	353
	IF (NHCHEK.EQ.2) GO TO 265	354
290	I = 5	355
	T=T+DT	356
	GO TO 265	357
C		358
	CALCULATION OF TIME STEP	358
315	DTSUB=.01*(VAIR+2000.0)/DSQRT(VRD(I)**2+VTHD(I)**2+VPHD(I)**2)	359
	DT=DTSUB	360
	IF(DTSUB.GT.DTMAX) DT=DTMAX	361
	IF(DTSUB.LT.DTMIN) DT=DTMIN	362
	DT2=DT/2.0	363
C		364
	OUTPUT CALCULATIONS	364
C	----	365
	-----INTEGRATIONS-----	365
320	IF((H(5).LT.200000.0).AND.(IPOUT.NE.1)) GO TO 137	366
	DELT = T - TLAST	367
	HHHH = H(5)	368
	HTS = VAIR**2/50062.7 + 0.24*(TEMP-536.69)	369
C	HEATING RATES FOR A 1-FT SPHERE, COLD WALL -----	370
C	RADIATION - TABULAR VALUES FROM MODIFIED CALLIS CODE - 11/3/72-LLP	371
C	ONE FOOT SPHERE	372
	QDR = 0.0	373
	IF (VAIR.LT.24000.) GO TO 124	374
	IF (HHHH.LT.75000.0) GO TO 124	375
	QDR = PIF11(VAIR,HHHH,TVER,LTV,TALR,LTZ,TQR,LTV,LTZ)	376
	QDR = EXP(QDR)	377
124	IF (MACH.GT.6.0) GO TO 121	378
C	SIBULKIN WITH GAMMA = 1.2 , SUPERSONIC & SUBSONIC	379
	GAM = 1.2	380
	A = 1.0 + (GAM-1.0)*MACH**2/2.0	381
	TS = TEMP*A	382
	VISS = 9.898E-7*(TS/1.8)**1.5/(110.4 + TS/1.8)	383
	P2 = PRS	384
	IF (MACH.LE.1.0) GO TO 122	385
C	SUPERSONIC FLOW	386
	TEMZ = GAM*MACH**2 - (GAM-1.0)/2.0	387
	P2 = PRS*2.0*TEMZ/(GAM + 1.0)	388
	XM2 = SQRT(A/TEMZ)	389
	A = 1.0 + (GAM-1.0)*XM2**2/2.0	390
122	PS = P2*A** (GAM/(GAM-1.0))	391
	RHOS= PS/TS/53.3	392
	BETZ = 1.1	393
	IF(MACH.LT.4.98)	394
	1BETZ= 2.740409 + MACH*(-0.7121196 + MACH*(-0.125607 +	395
	1 MACH*(0.0978086 - MACH*0.01148119))	396
	QDC = 0.945*SQRT(RHOS*VISS*BETZ*VAIR/2.0)*HTS	397
	GO TO 123	398
C	HYPERSONIC FLOW (DETRA,KEMP & RIDDEL)	399

121	C1 = 17600.0	400
	C2 = 3.15	401
	QDC = C1* ((RHO*GO/0.07647)**0.50)*(VAIR/26000.0)**C2	402
C	FREE MOLECULAR FLOW	403
123	QDFM = RHO*(VAIR**3)/2.0/778.0	404
C	ESTIMATE OF SURFACE RECESSION--DIFFUSION CONTROL	405
	QDT = QDC*FACTOR	406
	IF(QDT.LE.0.0) GO TO 126	407
	IF(QDFM/QDT.LT.10.0)	408
	1 QDT = QDT*(1.0-EXP(-QDFM/QDT))	409
	DIFMD = 0.1725*QDT/HTS	410
C	-----	411
126	QR = QR + (QDR+QDRL)*DELT/2.0	412
	QC = QC + (QDC+QDCL)*DELT/2.0	413
	QFM = QFM + (QDFM+QDFML)*DELT/2.0	414
	RECS = RECS + 12.0*(DIFMD + DIFMDL)*DELT/2.0/RHOG	415
	TLAST = T	416
	QDFML = QDFM	417
	QDCL = QDC	418
	QDRL = QDR	419
	DIFMDL = DIFMD	420
	THETAX = THETA(5)	421
	PHIX = PHI(5)	422
	IF (IPOUT.EQ.1) CALL OUTPT	423
	IF(MACH.LT.SWMCH) ISWH = 1	424
	IF (MACH.LT.1.0) RLD=RLD2	425
	IF (MACH.LT.1.0) RYD=RYD2	426
	IF(H(5).LT.SWALT) ISWH=1	427
C	CONTINUE INTEGRATION LOOP	428
	IF (NHCHK.EQ.2) GO TO 325	429
	VR(1)=VR(I)	430
	VTH(1)=VTH(I)	431
	VPH(1)=VPH(I)	432
	H(1)=H(I)	433
	THETA(1)=THETA(I)	434
	PHI(1)=PHI(I)	435
	VRD(1)=VRD(I)	436
	VTHD(1)=VTHD(I)	437
	VPHD(1)=VPHD(I)	438
	HREX(1) = HREX(I)	439
	I=1	440
	GO TO 260	441
C	CHECK ON CASE NUMBER	442
137	IPOUT = 1	443
	RECS = RECSL	444
	QDFM = QDFMLS	445
	QDC = QDCLS	446
	QDR = QDRLS	447
	GO TO 136	448
325	IF (IOUT.EQ.0) GO TO 611	449

CALL KEPLR	450
IF (IPASS.GE.NPASS) GO TO 611	451
136 IOUT=0	452
I = 5	453
NHCHK = 1	454
HCO = HCOX	455
LNKT1 = 50	456
KOUT = NOUT	457
GO TO 240	458
611 NKASE = NKASE + 1	459
IF (NKASE.LE.LKASE) GO TO 10	460
STOP	461
C READ FORMATS	462
40 FORMAT(8X,17HINPUT AERO TABLE / 5X,2HCD,8X,12HALTITUDE(FT))	463
41 FORMAT(F10.6,F14.2)	464
46 FORMAT(1X,2I10)	465
47 FORMAT(16F8.3)	466
56 FORMAT(1X,15F8.0)	467
58 FORMAT(1X,15F8.4)	468
120 FORMAT(/,30X,11HWEIGHT LOSS, /)	469
125 FORMAT(30X,8HALTITUDE)	470
130 FORMAT(30X,13HWT-MULTIPLIER)	471
425 FORMAT(20A4)	472
435 FORMAT(2I3)	473
440 FORMAT(6G12.8)	474
450 FORMAT(1H1,17A4,1X,I2 ,1H/,I2 ,3H/19,I2)	475
475 FORMAT(12X,16HINPUT VARIABLES ,//)	476
476 FORMAT(5X,13HSTART OF SKIP , I5)	477
485 FORMAT(22X,23H**** OPTION TABLES ****, /)	478
486 FORMAT(15X, 24H1962 STANDARD ATMOSPHERE)	479
487 FORMAT(15X, 24HCIRCULAR VELOCITY(FPS) = , F12.2)	480
490 FORMAT(1X,6F13.4)	481
491 FORMAT(8X,20HLOW MACH NO. TABLE /	482
1 17H SWITCH WHEN M < , F6.2,21H OR WHEN ALTITUDE < ,	483
2 F8.1 / 5X,2HCD, 8X, 5HMACH)	484
492 FORMAT(2X, 18HINITIAL CONDITIONS /25X,8HRELATIVE,6X,8HINERTIAL /	485
1 6X,17HVELOCITY(FPS) , F13.2 , F13.2 /	486
2 6X,17HFLIGHT PATH(DEG) , F13.4 , F13.4 /	487
3 6X,17HAZIMUTH(DEG) , F13.4 , F13.4 /	488
4 6X,17HTIME(SEC) , F13.2 /	489
5 6X,17HWEIGHT(LBS) , F13.2 /	490
6 6X,17HALTITUDE(FT) , F13.2 /	491
7 6X,17HLATITUDE(DEG) , F13.2 /	492
8 6X,17HLONGITUDE(DEG) , F13.2 /	493
9 6X,17HREF AREA(FT**2) , F13.5 /	494
1 6X,17HREF LENGTH(FT) , F13.2 /	495
2 6X,17HL/D SUPERSONIC , F13.4 /	496
3 6X,17HL/D SUBSONIC , F13.4 /	497
4 6X,17HY/D SUPERSONIC , F13.4 /	498
5 6X,17HY/D SUBSONIC , F13.4 /	499

6	6X,17HQ STAG. FACTOR , F13.4 /	500
7	6X,17HGRAP. DENS(PCF) , F13.4)	501
493	FORMAT(15X, 49HOBULATE EARTH MODEL ,POLAR & EQUATORIAL RADII (FT) = ,	502
1	/30X, 2E15.8)	503
494	FORMAT(15X, 31HSPHERICAL EARTH MODEL,RE(FT) = , E15.8)	504
495	FORMAT(1X,6F13.0)	505
496	FORMAT(15X, 16HSTATIONARY EARTH)	506
497	FORMAT(15X, 11HPRINT EVERY,I4 ,11H TIME STEP /	507
1	15X, 15HMAX TIME STEP = , F8.4,17H MIN TIME STEP =,F8.4/	508
2	15X, 17HCUTOFF ALT(FT) = ,F8.1, 4H OR , F10.1)	509
498	FORMAT(7X, 35HCONSTANTS IN DRAG BRIDGING EQUATION /	510
1	12X,14HCD(CONTINUM) =,F10.4,10H ED = , F10.5 /	511
2	12X,14HCD(FREE MOL) =,F10.4,10H RNOSE = , F10.5)	512
499	FORMAT(15X, 31HROTATING EARTH , WE(RAD/SEC) = , E15.8)	513
127	FORMAT(15X,32HRADIATIVE FLUX-MODIFIED CALLIS)	514
	END	515
C	*****	516
	SUBROUTINE CALC	517
C		518
C	SUBROUTINE CALC	519
	COMMON/DPRES/RE,H(5),AZR,GAMR,WE,T,GR,AD,AL,AY	520
	COMMON/FLOT /THETO,PHIO,THETAX,PHIX,GO,MASS,RAD,RHO,WTMULT,	521
1	TOLD,VAIR,MACH,QBAR,REY,CD,CA,HJACK,V SOUND,TEMP,WO,SREF,	522
2	TFIL,WFIL,CAFIL,SKINFR,DWT, QC,QR,QDC,QDR,AZO,TO,	523
3	PRS,MOLW,CASE(17),QDFM,QFM,CDC,CDFM,RNOSE,ED,HOUT,GAMI,VI,	524
4	AZI,XLAT,XLONG,DIFMD ,RANGE,RANGE0,HTS,RLD,RECS,DREF,RYD	525
	COMMON/FIXED/I,NWT,NALT,NVEL,JACK,NMACH,LNKT1,KOUT,NHCHK,	526
1	NOUT,KJACK,IAERO,NCD,NMAC,ISWH,IOUT,IPASS,NPASS,IPUNCH,JDATE(3)	527
	COMMON/TBLS/ DLWT(100),WALT(100),CATBL(100),ALTTBL(25),	528
1	CASFTB(25,10),TBLMAC(100),VELTBL(10),CDTBL(100),ALTTBL(100),	529
2	CDMTBL(100),TBLMA(100)	530
	DOUBLE PRECISION RE,H,AZR,GAMR,WE,T,GR,AD,AL,AY	531
	REAL MACH,MASS,MRAT,MOLW	532
	MACH = VAIR/V SOUND	533
	HHHH = H(I)	534
C	AERO TABLES CA	535
	IF(IAERO.LT.0) GO TO 91	536
	IF (IAERO.EQ.0) GO TO 92	537
	CA = PIF1(MACH,TBLMAC,NMACH,CATBL)	538
	GO TO 90	539
C	DRAG COEFFICEINT = F(ALT)	540
91	IF(ISWH.EQ.1) GO TO 93	541
	CA = PIF1(HHHH,ALTTBL,NCD,CDTBL)	542
	GO TO 90	543
C	DRAG COEFFICIENT WITH BRIDGING	544
92	IF(ISWH.EQ.1) GO TO 93	545
	B = (CDFM-CDC)/CDC	546
	C = (7.32E+6)*RNOSE*RHO*GO*(1.0 + ED)	547
	CA = CDC	548
	IF(C.LT.50) CA = CDC*(1.0 + B*EXP(-C))	549

	GO TO 90	550
	93 CA = PIF1(MACH,TBLMA ,NMAC ,CDMTBL)	551
C		552
C	WEIGHT LOSS	553
C		554
	90 IF (DWT.EQ.0.0) GO TO 110	555
	WTMULT= PIF1(HHHH,WALT,NWT,DLWT)	556
	MASS = WO/GO*WTMULT	557
C		558
C	WEIGHT, CA CHANGE VS. TIME	559
C		560
	110 IF (TFIL.LE.0.0) GO TO 135	561
	IF (T.GE.TFIL) GO TO 125	562
	MASS=(WFIL/GO)*WTMULT	563
	CA = CA*CAFIL	564
	GO TO 130	565
	125 MASS=(WO/GO)*WTMULT	566
	IF (JACK.GT.1) GO TO 135	567
	HJACK=COLD+ ((TFIL-TCLL)/(T-TOLD)) * (H(5)-COLD)	568
	JACK=2	569
	GO TO 135	570
	130 COLD=H(1)	571
	TOLD=T	572
	135 CONTINUE	573
C		574
C	SKIN FRICTION	575
C		576
	IF (SKINFR) 140,205,140	577
	140 DO 145 J=1,NALT	578
	IF (ALTTBL(J).GT.HHHH) GO TO 150	579
	145 CONTINUE	580
	J=NALT	581
	150 DO 155 K=1,NVEL	582
	IF (VELTBL(K).GT.VAIR) GO TO 160	583
	155 CONTINUE	584
	K=NVEL	585
	160 ALTRAT=(HHHH-ALTTBL(J-1))/(ALTTBL(J)-ALTTBL(J-1))	586
	VRAT=(VAIR-VELTBL(K-1))/(VELTBL(K)-VELTBL(K-1))	587
	E=CASFTB(J-1,K-1)+ALTRAT*(CASFTB(J,K-1)-CASFTB(J-1,K-1))	588
	F=CASFTB(J-1,K)+ALTRAT*(CASFTB(J,K)-CASFTB(J-1,K))	589
	CASF=E+VRAT*(F-E)	590
	CA = CA + CASF	591
C	PARAMETER CALCULATIONS	592
	205 QBAR=0.5*RHO*VAIR**2	593
	A = QBAR*SREF/MASS	594
	AX = CA*A/GO	595
	CD = CA	596
	CL = CD*RLD	597
	AD = CD*A	598
	AL = CL*A	599

AY = RYD*AD	600
RETURN	601
END	602
C*****	603
SUBROUTINE OUTPT	604
COMMON/DPRES/RE,H(5),AZR,GAMR,WE,T,GR,AD,AL,AY	605
COMMON/FLOT /THETO,PHIO,THETAX,PHIX,GO,MASS,RAD,RHO,WTMULT,	606
1 TOLD,VAIR,MACH,QBAR,REY,CD,CA,HJACK,VSOUND,TEMP,WO,SREF,	607
2 TFIL,WFIL,CAFIL,SKINFR,DWT, QC,QR,QDC,QDR,AZO,TO,	608
3 PRS,MOLW,CASE(17),QDFM,QFM,CDC,CDFM,RNOSE,ED,HOUT,GAMI,VI,	609
4 AZI,XLAT,XLONG,DIFMD ,RANGE,RANGE0,HTS,RLD,RECS,DREF,RYD	610
COMMON/FIXED/I,NWT,NALT,NVEL,JACK,NMACH,LNKT1,KOUT,NHCHK,	611
1 NOUT,KJACK,IAERO,NCD,NMAC,ISWH,IOUT,IPASS,NPASS,IPUNCH,JDATE(3)	612
DOUBLE PRECISION RE,H,AZR,GAMR,WE,T,GR,AD,AL,AY	613
REAL MACH,MASS,MRAT,MOLW,LAT,LON	614
C LIST OUTPUT	615
IF(NHCHK.EQ.2) GO TO 335	616
IF(KOUT.LT.NOUT) GO TO 330	617
GO TO 335	618
330 KOUT = KOUT + 1	619
GO TO 370	620
335 IF (LNKT1.LE.35) GO TO 345	621
WRITE (6,451)	622
WRITE(6,450) CASE,JDATE	623
WRITE (6,455)	624
LNKT1 = 0	625
345 IF(TFIL.LE.0.0) GO TO 365	626
IF (KJACK.GT.1) GO TO 365	627
IF (T.LT.TFIL) GO TO 365	628
WRITE (6,360) TFIL,HJACK	629
KJACK=2	630
365 LAT = 90.0 - THETAX *RAD	631
LON=PHIX *RAD-WE*(T-TO)*RAD	632
GAMMA=GAMR*RAD	633
AZ=AZR*RAD	634
DR=(THETAX -THETO)*RE	635
CR=(PHIX -PHIO)*RE* SIN(THETO)	636
DRANGE=-DR*COS(AZO/RAD)+CR*SIN(AZO/RAD)	637
CRANGE=DR*SIN(AZO/RAD)+CR*COS(AZO/RAD)	638
RANGE = SQRT(DRANGE**2 + CRANGE**2)/6080.0 + RANGE0	639
VIS = 9.898E-7*(TEMP/1.8)**1.5/(110.4+TEMP/1.8)	640
REY = RHO*VAIR*DREF*GO/VIS	641
XKNU = MACH/SQRT(REY)	642
WT = WO*WTMULT	643
BETA = WT/(CD *SREF)	644
REY = REY/1.0E+6	645
GSEC = AD/GO	646
C TOTAL PRESSURE	647
IF(MACH.LT.5.0) GO TO 301	648
C HYPERSONIC FLOW	649

PT2 = 1.35*MACH**2	650
GO TO 305	651
301 IF(MACH.GT.1.0) GO TO 302	652
C SUBSONIC FLOW	653
PT2 = (1.0 + 0.2*MACH**2)**(3.5)	654
GO TO 305	655
C SUPERSONIC FLOW	656
302 GA = 1.4	657
GAA = GA	658
DO 303 J = 1,5	659
TS = TEMP*(1.0+(GAA-1.0)*MACH**2/2.0)	660
IF(TS.LT.500.0) GO TO 304	661
G2 = 1.286	662
IF(TS.LT.3300.0) G2=(3.3+TS/2750.0)/(2.3+TS/2750.0)	663
GAA= (G2+GA)/2.0	664
303 CONTINUE	665
304 PT2 = ((GAA+1.0)*MACH**2/2.0)**(GAA/(GAA-1.0))	666
PT2 = PT2*((GAA+1.0)/(2.0*GAA*MACH**2-GAA+1.0))** (1.0/(GAA-1.0))	667
305 PT2 = PT2*PRS/2116.224	668
WRITE (6,460) T ,VAIR ,H(5) ,LAT ,QBAR, BETA, QDC , QDR, QDFM,	669
1 GSEC,MACH ,RANGE,LON ,REY , CD , QC , QR , DIFMD,	670
2 PRS ,AZ ,GAMMA,XKNU,WT , HTS,PT2, RECS	671
DR = DRANGE/6080.0	672
CR = CRANGE/6080.0	673
IF (NHCHEK.EQ.2) WRITE(6,462) CR,DR	674
C PUNCH CARDS FOR CMA INPUT	675
IF(IPUNCH.EQ.0) GO TO 369	676
IF(XKNU.LT.0.1) QDFM=0.0	677
DUM = 0.0	678
HHHH = H(5)/1000.0	679
PUNCH 461 , (T,HTS,QDR,QDC,QDFM,PT2,HHHH,VAIR,DUM)	680
369 LNKT1 = LNKT1 + 4	681
KOUT=1	682
370 CONTINUE	683
360 FORMAT(/,20X,3HT =,F9.4,2X,3HH =,F9.0,/,)	684
450 FORMAT(17A4,1X,I2 ,1H/,I2 ,3H/19,I2)	685
451 FORMAT(1H1,25X,24HAE C SAFETY ANALYSIS)	686
455 FORMAT(/ 90H TIME(SEC) VR(FPS) ALT(FT) LAT(DEG) Q(PSF) BET	687
1A QDCW QDRAD QDFM ,	688
2 / 90H GSEC MACH RANGE(NM) LON(DEG) RN*10-6 CD	689
3 QCW QRAD DIFMD ,	690
4 / 90H P(PSF) AZ(DEG) GAMMA KNUD # W(L	691
5BS) HT(BTU/LB) PTS(ATM) S(IN))	692
460 FORMAT(1H0, F9.3, 4F10.2,F10.4, 3F10.2 /	693
11X,F9.2 , 3F10.2,F10.6,F10.4,2F10.2 ,F10.6/	694
2 10X, 3F10.2,2F10.4,F10.1,2F10.6)	695
461 FORMAT(1X, F9.2 , F10.1, 3F10.2, F10.5,F6.1,F7.0,F7.2)	696
462 FORMAT(1H0// 5X,13H CROSS RANGE=,F10.3,5X,13H DOWN RANGE= ,	697
1 F10.3)	698
RETURN	699

END	700
*****	701
SUBROUTINE KEPLR	702
COMMON/DPRES/RE,H(5),AZR,GAMR,WE,T,GR,AD,AL,AY	703
COMMON/FLOT /THETO,PHIO,THETAX,PHIX,GO,MASS,RAD,RHO,WTMULT,	704
1 TOLD,VAIR,MACH,QBAR,REY,CD,CA,HJACK,V SOUND,TEMP,WO,SREF,	705
2 TFIL,WFIL,CAPIL,SKINFR,DWT, QC,QR,QDC,QDR,AZO,TO,	706
3 PRS,MOLW,CASE(17),QDFM,QFM,CDC,CDFM,RNOSE,ED,HOUT,GAMI,VI,	707
4 AZI,XLAT,XLONG,DIFMD ,RANGE,RANGE0,HTS,RLD,RECS,DREF,RYD	708
COMMON/FIXED/I,NWT,NALT,NVEL,JACK,NMACH,LNKT1,KOUT,NHCHEK,	709
1 NOUT,KJACK,IAERO,NCD,NMAC,ISWH,IOUT,IPASS,NPASS,IPUNCH,JDATE(3)	710
DOUBLE PRECISION RE,H,AZR,GAMR,WE,T,GR,AD,AL,AY	711
REAL MACH,MASS,MRAT,MOLW	712
IPASS = IPASS + 1	713
GAMJ = GAMR	714
AZJ = AZR	715
XLO = PHIX - WE*(T-TO)	716
HI = H(I)	717
XL = 1.5707963 - THETAX	718
C CONVERT TO INERTIAL VALUES	719
HRE = RE + HI	720
C1 = HRE * WE*COS(XL)/VAIR	721
VI = VAIR*SQRT(1.0+C1**2 + 2.0*COS(GAMJ)*SIN(AZJ)*C1)	722
GAMI = ARSIN(VAIR*SIN(GAMJ)/VI)	723
AZI = ATAN2(SIN(AZJ)*COS(GAMJ) + C1 , COS(GAMJ)*COS(AZJ))	724
C CIRCULAR VELOCITY	725
VCIRC = DSQRT(GR*HRE)	726
VR = VI/VCIRC	727
IF (VR.GT.SQRT(2.0)) GO TO 5	728
C ELLIPTICAL ORBIT	729
RR = HRE/RE	730
A = (VR*COS(GAMI))**2	731
E = SQRT(1.0+ A*(VR**2- 2.0))	732
RP = HRE*A/(1.0 + E)/5280.0	733
RA = HRE*A/(1.0 - E)/5280.0	734
XA=(((RP+RA)*2640.0)**1.5)/(RE*SQRT(GO))	735
TM = 2.0*3.14*XA/3600.0	736
SIO = ARCOS((A-1.0)/E)	737
C REENTRY CONDITIONS	738
VIE = VI	739
HE = H(I)	740
GIE = -GAMI	741
SIE = 360.0/RAD - SIO	742
C ORBIT INCLINATION	743
AI = ARCOS(COS(XL)*SIN(AZI))	744
C LONGITUDE FROM LINE OF NODES	745
XLIP = ARSIN(TAN(XL)/TAN(AI))	746
C CENTRAL ANGLE FROM LINE OF NODES	747
SII = ARSIN(SIN(XL)/SIN(AI))	748
C REENTRY CENTRAL ANGLE FROM LINE OF NODES	749

	SIR = SIE - SIO + SII	750
C	REENTRY LATITUDE	751
	XLAT = ARSIN(SIN(SIR)*SIN(AI))	752
C	REENTRY AZIMUTH	753
	AZE = ARSIN(COS(AI)/COS(XLAT))	754
C	REENTRY LONGITUDE FROM LINE OF NODES	755
	XLOR = ARSIN(COS(XLAT)*SIN(AZE))	756
C	TIME(SEC)	757
	TIO = T	758
	C1 = SQRT((1.0-E)/(1.0+E))	759
	C2 = C1*SIN(SIO/2.0)	760
	C3 = COS(SIO/2.0)	761
	T1 = XA*(2.0*ATAN2(C2,C3) -	762
	1 E*SQRT(1.0-E**2)*SIN(SIO)/(1.0+E*COS(SIO)))	763
	C2 = C1*SIN(SIE/2.0)	764
	C3 = COS(SIE/2.0)	765
	T2 = XA*(2.0*ATAN2(C2,C3) -	766
	1 E*SQRT(1.0-E**2)*SIN(SIE)/(1.0+E*COS(SIE)))	767
	TIE = TIO + (T2-T1)	768
C	RELATIVE TRUE REENTRY LONGITUDE	769
	XLONG = XLOR + XLO - WE*(TIE - TIO)	770
C	RANGE(N.M.)	771
	RNO = RANGE	772
	DR = (XLAT-XL)*RE	773
	CR = (XLONG-XLO)*RE*SIN(XL)	774
	DRN= -DR*COS(AZJ) + CR*SIN(AZJ)	775
	CRN= DR*SIN(AZJ) + CR*COS(AZJ)	776
	RNF = RNO + SQRT(DRN**2 + CRN**2)/6080.0	777
	GO TO 100	778
C	ESCAPE TRAJECTORY	779
	5 CONTINUE	780
	IPASS = NPASS + 1	781
	WRITE(6,206)	782
	GO TO 99	783
100	AZI = AZI*RAD	784
	GIE = GIE*RAD	785
	GAMI= GAMI*RAD	786
	XLAT = XLAT*RAD	787
	XLONG = XLONG*RAD	788
	XLONG = XLONG/360.0	789
	IX = IFIX(XLONG)	790
	XLONG = (XLONG- FLOAT(IX))*360.0	791
	XLO = XLO*RAD	792
	XL = XL*RAD	793
	AZE = AZE*RAD	794
	AI = AI*RAD	795
	IF (IPOUT.NE.NPOUT) GO TO 101	796
	IPOUT = 0	797
C	PRINT	798
	WRITE(6,201) CASE,JDATE	799

IF(VR.GT.1.0) GO TO 10	800
WRITE(6,203) IPASS	801
GO TO 11	802
10 WRITE(6,202) IPASS	803
11 CONTINUE	804
WRITE(6,204) E,RP,RA,TM,AI	805
WRITE(6,205) HI, HE , VI,VIE , GAMI,GIE , AZI,AZE,	806
1XL ,XLAT , XLO , XLONG, TIO , TIE , RNO , RNF	807
101 IPOUT = IPOUT + 1	808
IRI = 0	809
RANGE0 = 0.0	810
VI = VIE	811
AZI = AZE	812
GAMI = GIE	813
TO = 0.0	814
VI = VIE	815
HI = HE	816
C FORMAT STATEMENTS	817
201 FORMAT(1H1,17A4,1X,I2 ,1H/,I2 ,3H/19,I2)	818
202 FORMAT(23X,17HMULTICRBIT. PASS, I3)	819
203 FORMAT(23X,10HSKIP. PASS, I2)	820
204 FORMAT(4X,16HORBIT PARAMETERS /	821
1 8X,20HECCENTRICITY , F10.4 /	822
2 8X,20HPERIGEE (MILES) , F10.2 /	823
3 8X,20HAPPOGEE (MILES) , F10.2 /	824
4 8X,20HPERIOD (HR) , F10.2 /	825
5 8X,20HORBIT INCLIN. (DEG) , F10.2)	826
205 FORMAT(41X,4HEXIT,10X,5HENTRY /	827
1 8X, 25HGEOCENTRIC ALT (FT) , F12.1,4X,F12.1 /	828
2 8X, 25HVELOCITY (FPS) , F12.1,4X,F12.1 /	829
3 8X, 25HFLIGHT PATH ANG (DEG) , F12.3,4X,F12.3 /	830
4 8X, 25HAZIMUTH (DEG) , F12.3,4X,F12.3 /	831
5 8X, 25HLATITUDE-GEOCENTRIC (DEG) , F12.3,4X,F12.3 /	832
6 8X, 25HLONGITUDE (DEG) , F12.3,4X,F12.3 /	833
7 8X, 25HTIME (SEC) , F12.2,4X,F12.2 /	834
8 8X, 25HRANGE (N.M) , F12.2,4X,F12.2)	835
206 FORMAT(4X, 46HCONFIGURATION IS ON ESCAPE ORBIT - ALL IS WELL)	836
99 RETURN	837
END	838
C*****	839
FUNCTION AZMUTH(YN,XD)	840
C	841
C	842
C	843
AT=ABS(ATAN(YN/XD))	844
AC=ABS(ATAN(XD/YN))	845
IF (ABS(XD).LT.ABS(YN)) GO TO 45	846
IF (YN) 15,80,30	847
15 IF (XD.GT.0.0) GO TO 25	848
20 ARCTAN=-3.14159265+AT	849

GO TO 90	850
25 ARCTAN=-AT	851
GO TO 90	852
30 IF (XD.GT.0.0) GO TO 40	853
ARCTAN=3.14159265-AT	854
GO TO 90	855
40 ARCTAN=AT	856
GO TO 90	857
45 IF (YN.GT.0.0) GO TO 65	858
IF (XD.GT.0.0) GO TO 60	859
ARCTAN=-3.14159265/2.0-AC	860
GO TO 90	861
60 ARCTAN=-3.14159265/2.0+AC	862
GO TO 90	863
65 IF (XD.GT.0.0) GO TO 75	864
ARCTAN=3.14159265/2.0+AC	865
GO TO 90	866
75 ARCTAN=3.14159265/2.0-AC	867
GO TO 90	868
80 IF (XD) 20,85,25	869
85 ARCTAN=0.0	870
90 AZMUTH=ARCTAN	871
RETURN	872
END	873
C*****	874
SUBROUTINE ATM(Z1,P1,T1,W1,A1,D1)	875
C U.S. STANDARD ATMOSPHERE TO 700000 METERS.	876
C INPUT IS ALTITUDE IN FT (GEOMETRIC). OUTPUT IS,	877
C P1 PRESSURE (LB/FT**2)	878
C T1 TEMPERATURE (DEG. RANKINE)	879
C W1 MOLECULAR WEIGHT (LB/LB-MOLE)	880
C A1 SPEED OF SOUND (FT/SEC)	881
C D1 DENSITY (LB-SEC**2)/FT**4	882
COMMON /ATMOT/ Z(22),TMB(22),R(21),PB(22),C1,C2,C3,	883
1 C7,C8,ZM,RO,GM,GAM,RST,GO,PO,WO,GO1	884
Z1 = C1*Z1	885
DO 1 I = 1, 22	886
1 IF (Z1.LT.Z(I)) GO TO 2	887
I = 23	888
2 I = I-1	889
IF (I.EQ.0) I = 1	890
A1 = RO + Z(I)	891
A2 = RO + Z1	892
A3 = Z(I)**2 - Z1**2	893
IF (I.GE.9) GO TO 50	894
C ALTITUDE BELOW 90000 METERS	895
DH = (GM/GO)*((1./A1) - (1./A2)) + C7*A3/(2.*GO)	896
T1 = TMB(I) + (R(I)*DH/C2)	897
W1 = WO	898
A = GO*WO/RST	899


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DO 11 K = 1,3                                900
J      = -1 + 3*K                             901
11 IF (I.EQ.J) GO TO 12                       902
P1 = PB(I) * ((TMB(I)/(TMB(I) + (R(I)*DH/C2)))** (A/R(I))) 903
GO TO 200                                     904
12 P1 = PB(I) * EXP (- A*DH/(TMB(I)*C2))      905
GO TO 200                                     906
ALTITUDE ABOVE 90000 METERS                  907
50 Z1 = Z1/C2                                908
IF (Z1.GE.110.0) GO TO 51                    909
W1 = 17.98 + 0.239*Z1 - 0.0013*(Z1**2)       910
GO TO 53                                     911
51 IF (Z1.GT.170.0) GO TO 57                 912
W1 = -.41873644E+02 + .22496378E+01*Z1 - .25825938E-01*(Z1**2) 913
1    +.12705198E-03*(Z1**3) - .22989608E-06*(Z1**4) 914
GO TO 53                                     915
57 W1 = +.28312068E+02 + .11190901E-01*Z1 - .18061034E-03*(Z1**2) 916
1    +.31829429E-06*(Z1**3) - .16924926E-09*(Z1**4) 917
53 Z1 = Z1*C2                                918
TM = TMB(I) + (R(I)*(Z1 - Z(I))/C2)          919
T1 = (W1/WO)* TM                             920
A4 = -Z(I) + (TMB(I)*C2/R(I))                921
A5 = WO*C2/(R(I)*RST)                        922
A6 = Z(I) + A4                                923
A7 = Z1 + A4                                  924
A8 = RO - A4                                  925
A9 = ((Z(I) - Z1)/(A1*A2)) + (1./A8)*ALOG(A7*A1/(A6*A2)) 926
A10 = (Z(I) - Z1) + A4*ALOG(A7/A6)           927
A11 = (-{GM/A8}*A9 - C7*A10)*WO/(R(I)*RST)   928
P1 = PB(I)*EXP (A11)                         929
PRESSURE,TEMPERATURE AND MOLECULAR WEIGHT FOUND. 930
200 P1 = PO*P1                               931
Z1 = Z1/C1                                   932
T1 = T1*C3                                  933
A2 = RST*185.86126/W1                       934
A1 = SQRT (GAM*A2*T1*GO*C8)                 935
D1 = P1/(A2*T1*GO1)                         936
RETURN                                       937
END                                         938
C*****                                     939
FUNCTION PIF1(X,XLIST,N,FLIST)              940
NEW PIF1                                    941
CPIF1 LINEAR INTERPOLATION IN ONE VARIABLE 942
CORRECTED 6-8-66 WTR                      943
DIMENSION XLIST(1), FLIST(1)               944
DO 6 I = 2,N                               945
IF (X-XLIST(I)) 7,7,6                      946
6 CONTINUE                                  947
I=N                                          948
70PIF1 = FLIST(I-1) + (X-XLIST(I-1))* (FLIST(I)-FLIST(I-1)) / 949

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71 (XLIST(I)-XLIST(I-1))  
   RETURN  
   END
```

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APPENDIX II
LISTING OF INPUT DECK

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/XXXX      JOB (XXXXX,C,U,N),XXXXXX,MSGLEVEL=1,RD=R
/JOBLIB    DD  DSN=BHP.AEC,DISP=SHR
/          EXEC  PGM=TDOF,REGION=140K,TIME=3
/FT06F001 DD  SYSOUT=A,DCB=(RECFM=FBA,LRECL=133,BLKSIZE=3458)
/FT05F001 DD  *
  ORBITIAL DECAY TRAJECTORY---
&INPUT
HO=400000.0, TO=0.0, AZI=120.0, VI=25690.0, GAMI=-0.10,
HCO=115.0, XLAT=0.0, XLONG=0.0, SWALT=0.0,
WO=11.31,SREF=0.158, DREF=1.0, NOUT=10, LKASE=1, IRI=0, SWMCH=1.0,
ROTOPT=1.0, TFIL=0.0, WFIL=0.0, CAFIL=0.0, IAERO=-1,
CDC = 1.5, CDFM = 2.0, JAERO=1, RNOSE=0.50, ED = 0.0,
SKINFR=0.0, DWT=0.0, IOBL=1, HOUT=451000.0,
NPASS = 1, DTMAX = 1.0, DTMIN = 0.10, RANGE0=0.0,IPUNCH=0,
RLD1=0.0,RLD2=0.0,RYD1=0.0,RYD2=0.0,FACTOR=1.26,RHOG=110.0,NPOUT=1,
&END
32
      0.0      200000.0      210000.0      220000.0      230000.0      240000.0
250000.0      260000.0      270000.0      280000.0      290000.0      300000.0
310000.0      320000.0      330000.0      340000.0      350000.0      360000.0
370000.0      380000.0      390000.0      400000.0      410000.0      420000.0
430000.0      440000.0      450000.0      460000.0      470000.0      480000.0
490000.0      500000.0
      1.340      1.340      1.340      1.340      1.340      1.340
      1.340      1.341      1.357      1.447      1.640      1.891
      2.115      2.271      2.371      2.434      2.471      2.493
      2.508      2.516      2.521      2.525      2.527      2.529
      2.529      2.530      2.531      2.531      2.531      2.531
      2.531      2.532
2
0.0      2.0
0.951      0.951
/*

```