JPL ENTRY VEHICLE DESIGN
COMPUTER PROGRAM USERS' MANUAL

Prepared by

SPACE SYSTEMS DIVISION
AVCO CORPORATION
Lowell, Massachusetts

AVSSD-0001-66-RR
Contract JPL 951070

THIS REPORT WAS PREPARED IN ACCORDANCE WITH JPL CONTRACT 951070. IT IS SUBMITTED IN PARTIAL FULFILLMENT OF THIS CONTRACT.

26 May 1966

Prepared for

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
Pasadena, California

678

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BOOK I

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APPROVED

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Special Projects

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FOREWORD

This Program Users Manual and the associated computer programs represent the final objectives of JPL Contract 951070. Several of the computer programs covered in the manual were largely developed under a prior contract (JPL-950626) and are partially described in the final report Avco/RAD Mars Venus Capsule Parameter Study, Vol. I, "Introduction and Analysis," TR-64-1, dated 21 March 1964.

The two JPL contracts leading to the development of the computer programs and the Users Manual were performed in the Advanced Space Systems Directorate at the Space Systems Division of Avco, Lowell, Massachusetts. Mr. P. Levine was the Project Engineer responsible for all technical work, and was assisted by other members of Avco's technical staff, including Messrs. P. Dicarlo, A. Robb, M. Russell, J. Cloutier, O. Zappa, M. Moge, J. Brown, P. Norton, G. Waldman, J. Serpico, R. Davis, and D. Flinn. The programming was done principally by Miss S. Sillers, Mr. D. Gillespie and Mr. J. Klugerman of Avco's Technical Programming Staff with assistance from Messrs. A. Picado, M. Greenberg, E. Sova, C. Berndtson, and with overall guidance from Dr. J. Warga, Manager of the Mathematics Department.

Minor typographical corrections made by JPL 1 December 1966. The following pages are affected:

Program 1880; pg 16, 23, 48, 49, 67, 69
Program 1882; pg 31, 47, 48
Program 1883; pg 33, 50
Program 1885; pg 3, 12, 18, 92

CONTENTS

This manual has been divided into a number of sections, each treated as a separate document with its own table of contents and list of illustrations. The sections are listed below, and each section may be easily located by referring to its tabbed cover.

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- Structure Weight

PROGRAM 1889

- Integrated Design Program
- Linking Programs 1880, 1882, 1884, 1885, 1886, and 1888
- Component Weights
- Center of Gravity
- Moments of Inertia

INTRODUCTION

A. OBJECTIVE

The objective of this manual is to provide the program user with the necessary understanding of the approximations contained in the series of entry vehicle design programs developed under contracts JPL 950626 and 951070 and of the input procedures, so that the programs can be utilized with ease and confidence. In view of the stated objective, the manual contains a description of each program and its specific purpose. The mathematical model used in each program and a list of basic limitations is provided, so that the user can establish the applicability of the program to the particular problem at hand.

Should the program user wish additional information about the calculations being performed in the program, the specific equations which are programmed are provided. Furthermore, should questions arise as to the manner in which the programming was done, a section describing the IBM routines is also provided in the manual.

The intent of the set of computer programs is to ascertain the effects of all important parameters known to influence significantly the choice of vehicle shape and the calculation of the heat shield, structural, descent, and landing system weights. To cover the complete design problem, one must consider the interrelated aspects of the vehicle aerodynamics, heat transfer, thermal protection, and structural design. Furthermore, the entry problem is often bounded by overall systems considerations as to vehicle diameter and weight limitations, range of entry conditions, descent and impact system requirements, and special heat shield and structure material and shape requirements.

Although it is indeed commendable to achieve a complete set of computer programs which utilize the very "best" calculation models, the use of such a set of programs would not be compatible with the overall objectives to provide a set of computer programs suitable for preliminary tradeoff and parametric studies. A compromise was sought in formulating the computer programs, whereby the necessary inputs are not unduly excessive and are readily available. Programming compromises were also needed to avoid excessive computational time and wasteful generation of information that is not directly usable for the problem at hand. The computer programs are not intended to be used for detailed design studies but rather to screen the range of design parameters, to narrow their scope, and to establish trends.

B. INFORMATION FLOW

The thermo-structural design problem of evolving the heat shield and structural weights centers about the heating and loads predictions arising from the entry trajectory calculations. The degree of sophistication in the whole design approach is therefore related to the nature of the approximations used in computing the trajectory. The simplest trajectory approximation considers the vehicle as a particle without lift and of constant drag coefficient. For the particle trajectory calculation, the exact shape of the vehicle is not necessary to compute the trajectory as the entry vehicle is completely characterized by its ballistic coefficient $(M/C_D A)$.

The limitations of a particle trajectory are often prohibitive for the prediction of accurate heating and loads environment, except in the cases of spherical bodies or where the entry angle of attack and angular rates are very small. Hence, in the most general case, an aerodynamic configuration and the corresponding aerodynamic force and moment coefficients must be assessed prior to a trajectory calculation. Program 1881 provides a first estimate of the hypersonic aerodynamic coefficients based on Newtonian flow theory if wind tunnel data is not available. Frequently, limited test data is sufficient for preliminary design studies when combined with the results of Program 1881.

Specification of the entry vehicle geometry provides only part of the information necessary to calculate the angle-of-attack motions during entry. A major aspect of the entry motion centers about the vehicle's stability, which is highly dependent on the center-of-gravity location and the moments of inertia. The first estimate of the center of gravity and the corresponding moments of inertia can be obtained from Program 1881, based on prescribed stability criteria. As the preliminary design studies progress, the estimates of center of gravity and moments of inertia must be updated and certain changes could significantly alter the entry vehicle's stability and further change the heating and loads environments. The information flow diagram depicted in Figure 1, indicates the manner in which Program 1881 can provide aerodynamic coefficients and the first pass estimates of the center of gravity (XCG) and the moments of inertia about the roll and pitch axes given in terms of the respective radii of gyration (RGX) and (RGY). The trajectory computation performed by Program 1880 provides the angle of attack, velocity, and altitude history during entry. The variation of the drag and lift forces arising from the angle of attack motions is computed, and the effect of their variation on the trajectory kinematics is accounted for. As part of Program 1880, dynamic pressure

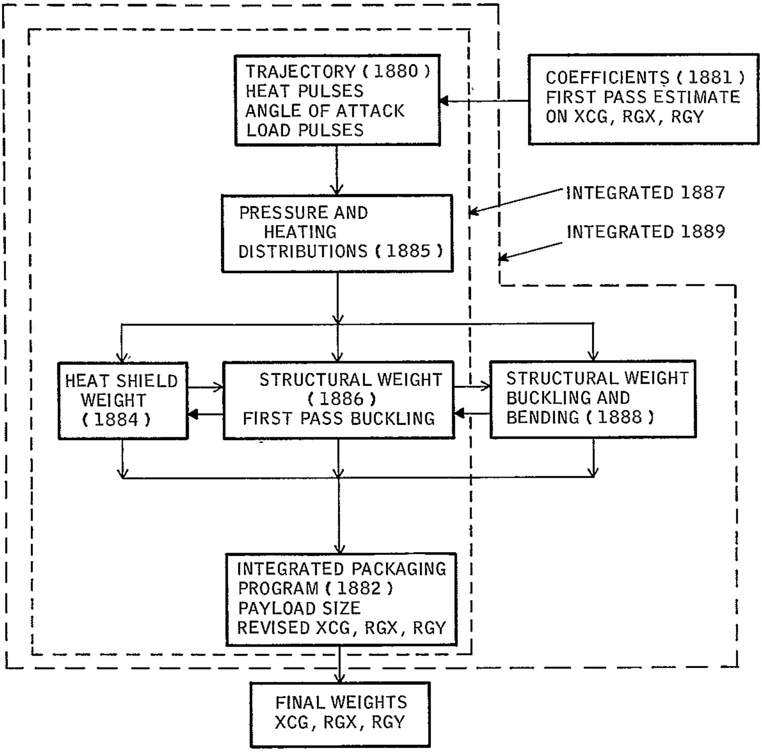

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Figure 1 INFORMATION FLOW WITHIN VEHICLE DESIGN PROGRAMS (XCG = DISTANCE OF CG FROM STAGNATION POINT, RGX, RGY = RADII OF GYRATION ABOUT X, AND Y AXES, RESPECTIVELY) and convective and radiative heat pulses are computed based on the instantaneous flight conditions; hence, the heating and loads environment is related to the vehicle dynamics which, in turn, depends on the estimates of the coefficients, center of gravity, and the moments of inertia.

The heat pulses calculated in Program 1880 are considered to be reference values, and the heating at a point of the body is expressible as a fraction (or multiple) of this value. Similarly, the pressures about the body are expressible as fractions (or multiples) of the dynamic pressure. The factors by which the reference pulses evolved from Program 1880 must be multiplied to provide the local pressure and heating may be found using Program 1885, if test data is unavailable. As shown in Figure 1, the output of Programs 1880 and 1885 are required simultaneously to compute the first pass on the structural weight. Program 1885 requires the vehicle geometry, atmosphere composition, and flight conditions as input, as well as the angles of attack for which the pressure and heating distributions are required. The output of Program 1885 is set forth as factors which can be applied directly to the heating and dynamic pressure pulses using the results of Program 1880. The distributions of Program 1880 are given for the windward and leeward meridians only. In actuality, a point on the vehicle is subject to a heating and loads environment which is affected by the roll attitude of the vehicle as well as its angle of attack. From the viewpoint of structural design, identification of the roll history of a particular point on a shell is unnecessary, provided thermal effects are not important. In order to perform an exact heat shield analysis, a streamline pattern around the complete vehicle would be required and a statistical treatment of the entry conditions would generally be required to establish the design requirements. With the view of obtaining preliminary design evaluations with assurance that the heat shield weights will be conservative, a simple approach can be taken (and is used in Programs 1887 and 1889) which considers the heating on the vehicle as if it were in a lunar motion utilizing the maximum angle-of-attack envelope generated by Program 1880.

An important structural consideration is that environments obtained from other trajectories on launch conditions may be more critical than the one for which the heating environment is most severe. By permitting optional inputs on peak dynamic pressure and deceleration (or acceleration) arbitrary combinations of heating and loads environments can be studied.

The information flow diagram of Figure 1, indicates that the appropriate outputs of Programs 1880 and 1885 are input to Program 1886. In addition, structural materials data and design criteria are input for Program 1886. Program 1886 provides for several options of construction: sandwich, stiffened, or monocoque. The failure criteria considers buckling and yield stress with further limitations due to minimum gage.

As the structural weight may be dependent on its temperature rise due to loss of strength at elevated temperatures, an interaction exists between the heat shield and the structural analyses. Furthermore, the heat shield interacts with the structural calculation by creating inertial loads on the structure.

Following the initial sizing of the structure, from Program 1886, and the heat pulses via Programs 1880 and 1885, sufficient information is on hand to perform the heat shield analysis. Program 1884 calculates the heat shield requirements, if indeed one is needed. The heat shield material properties and design criteria are required input as well as the results of Programs 1880 and 1885. There are several interaction mechanisms between the heat shield and structure, two of which are noted above; hence, the flow diagram of Figure 1 indicates a thermo-structural loop.

The internal payload is dependent on the total entry weight, the heat shield and structural weight, internal structural weight, and various system constraints placed on the descent and impact systems. Program 1882 integrates the system constraints and the results of Programs 1884 and 1886 to determine the net usable payload weight. In order to provide sufficient flexibility in a program of this sort, numerous options are possible, e.g. single chute, two parachutes, parachute and retro-rocket combinations, spherical payloads, cylindrical payloads, and conical payloads. System constraints (as impact deceleration limits) are inputs to Program 1882. Upon solving for the weight of the subsystem and determing the size and weight of each element, and of the payload, a packaging calculation is performed to ascertain whether the payload fits into the vehicle satisfactorily and provides a suitable center-of-gravity position. In addition, the overall moments of inertia are computed based on the detailed heat shield and structures and subsystems information evolved. As noted at the very outset, the initial estimates of center of gravity and moments of inertia may be sufficient for preliminary design purposes; however, the refined values arising from Program 1882 can now be tested by rerunning Program 1880 and observing the changes in the heating and loads environment. If the heating and loads change significantly due to the moment of inertia and center-of-gravity changes, then a complete iteration on the structure, heat shield, and subsystem weights is required.

The last step in the design study is the complete shell analysis by Program 1888, including the effects of payload attachment, bending, and shear. In order to perform this analysis, detailed pressure distribution information is required for which Program 1885 may be used. The inputs to Program 1888 include the preliminary structural sizing and the heat shield thicknesses, as well as the structural material properties and failure criteria. As a result of the refined structural analyses of Program 1888, any significant changes in structural weight can alter the complete internal structure and subsystem weight breakdown, requiring further iteration on these weights.

The final overall loop, including Programs 1888 and 1887, is considered as Program 1889. The input of Program 1889 is clearly the input and output of all the other programs and/or experimental data when available. The results of Program 1889 are the complete vehicle weight breakdown of the heat shield, structure, internal structure, descent system, impact system, and usable payload. Program 1889 closes the aero-thermo-structures-systems loop, and as such arrives at a preliminary design suitable for a particular entry problem.

C. PROGRAM FORMAT

A primary objective sought throughout all the programs is the achievement of uniformity of format, such as notation, units, and input procedures. The problem of units arises due to the multidiscipline nature of the various programs. In dealing with each program a set of units was established which appeared both convenient in that they are in widespread use and logical. In dealing with gas dynamics and atmosphere calculations, temperature is commonly given in degrees Kelvin (°K), whereas in dealing with the heat shield and structure calculations, temperatures are commonly given in degrees Fahrenheit (°F).

The aerodynamicist deals with density in slugs/ft^3, whereas the thermodynamicist and structural analyst prefers lb (mass)/ft^3 and these conventions are observed. The gas dynamicist deals with pressures in terms of atmospheres, the aerodynamicist in PSI or PSF, and similarly the thermo- and structural analysts. The units of length are restricted to either feet or inches throughout the programs.

D. PROGRAMMING METHOD

All programs are written in Fortran IV computer language. All data is read into the computer through use of the NAMELIST feature of Fortran IV. The use of machine language subroutines (other than the standard IBM library subroutines) are avoided whenever possible. All Fortran IV input and output statements refer to specific logical tape units.

The program linking for 1887 and 1889 employs the IBSYS overlay feature. As much independence as possible is retained among the links.

This users' manual provides input forms and the Fortran variable names of input and output quantities. This manual includes sample results, along with instructions for preparing data and running the programs.

TRAJECTORY PROGRAM (1880)

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I. INTRODUCTION

A. GENERAL DESCRIPTION

The purpose of this program is to determine the flight path, angle of attack envelope, heating, and loads as a function of time for an axisymmetric vehicle during its entry trajectory into planetary atmospheres. The general inputs required include:

1. Vehicle mass and moment of inertia data
2. Aerodynamic coefficients
3. Entry conditions
4. Planet and atmospheric data
5. Heating factors based on vehicle shape.

Convective heat pulses are computed at the stagnation point (laminar) and at the sonic point (laminar and turbulent). In addition, both equilibrium and non-equilibrium radiative heat pulses are computed.

B. CALCULATION MODEL

A detailed description at the calculation model is given in Reference 1. A brief summary description is provided herein for the program user.

1. Coordinate Systems

The treatment of the force equations during atmospheric entry is simplified by considering a coordinate system which uses only the elevation angle gamma to define its orientation relative to the local horizontal space plane. A heading angle is unnecessary because of the assumption of a spherical, nonrotating planet The velocity vector is specified by its scalar value and the elevation angle γ measured positive above the horizon.

Since planar trajectories are of primary interest, only two equations of motion are required to calculate the flight path of the vehicle in the plane of the velocity and gravity vectors.

The body axes are oriented with respect to a system of wind axes using a conventional system of Euler angles. The curvature of the flight path is reflected in a rotation of the wind axes with respect to a set of fixed (inertial) axes.

The coordinate systems used in deriving the force and moment equations are depicted in Figure 1. The wind axes are X_o, Y_o, and Z_o, where X_o coincides with the velocity vector, and Z_o lies in the plane of the velocity and gravity vectors. The origin of the body axes X_B, Y_B, Z_B, and of the wind axes are taken at the c.g. of the vehicle. The total angle of attack α' is the angle between the body axis X_B and the velocity vector (or X_o).

2. Aerodynamic Coefficients

The aerodynamic coefficients utilized in the program may be either experimental or theoretical values. The coefficients can be input as a double table of angle of attack and Mach number dependency, including C_N, C_X, C_m (or X_{cp}), $(C_{m_q} + C_{m_{\dot\alpha}})$. The coefficients can also be input to solve the angle-of-attack motions using linear coefficients in which case the values are required only at zero angle of attack, but as functions of Mach number including C_D, $C_{L\alpha}$, C_{m_α}, and $C_{m_q} + C_{m_{\dot\alpha}}$. The sign and axes conventions used in the aerodynamic coefficients are depicted in Figure 2. The damping coefficient is nondimensionalized by $\frac{d}{2V}$, for example,

$$C_{m_{\dot\alpha}} = \frac{\partial C_m}{\partial\left(\frac{\dot\alpha d}{2V}\right)}$$

The reference area corresponds to the reference length, which is the vehicle diameter.

3. Force Equations

The calculation model assumes a spherical nonrotating planet. The force equations are written in wind axes (X_o, Y_o, Z_o) aligned along the instantaneous velocity vector as shown in Figure 1. The side force equation was omitted, and the resulting drag and lift equations describe the motion of the vehicle's center of gravity in the instantaneous plane of the trajectory.

The component of the total lift that lies in the plane of the trajectory depends on the orientation of the vehicle. Using a set of Euler angles, ψ, θ, φ as shown in Figure 1, which determine the orientation of the body fixed axes (X_B, Y_B, Z_B) with respect to the wind axes, the force equations have the form,

DRAG: $m\dot V = -C_D A q - mg\sin\gamma$

LIFT: (In the plane of $\bar g$ and $\bar V$)

$$m V \dot\gamma = \frac{mV^2}{R_Z}\cos\gamma - mg\cos\gamma + C_L A q \frac{\sin\theta}{\sin\alpha'}$$

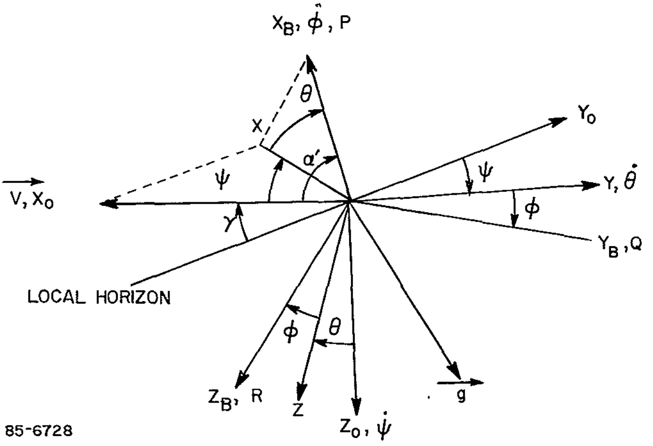
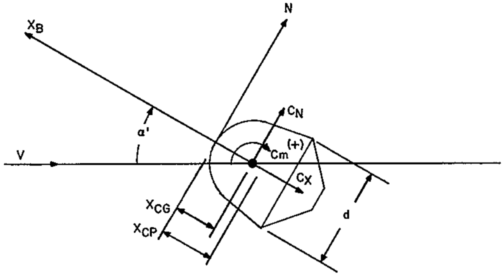
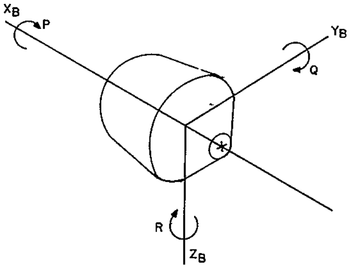


Figure 1 COORDINATE SYSTEM FOR ENTRY TRAJECTORIES



AXISYMMETRIC COEFFICIENT CONVENTIONS



ANGULAR RATE CONVENTIONS

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Figure 2 AERODYNAMIC COEFFICIENTS CONVENTIONS where α' is the total angle of attack and is related to the Euler angles by,

$$\sin^2 \alpha' = \sin^2 \psi + \cos^2 \psi \sin^2 \theta$$

The gravity vector is taken as radial, and pointed towards the center of the planet. The gravitational field assumes an inverse square relationship. The force coefficients required to solve the force equations can be specified as a function of angle of attack and Mach number.

4. Moment Equations

The moment equations are derived using the body axes indicated in Figure 1 and the total angular rates are taken with respect to a fixed set of axes. The angular rates are divided into two parts; those with respect to the wind axes, and those due to the motion of wind axes with respect to the fixed axes. The motion of the body axes with respect to the wind axes is given by the changes in Euler angles and also in a set of rate components P, Q, R about each axis, where P, Q, R are related only to the changes in the Euler angles. The additional angular rate effects arise because of flight path curvature (changes in the direction of the velocity vector) due to lift and gravity.

The changes in flight path curvature due to lift is used in its entirety, i.e., the total lift force is used including the out of plane component. The analysis proceeds along the lines of Reference 1. An order of magnitude analysis is made and only those terms which could affect the results significantly are retained.

The total angular rate $\bar{\Omega}$ with respect to a set of fixed axes has components P', Q', R' along the body axes such that,

$$\bar{\Omega} = \bar{i}\, P' + \bar{j}\, Q' + \bar{k}\, R' \quad .$$

The calculation model is restricted to axisymmetric ballistic vehicles for which the products of inertia are zero, and $I_Y = I_Z$, hence, the external moment vector is related to the rate of change of angular momentum by

$$\bar{M} = \bar{i}\; I_X \dot{P}' + \bar{j}\left[I_Y \dot{Q}' - P'R'(I_Y - I_X)\right] + \bar{k}\left[I_Y \dot{R}' + P'Q'(I_Y - I_X)\right] \quad .$$

The external moment vector may be expressed as

$$\bar{M} = M' \left(\frac{\bar{j} \sin \alpha}{\sin \alpha'} + \frac{\bar{k} \sin \beta}{\sin \alpha'} \right) + N' \left(- \frac{\bar{j} \sin \beta}{\sin \alpha'} + \frac{\bar{k} \sin \alpha}{\sin \alpha'} \right)$$

The aerodynamic moments (M') and (N') are given approximately by

$$M' = C_m qAd + (C_{m_q} + C_{m_{\dot{\alpha}}}) \frac{qAd^2}{2V} \dot{\alpha}' \; ; \quad N' = (C_{m_q} + C_{m_{\dot{\alpha}}}) \frac{qAd^2}{2V} \dot{\eta} \sin \alpha' .$$

where $\dot{\eta}$ is the rate of precession of the plane containing $\overline{V}$ and $\overline{i}$.

The wind axes pitch about the Y_o axis due to gravity at a rate,

$$\dot{\gamma}_T = - \frac{g \cos \gamma}{V}$$

(Gravity term in above lift equation.)

Due to lift, the flight path curvature can be out of the plane of the trajectory and is given by

$$\dot{\gamma}_L = \frac{L}{mV}$$

(Lift term in above lift equation is in-plane component only.)

As $\overline{\dot{\gamma}}_L$ lies along $\overline{M}'$, the expressions for P', Q', R' can be written as,

$$P' = P + \dot{\gamma}_{TX}$$

$$Q' = Q + \dot{\gamma}_L \frac{\sin \alpha}{\sin \alpha'} + \dot{\gamma}_{TY}$$

$$R' = R + \dot{\gamma}_L \frac{\sin \beta}{\sin \alpha'} + \dot{\gamma}_{TZ}$$

where $\dot{\gamma}_{TX}$, $\dot{\gamma}_{TY}$ and $\dot{\gamma}_{TZ}$ are the components of $\dot{\gamma}_T$ along the body axes X_B, Y_B, and Z_B, respectively.

Introducing the further approximations,

$$\ddot{\gamma}_L = C_{L_\alpha} \frac{A}{m} q \frac{\dot{\alpha}'}{V}$$

$$\dot{\gamma}_L << \dot{\alpha}'$$

$$\dot{\gamma}_{TX} << P$$

then the resultant expression for the moment equations are,

$$\dot{Q} = \frac{qAd}{I_Y} \left[C_m \frac{\sin \alpha}{\sin \alpha'} + \frac{Qd}{V} \left(\frac{C_{m_q} + C_{m_{\dot{\alpha}}}}{2} - \frac{C_{L_\alpha} I_Y}{md^2} \right) \right] + PR \; 1 - \frac{I_X}{I_Y}$$

$$- \frac{PI_X}{I_Y} \frac{C_L Aq}{mV} \frac{\sin \beta}{\sin \alpha'} + \frac{PI_X}{I_Y} \frac{g \cos \gamma}{V} (\sin \psi \sin \theta \cos \varphi - \cos \psi \sin \varphi)$$

$$\dot{R} = \frac{qAd}{I_Y}\left[C_m \frac{\sin\beta}{\sin\alpha'} + \frac{Rd}{V}\left(\frac{C_{m_q} + C_{m_{\dot{\alpha}}}}{2} - \frac{C_{L_\alpha} I_Y}{md^2}\right)\right] - PQ\left(1 - \frac{I_X}{I_Y}\right)$$

$$+ \frac{PI_X}{I_Y}\frac{C_L Aq}{mV}\frac{\sin\alpha}{\sin\alpha'} - \frac{PI_X}{I_Y}\frac{g\cos\gamma}{V}(\cos\psi\cos\varphi + \sin\psi\sin\theta\sin\varphi)$$

$$\dot{P} = 0$$

The moment equations display the coupling of the plunge damping term C_{L_α} frequently found, e.g., References 3, 4, and 5. It should be noted that the C_{L_α} is now a function of angle of attack (and also of Mach number if desired). The terms yielding the coupling effects of flight path curvature due to lift and gravity with spin have also been retained.

The occurrence of the C_{L_α} explicitly is of interest as the usual six-degree of freedom computation effectively computes C_{L_α} implicitly by interpolating C_N and C_X from input tables. Hence differences between the two formulations are likely at small values of $C_{m_q} + C_{m_{\dot{\alpha}}}$ and especially at large negative values of C_{L_α} where the C_{L_α} controls the angle-of-attack envelope below peak dynamic pressure. The present program provides for accurate simulation of C_{L_α} by direct input tables or by curve fitting computed values of C_L obtained from C_N and C_X input data.

To permit elementary studies of lifting vehicles, the $(\dot{Q})$ equation given above has the additional aerodynamic term,

$$\frac{-C_X \cdot Z_{CG}\, qAd}{I_Y} \quad .$$

By input of the quantity Z_{CG}, a trim condition at other than zero angle of attack can be achieved, resulting in a lifting trajectory. The use of the off-set center of gravity is restricted to planar motions, i.e. zero spin, and zero sideslip angle.

The dynamic solution is programmed for the two moment equations discussed above and also for the linearized solution discussed in Reference 1. The adequacy of the approximate dynamical treatment for most practical entry problems of ballistic vehicles has been studied and comparisons made with six-degree-of-freedom solutions in Reference 1 (Vol. II) and a typical result is shown in Figure 3, for a planar oscillation and for a spin case.

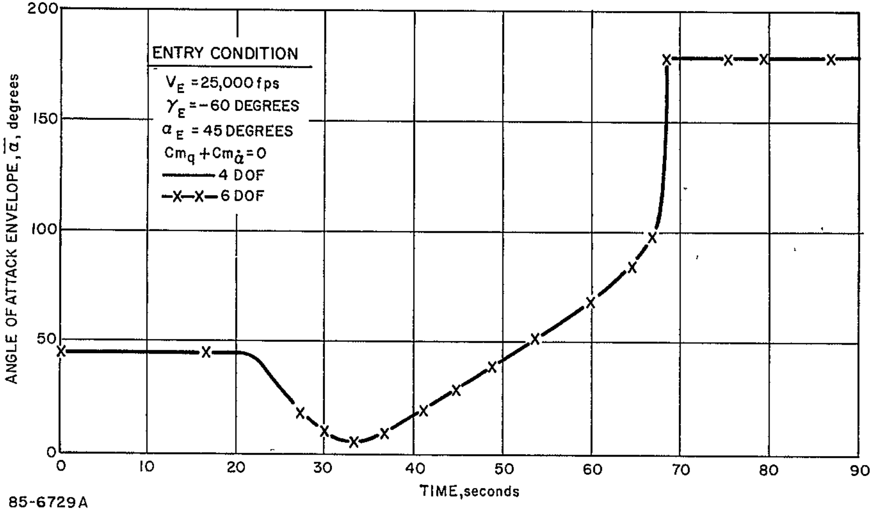

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Figure 3a TRAJECTORY COMPARISONS WITH SIX DEGREE OF FREEDOM RESULTS

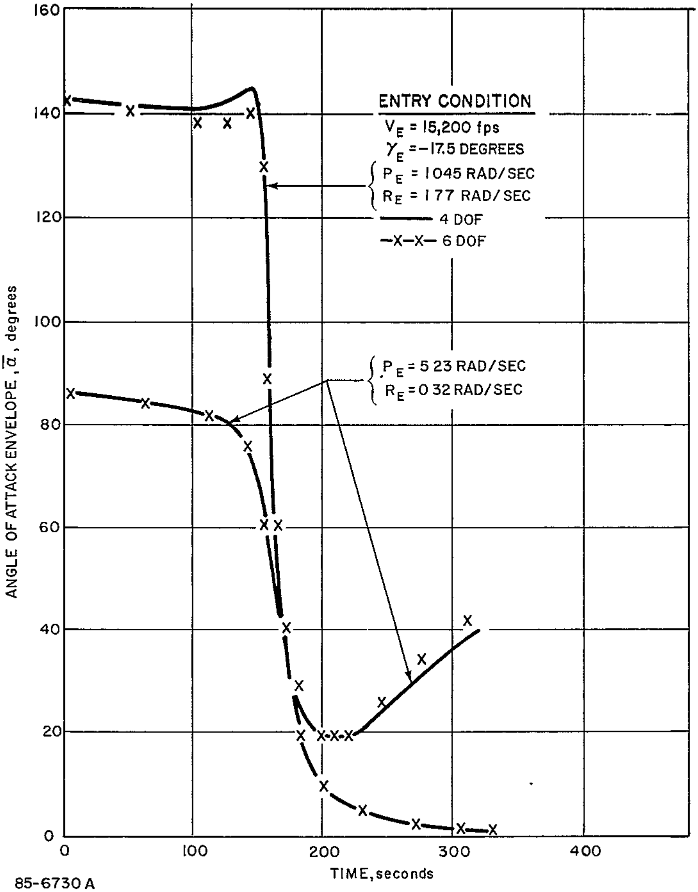

Figure 3b TRAJECTORY COMPARISONS WITH SIX DEGREE OF FREEDOM RESULTS

5. Heat Pulses

Convective and radiative heat pulses are computed along the trajectory. The convective pulse at the stagnation point utilizes the stagnation point velocity gradient data for the particular shaped vehicle being studied. The stagnation heating is based on the correlations of Reference 1 for CO_2, N_2, O_2 mixtures. Turbulent heating at the sonic point is computed by testing against a specified local (not ambient) transition Reynolds number criterion. The turbulent heating correlation is for air as given by Detra.[2] Comparison of the program calculations with data of Reference 3 is shown for the stagnation point in Figure 4. Limited data on turbulent heating in N_2 - CO_2 mixtures given in Reference 4, indicates a negligible difference in the heat rates due to composition when compared with air data.

The equilibrium radiation heating is calculated via Program 1883 which is connected directly to the trajectory computation. A description of the equilibrium radiation model is given in Program 1883. A comparison of the program calculations with data and other predictions is given in Figure 5.

The nonequilibrium model is discussed in Reference 1 and summarized in Figure 6. The relative features of the model can be controlled using experimental data to adjust the ratios of I_{NE}/I_E by input of IRNE, and the extent of the nonequilibrium zone by input of KNE.

An alternate, nonequilibrium model is possible wherein the nonequilibrium radiation contribution is assumed to be independent of density (except for truncation effects) and only a function of velocity. A simplified model is utilized such that $I_{NE}\,\Delta_{NE} = f\,(V)$, with the nonequilibrium intensity specified as a function of velocity based on experimental data, e.g., References 5 and 6.

6. Summary of Calculation Model

The calculation model can be used to study any of the following problems.

a. Parachute Problem--The vehicle m/C_DA requirements for achieving a prescribed Mach number at/or prior to a specified altitude.

b. Vehicle Stability--The adequacy of the vehicle's stability as a function of entry pitch, yaw, roll rates, and angle of attack.

c. Vehicle Performance--The change in the trajectory, heating, and loads caused by the effects of the angle-of-attack motions on the flight path (velocity-altitude history).

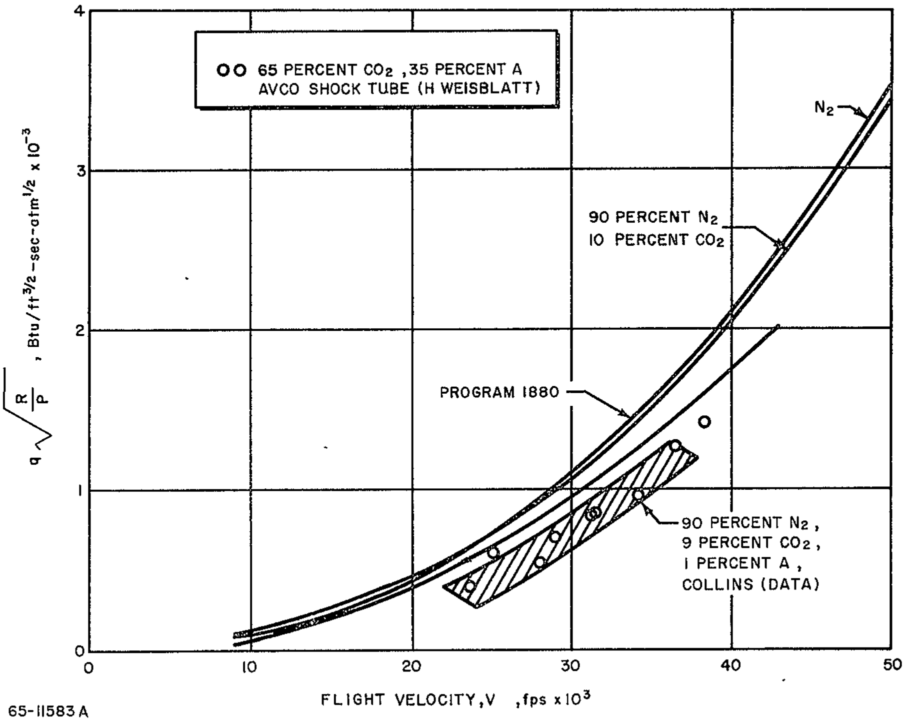

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Figure 4 STAGNATION POINT HEATING COMPARISONS WITH DATA

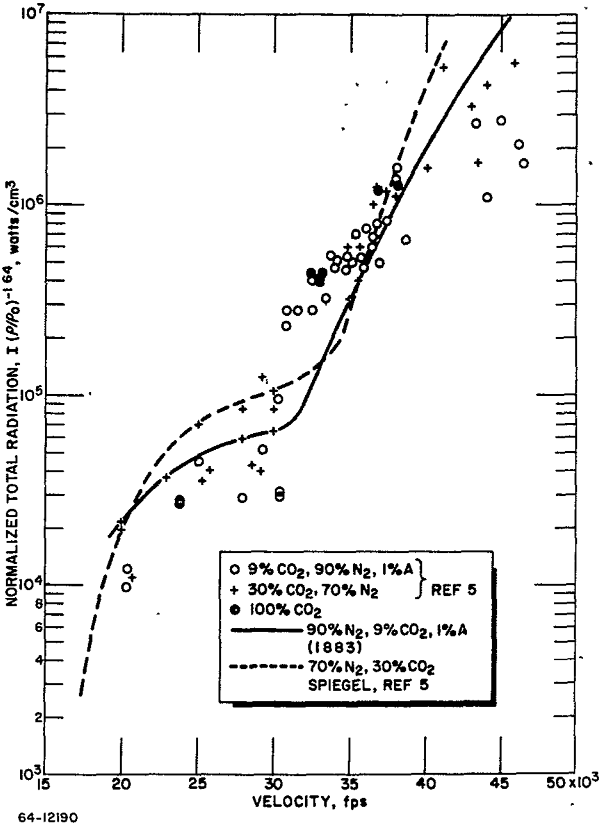
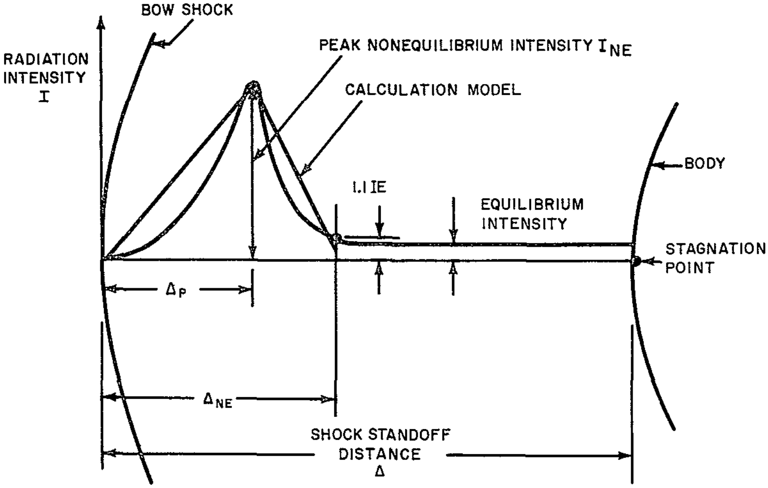


Figure 5 RADIATION HEATING COMPARISONS WITH DATA



1880 INPUTS: IRNE, KNE

CORRELATION	SOURCE
IE (ϵ_i, N_i, T_S)	PROGRAM 1883
Δ_P (ρ_A, V)	EQ.67, REFS 5,13
Δ_{NE}(ρ_A, V, KNE)	EQ.66, REFS 5,13
$\frac{I_{NE}}{I_E}$(IRNE)	REFS 5,13

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Figure 6 NONEQUILIBRIUM RADIATION CALCULATION MODEL

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d. Convective Heating--The stagnation-point and sonic-point convective heating pulses as well as an indication of transition.

e. Radiative Heating--The stagnation-point equilibrium and non-equilibrium radiative heating pulses.

f. Loads--The dynamic pressure, and axial and normal load pulses.

g. Atmosphere--The effects of atmosphere composition and vertical structure on all the trajectory variables.

h. Planet--The effects of planet parameters on all the trajectory variables.

i. Scaling--The effects of changing vehicle diameter and/or mass.

C. PROGRAM LIMITATIONS

The calculation model imposes several basic limitations on the range of trajectory problems that can be simulated with the program. These limitations include:

1. The approximations utilized prevent the entry vehicle from developing an angle of attack due to flight path curvature alone; hence, vehicles entering with zero rates and $\alpha_e = 0$ or $\alpha_e = 180$ will remain at the same angle of attack throughout entry.

2. The vehicle motions which can be simulated are limited by the assumptions of an axisymmetric inertia ellipsoid (spin rate stays constant throughout entry).

II. USAGE

A. INPUT DEFINITIONS

Name	Preset Values	Symbol	Parameter	Units
ALAM	0.5	a_L	Density exponent in QS formula.	--
ALPCR	0.		Critical angle of attack; if angle of attack at peak dynamic pressure is < ALPCR, the dynamics computation switches to the linearized equations.	degrees
ALPHAE		α_e	Angle of attack at entry.	degrees
AR	89516.	R	Gas constant	$\mathrm{ft}^2/\mathrm{sec}^2\text{-mole-}^\circ\mathrm{K}$
ATMØS			Number used to identify atmosphere used for the calculations.	--
ATRB	0.8	a_T	Density exponent used in QSTAR formula after transition occurs.	--
BLAM	0.	b_L	(Velocity/10^4)exponent used in QS formula. If = 0 (preset value), it is computed by the program to be 3.909 - .0229M where M is the molecular weight of the atmosphere.	--
BTRB	3.18	b_T	(Velocity/10^4) exponent used in QSTAR formula after transition occurs.	--
CASE			Number used to identify the case being run.	--
CDFM		C_D	Table of zero angle of attack drag coefficient variation as a function of Mach number only. Maximum number of entries = 10. See MØNLY.	--

Name	Preset Values	Symbol	Parameter	Units
CDRØP	2.		Number used to delete moment equations after peak dynamic pressure. Switches to MØNLY coefficients . When, $1/2\,\rho V^2 < \mathrm{CDRØP}\left(\frac{m\,g_{sl}}{C_D A}\right)$.	--
CLAFM		$C_{L\alpha}$	Table of lift curve slope variation as a function of Mach number only. Used with MØNLY table; maximum number of entries = 10.	per radian
CMAFM		C_{m_α}	Table of pitching moment derivative $\left(\frac{\partial C_m}{\partial \alpha}\right)$, as a function of Mach number only. Used with MØNLY table; maximum number of entries = 10.	per radian
CMCØD		$\frac{x_{CM}}{d}$	Nondimensional center-of-gravity location for CMFA data.	--
CMFA		C_m	Table of pitching moment coefficient as a function of angle of attack and Mach number. Used with CMCØD and CMIN = 1.0. Maximum number of entries: 19 angles of attack (corresponding to TABAL) and 5 Mach numbers when used with MANDAL table.	--
CMIN	0.		Number which if > 0 provides the pitching moment from CMFA and CMCØD, and if ≤ 0 from XCPFA.	--
CMQFA		$C_{m_q} + C_{m_{\dot\alpha}}$	Table of damping coefficient, $\left(\frac{\partial C_m}{\partial \frac{Qd}{2V}}\right)$, as a function of angle of attack and Mach number. Maximum number of entries: 19 angles of attack (corresponding to TABAL) and 5 Mach numbers when used with MANDAL table.	per radian

External Name	Preset Values	Symbol	Parameter	Units
CMQFM		$C_{m_q} + C_{m_{\dot{\alpha}}}$	Table of damping coefficient variation as a function of Mach number only. Maximum number of entries = 10. Used with MØNLY table.	per radian
CNFA		C_N	Table of normal force coefficient specified as a function of angle of attack and Mach number. Maximum number of entries: 19 angles of attack (corresponding to TABAL) and 5 Mach numbers when used with MANDAL table.	--
CXFA		C_X	Table of axial force coefficient, specified as a function of angle of attack and Mach number. Maximum number of entries· 19 angles of attack (corresponding to TABAL) and 5 Mach numbers, when used with MANDAL table.	--
		d	Vehicle diameter (reference length).	feet
DATE			Number used to identify the problem being run.	--
DELMAC	0.5		When the Mach number ≤ 5, output will be provided whenever the difference in Mach number from the last output value is $\geq$ DELMAC	--
DELMT	0.00001		This is the lower limit in Δt to which the predictor-corrector integration method is allowed to cut Δt to improve accuracy. See description of ADAMS4.	--
DELØRC		Δ/R_C	Table of stagnation shock standoff distance $\left(\frac{\Delta}{D/2}\right)$ corresponding to TABDR. Maximum of 10 entries.	--

Name	Preset Values	Symbol	Parameter	Units
DELTAT	0.01		Initial Δt used by the predictor-corrector integration method. See description of ADAMS4.	sec
DIRNE			Total nonequilibrium radiation intensity. (Twice the body rate).	Btu/ft^2-sec
DNBND	0.001, 1.E-6, 0.01, 0.0001, 0.0001, 1.E-5, 1.E-5, 1.E-5		Array of lower limits used by the predictor-corrector subroutine ADAMS4, as accuracy bounds on V, γ, Z, Q, R, ψ, θ, φ.	--
FALR		L_1	Temperature gradient in troposphere expressed as a fraction of the adiabatic lapse rate.	--
GAME		γ_e	Entry flight path angle (positive up).	degrees
GSL		g_{SL}	Gravitational acceleration at the planet surface.	ft/sec^2
GTST	2.		When the reference convective heat pulse is ≥ 1, output will be provided if the difference in the current flight path angle from the last output value is $\geq$ GTST.	degrees
IPHEAT	0.		When IPHEAT ≥ 1, tables of time, QS, QSTAR, HM/RT0, and QRNE are provided on punched cards from logical Tape 7.	--
IPRINT	0.		When IPRINT ≥ 1, output is provided at each integration step. The angle of attack (not the envelope) is printed. Use of this option more than doubles running time and increases output by 3 to 4 orders of magnitude.	--
IPRQRD	0.		When IPRQRD is ≥ 1, the complete output (chemical composition, etc.) of each radiation heating calculation is provided.	--

Name	Preset Values	Symbol	Parameter	Units
IRNE	10.	I_{NE}/I_E	Nonequilibrium intensity ratio.	--
KNE	2.3		Multiplicative constant used to compute the nonequilibrium thickness Δ_{NE}.	--
LS	-5.		Sentinel used to control the predictor-corrector integration method, used for initialization and to follow the course of the integration. See description of ADAMS4.	--
LTH		L_{TH}	Temperature gradient in thermosphere.	$^{o}K/ft$
MANDAL			(Preset = 0 for coefficients as a function of α only). Mach number table (maximum 5 values) for coefficients as function of both Mach number and angle of attack. When this table is specified, tables CXFA, CNFA, CMQFA, and either XCPFA or CMFA must be specified for each Mach number in MANDAL. At Mach numbers below (or above) those specified in MANDAL table, program uses coefficients corresponding to lowest (or highest) Mach number listed.	--
MASS		m	Mass of vehicle.	slugs
MEM0			Number, used to identify the problem being run.	--
M0NLY			Independent variable table of Mach numbers used to compute coefficients as a function of Mach number only. Maximum number of entries is 10. See CDFM, CMAFM, CLAFM, CMQFM.	--

Name	Preset Values	Symbol	Parameter	Units
MVE	1.		If MVE = 1.0 (preset value), the atmosphere is computed from the input parameters. If MVE = 2.0, the atmosphere is computed from tables in which the altitude (ZTBL) is the independent variable.	--
NPTST	51		Maximum number of lines of trajectory output per page.	line/page
PE		P_e	Spin rate at entry.	rad/sec
PTH		P_{TH}	Atmospheric pressure at base of thermosphere.	lb/ft^2
PTMAC	-100.		If PTMAC > 0, linearly interpolated values of the trajectory output quantities will be printed at the Mach number = PTMAC Do not use simultaneously with QDYPT (see below).	--
QDYPT	-100.		If QDYPT > 0, linearly interpolated values of the trajectory output quantities will be printed at the dynamic pressure = QDYPT . Do not use simultaneously with PTMAC (see above)	lb/ft^2
QE		Q_e	Pitch rate at entry.	rad/sec
QTST	200.		When the reference convective heat pulse is ≥ 1, output will be provided if the difference of the integrated reference convective heat pulse from the last output value is ≥ QTST.	Btu/ft^2
RE		R_e	Yaw rate at entry.	rad/sec
REYT	3.E5	R_{e_t}	Transition Reynolds number for QSTAR based on SSØD.	--

Name	Preset Values	Symbol	Parameter	Units
RGX		σ_x	Nondimensional radius of gyration for roll moment of inertia.	--
RGY		σ_y	Nondimensional radius of gyration for pitch moment of inertia.	--
RH0SL		ρ_{SL}	Density of the atmosphere at the planet surface.	$slug/ft^3$
R0TBL		ρ	Dependent variable table of density used with ZTBL to compute atmospheric density when MVE = 2.0 (see above). Maximum number of entries is 101.	$slug/ft^3$
RSL		R_{SL}	Radius of the planet.	feet
SS0D		S^*/d	Ratio of distance from sonic point to the stagnation point at zero angle of attack to the vehicle diameter.	--
TABAL		α	Independent variable of angle of attack used to compute coefficients as a function of Mach number and angle of attack. Maximum number of entries is 19.	degrees
TABDR		ρ_s/ρ_a	Independent variable table of stagnation point density ratios (ρ_s / $\rho_a)_s$ used with DEL0RC (see above) and VGFDR (see below). Maximum number of values is 10.	--
TETBL		T	Dependent variable table of temperature used with ZTBL to compute atmospheric temperature when MVE = 2.0 (see above). Maximum number of entries is 101.	°K
THF	1.		Turbulent heating factor used to compute QSTAR after transition has occurred.	--

Name	Preset Values	Symbol	Parameter	Units
TSL		T_{SL}	Atmospheric temperature at the planet surface.	^{o}K
TST		T_{ST}	Atmospheric temperature in the stratosphere.	^{o}K
TSTØP	1000.		Maximum permitted value of the independent variable time for the integration of the trajectory equations.	seconds
TZERØ	0.		Initial value of the independent variable time for the integration of the trajectory equations.	seconds
UPBND	0.01, 1.E-5, 0.1, 0.001, 0.001, 0.0001, 0.0001, 0.0001		Array of upper limits used by the predictor-corrector subroutine ADAMS4 as accuracy bounds on V, γ, Z, Q, R, ψ, θ, φ, respectively.	--
UPDN	0.2		Factor by which the predictor-corrector method increases or decreases Δt (depending on accuracy) during the integration. See description of ADAMS4.	--
VE		V_e	Entry velocity.	ft/sec
VEHICL			Identification number for vehicle.	--
VIRNE			Velocity table used when DIRNE is specified maximum of 10 values.	ft/sec
VGFDR		$\frac{d}{2V}\left(\frac{du}{ds}\right)_s$	Dependent table of velocity gradient, used with TABDR (see above). Maximum number of entries is 10.	--

Name	Preset Values	Symbol	Parameter	Units
VSTØPQ	12000.		The slowest velocity at which the radiation heating calculation will be done. It must be $\geq$ 5000.	ft/sec
VTST	600.		When the reference convective heat pulse is ≥ 1, output will be provided if the difference between the velocity and the last output velocity is $\geq$ VTEST.	ft/sec
XA			Mole fraction of molecular Argon in the atmosphere.	in
XC			Mole fraction of CO_2 in the atmosphere.	--
XCGØD			Center-of-gravity location of the vehicle as a fraction of vehicle diameter.	--
XCPFA			Aerodynamic center-of-pressure location as a fraction of vehicle diameter. This table as a function of angle of attack and Mach number is used to provide the pitching moment when CMIN = 0. Maximum number of entries: 19 angles of attack (corresponding to TABAL) and 5 Mach numbers when used with MANDAL.	--
XN			Mole fraction of N_2 in the atmosphere (must $\geq$ 0.001).	--
XØ			Mole fraction of O_2 in the atmosphere.	--
XPRIN	1		If the value of LS (see above) is 1.0, output will be provided in even intervals of XPRIN. Using this option will generally invalidate the angle-of-attack envelope values printed in the output.	sec

Name	Preset Values	Symbol	Parameter	Units
ZCG0D			Center-of-gravity offset.	feet
ZE		Z_e	Entry altitude.	feet
ZST0P	0.		The integration of the trajectory equations is terminated when the value of the dependent variable Z is $<$ ZST0P	--
ZTBL			Independent variable table of altitude used with R0TBL and TETBL to compute atmospheric properties when MVE = 2. 0 (see above). Maximum number of entries is 101.	feet
ZTST	2.E4		Where the reference convective heat pulse is $>$ 1, output will be provided if the change in altitude is $\geq$ ZTEST.	feet

B. INPUT PROCEDURES

1. General

a. Decimal points can be used on all inputs. However, omitting decimal points on integers will not cause difficulty.

b. A preset variable need not be input unless a different value is desired.

c. After the first data case of a set of stacked cases, only changed inputs must be specified.

d. Inputs DATE, MEM0, CASE, ATM0S, and VEHICL have no effect on the computation and may be omitted. They appear at the top of the trajectory printout as a convenience in identification.

e. All independent variable tables must be specified in monotonic ascending order.

f. The output is adjusted to allow for a maximum of 150 lines of printout; the amount of printout is adjusted by optional program controls.

g. A set of computer input forms are provided for the user. All the data shown on the form is keypunched when the variable is supplied.

2. Atmosphere

a. The atmosphere may be specified by either of two methods, parametric or tables. Optional input MVE,preset for parametric inputs, selects the input method.

b. The parametric input method is more convenient for theoretical atmospheres such as JPL Mars models G, H, I, J, and K[7] and NASA Mars models 1, 2, and 3[9]. The program inputs are readily obtainable from the definitions of these atmospheres (see Table I).

c. For precise atmosphere specification, e.g. Earth, complete tables of density and temperature versus altitude may be input.

d. Additional to the temperature and density properties of the atmosphere, the composition is input as mole fractions of oxygen, nitrogen, carbon dioxide, and argon. The sum of these fractions must equal 1. The nitrogen fraction must not be less than 0.001.

3. Calculation Time

The input CDR0P was introduced to permit a reduction in computation time where a vehicle undergoing large oscillations has reached close to terminal velocity at high altitude. Calculation of the angle of attack motions until impact, using the moment equations, would consume a great deal of time for such a case. Hence, specifying CDR0P places a restraint on the computational time.

Other controls on calculation time are possible by specifying TST0P, the maximum permitted trajectory time, or by specifying ZST0P as the altitude at which the trajectory calculation must be stopped.

Use of the linearized dynamics solution below peak dynamic pressure, when appropriate, also can save considerable time.

4. Amount of Output

The output is limited to 150 lines, which can be regulated by program controls on the interval of printout. The printout interval controls include successive output points in integrated stagnation point heating, altitude, and velocity.

TABLE I

MARS MODEL ATMOSPHERES

Inputs		JPL					NASA		
Program Name	Units	G	H	I	J	K	1	2	3
RSL	ft	11.E6	11.E6	11.E6	11.E6	11.E6	11.E6	11.E6	11.E6
GSL	ft/sec^2	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12
RHØSL	$slug/ft^3$	4.21E-5	4.21E-5	5.9E-5	1.042E-4	9.54E-5	8.97E-5	6.94E-5	4.19 E-5
TSL	°K	260	260	230	210	230	300	250	200
TST	°K	130	230	180	130	230	260	180	100
PTH	lb/ft^2	1.E-20	1.E-20	1.E-20	1.E-20	1.E-20	6.636E-2	1.454E-3	4.939-E9
FALR*	-	0.935	0.935	0.952	0.982	0	0.987	1.032	1.053
LTH	°K/ft	1.E-20	1.E-20	1.E-20	1.E-20	1.E-20	6.096E-4	6.096E-4	6.096E-4
XN	-	0.001	0.001	0.245	0.765	0.765	0.951	0.892	0.512
XØ	-	0	0	0	0	0	0	0	0
XC	-	0.647	0.647	0.433	0.105	0.105	0.049	0.108	0.488
XA	-	0.352	0.352	0.322	0.13	0.13	0	0	0

*Note Values of FALR have been adjusted to account for the difference between the C_P specified for the atmosphere model and the C_P computed in the program to provide the intended temperature variation (see Equations (3) and (6).

5. Vehicle Data

a. Mass and diameter are the key inputs which affect the trajectory, coefficient calculation, heating, and scaling.

b. The radii of gyration and center of gravity, which affect the dymamics, are input as fractions of the diameter to simplify scaling. If these ratios can be assumed independent of size, only the mass and diameter need be respecified when the vehicle size is changed.

6. Aerodynamic Coefficients

a. Coefficients which are functions of angle of attack are specified only from 0 to 180 degrees, corresponding to the angles of attack listed in TABAL (up to 19 values). The program computes values of coefficients between 180 and 360 degrees.

b. When MANDAL table is specified, tables of all coefficients based on TABAL must be specified for each Mach number in MANDAL (maximum 5 values). At Mach numbers smaller (or larger) than those listed in MANDAL, the program uses coefficients corresponding to the smallest (or largest) Mach number specified.

c. An option is provided to input CMFA in place of XCPFA. To use this option, CMIN is set = 1.0 and specify CMC0D. With either CMFA or XCPFA input, the program computes the correct pitching moment for the input center-of-gravity location XCG0D.

d. For constant coefficients (invariant with Mach number) MANDAL is set = 0, in which case the program uses the first table of coefficients (lowest Mach number).

e. Computation of the dynamic motions can be switched to the linear solution at peak dynamic pressure by specifying ALPCR larger than the angle of attack envelope at that time.

f. Coefficients which are functions of Mach number only are specified for each Mach number listed in M0NLY (maximum 10 values). These are used by the program in the linear equations of motion, and to compute D/W, $M/C_D A$, and frequency.

g. CMAFM must be specified if printout is desired in the FREQ column.

h. CDFM must always be specified (will switch to CDRØP at peak dynamic pressure otherwise).

7. Entry Conditions

a. ZE, VE, and GAME must always be specified.

b. As the integration interval is determined by accuracy limits, large angular rates may lead to excessive computational time. To prevent usage of excessive computer time, a stop exists in the program, whereby a requirement for an integrating interval less than a prescribed value stops the calculations and a message is printed out DELTAT TOO SMALL. A possible source of this problem are inputs which create very large angular rates.

8. Particle Trajectories

Trajectories which do not allow for any effects of angle of attack can be computed by using the MANDAL coefficient table and specifying ALPHAE = 0.0 and ALPCR = 0.0.

The MANDAL table must have data at $\alpha = 0$ and for at least one other non-zero angle of attack. Tabular input for CDFM is required if M/CDA and D/W printout is desired.

9. Heating Data

a. Velocity gradient (VGFDR) and shock standoff distance (DELØRC) at the stagnation point are input (wind tunnel data or theory) as functions of the stagnation point density ratio (TABDR). Figures 7 and 8 obtained from Vinokur's[9] results show how these parameters vary theoretically with nose shape; comparison with the methods of References 10 and 11 are also shown. Correlation of Vinokur's[9] results with those of Traugott[12] and Kaattari[10] is shown in Figure 9, wherein all of Vinokur's[9] results are seen to compress into a single correlation curve at low density ratios (which agrees with Kaattari's[10] recommended correlation).

b. The stagnation point quantities VGFDR and DELØRC are required to predict the convective and radiative heating. Sufficient information is provided to estimate these quantities using Figures 6 and 7. The suggested use of these curves for vehicles with various nose shapes is depicted in Figure 10.

c. SSØD defines the approximate sonic point for turbulent heating calculation, and is determined by the nose shape of the vehicle.

42<

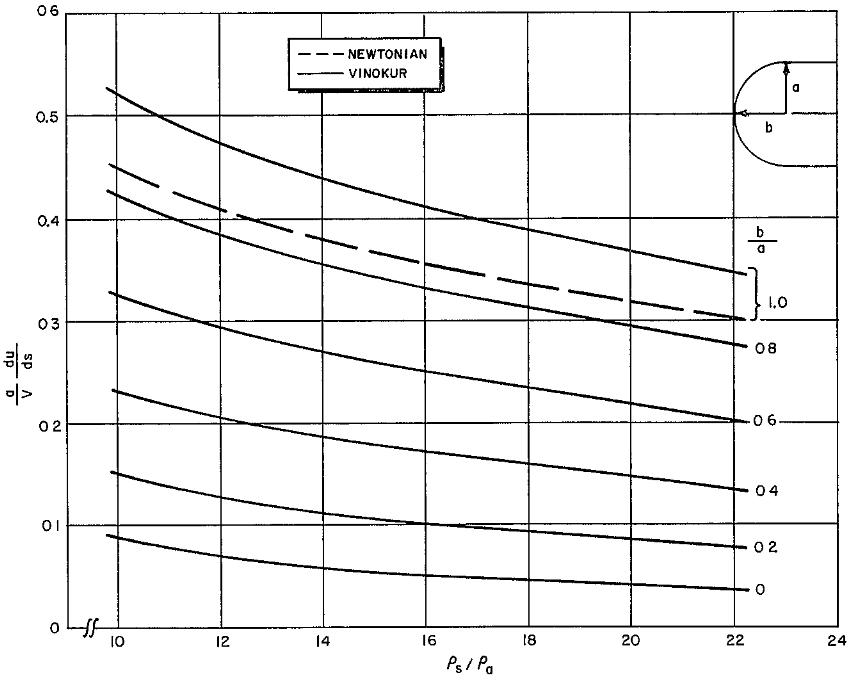

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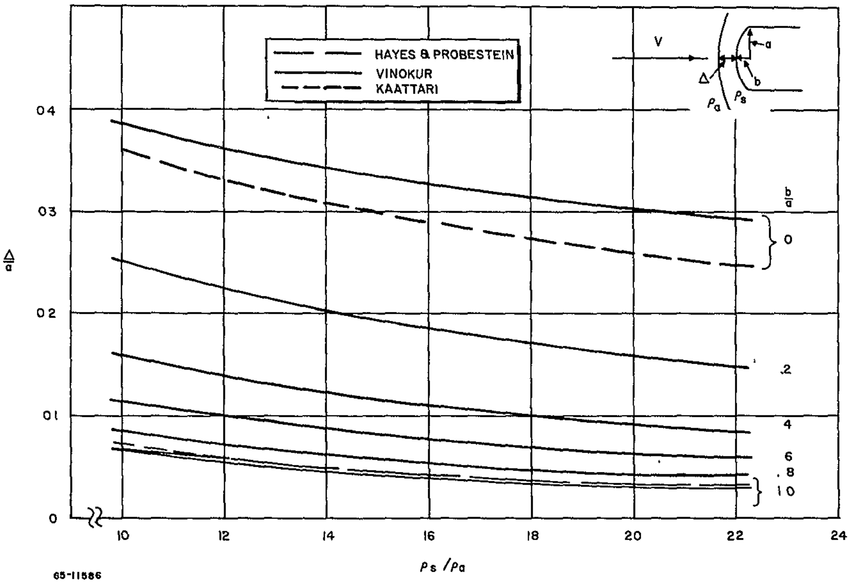
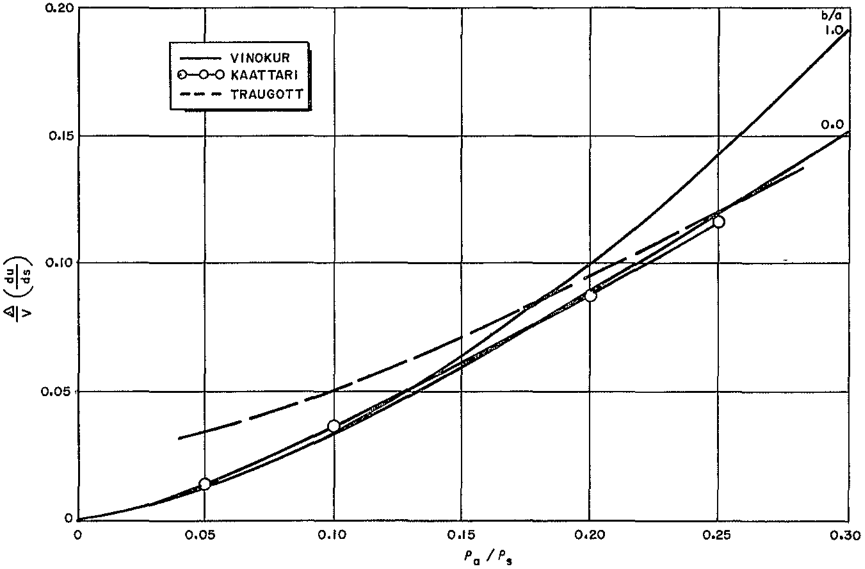
Figure 7 STAGNATION POINT VELOCITY GRADIENT WITH VARYING BLUNTNESS AND DENSITY RATIO



65-11586

Figure 8 STAGNATION POINT SHOCK STANDOFF DISTANCE WITH VARYING BLUNTNESS AND DENSITY RATIO

43<

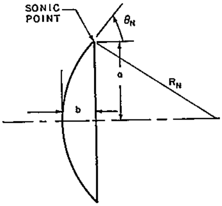


65-11587

Figure 9 HYPERSONIC CORRELATIONS OF STAGNATION POINT STANDOFF DISTANCE AND VELOCITY GRADIENT

Case 1 Sharp Corner on Spherial Cap.
Define θ^* as sonic point flow angle,

$$\theta^* \approx \sin^{-1}\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma}{2(\gamma-1)}}$$



Two possibilities

(a) $\theta_N > \theta^*$

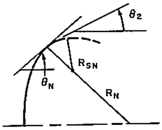
$b = R_N\,(1 - \sin\theta_N)$

$a = R_N \cos\theta_N$

(b) $\theta_N \leq \theta^*$

$\frac{b}{a} = 1\,,\ a = R_N$

Case 2 Nose Cap With Two Radii
Three possibilities:



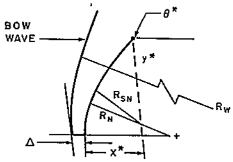
(a) $\theta_N < \theta^*$, $b/a = 1.0$

(b) $\theta_N > \theta^*$, bow wave follows body contour

$b = R_N\,(1 - \sin\theta_N) + R_{SN}\ \sin\theta_N)$

$a = R_N \cos\theta_N + R_{SN}\,(1 - \cos\theta_N)$

(c) $\theta_N > \theta^*$, bow wave stands off.



For stagnation point velocity gradient,

$b/a = 1,\ \ a = R_W$

For stand off distance,

$\Delta = \Delta_o - X^*$

R_W and Δ_o for flat nosed cylinder of radius y^*

Figure 10 METHODS FOR ESTIMATING VGFDR AND DEL/RC FOR VARIOUS NOSE SHAPES

d. REYT specifies the Reynolds number (based on S*) at which transition occurs at the sonic point. The Reynolds number computation is based on the viscosity-temperature dependency of Jos[13] for nitrogen and is shown in Figure 11.

e. IRNE and KNE are nonequilibrium radiation heating parameters, preset at typical air values.[14] Additional data for N_2-CO_2 mixtures is given in Reference 5.

f. DIRNE specifies the nonequilibrium radiation intensity as a tabular function of the velocity (VIRNE). When DIRNE is used, IRNE must be specified as equal to zero.

10. Tabular Inputs of Coefficients

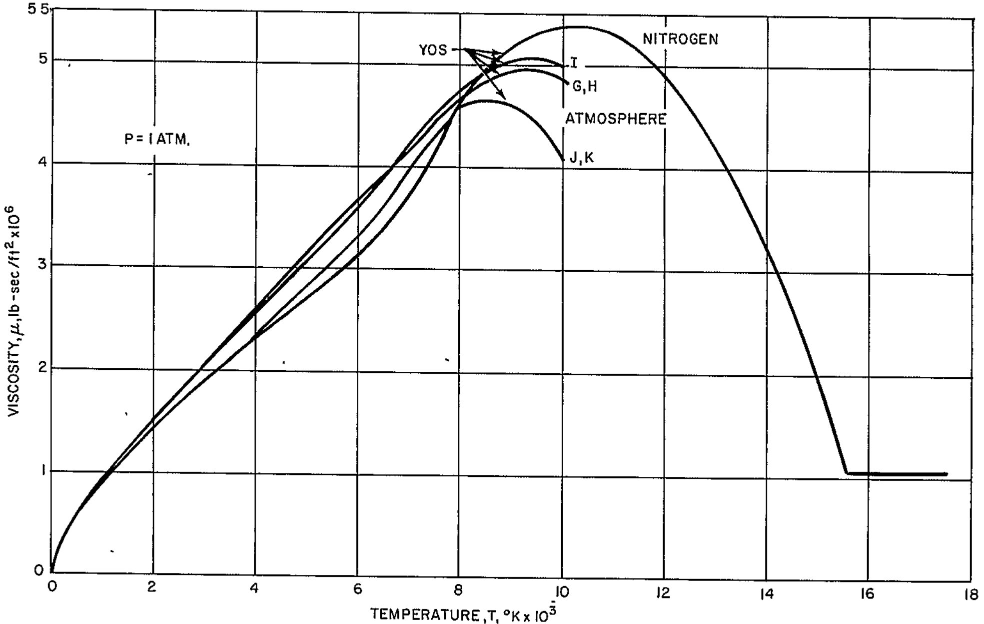
Since much of the input data for Program 1880 consists of one- and two-dimensional tables, time and effort can be saved by understanding the following facts.

All independent variable tables must be specified in monotonic ascending order.

The total range of the variable of interest should be covered by the independent variable table. If the variable is smaller than the first entry of the array, then the table lookup is done by a linear extrapolation. If the independent variable is greater than or equal to the last entry in the array, then either an incorrect answer, a loop, or an unexpected stop is the result. The only exception to this in Program 1880 is in the calculation of coefficients of a function of angle of attack, since for angles between 180 and 360 degrees the coefficient is computed by a change of variable and a simple transformation of the coefficient in the range between 0 and 180. Hence the independent variable table TABAL need be specified only to the value 180.

Constant functions must be described for the table lookup by at least two different values of the independent variable.

The only (optional) exception to the above rule, applied to tables of coefficients as a function of angle of attack and Mach number, and in the special case where there is no Mach number dependence for the coefficient, is described below.



65-11588 A

Figure 11 VISCOSITY-TEMPERATURE MODEL

The tables of aerodynamic coefficients have as independent variable tables TABAL for angle-of-attack dependence and MANDAL for Mach-number dependence. The coefficient tables are matrices of maximum size 19 rows and 5 columns (or 19 angles of attack and 5 Mach numbers). The program has assumed that for Mach numbers less than the first (smallest) Mach number in the array MANDAL, the coefficient is equal to its value at the angle of attack and the smallest Mach number in MANDAL. Similarly, for Mach numbers greater than the largest entry in MANDAL, the coefficient is assumed to have the value of the angle of attack and the largest Mach number in the array MANDAL. Thus the Mach number dependence of the coefficient is treated as piece-meal constant off the ends of the table.

The coefficient matrices may be regarded as of the form a_{ij}, where i references the angle-of-attack value and j the Mach number. The coefficient is specified on a punched card as, for example,

CNFA (1, 1) = 1., 2., 3., 4., CNFA (1, 2) = 4., 3., 2., 1.

The double subscript specifies that the array is two-dimensional and that the left-most index varies the most rapidly. Hence, given a starting location such as CNFA (1, 1), the program loads information into successive storage locations (columnwise, in matrix notation), until a new starting location is specified. Since the maximum dimensions of the array are referenced for loading, here (19, 5), the above example could not be rewritten as

CNFA (1, 1) = 1., 2., 3., 4., 4., 3., 2., 1.

All columns of the matrix do not have to be filled, but there must be a one-to-one correspondence between columns and entries in MANDAL.

It was stated above that for constant functions at least two different values of the independent variable must be specified with the corresponding (equal) values of the dependent variable. The single exception to this rule in Program 1880 is for aerodynamic coefficients which are dependent on angle of attack and independent of Mach number. For this case, two different values of Mach number may be specified, and the first two columns of the coefficient matrix made identical ($a_{I,1} = a_{I,2}$, I = 1, 2 ..., 19). However, the same effect may be achieved by making all entries of MANDAL = 0 and specifying only the first column of the coefficient matrix. This latter may be done either by the CNFA (1, 1) a_{11}, $a_{2,1}$, a_{31}, ...

C. OUTPUT DEFINITIONS

External Name	Internal Name	Symbol	Parameter	Units
ALBAR	ALENV	$\bar{\alpha}$	Total angle of attack envelope (max. envelope, interpolated linearly between peak amplitudes).	degrees
ATM	ATMØS	--	Atmosphere identification.	---
CASE	CAS	--	Case identification.	---
D	D	d	Diameter of vehicle (reference length).	feet
DATE	DATE		Date identification.	---
D/W	XØW	D/W	Zero angle-of-attack deceleration.	Earth g
DYN-PR	QDY	Q	Dynamic pressure.	lb/ft^2
FREQ	FRNAT	f	Natural undamped frequency of the vehicle based on CMAFM input.	cps
GAMMA	GAM	γ	Local flight path angle.	degrees
HD/HS	HDHS	H_D/H_S	Ratio of dissociation enthalpy to total gas enthalpy.	---
HMRTØ	HRT	HM/RT_O	Stagnation enthalpy.	---
IX	ZIX	I_X	Moment of inertia about roll axis.	$slug/ft^2$
IY	ZIY	I_Y	Moment of inertia about pitch and yaw axes.	$slub/ft^2$
MACH	XMCH	M	Flight Mach number.	---
M/CDA	EMØCDA	m/C_DA	Ballistic coefficient.	$slug/ft^2$
MEMØ	MEMØ		Memo identification.	---

External Name	Internal Name	Symbol	Parameter	Units
N/W	ENØW	N/W	Normal acceleration at angle-of-attack value.	Earth g
PE	PI	p_e	Spin rate at entry.	rad/sec
QE	QI	Q_e	Pitch rate at entry.	rad/sec
QI	QI*	q_i^*	Radiative heating contribution of each specie.	Btu/ft^2-sec
QR	QSUM	q_R	Same as QRE (below).	
QRE	QR	q_E	Zero angle-of-attack equilibrium radiation heating rate at the stagnation point.	Btu/ft^2-sec
QRNE	QRNE	q_{RAD}	Corrected value of QRE accounting for nonequilibrium effects.	Btu/ft^2-sec
QS	QS	q_S	Zero angle-of-attack stagnation point convective heating rate.	Btu/ft^2-sec
QSTAR	QT	q^*	Zero angle-of-attack convective heating rate at the sonic point (laminar before transition, turbulent after transition).	Btu/ft^2-sec
RE	RI	R_e	Yaw rate at entry.	rad/sec
REY	RTX	--	Free stream Reynold's number based on vehicle diameter.	---
RHØA	RØ	ρ_a	Ambient density.	slug/ft^3
RHØS/RHØ	RHØST	ρ_s/ρ_a	Normal shock density ratio at stagnation point.	---
TIME	TIME	t	Flight time measured from entry.	seconds
TS	T	T_S	Stagnation temperature.	°K
V	V		Flight velocity.	ft/sec

External Name	Internal Name	Symbol	Parameter	Units
VEHICL	VEHICL		Case identification	---
X	X	X	Specie Concentration	moles
XCG/D	XCG0D	X_{CG}/D	Center-of-gravity location as a fraction of vehicle diameter	---
Z	Z	Z	Altitude	feet
ZS	Z		Compressibility factor; number moles per initial mole cold gas	---
ZST	ZST	Z_{ST}	Altitude of the base of the stratosphere	feet
ZTH	ZTH	Z_{TH}	Altitude at the base of the thermosphere	feet

D. SAMPLE PROBLEM

1. Statement of Problem -- Determine the angle-of-attack envelope and heating history for a Mars entry of a blunt cone configuration. The vehicle parameters entry conditions, atmosphere, and planet data are to be prescribed as input. An orbital entry was chosen, for which the entry velocity is low.

Two trajectories were computed to provide both the heating and load data, for a typical entry to Mars following the orbit.

2. Computer Input Forms -- The computer input forms for the two sample cases containing all the necessary input data to be keypunched are shown on the following pages. All of the input on these forms are written with decimals, and everything shown on the forms are keypunched. Unused copies of the input forms are provided on pages in this report, from which the program user can make copies and use for further cases.

3. Output -- The output lists the cards read in and should be checked to ensure that the data have been keypunched correctly. The trajectory output format lists key data across the top of the page. The output of the two cases are given on pages following the input pages.

The trajectory of Case 1 indicates a peak deceleration of 25.8 g (Earth g), negligible radiation, an impact time of 301.28 seconds, and a subsonic impact. The time of transition was 189.97 seconds at which time the free stream Reynold's number was 2.1E+06, occurring at peak laminar heating. The data requested at Mach 1.2 are given at the end of the output as well as integrals of the heat pulses.

The trajectory for Case 2, which has the smaller entry angle and is the heat shield design trajectory, has a peak deceleration of 6.7 g and an impact time of 473 seconds. Transition did not occur on this trajectory. Additional messages are printed out for this case indicating (no valid solutions in zones) which refers to points along the trajectory where no solutions were obtained for the equilibrium gas composition. The reason for this occurrence is because of the nature of the approximate solution and requirements that the solution, in order to be valid, satisfy physical criteria.

E. DIAGNOSTICS

A number of messages are given in the printout reflecting the following program diagnostics.

1. NØ WØBBLES

The angle of attack did not oscillate, and the envelope value ALBAR is equal to the current angle of atack.

2. DELTAT TØØ SMALL

The integration interval required decreased to less than the input (preset) minimum allowable value.

3. NØ VALID SØLUTIØN

The equilibrium gas dynamics (1883) solution was not able to obtain a solution with positive concentrations for all the species satisfying the elemental and charge conservation relationships. In this case the data is linearly interpolated between the last and the next point for which a solution is found.

4. NØT CØNVERGED IN 30 ITERATIØNS

The equilibrium gas dynamics (1883) solution was unable to converge within 30 iterations to within 1 percent on the enthalpy; use the last value found.

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DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO 1880				PROGRAMMER D. Gillespie		
	TITLE Trajectory Dynamics Program						
MEMO NO	SECTION NO	WORK ORDER NO	(E240 USE ONLY)	REQUESTED BY	EXT	EST TIME	PAGE 1 OF 6 PAGES

$ INPUT

DATE= ________, MEMØ= ______, CASE= _____, ATMØS= _______, VEHICL= ________

ALAM = ________,
ALPCR = ________,
ALPHAE = ________,
AR = ________,
ATRB = ________,
BLAM = ________,
BTRB = ________,
CDRØP = ________,
CMCØD = ________,
CMIN = ________,
D = ________,
DELMAC = ________,
DELMT = ________,
DELTAT = ________,
FALR = ________,
GAME = ________,
GSL = ________,
GTST = ________,
IPHEAT = ________,
IPRINT = ________,
IPRQRD = ________,

IRNE = ________,
KNE = ________,
LS = ________,
LTH = ________,
MASS = ________,
MVE = ________,
NPTST = ________,
PE = ________,
PTH = ________,
PTMAC = ________,
QDYPT = ________,
QE = ________,
QTST = ________,
RE = ________,
REYT = ________,
RGX = ________,
RGY = ________,
RHØSL = ________,
RSL = ________,
SSØD = ________,
THF = ________,

TSL = ________,
TST = ________,
TSTØP = ________,
TZERØ = ________,
UPDN = ________,
VE = ________,
VSTØPQ = ________,
VTST = ________,
XA = ________,
XC = ________,
XCGØD = ________,
XKT = ________,
XN = ________,
XØ = ________,
XPRIN = ________,
ZCGØD = ________,
ZE = ________,
ZSTØP = ________,
ZTST = ________,

MANDAL = ________, ________, ________, ________, ________,
CDFM = ________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
CLAFM = ________, ________, ________, ________, ________,
________, ________, ________, ________, ________,

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DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO 1880	MEMO NO	SECTION NO	CONTINUATION SHEET PAGE 2 OF 6 PAGES

CMAFM = ________, ________, ________, ________, ________,
________, ________, ________, ________, ________,

CMQFM = ________, ________, ________, ________, ________,
________, ________, ________, ________, ________,

DELØRC = ________, ________, ________, ________, ________,
________, ________, ________, ________, ________,

DIRNE = ________, ________, ________, ________, ________,
________, ________, ________, ________, ________,

DNBND = ________, ________, ________, ________, ________,
________, ________, ________,

MØNLY = ________, ________, ________, ________, ________,
________, ________, ________, ________, ________,

TABDR = ________, ________, ________, ________, ________,
________, ________, ________, ________, ________,

UPBND = ________, ________, ________, ________, ________,
________, ________, ________,

VGFDR = ________, ________, ________, ________, ________,
________, ________, ________, ________, ________,

VIRNE = ________, ________, ________, ________, ________,
________, ________, ________, ________, ________,

CMFA (1, 1)= ________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________,

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DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO. 1880	MEMO NO	SECTION NO	CONTINUATION SHEET PAGE 3 OF 6 PAGES

CMFA(1, 2) = ________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________,

CMFA(1, 3) = ________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________,

CMFA(1, 4) = ________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________,

CMFA(1, 5) = ________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________,

CMQFA(1, 1) = ________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________,

CMQFA(1, 2) = ________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________,

CMQFA(1, 3) = ________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________,

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DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO 1880	MEMO NO	SECTION NO	CONTINUATION SHEET PAGE 4 OF 6 PAGES

CMQFA(1, 4) = __________, __________, __________, __________, __________,
__________, __________, __________, __________, __________,
__________, __________, __________, __________, __________,
__________, __________, __________, __________,

CMQFA(1, 5) = __________, __________, __________, __________, __________,
__________, __________, __________, __________, __________,
__________, __________, __________, __________, __________,
__________, __________, __________, __________,

CNFA (1, 1) = __________, __________, __________, __________, __________,
__________, __________, __________, __________, __________,
__________, __________, __________, __________, __________,
__________, __________, __________, __________,

CNFA (1, 2) = __________, __________, __________, __________, __________,
__________, __________, __________, __________, __________,
__________, __________, __________, __________, __________,
__________, __________, __________, __________,

CNFA (1, 3) = __________, __________, __________, __________, __________,
__________, __________, __________, __________, __________,
__________, __________, __________, __________, __________,
__________, __________, __________, __________,

CNFA (1, 4) = __________, __________, __________, __________, __________,
__________, __________, __________, __________, __________,
__________, __________, __________, __________, __________,
__________, __________, __________, __________,

CNFA (1, 5) = __________, __________, __________, __________, __________,
__________, __________, __________, __________, __________,
__________, __________, __________, __________, __________,
__________, __________, __________, __________,

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DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO 1880	MEMO NO.	SECTION NO	CONTINUATION SHEET PAGE 5 OF 6 PAGES

CXFA (1, 1) = ________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________,

CXFA (1, 2) = ________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________,

CXFA (1, 3) = ________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________,

CXFA (1, 4) = ________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________,

CXFA (1, 5) = ________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________,

XCPFA (1, 1) = ________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________,

XCPFA (1, 2) = ________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________,

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DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO 1880	MEMO NO	SECTION NO	CONTINUATION SHEET PAGE 6 OF 6 PAGES

XCPFA (1, 3)= ________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________,

XCPFA(1, 4)= ________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________,

XCPFA(1, 5)= ________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________,

TABAL = ________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________,

$

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DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO 1880			PROGRAMMER D. Gillespie			
	TITLE: TRAJECTORY DYNAMICS PROGRAM						
MEMO NO PL-167	SECTION NO K420	WORK ORDER NO W305-050-0005	(E240 USE ONLY)	REQUESTED BY P. Levine	EXT 2996	EST TIME	PAGE 1 OF 6 PAGES

$INPUT

DATE = 5.11 , MEMØ= 167. , CASE = 1 , ATMØS= 3.8 , VEHICL= 60. ,

ALAM = ,
ALPCR = ,
ALPHAE = 142.3 ,
AR = ,
ATRB = ,
BLAM = ,
BTRB = ,
CDRØP = 0.0 ,
CMCØD = 0.27 ,
CMIN = 1.0 ,
D = 15.0 ,
DELMAC = ,
DELMT = ,
DELTAT = ,
FALR = 1.11367 ,
GAME = 17.5 ,
GSL = 12.3 ,
GTST = ,
IPHEAT = ,
IPRINT = ,
IPRQRD = ,

IRNE = ,
KNE = ,
LS = ,
LTH = 1.0E-20 ,
MASS = 57.6 ,
MVE = 1.0 ,
NPTST = ,
PE = 1.045 ,
PTH = 1.3843E-11,
PTMAC = 1.2 ,
QDYPT = ,
QE = 0.0 ,
QSTST = ,
RE = 1.77 ,
REYT = ,
RGX = 0.30 ,
RGY = 0.22 ,
RHØSL = 2.56E-5 ,
RSL = 11.1089E6,
SSØD = 0.57 ,
THF = ,

TSL = 200.0 ,
TST = 100.0 ,
TSTØP = ,
TZERØ = ,
UPDN = ,
VE = 15,200.0 ,
VSTØPQ = ,
VTST = ,
XA = 0.0 ,
XC = 0.999 ,
XCGØD = 0.25 ,
XKT = ,
XN = 0.001 ,
XØ = 0.0 ,
XPRIN = ,
Z = ,
ZE = 8.0E5 ,
ZSTØP = ,
ZTST = ,

MANDAL = 0.5 , 1.5 , 3.0 , 9.0 , 19.0 ,

CDFM = 1.0 , 1.0 , 1.52 , 1.55 , 1.59 ,
1.63 , 1.63 , , , ,

CLAFM = -0.675 , -0.675 , -1.231 , -1.227 , -1.163 ,
-1.212 , -1.212 , , , ,

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DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO 1880	MEMO NO	SECTION NO	CONTINUATION SHEET PAGE 2 OF 6 PAGES

CMAFM = -0.183, -0.183, -0.12, -0.115, -0.138,
-0.138, -0.138, , , ,

CMQFM = -0.392, -0.392, -0.392, -0.392, -0.392,
-0.392, -0.392, , , ,

DELØRC = 0.0192, 0.0104, 0.0054, , ,
, , , , ,

DIRNE = , , , , ,
, , , , ,

DNBND = , , , , ,
, , , , ,

MØNLY = 0.0, 0.5, 1.5, 3.0, 9.0,
19.0, 100., , , ,

TABDR = 6.25, 12.5, 25.0, , ,
, , , , ,

UPBND = , , , , ,
, , , , ,

VGFDR = 3.90, 2.70, 1.80, , ,
, , , , ,

VIRNE = , , , , ,
, , , , ,

CMFA (1, 1)= 0.0, -0.032, -0.062, -0.083, -0.095,
-0.095, -0.084, -0.064, -0.043, -0.024,
-0.010, -0.002, -0.0003, -0.0003, -0.0002,
-0.0002, -0.0001, -0.0001, -0.0,

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DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO 1880	MEMO NO	SECTION NO	CONTINUATION SHEET PAGE 3 OF 6 PAGES

CMFA(1, 2)=	0.0 ,	-0.021 ,	-0.040 ,	-0.053 ,	-0.057 ,
	-0.-57 ,	-0.050 ,	-0.038 ,	-0.026 ,	-0.0140 ,
	-0.006 ,	-0.001 ,	-0.0002 ,	-0.0002 ,	-0.0001 ,
	-0.0001 ,	-0.0001 ,	-0.0001 ,	-0.0 ,	
CMFA(1, 3)=	0.0 ,	-0.020 ,	-0.040 ,	-0.053 ,	-0.057 ,
	-0.057 ,	-0.050 ,	-0.038 ,	-0.026 ,	-0.014 ,
	-0.006 ,	-0.001 ,	-0.0002 ,	-0.0002 ,	-0.0001 ,
	-0.0001 ,	-0.0001 ,	-0.0001 ,	-0.0 ,	
CMFA(1, 4)=	0.0 ,	-0.024 ,	-0.058 ,	-0.077 ,	-0.089 ,
	-0.089 ,	-0.079 ,	-0.060 ,	-0.041 ,	-0.022 ,
	-0.009 ,	-0.002 ,	-0.0003 ,	-0.0003 ,	-0.0002 ,
	-0.0002 ,	-0.0001 ,	-0.0001 ,	-0.0 ,	
CMFA(1, 5)=	0.0 ,	-0.024 ,	-0.058 ,	-0.077 ,	-0.089 ,
	-0.089 ,	-0.079 ,	-0.060 ,	-0.041 ,	-0.022 ,
	-0.009 ,	-0.002 ,	-0.0003 ,	-0.0003 ,	-0.0002 ,
	-0.0002 ,	-0.0001 ,	-0.0001 ,	-0.0 ,	
CMQFA(1, 1)=	-0.392 ,	-0.386 ,	-0.369 ,	-0.340 ,	-0.301 ,
	-0.253 ,	-0.197 ,	-0.161 ,	-0.131 ,	-0.102 ,
	-0.150 ,	-0.200 ,	-0.254 ,	-0.326 ,	-0.387 ,
	-0.437 ,	-0.474 ,	-0.497 ,	-0.505 ,	
CMQFA(1, 2)=	-0.392 ,	-0.386 ,	-0.369 ,	-0.340 ,	-0.301 ,
	-0.253 ,	-0.197 ,	-0.161 ,	-0.131 ,	-0.102 ,
	-0.150 ,	-0.200 ,	-0.254 ,	-0.326 ,	-0.387 ,
	-0.437 ,	-0.474 ,	-0.497 ,	-0.505 ,	
CMQFA(1, 3)=	-0.392 ,	-0.386 ,	-0.369 ,	-0.340 ,	-0.301 ,
	-0.253 ,	-0.197 ,	-0.161 ,	-0.131 ,	-0.102 ,
	-0.150 ,	-0.200 ,	-0.254 ,	-0.326 ,	-0.387 ,
	-0.437 ,	-0.474 ,	-0.497 ,	-0.505 ,	

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DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO. 1880	MEMO NO	SECTION NO	CONTINUATION SHEET PAGE 4 OF 6 PAGES

CMQFA (1, 4)= -0.392, -0.386, -0.369, -0.340, -0.301,
-0.253, -0.197, -0.161, -0.131, -0.102,
-0.150, -0.200, -0.254, -0.326, -0.387,
-0.437, -0.474, -0.497, -0.505,

CMQFA (1, 5)= -0.392, -0.386, -0.369, -0.340, -0.301,
-0.253, -0.197, -0.161, -0.131, -0.1020,
-0.150, -0.200, -0.254, -0.326, -0.387,
-0.437, -0.474, -0.497, -0.505,

CNFA (1, 1)= 0.0, 0.053, 0.114, 0.155, 0.177,
0.181, 0.167, 0.139, 0.108, 0.081,
0.062, 0.052, 0.050, 0.048, 0.043,
0.036, 0.026, 0.014, 0.0,

CNFA (1, 2)= 0.0, 0.041, 0.080, 0.107, 0.122,
0.124, 0.115, 0.096, 0.074, 0.051,
0.043, 0.036, 0.034, 0.033, 0.030,
0.025, 0.018, 0.009, 0.0,

CNFA (1, 3)= 0.0, 0.040, 0.100, 0.133, 0.152,
0.155, 0.143, 0.119, 0.093, 0.069,
0.053, 0.045, 0.043, 0.041, 0.037,
0.031, 0.022, 0.012, 0.0,

CNFA (1, 4)= 0.0, 0.060, 0.130, 0.174, 0.198,
0.204, 0.188, 0.156, 0.121, 0.091,
0.070, 0.058, 0.056, 0.054, 0.048,
0.041, 0.029, 0.016, 0.0,

CNFA (1, 5)= 0.0, 0.060, 0.130, 0.174, 0.198,
0.204, 0.188, 0.156, 0.121, 0.091,
0.070, 0.058, 0.056, 0.054, 0.048,
0.041, 0.029, 0.016, 0.0,

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DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO 1880	MEMO NO	SECTION NO	CONTINUATION SHEET PAGE 5 OF 6 PAGES

CXFA (1, 1)= 1.0, 0.98, 0.93, 0.82, 0.67,
0.53, 0.39, 0.27, 0.16, 0.07,
-0.04, -0.18, -0.34, -0.52, -0.69,
-0.85, -0.98, -1.04, -1.06,

CXFA (1, 2)= 1.52, 1.47, 1.37, 1.23, 1.07,
0.78, 0.56, 0.38, 0.22, 0.11,
0.02, -0.21, -0.44, -0.72, -1.0,
-1.24, -1.45, -1.55, -1.57,

CXFA (1, 3)= 1.55, 1.46, 1.33, 1.17, 1.00,
0.76, 0.54, 0.36, 0.2, 0.09,
-0.04, -0.23, -0.46, -0.74, -1.02,
-1.26, -1.47, -1.58, -1.60,

CXFA (1, 4)= 1.59, 1.51, 1.3, 1.12, 0.94,
0.74, 0.52, 0.34, 0.17, 0.06,
-0.07, -0.26, -0.49, -0.78, -1.06,
-1.3, -1.51, -1.62, -1.64,

CXFA (1, 5)= 1.63, 1.56, 1.34, 1.15, 0.97,
0.76, 0.57, 0.38, 0.2, 0.08,
-0.06, -0.25, -0.47, -0.77, -1.05,
-1.3, -1.52, -1.67, -1.69,

XCPFA (1, 1)= ______, ______, ______, ______, ______,
______, ______, ______, ______, ______,
______, ______, ______, ______, ______,
______, ______, ______, ______,

XCPFA (1, 2)= ______, ______, ______, ______, ______,
______, ______, ______, ______, ______,
______, ______, ______, ______, ______,
______, ______, ______, ______,

RAD 2-0964
5 63

DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO 1880	MEMO NO.	SECTION NO	CONTINUATION SHEET PAGE 6 OF 6 PAGES

XCPFA (1, 3) = __________, __________, __________, __________, __________,
__________, __________, __________, __________, __________,
__________, __________, __________, __________, __________,
__________, __________, __________, __________,

XCPFA (1, 4) = __________, __________, __________, __________, __________,
__________, __________, __________, __________, __________,
__________, __________, __________, __________, __________,
__________, __________, __________, __________,

XCPFA (1, 5) = __________, __________, __________, __________, __________,
__________, __________, __________, __________, __________,
__________, __________, __________, __________, __________,
__________, __________, __________, __________,

TABAL = 0., 10., 20., 30., 40.,
50., 60., 70., 80., 90.,
100., 110., 120., 130., 140.,
150., 160., 170., 180., __________,

$

RAD 2-0963
5 63

DIGITAL COMPUTER INPUT REQUEST FORM		PROBLEM NO 1880			PROGRAMMER D. Gillespie		
		TITLE Trajectory Dynamics Program					
MEMO NO PL-167	SECTION NO K420	WORK ORDER NO W305-050-0005	(E240 USE ONLY)	REQUESTED BY P. Levine	EXT 2996	EST TIME	PAGE 1 OF 6 PAGES

$INPUT

DATE= 5.11 MEMØ= 167., CASE= 2., ATMØS= 3.8, VEHICL= 60.,

ALAM = ________,
ALPCR = ________,
ALPHAE = ________,
AR = ________,
ATRB = ________,
BLAM = ________,
BTRB = ________,
CDROP = ________,
CMCOD = ________,
CMIN = ________,
D = ________,
DELMAC = ________,
DELMT = ________,
DELTAT = ________,
FALR = 0.994,
GAME = -13.,
GSL = ________,
GTST = ________,
IPHEAT = ________,
IPRINT = ________,
IPRQRD = ________,

IRNE = ________,
KNE = ________,
LS = ________,
LTH = ________,
MASS = ________,
MVE = ________,
NPTST = ________,
PE = ________,
PTH = .525E-3,
PTMAC = ________,
QDYPT = ________,
QE = ________,
QSTST = ________,
RE = ________,
REYT = ________,
RGX = ________,
RGY = ________,
RHØSL = 0.132E-4,
RSL = ________,
SSØD = ________,
THF = ________,

TSL = 275.0,
TST = 200.0,
TSTØP = ________,
TZERØ = ________,
UPDN = ________,
VE = 14000.0,
VSTØPQ= ________,
VTST = ________,
XA = ________,
XC = 0.2,
XCGØD = ________,
XKT = ________,
XN = 0.8,
XØ = ________,
XPRIN = ________,
ZCGØD = ________,
ZE = ________,
ZSTØP = ________,
ZTST = ________,

```
              IBLDR                                                      12/01/64

                       * MEMORY MAP *

SYSTEM                                00000 THRU  02717
FILE BLOCK ORIGIN                     02720
FILES        1.      UNIT05
             2.      UNIT06
             3.      UNIT07
FILE LIST ORIGIN                      02764
PRE-EXECUTION INITIALIZATION          02772
CALL ON OBJECT PROGRAM                03023
OBJECT PROGRAM                        03030 THRU  66025

     DECK  ORIGIN        CONTROL SECTIONS  (/NAME/=NON 0 LENGTH, (LOC)=DELETED, *=NOT REFERENCED)

  1. 1880     03030      ///     /(73566)    ......  14650 *
  2. SHVST    14671      HVST     20660
  3. SGETK    21676      GETK     22230
  4. SINTRP   22370      INTRP    23173
  5. SDERQ0   23367      ///     /(73566)    DERQ0   25500
  6. SGETCL   25613      GETCLA   26066
  7. SHEAT    26126      HEAT     26775
  8. SNONEQ   27200      NONEQU   27402
  9. SCKTRB   27472      CKTRB    27612
 10. SGETN    27651      GETN     31555
 11. SGETQ    31620      GETQ     33674
 12. SFINDT   34016      FINDT    34247
 13. SCOOL    34363      COOL     34725
 14. SFINDH   35032      FINDH    35371
 15. SZONES   35506      ZONES    41242
 16. SADAMS   41405      ADAMS4   44550
 17. SARTLU   44710      ARTLU    45235
 18. .LXCON   45415      .LXSTR   45415 *   .LXSTP   45421     .LXOUT   45467     .LXRTN   45501     IBEXIT   45501 *
                         .LXCAL   45504 *   .LXERR   45504     .DBCLS   45666 *   .LXARG   46035     .LO      46060 *
                         .CLSE    46066     .LFBL    46067 *   .LUNB    46070     .DFOUT   46071
 19. .IODEF   46075      .DEFIN   46075     .ATTAC   46101 *   .CLOSE   46103     .OPEN    46105     .READ    46107
                         .WRITE   46111     .BSR     46121 *   .READR   46131     .RELES   46133 *   .LAREA   46144
                         .LFBLK   46162     .LTSX    46165 *   .AREA1   46177     .LUNBL   46205     .ENTRY   46211
                         .GOA     46244     .GO      46250     .DERR    46264     .NOPXI   46265     .COMXI   46267
                         .EX34    46311
 20. .LXSL    46316      .LXSEL   46316     LXCSEL   46317     .LXTST   46322 *   .LXOVL   46362 *   .LXRGT   46373 *
                         .LXIND   46442 *   .LXDIS   46445 *   .LXFLG   46446 *   .LTCH    46447
 21. .FPTRP   46455      .FFPT.   46455 *   .FPOUT   46614     .FPARG   46633     /.COUNT/ 46635 *   OVFLOW   46706 *
 22. .ERAS.   46715      E.1      46715     E.2      46716     E.3      46717     E.4      46720
 23. .XCC.    46721      CC.1     46721     CC.2     46722     CC.3     46723     CC.4     46724
 24. XIT      46725      EXIT     46725     .EXIT.   46725 *
 25. FXEM     46726      .FXEM.   46726     .FXOUT   47263     .FXARG   47271     /.OPTW./ 47345
 26. FOUT     47356      .FOUT.   47356
 27. FCNV     47720      .FCON.   47720     .FCNV.   47743     .ENDFS   47756     .CNVSW   47760     .FDX1    47764
                         .FDX2    47765     .DBC     47767     .DBC8    50110     .DBC9    50113     .DBC10   50120
                         .DBC20   50146     .DDSW    50156     .DDFIX   50165     .FIXSW   50173     .DDBC    50250
                         .DDRS1   50522     .DDRS2   50524     .D1      50527     .D2      50531     .FERR2   50616 *
                         .ANPT    50652     .ONPT    50667     .LNTP    50743     .AOUT    51012     .DFLT    51030
                         .FLT     51164     .DEXPN   51254     .FXD     51255     .HOUT    51405     .INTG    51455
                         .LOUT    51573     .OOUT    51612     .XCF     51643     .TEST    52350     .KOUNT   52353
                         .LIST    52356     .DONE    52367     .OUTBF   52433     .BUF     52461     .QSTO    52462
                         .WIDTH   52463     .GAIN    52464     .GAIN1   52465     .FBDBF   52475     .DDDFL   52520


              IBLDR                                                      12/01/64

                         .DDFLG   52521     .MQD     52522     .PEX     52523     .FEXP    52524     .DIG     52525
 28. FIOS     52545      .FIOS.   52545     .FSEL.   52705     .FILR.   52711     .FRTB.   52720 *   .FRTD.   52725
                         .FILL.   52730     .FCLS    52732 *   .FOPN    52736 *   REOF     52742 *   .TOUT.   53105
                         .REED    53113 *   .BIN     53114 *   .FCT     53115     .FCKSZ   53117 *
 29. FIOH     53201      .FIOH.   53201     .FFIL.   53770     .FRTN.   54015 *
 30. FWRD     54202      .FWRD.   54202
 31. FWRU     54226      .FWRU.   54226
 32. FWRO     54252      .FWRO.   54252     .FREST   54555 *
 33. FRDU     54657      .FRDU.   54657
 34. UN05     54720      .UN05.   54720
 35. UN06     54721      .UN06.   54721     .BUFSZ   54722
 36. UN07     54725      .UN07.   54725
 37. FIOU     54726      .FIOU.   54726     .CTUIO   55401     .NMLST   55424     .NAME.   56527     .INTAP   56530
 38. JTNQR    57153      ATANQR   57231 *   ATANQ    57240 *   ATANQD   57247
 39. JPLRT    57256      POLROT   60443
 40. JCDIV    60516      COMDIV   60557
 41. JPRT1    60615      POLRT1   61000
 42. FLOG     61077      ALOG10   61077 *   ALOG     61101
 43. FXPF     61240      EXP      61240
 44. FSCN     61360      COS      61360     SIN      61362
 45. FSQR     61571      SQRT     61571
 46. FATN     61676      ATAN2    61676     ATAN     61700 *
 47. FXP3     62104      .XP3.    62104
 48. .IOCS    62231      .L(0)    62231     .MONSW   62251     .TEOR    62320     .DEFI.   62400     .JOINX   62444 *
                         .CLOS.   62463     .ATTC.   62476     .SH1     62710 *   .SH9     62752 *   .OPEN.   62773
                         .OP4     63021 *   .OP7     63052 *   .OP9.2   63066 *   .RLSE.   63140     .RER2.   63140
                         .READ.   63141     .RER1.   63164     .WRIT.   63166     .MNT1A   63354 *   .EOFEX   63435 *
                         .FEEIT   63505     .GTIOX   63526     .RW7     63644 *   .RE7     64263 *   .ENDTR   64724
                         .SEL59   64726 *   .BSR.    65337     .EOTOF   65464     .ETOF3   65472 *   .SWITC   65521
                         .TGHEX   66022     .BASIO   66025 *
 49. .IOCSM   66026
 50. //       73566

I/O BUFFERS                           66026 THRU  73545

UNUSED CORE                           73546 THRU  73565
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ZTBL   =         -0.00000000E-19,  -0.00000000E-19,  -0.00000000E-19,  -0.00000000E-19,  -0.00000000E-19,
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MONLY  =            0.00000000E-38,    0.50000000E 00,    0.15000000E 01,    0.30000000E 01,    0.90000000E 01,
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GDFH   =            0.10000000E 01,    0.10000000E 01,    0.15200000E 01,    0.15500000E 01,    0.15900000E 01,
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VE     =            0.15200000E 05,

GAME   =           -0.17500000E 02,

ZE     =            0.80000000E 06,

MASS   =            0.57600000E 02,

TSTOP  =            0.10000000E 04,

ZSTOP  =            0.00000000E-38,

FALR   =            0.11136700E 01,

LTH    =            0.10000000E-19,

RSL    =            0.11108900E 08,

GSL    =            0.12300000E 02,

XN     =            0.10000000E-02,

XC     =            0.99900000E 00,

TSL    =            0.20000000E 03,

TST    =            0.10000000E 03,

PTH    =            0.13843000E-10,

RHOSL  =            0.25600000E-04,

DELTAT =            0.10000000E-01,

UPBND  =            0.10000000F-01,    0.10000000E-04,    0.10000000E 00,    0.10000000E-02,    0.10000000E-02,
                    0.10000000E-03,    0.10000000E-03,    0.10000000E-03,

DNBND  =            0.10000000E-02,    0.10000000E-05,    0.10000000E-01,    0.10000000E-03,    0.10000000E-03,
                    0.10000000E-04,    0.10000000E-04,    0.10000000E-04,

UPDN   =            0.20000000E 00,

XPRIN  =            0.10000000E 01,
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                     0.18100000E 00,     0.16700000E 00,     0.13900000E 00,     0.10800000E 00,     0.81000000E-01,
                     0.62000000E-01,     0.52000000E-01,     0.50000000E-01,     0.48000000E-01,     0.43000000E-01,
                     0.36000000E-01,     0.26000000E-01,     0.14000000E-01,    -0.00000000E-38,     0.00000000E-38,
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                     0.11500000E 00,     0.96000000E-01,     0.74000000E-01,     0.51000000E-01,     0.43000000E-01,
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D       =        0.15000000E 02,

VTST    =        0.60000000E 03,

GTST    =        0.20000000E 01,

ZTST    =        0.20000000E 05,

QTST    =        0.20000000E 03,

XKT     =       -0.00000000E-19,

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BTRB    =        0.31800000E 01,

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ALPCR   =        0.00000000E-38,

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CMCOD   =        0.27000000E 00,

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IPRINT  =             0,

IPHEAT  =             0,

VSTOPO  =        0.12000000E 05,

XA      =        0.00000000E-38,

IRNE    =        0.10000000E 02,

KNE     =        0.23000000E 01,

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 SSOD   =      0.57000000E 00,

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 DATE   =      0.51100000E 01,

 CASE   =      0.10000000E 01,

 MEMO   =      0.16700000E 03,

 $ END
 UNDRFLOW AT 60545 IN MQ                                                                                  ILL. CRG.
 UNDRFLOW AT 60545 IN MQ                                                                                  ILL. CRG.
 UNDRFLOW AT 60535 IN MQ                                                                                  ILL. CRG.
 UNDRFLOW AT 60540 IN MQ                                                                                  ILL. CRG.
 UNDRFLOW AT 60541 IN MQ                                                                                  ILL. CRG.

                      DATE    5.11  CASE     1.00  MEMO  167.00  ATM    3.80  VEHICLE  60.00

       D            PE            QE            RE          XCG/D          IX            IY          W/CDA         ZST          ZTH

 1.5000E 01    1.0450E 00    0.0000E-39    1.7700E 00    2.5000E-01    1.1664E-03    6.2726E-02    1.9997E-01    5.9422E-04    4.9148E-05

  TIME      V        Z        RHOA    GAMMA   MACH     QS      QSTAR    QRE    REY    HM/RTO ALBAR   DYN-PR  FREQ    QRNE    D/W     N/W
   0.00  15200.  800000.  3.97E-24 -17.50 29.18     0.0      0.0     0.0  6.2E-12  208.9 142.3     0.0   0.0     0.0     0.0    0.0
 138.72  15609.  239162.  1.16E-10 -12.92 29.96     0.8      0.8     0.0  1.9E 02  220.2 144.2     0.0   0.0     0.0     0.0    0.0
 144.50  15624.  218110.  3.73E-10 -12.72 29.99     1.5      1.5     0.0  6.0E 02  220.6 144.1     0.0   0.0     0.0     0.0    0.0
 150.38  15639.  198051.  1.20E-09 -12.52 30.02     2.7      2.7     0.0  1.9E 03  221.0 142.1     0.1   0.0     0.0     0.0    0.0
 156.36  15652.  177916.  3.89E-09 -12.31 30.05     4.9      4.9     0.0  6.2E 03  221.4 143.3     0.5   0.1     0.0     0.1    0.0
 162.45  15651.  157768.  1.27E-08 -12.09 30.06     8.9      8.9    -0.0  2.0E 04  221.7 144.1     1.6   0.2    -0.0     0.2    0.0
 168.61  15654.  137756.  4.12E-08 -11.85 30.05    16.1     16.1    -0.0  6.6E 04  221.5 143.1     5.0   0.3    -0.0     0.8    0.0
 174.90  15593.  117725.  1.34E-07 -11.65 29.93    28.7     28.7     0.0  2.1E 05  219.7 132.4    16.3   0.5    -0.0     2.5    0.1
 179.64  15459.  102958.  3.22E-07 -11.44 29.68    44.0     44.0     0.0  5.1E 05  216.0  76.4    38.5   0.8     0.0     6.0    0.5
 183.07  15097.   92558.  5.98E-07 -11.40 28.98    56.8     56.8     0.0  9.2E 05  206.1  56.6    68.1   1.0     0.0    10.6    1.3
 185.70  14496.   84907.  9.43E-07 -11.21 27.83    64.1     64.1     0.0  1.4E 06  190.1  46.6    99.0   1.2     0.0    15.4    1.9
 187.42  13895.   80128.  1.25E-06 -11.18 26.67    66.1     66.1     0.0  1.8E 06  174.8  41.1   120.9   1.3    -0.0    18.8    2.3
 188.81  13293.   76438.  1.56E-06 -11.13 25.52    65.7     65.7     0.0  2.1E 06  160.1  37.1   137.9   1.4     0.0    21.4    2.5
 189.99  12688.   73437.  1.87E-06 -11.20 24.36    63.5     19.6     0.0  2.4E 06  146.0  34.1   150.3   1.5     0.0    23.4    2.6
 191.06  12085.   70875.  2.18E-06 -11.31 23.20    60.2     18.9     0.0  2.7E 06  132.6  31.5   158.8   1.5     0.0    24.7    2.7
 192.03  11482.   68640.  2.49E-06 -11.11 22.04    55.4     17.9     0.0  2.9E 06  119.8  29.3   163.8   1.6     0.0    25.5    2.7
 192.96  10881.   66615.  2.80E-06 -11.29 20.89    50.4     16.6     0.0  3.1E 06  107.8  27.1   166.1   1.6     0.0    25.8    2.6
 193.87  10281.   64743.  3.14E-06 -11.17 19.74    45.2     15.2     0.0  3.3E 06   96.4  25.5   165.8   1.6     0.0    25.8    2.4
 194.78   9677.   62987.  3.48E-06 -11.28 18.58    40.0     13.6     0.0  3.4E 06   85.5  23.9   163.1   1.6     0.0    25.3    2.3
 195.69   9072.   61317.  3.85E-06 -11.23 17.42    34.8     12.0     0.0  3.6E 06   75.4  22.6   158.4   1.5     0.0    24.5    2.1
 196.61   8471.   59732.  4.23E-06 -11.30 16.26    29.9     10.4     0.0  3.7E 06   65.9  21.3   151.8   1.5     0.0    23.5    2.0
 197.58   7870.   58185.  4.54E-06 -11.38 14.95    25.1      8.7     0.0  3.6E 06   57.1  20.1   140.7   1.4     0.0    21.7    1.8
 198.62   7266.   56632.  4.85E-06 -11.31 13.63    20.5      7.1     0.0  3.5E 06   48.9  19.1   128.0   1.4     0.0    19.6    1.5
 199.78   6666.   55039.  5.17E-06 -11.49 12.35    16.5      5.7     0.0  3.3E 06   41.5  18.0   114.9   1.3    -0.0    17.6    1.3
 201.06   6051.   53416.  5.51E-06 -11.55 11.09    12.9      4.4     0.0  3.1E 06   34.6  16.9   101.3   1.2     0.0    15.4    1.0
 202.52   5457.   51714.  5.89E-06 -11.63  9.86     9.9      3.4     0.0  3.0E 06   28.4  15.8    87.7   1.1     0.0    13.3    0.8
 204.21   4855.   49935.  6.30E-06 -11.94  8.66     7.3      2.4     0.0  2.7E 06   22.9  14.8    74.2   1.0     0.0    11.2    0.7
 206.24   4253.   48020.  6.75E-06 -12.22  7.48     5.1      1.7     0.0  2.5E 06   18.0  14.0    61.1   0.9     0.0     9.2    0.5
 208.74   3652.   45921.  7.28E-06 -12.61  6.33     3.4      1.1     0.0  2.3E 06   13.8  13.1    48.5   0.8     0.0     7.3    0.3
 211.97   3050.   43530.  7.90E-06 -13.23  5.20     2.1      0.7     0.0  2.0E 06   10.2  12.3    36.8   0.7     0.0     5.5    0.2
 213.82   2775.   42295.  8.24E-06 -13.67  4.69     1.6      0.5     0.0  1.9E 06    8.8  11.8    31.7   0.6     0.0     4.7    0.2
 215.97   2500.   40942.  8.62E-06 -14.17  4.19     1.2      0.4     0.0  1.7E 06    7.5  11.5    26.9   0.6     0.0     4.0    0.1
 218.63   2218.   39387.  9.07E-06 -14.78  3.68     0.9      0.3     0.0  1.6E 06    6.4  10.9    22.3   0.5     0.0     3.3    0.1
 221.91   1935.   37597.  9.60E-06 -15.63  3.18     0.6      0.2     0.0  1.4E 06    5.4  10.5    18.0   0.5     0.0     2.7    0.1
 226.16   1649.   35433.  1.03E-05 -17.50  2.67     0.4      0.1     0.0  1.3E 06    4.5  10.1    14.0   0.4     0.0     2.1    0.1
 231.91   1363.   32688.  1.12E-05 -19.75  2.17     0.2      0.1     0.0  1.1E 06    3.8   9.8    10.4   0.4     0.0     1.5    0.0
 240.56   1070.   28772.  1.25E-05 -24.45  1.67     0.1      0.0     0.0  9.5E 05    3.2   9.6     7.2   0.3     0.0     1.0    0.0
 256.80    777.   21573.  1.53E-05 -35.65  1.17     0.1      0.0     0.0  7.8E 05    2.9   9.7     4.6   0.3     0.0     0.6    0.0
 301.38    556.     -51.  2.56E-05 -65.56  0.75     0.0      0.0     0.0  7.8E 05    3.2   6.7     4.0   0.3     0.0     0.4   -0.0
```

```
QS INTEGRAL =   1.63741E 03 QSTAR INTEGRAL =   1.28206E 03 QRE INTEGRAL =   1.13303E-03 QRNE INTEGRAL =   3.49088E-03
---AT MACH =   1.20000E 00, THE DATA ARE AS-FOLLOWS.

  TIME        V        Z       RHOA      GAMMA   MACH     QS     QSTAR    QRE     REY     HM/RTO ALBAR  DYN-PR-  FREQ    QRNE     D/W     N/W
 255.68     797.    22071.  1.51E-05 -34.88  1.20     0.1     0.0     0.0  7.9E 05    3.0    9.7      4.8   0.3     0.0     0.6     0.0

 TIME AT TRANSITION =  189.99


$INPUT

ZTBL          -0.00000000E-19,   -0.00000000E-19,   -0.00000000E-19,   -0.00000000E-19,   -0.00000000E-19,
              -0.00000000E-19,   -0.00000000E-19,   -0.00000000E-19,   -0.00000000E-19,   -0.00000000E-19,
              -0.00000000E-19,   -0.00000000E-19,   -0.00000000E-19,   -0.00000000E-19,   -0.00000000E-19,
              -0.00000000E-19,   -0.00000000E-19,   -0.00000000E-19,   -0.00000000E-19,   -0.00000000E-19,
              -0.00000000E-19,   -0.00000000E-19,   -0.00000000E-19,   -0.00000000E-19,   -0.00000000E-19,
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              -0.00000000E-19,

TFTBL         -0.00000000E-19,   -0.00000000E-19,   -0.00000000E-19,   -0.00000000E-19,   -0.00000000E-19,
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              -0.00000000E-19,

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 MONLY  =          0.00000000E-38,   0.50000000E 00,   0.15000000E 01,   0.30000000E 01,   0.90000000E 01,
                   0.19000000E 02,   0.10000000E 03,  -0.00000000E-19,  -0.00000000E-19,  -0.00000000E-19,

 CDFM   =          0.10000000E 01,   0.10000000E 01,   0.15200000E 01,   0.15500000E 01,   0.15900000E 01,
                   0.16300000E 01,   0.16300000E 01,  -0.00000000E-19,  -0.00000000E-19,  -0.00000000E-19,

 VE     =          0.14000000E 05,

 GAME   =          0.13000000E 02,

 ZE     =          0.80000000E 06,

 MASS   =          0.57600000E-02,

 TSTOP  =          0.10000000E 04,

 ZSTOP  =          0.00000000E-38,

 FALR   =          0.99400000E-00,

 LTH    =          0.10000000E-19,

 RSL    =          0.11108900E 08,

 GSL    =          0.12300000E-02,

 XN     =          0.80000000E-00,

 XC     =          0.20000000E 00,

 TSL    =          0.27500000E 03,

 TST    =          0.20000000E-03,

 PTH    =          0.52500000E-03,

 RHOSL  =          0.13200000E-04,

 DELTAT =          0.10000000E-01,

 UPBND  =          0.10000000E-01,   0.10000000E-04,   0.10000000E-00,   0.10000000E-02,   0.10000000E-02,
                   0.10000000E-03,   0.10000000E-03,   0.10000000E-03,

 DNBND  =          0.10000000E-02,   0.10000000E-05,   0.10000000E-01,   0.10000000E-03,   0.10000000E-03,
                   0.10000000E-04,   0.10000000E-04,   0.10000000E-04,

 UPDN   =          0.70000000E-00,

 XPRIN  =          0.10000000E-01,

 TZERO  =          0.00000000E-38,
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AR     =        0.89516000F 05,
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LS     =                 5,
NPTST  =                51,
PE     =        0.10450000E 01,
QE     =       -0.00000000E-38,
RE     =        0.17700000E-01,
CNFA   =        0.00000000E-38,  0.53000000E-01,  0.11400000E 00,  0.15500000E 00,  0.17700000E 00,
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                0.19800000E 00,  0.20400000E 00,  0.18800000E 00,  0.15600000E 00,  0.12100000E 00,
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               -0.40000000F-01, -0.53000000E-01, -0.57000000E-01, -0.57000000E-01, -0.50000000E-01,
               -0.38000000E-01, -0.26000000E-01, -0.14000000E-01, -0.60000000E-02, -0.10000000E-02,
               -0.20000000E-03, -0.20000000E-03, -0.10000000E-03, -0.10000000E-03, -0.10000000E-03,
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               -0.00000000E-19, -0.00000000E-19, -0.00000000E-19, -0.00000000E-19, -0.00000000E-19,
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                 -0.15000000E 00,   -0.20000000E 00,   -0.25400000E 00,   -0.32600000E 00,   -0.38700000E 00,
                 -0.43700000E 00,   -0.47400000E 00,   -0.49700000E 00,   -0.50500000E 00,   -0.39200000E 00,
                 -0.38600000E 00,   -0.36900000E 00,   -0.34000000E 00,   -0.30100000E 00,   -0.25300000E 00,
                 -0.19700000E 00,   -0.16100000E 00,   -0.13100000E 00,   -0.10200000E 00,   -0.15000000E 00,
                 -0.20000000E 00,   -0.25400000E 00,   -0.32600000E 00,   -0.38700000E 00,   -0.43700000E 00,
                 -0.47400000E 00,   -0.49700000E 00,   -0.50500000E 00,   -0.39200000E 00,   -0.38600000E 00,
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                 -0.25400000E 00,   -0.32600000E 00,   -0.38700000E 00,   -0.43700000E 00,   -0.47400000E 00,
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                 -0.30100000E 00,   -0.25300000E 00,   -0.19700000E 00,   -0.16100000E 00,   -0.13100000E 00,
                 -0.10200000E 00,   -0.15000000E 00,   -0.20000000E 00,   -0.25400000E 00,   -0.32600000E 00,
                 -0.38700000E 00,   -0.43700000E 00,   -0.47400000E 00,   -0.49700000E 00,   -0.50500000E 00,

CXFA    =         0.10000000E 01,    0.98000000E 00,    0.93000000E 00,    0.82000000E 00,    0.67000000E 00,
                  0.53000000E 00,    0.39000000E 00,    0.27000000E 00,    0.16000000E 00,    0.70000000E-01,
                 -0.40000000E-01,   -0.18000000E 00,   -0.34000000E 00,   -0.52000000E 00,   -0.69000000E 00,
                 -0.85000000E 00,   -0.98000000E 00,   -0.10400000E 01,   -0.10600000E 01,   -0.15200000E 01,
                  0.14700000E 01,    0.13700000E 01,    0.12300000E 01,    0.10700000E 01,    0.78000000E 00,
                  0.56000000E 00,    0.38000000E 00,    0.22000000E 00,    0.11000000E 00,    0.20000000E-01,
                 -0.21000000E 00,   -0.44000000E 00,   -0.72000000E 00,   -0.10000000E 01,   -0.12400000E 01,
                 -0.14500000E 01,   -0.15500000E 01,   -0.15700000E 01,   -0.15500000E 01,   -0.14600000E 01,
                  0.13300000E 01,    0.11700000E 01,    0.10000000E 01,    0.76000000E 00,    0.54000000E 00,
                  0.36000000E 00,    0.20000000E 00,   -0.90000000E-01,   -0.40000000E-01,   -0.23000000E 00,
                 -0.46000000E 00,   -0.74000000E 00,   -0.10200000E 01,   -0.12600000E 01,   -0.14700000E 01,
                 -0.15800000E 01,   -0.16000000E 01,   -0.15900000E 01,   -0.15100000E 01,   -0.13000000E 01,
                  0.11200000E 01,    0.94000000E 00,    0.74000000E 00,    0.52000000E 00,    0.34000000E 00,
                  0.17000000E 00,    0.60000000E-01,   -0.70000000E-01,   -0.26000000E 00,   -0.49000000E 00,
                 -0.78000000E 00,   -0.10600000E 01,   -0.13000000E 01,   -0.15100000E 01,   -0.16200000E 01,
                 -0.16400000E 01,   -0.16300000E 01,   -0.15600000E 01,   -0.13400000E 01,   -0.11500000E 01,
                  0.97000000E 00,    0.76000000E 00,    0.57000000E 00,    0.38000000E 00,    0.20000000E 00,
                  0.80000000E-01,   -0.60000000E-01,   -0.25000000E 00,   -0.47000000E 00,   -0.77000000E 00,
                 -0.10500000E 01,   -0.13000000E 01,   -0.15200000E 01,   -0.16700000E 01,   -0.16900000E 01,

ALPHAE =          0.14230000E 03,

TABAL   =         0.00000000E-38,    0.10000000E 02,    0.20000000E 02,    0.30000000E 02,    0.40000000E 02,
```

```
                  0.50000000E-02,     0.60000000E-02,     0.70000000E-02,     0.80000000E-02,     0.90000000E-02,
                  0.10000000E 03,     0.11000000E 03,     0.12000000E 03,     0.13000000E 03,     0.14000000E 03,
                  0.15000000E-03,     0.16000000E-03,     0.17000000E-03,     0.18000000E-03,

 CLAFM  =        -0.67500000E-00,    -0.67500000E-00,    -0.12310000E-01,    -0.12270000E-01,    -0.11630000E-01,
                 -0.12120000E 01,    -0.12120000E 01,    -0.00000000E-19,    -0.00000000E-19,    -0.00000000E-19,

 CMQFM  =        -0.39200000E 00,    -0.39200000E 00,    -0.39200000E 00,    -0.39200000E 00,    -0.39200000E 00,
                 -0.39200000E-00,    -0.39200000E-00,    -0.00000000E-19,    -0.00000000E-19,    -0.00000000E-19,

 CMAFM  =        -0.18300000E-00,    -0.18300000E-00,    -0.12000000E-00,    -0.11500000E-00,    -0.13800000E-00,
                 -0.13800000E 00,    -0.13800000E 00,    -0.00000000E-19,    -0.00000000E-19,    -0.00000000E-19,

 XCGOD  =         0.25000000E 00,

 D      =         0.15000000E 02,

 VTST   =         0.60000000E 03,

 GTST   =         0.20000000E 01,

 ZTST   =         0.20000000E 05,

 QTST   =         0.20000000E 03,

 XKT    =        -0.00000000E-19,

 ATRB   =         0.80000000E 00,

 BTRB   =         0.31800000E 01,

 CDROP  =         0.00000000E-38,

 ALPCR  =         0.00000000E-38,

 DELMAC =         0.50000000E 00,

 PTMAC  =         0.12000000E 01,

 QDYPT  =        -0.10000000E 03,

 CMIN   =         0.10000000E 01,

 CMCOD  =         0.27000000E 00,

 IPRQRD =                  0,

 IPRINT =                  0,

 IPHEAT =                  0,

 VSTOPQ =         0.12000000E 05,

 XA     =         0.00000000E-38,

 IRNE   =         0.10000000E 02,

 KNE    =         0.23000000E 01,

 VIRNE  =        -0.00000000E-19,    -0.00000000E-19,    -0.00000000E-19,    -0.00000000E-19,    -0.00000000E-19,
                 -0.00000000E-19,    -0.00000000E-19,    -0.00000000E-19,    -0.00000000E-19,    -0.00000000E-19,

 DIRNE  =         0.00000000E-19,     0.00000000E-19,     0.00000000E-19,     0.00000000E-19,     0.00000000E-19,
                 -0.00000000E-19,    -0.00000000E-19,    -0.00000000E-19,    -0.00000000E-19,    -0.00000000E-19,

 VGFDR  =         0.39000000E 01,     0.27000000E 01,     0.18000000E 01,    -0.00000000E-19,    -0.00000000E-19,
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 TABDR  =         0.62500000E 01,     0.12500000E 02,     0.25000000E 02,    -0.00000000E-19,    -0.00000000E-19,
                 -0.00000000E-19,    -0.00000000E-19,    -0.00000000E-19,    -0.00000000E-19,    -0.00000000E-19,

 BLAM   =         0.00000000E-38,

 DELORC =         0.19200000E-01,     0.10400000E-01,     0.54000000E-02,    -0.00000000E-19,    -0.00000000E-19,
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~~RGY    =         0.22000000E 00,~~

~~SSOD   =         0.57000000E-00,~~

~~REYT   =         0.30000000E 06,~~

~~XO     =         0.00000000E-38,~~

~~ALAM   =         0.50000000E 00,~~

~~THF    =         0.10000000E-01,~~

~~ATMOS  =         0.38000000E 01,~~

~~VEHIGL =         0.60000000E-02,~~

~~ZCGOD  =         0.00000000E-38,~~

~~DATE   =         0.51100000E 01,~~

~~CASE   =         0.20000000E-01,~~

~~HEMO   =         0.16700000E 03,~~

~~$ END~~

~~NO VALID SOLU. IN ZONE2~~
```

```
                          DATE     5.11  CASE     2.00  MEMO  167.00  ATM     3.80  VEHICLE  60.00

       D              PE              QE              RE             XCG/D             IX             IY            H/CDA           ZST            ZTH

  1.5000E 01    1.0450E 00     0.0000E-39    1.7700E 00    2.5000E-01    1.1664E 03    6.2726E 02    2.0292E-01    6.3360E-04    4.9202E-05

  TIME      V        Z       RHOA     GAMMA   MACH    QS     QSTAR     QRE    REY     HM/RTO ALBAR   DYN PR   FREQ   QRNE    D/W     N/W
   0.00  14000.  800000.  2.51E-12 -13.00 15.71     0.1     0.1     0.0  1.9E 00  127.5 142.3     0.0    0.0     0.0    0.0     0.0
  83.61  14189.  554528.  2.70E-10 -11.03 15.92     1.0     1.0     0.0  2.1E 02  130.9 141.5     0.0    0.0     0.0    0.0     0.0
  91.06  14205.  534457.  3.99E-10 -10.85 15.94     1.2     1.2     0.0  3.1E 02  131.1 141.2     0.0    0.0     0.0    0.0     0.0
  98.66  14220.  514303.  5.91E-10 -10.66 15.95     1.5     1.5     0.0  4.6E 02  131.4 141.3     0.1    0.0     0.0    0.0     0.0
 106.34  14236.  494265.  8.75E-10 -10.47 15.97     1.8     1.8     0.0  6.8E 02  131.7 142.5     0.1    0.0     0.0    0.0     0.0
 114.20  14251.  474110.  1.30E-09 -10.28 15.99     2.3     2.3     0.0  1.0E 03  132.0 142.5     0.1    0.0     0.0    0.0     0.0
 122.15  14265.  454074.  1.93E-09 -10.08 16.00     2.8     2.8     0.0  1.5E 03  132.2 143.7     0.2    0.1     0.0    0.0     0.0
 130.24  14278.  434052.  2.88E-09  -9.88 16.02     3.4     3.4     0.0  2.3E 03  132.5 142.7     0.3    0.1     0.0    0.0     0.0
 138.51  14291.  414007.  4.28E-09  -9.67 16.03     4.1     4.1     0.0  3.4E 03  132.7 144.2     0.4    0.1     0.0    0.1     0.0
 146.93  14302.  393995.  6.39E-09  -9.45 16.04     5.1     5.1     0.0  5.0E 03  132.9 144.2     0.7    0.1     0.0    0.1     0.0
 155.55  14310.  373969.  9.54E-09  -9.24 16.05     6.2     6.2     0.0  7.5E 03  133.0 143.5     1.0    0.1     0.0    0.2     0.0
 164.37  14313.  353953.  1.43E-08  -9.01 16.06     7.6     7.6     0.0  1.1E 04  133.1 143.8     1.5    0.1     0.0    0.2     0.0
 173.44  14310.  333864.  2.14E-08  -8.79 16.05     9.3     9.3     0.0  1.7E 04  133.0 143.3     2.2    0.2     0.0    0.3     0.0
 182.71  14298.  313856.  3.21E-08  -8.57 16.04    11.4    11.4     0.0  2.5E 04  132.8 142.2     3.3    0.2     0.0    0.5     0.0
 192.25  14270.  293783.  4.82E-08  -8.35 16.01    13.9    13.9     0.0  3.8E 04  132.3 141.2     4.9    0.3     0.0    0.8     0.0
 202.10  14222.  273728.  7.25E-08  -8.09 15.96    16.9    16.9     0.0  5.7E 04  131.4 139.0     7.3    0.3     0.0    1.1     0.0
 212.27  14137.  253707.  1.09E-07  -7.84 15.86    20.4    20.4     0.0  8.5E 04  129.9 134.2    10.9    0.4     0.0    1.7     0.1
 221.55  14033.  236076.  1.57E-07  -7.63 15.74    23.9    23.9     0.0  1.2E 05  128.0 124.8    15.4    0.5     0.0    2.4     0.1
 229.58  13939.  221300.  2.13E-07  -7.45 15.64    27.3    27.3     0.0  1.6E 05  126.4  94.8    20.7    0.6     0.0    3.2     0.2
 236.80  13723.  208437.  2.77E-07  -7.33 15.40    29.7    29.7     0.0  2.1E 05  122.6  73.3    26.1    0.6     0.0    4.0     0.4
 243.58  13367.  196824.  3.52E-07  -7.14 15.00    30.0    30.0    -0.0  2.6E 05  116.4  62.3    31.5    0.7    -0.0    4.8     0.5
 250.28  12862.  185890.  4.42E-07  -7.05 14.43    30.4    30.4     0.0  3.1E 05  108.0  54.1    36.6    0.7     0.0    5.6     0.7
 256.29  12261.  176599.  5.36E-07  -7.00 13.76    28.6    28.6     0.0  3.6E 05   98.4  47.9    40.3    0.8     0.0    6.2     0.8
 261.33  11660.  169223.  6.25E-07  -7.06 13.08    26.3    26.3     0.0  4.0E 05   89.2  43.6    42.5    0.8     0.0    6.5     0.8
 265.91  11060.  162846.  7.13E-07  -7.04 12.41    23.8    23.8     0.0  4.3E 05   80.5  39.8    43.6    0.8     0.0    6.7     0.8
 270.20  10459.  157185.  8.03E-07  -7.01 11.73    21.1    21.1     0.0  4.6E 05   72.3  36.5    43.9    0.8     0.0    6.7     0.8
 274.35   9858.  151982.  8.95E-07  -7.07 11.06    18.4    18.4     0.0  4.8E 05   64.5  34.1    43.5    0.8     0.0    6.6     0.8
 278.44   9255.  147092.  9.91E-07  -7.21 10.38    15.8    15.8     0.0  5.0E 05   57.2  31.8    42.4    0.8     0.0    6.5     0.7
 282.53   8651.  142452.  1.09E-06  -7.35  9.71    13.4    13.4     0.0  5.2E 05   50.3  29.3    40.9    0.8     0.0    6.2     0.7
 286.68   8048.  137972.  1.20E-06  -7.51  9.03    11.2    11.2     0.0  5.3E 05   43.9  27.4    38.8    0.8     0.0    5.9     0.6
 290.97   7447.  133566.  1.31E-06  -7.72  8.35     9.1     9.1     0.0  5.4E 05   38.0  25.7    36.5    0.7     0.0    5.5     0.5
 295.47   6847.  129166.  1.44E-06  -7.97  7.68     7.3     7.3     0.0  5.4E 05   32.5  24.0    33.8    0.7     0.0    5.1     0.5
 300.29   6246.  124689.  1.58E-06  -8.30  7.01     5.7     5.7     0.0  5.4E 05   27.5  22.8    30.9    0.7     0.0    4.6     0.4
 305.53   5645.  120061.  1.74E-06  -8.72  6.33     4.3     4.3     0.0  5.4E 05   22.9  21.4    27.8    0.6     0.0    4.2     0.3
 311.32   5043.  115189.  1.93E-06  -9.30  5.66     3.2     3.2     0.0  5.3E 05   18.8  20.1    24.6    0.6     0.0    3.7     0.3
 317.72   4456.  110057.  2.15E-06 -10.04  5.00     2.3     2.3     0.0  5.3E 05   15.3  18.9    21.4    0.5     0.0    3.2     0.2
 323.28   4007.  105772.  2.36E-06 -10.96  4.50     1.7     1.7     0.0  5.2E 05   12.9  18.0    18.9    0.5     0.0    2.8     0.2
 329.61   3558.  101043.  2.60E-06 -11.98  3.99     1.2     1.2     0.0  5.1E 05   10.7  17.2    16.5    0.5     0.0    2.4     0.1
 336.98   3109.   95705.  2.91E-06 -13.21  3.49     0.8     0.8     0.0  5.0E 05    8.8  16.4    14.1    0.4     0.0    2.1     0.1
 345.79   2660.   89474.  3.32E-06 -15.32  2.98     0.5     0.5     0.0  4.8E 05    7.1  15.6    11.7    0.4     0.0    1.7     0.1
 356.68   2211.   81938.  3.89E-06 -18.19  2.48     0.3     0.3     0.0  4.7E 05    5.7  15.0     9.5    0.3     0.0    1.4     0.1
 370.79   1764.   72306.  4.77E-06 -22.75  1.98     0.2     0.2     0.0  4.6E 05    4.6  14.4     7.4    0.3     0.0    1.1     0.0
 390.21   1335.   59151.  6.15E-06 -30.44  1.48     0.1     0.1     0.0  4.4E 05    3.8  14.1     5.5    0.3     0.0    0.8     0.0
 429.26    949.   32015.  8.96E-06 -49.30  0.98     0.0     0.0     0.0  4.0E 05    3.7  12.6     4.0    0.3     0.0    0.5     0.0
 473.07    791.     -16.  1.32E-05 -67.55  0.76     0.0     0.0     0.0  4.3E 05    4.0   9.4     4.1    0.3     0.0    0.4*******

QS INTEGRAL =   2.98912E 03 QSTAR INTEGRAL =   2.98912E 03 QRE INTEGRAL =   7.94109E-02 QRNE INTEGRAL =   5.51493E-02
AT MACH =   1.20000E 00, THE DATA ARE AS FOLLOWS.

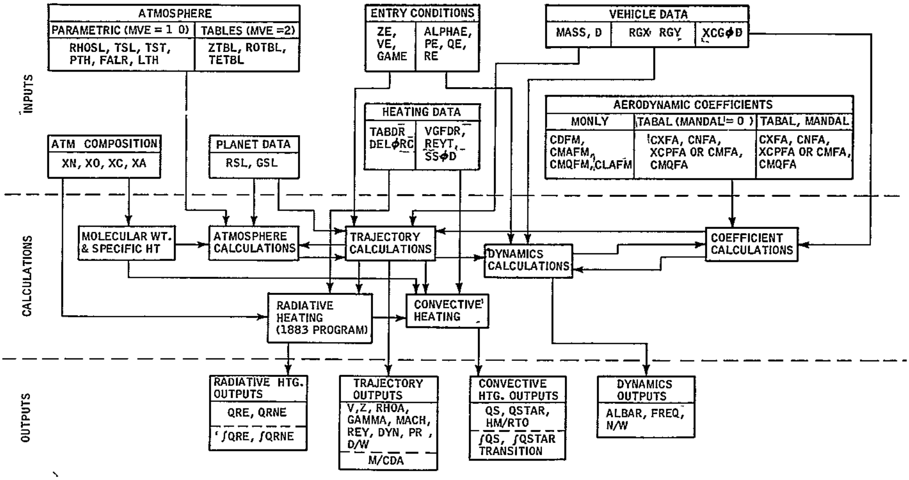
  TIME      V        Z       RHOA     GAMMA   MACH    QS     QSTAR     QRE    REY     HM/RTO ALBAR   DYN PR   FREQ   QRNE    D/W     N/W
 411.96   1120.   44036.  7.71E-06 -40.95  1.20     0.1     0.1     0.0  4.2E 05    3.8  13.3     4.7    0.3     0.0    0.6     0.0

TRANSITION DID NOT OCCUR.
```

III. COMPUTATIONS

A. BLOCK DIAGRAM

In the following pages are presented a block diagram (Figure 12) illustrating the operation of Program 1880, and a list of equations which are solved by the computer. The block diagram is arranged to indicate the sequence of operations as they are performed within the computer. Input data are located at the top of the diagram, computations are shown in the center, and outputs are grouped at the bottom. The list of equations which follow the diagram is divided into groups corresponding to the computation blocks in the diagram. Symbols used precede the equations.



65-11589A

Figure 12 BLOCK DIAGRAM ILLUSTRATING OPERATION OF PROGRAM 1880

B. SYMBOLS:

a	Speed of sound, ft/sec
a	(with subscript) density exponent in convective heating formula
A	reference area $\left(\frac{\pi d^2}{4}\right)$, ft^2
b	(with subscript) velocity exponent in convective heating formula
c_p	specific heat at constant pressure, Btu/lb
C_D	drag coefficient
C_L	lift coefficient
$C_{L\alpha}$	lift coefficient derivative, per radian
C_m	pitching moment coefficient
$C_{m\dot{\alpha}}$	pitching moment derivative, per radian
C_{m_q}	pitch damping coefficient, per radian
C_N	normal force coefficient
C_X	axial force coefficient
d	reference length (diameter), feet
D	drag, pounds
g	local acceleration of gravity, ft/sec^2
$g_{\oplus}$	Earth gravity at sea level, 32.17 ft/sec^2
H	enthalpy, ft^2/sec^2
I_X	roll moment of inertia, slug-ft^2
I_Y	moment of inertia in pitch and yaw, slug-ft^2

K	(with subscript) heating constant
L	temperature gradient, °K/ft
m	mass, slugs
M	molecular weight and Mach number
N	normal force, pounds
p	pressure, lb/ft^2
P	vehicle roll rate, rad/sec
q	dynamic pressure ($\rho_a V^2/2$), lb/ft^2
q	(with subscript) heating rate, Btu/ft^2-sec
Q	vehicle pitch rate, rad/sec
R	vehicle yaw rate, rad/sec
R	universal gas constant, 89,516 ft^2/sec^2-mole-°K
R_Z	radius from center of planet, feet
Re	Reynolds number
S*	distance from stagnation point to sonic point, feet
t	time, seconds
T	temperature, °K
V	velocity, ft/sec
W	Earth weight, pounds
X_{cg}	distance from nose to center of gravity, feet
X_{cm}	distance from nose to center of gravity for C_m data, feet
X_{cp}	distance from nose to center of pressure, feet
X_A	mole fraction of argon in atmosphere
X_C	mole fraction of carbon dioxide in atmosphere

X_N	mole fraction of nitrogen in atmosphere
X_O	mole fraction of oxygen in atmosphere
Z	altitude, feet
α	angle of attack, degrees
α'	total angle of attack (angle between vehicle axis of symmetry and velocity vector), degrees
$\bar{\alpha}$	total angle of attack envelope, degrees (max. value)
β	angle of sideslip, degrees
β	inverse scale height, feet^{-1}
γ	flight path angle (positive in climb), degrees
γ	adiabatic exponent
θ	pitch angle, degrees
μ	viscosity, lb-sec/ft^2
ρ	density, slug/ft^3
σ	non-dimensional radius of gyration, $\left(\sqrt{\frac{I}{md^2}}\right)$
ϕ	roll angle, degrees
ψ	yaw angle, degrees
ω_n	undamped natural frequency, rad/sec

Superscript:

$*$	sonic point

Subscripts:

a	ambient
L	laminar
RE	radiant equilibrium

RNE	radiant nonequilibrium
S	stagnation point
SL	sea level
ST	stratosphere
T	turbulent
TH	thermosphere
TR	troposphere
Z	at altitude Z

C. EQUATIONS

1. Molecular Weight and Specific Heat

$$X_N + X_O + X_C + X_A = 1.0 \tag{1}$$

$$M = 28\,X_N + 32\,X_O + 44\,X_C + 40\,X_A \tag{2}$$

$$\frac{c_p}{R} = \frac{3.5\,X_N + 3.5\,X_O + 4.0\,X_C + 2.5\,X_A}{M} \tag{3}$$

2. Atmosphere Calculations

a. Troposphere

$$T = T_{SL} + L_{TR}\,Z \tag{4}$$

$$\rho = \rho_{SL}\,\frac{T_{SL}}{T_Z}\,e^{-\left\{\frac{M\,g_{SL}}{R(T_{SL} - L_{TR}\,R_{SL})}\left[\frac{Z\,R_{SL}}{R_{SL} + Z} + \frac{L_{TR}\,R_{SL}^2\,\ln\left\{\frac{R_{SL}(T_{SL} + L_{TR}\,Z)}{T_{SL}(R_{SL} + Z)}\right\}}{T_{SL} - L_{TR}\,R_{SL}}\right]\right\}} \tag{5}$$

where,

$$L_{TR} = -L_1 \, g_{SL}/c_p \tag{6}$$

L_1 = temp gradient in troposphere expressed as a fraction of the adiabatic lapse rate

b. Stratosphere

$$\rho = \rho_{ST} \, e^{\beta_{ST} Z_{ST}} \, e^{-\beta_Z Z}$$

$$\beta = \frac{M \, g_{SL} \, R_{SL}}{R \, T_{ST} (R_{SL} + Z)}$$

$$\rho_{ST} = \rho_{SL} \, \frac{T_{SL}}{T_{ST}} \, e^{-\left\{ \frac{M \, g_{SL}}{R \, (T_{SL} - L_{TR} R_{SL})} \left[\frac{Z_{ST} \, R_{SL}}{R_{SL} + Z_{ST}} + \frac{L_{TR} \, R_{SL}^2 \, \ln \left\{ \frac{R_{SL} (T_{ST} + L_{TR} Z_{ST})}{T_{SL} (R_{SL} + Z_{ST})} \right\}}{T_{SL} - L_{TP} R_{SL}} \right] \right\}} \tag{9}$$

$$\beta_{ST} = \frac{M \, g_{SL} \, R_{SL}}{R \, T_{ST} (R_{SL} + Z_{ST})} \tag{10}$$

$$Z_{ST} = \frac{(T_{ST} - T_{SL})}{L_{TR}} \tag{11}$$

c. Thermosphere:

$$T = T_{ST} + L_{TH} (Z - Z_{TH}) \tag{12}$$

$$\rho = \rho_{TH} \, \frac{T_{ST}}{T_Z} \, e^{-\left\{ \frac{M \, g_{SL}}{R \, [T_{ST} - L_{TH} (R_{SL} + Z_{TH})]} \left[\frac{R_{SL}^2 \, (Z - Z_{TH})}{(R_{SL} + Z)(R_{SL} + Z_{TH})} + \frac{L_{TH} \, R_{SL}^2 \, \ln \left\{ \frac{[T_{ST} + L_{TH} (Z - Z_{TH})] (R_{SL} + Z_{TH})}{T_{ST} (R_{SL} + Z)} \right\}}{T_{ST} - L_{TH} (R_{SL} + Z_{TH})} \right] \right\}} \tag{13}$$

$$\rho_{TH} = P_{TH}\, M/R\, T_{ST} \qquad (14)$$

$$Z_{TH} = \frac{R\, T_{ST}\, R_{SL}\, \ln(\bar{\rho}/\rho_{TH})}{M\, g_{SL}\, R_{SL} - R\, T_{ST}\, \ln(\bar{\rho}/\rho_{TH})} \qquad (15)$$

$$\rho = \rho_{ST}\, e^{(\beta_{ST}\, Z_{ST})} \qquad (16)$$

d. Speed of Sound:

$$a = \left[\frac{\left(\frac{c_P}{R}\right) RT}{\left(\frac{c_P}{R}\right) M - 1} \right]^{1/2} \qquad (17)$$

3. Trajectory Calculations

a. Equations of Motion:

$$\dot{V} = \frac{-C_D\, q\, A}{m} - g \sin\gamma \qquad (18)$$

$$V\dot{\gamma} = \frac{V^2 \cos\gamma}{R_Z} - g\cos\gamma + \frac{C_L A q}{m}\, \frac{\sin\theta}{\sin\alpha'} \qquad (19)$$

b. Supplementary Relationships

$$\dot{Z} = V \sin\gamma \qquad (20)$$

$$M = V/a \qquad (21)$$

$$q = \rho_a\, V^2/2 \qquad (22)$$

$$g = g_{SL}\, (R_{SL}/R_Z)^2 \qquad (25)$$

$$R_Z = R_{SL} + Z \qquad (24)$$

ρ = f(Z) from atm calcs.

$$Re = \rho_a\, V\, d/\mu \qquad (25)$$

μ = f(T) from built in viscosity table

$$T = f(Z) \text{ from atm. calcs.}$$

$$D/W = (C_D)_{\alpha = 0}\, q A / m g_{\oplus} \qquad (26)$$

$$C_D = f(M, \alpha') \text{ from coefficient calculations}$$

4. Dynamics Calculations

a. Equations of Motion

The $\dot{Q}$ equation is given in Section I. B. 4 (Calculation Model) (27)

The $\dot{R}$ equation is given in Section I. B. 4 (Calculation Model) (28)

b. Supplementary Relationships:

$$\dot{\psi} = (R \cos\phi + Q \sin\phi) \sec\theta \qquad (29)$$

$$\dot{\theta} = (Q \cos\phi - R \sin\phi) \qquad (30)$$

$$\dot{\phi} = (P + \dot{\psi} \sin\phi) \qquad (31)$$

$$I_X = m\, \sigma_x^2\, d^2 \qquad (32)$$

$$I_Y = m\, \sigma_y^2\, d^2 \qquad (33)$$

$$\sin\alpha = (\sin\theta \cos\psi \cos\phi + \sin\psi \sin\phi) \qquad (34)$$

$$\sin\beta = (\sin\psi \cos\phi - \sin\theta \cos\psi \sin\phi) \qquad (35)$$

$$\sin\alpha' = (\sin^2\psi + \cos^2\psi \sin^2\theta)^{1/2} \qquad (36)$$

$$N/W = C_N(\bar{\alpha})\, q A / m g_{\oplus} \qquad (37)$$

$$C_N, C_m, C_{m_q}, C_{L_\alpha} = f(M, \alpha') \quad \text{from coefficient calculations}$$

c. Linearized Equations of Motion

$$\left(\frac{\bar{\alpha}}{\bar{\alpha}_o}\right)_{P=0} = \left[\frac{-C_{m_{\alpha,0}}\, q_o}{-C_{m_\alpha}\, q}\right]^{1/4} e^{1/2 \int_0^t P_1 V\, dt} \qquad (38)$$

$$P_1 = -\frac{\rho A}{2m}\left(C_{L_\alpha} - \frac{C_{m_q}}{2\sigma_y^2}\right) \tag{39}$$

$$\frac{\bar{\alpha}}{\bar{\alpha}_o} = \left(\frac{\bar{\alpha}}{\bar{\alpha}_o}\right)_{P=0} \left[\frac{1 + \left(\frac{I_X P}{2 I_Y \omega_n}\right)_0^2}{1 + \left(\frac{I_X P}{2 I_Y \omega_n}\right)^2}\right]^{1/4} \left[\frac{(1+K)\, e^{\int_0^t \Delta\lambda\, dt}}{2} + \frac{(1-K)\, e^{-\int_0^t \Delta\lambda\, dt}}{2}\right] \tag{40}$$

$$\omega_n^2 = -\frac{C_{m_\alpha}\, q\, A\, d}{I_Y} \tag{41}$$

$$\Delta\lambda = \frac{\frac{I_X}{I_Y}\,\frac{P}{2}\,\frac{\rho A V}{m}\left[C_{L_\alpha} + \frac{C_{m_q}}{2\sigma_y^2}\right]}{4\left[\omega_n^2 + \left(\frac{I_X P}{2 I_Y}\right)^2\right]^{1/2}} \tag{42}$$

$$\text{Freq} = \omega_n/2\pi \tag{43}$$

5. Coefficients Calculations

$$C_D = C_X \cos\alpha + C_N \sin\alpha \tag{44}$$

$$C_m = C_N\left(\frac{X_{cg}}{d} - \frac{X_{cp}}{d}\right), \tag{45}$$

or

$$C_m = C_{m_{X_{cm}}} + C_N\left(\frac{X_{cg}}{d} - \frac{X_{cm}}{d}\right) \tag{46}$$

$$C_{L_\alpha} = \frac{(C_L)_{\alpha + \Delta\alpha} - (C_L)_\alpha}{\Delta\alpha} \qquad (47)$$

where,

$$C_L = C_N \cos\alpha - C_X \sin\alpha \qquad (48)$$

$$(C_N)_{\alpha > 180} = -(C_N)_{180 - (\alpha - 180)} \qquad (49)$$

$$(C_X)_{\alpha > 180} = (C_X)_{180 - (\alpha - 180)} \qquad (50)$$

$$(C_m)_{\alpha > 180} = -(C_m)_{180 - (\alpha - 180)} \qquad (51)$$

$$(X_{cp})_{\alpha > 180} = (X_{cp})_{180 - (\alpha - 180)} \qquad (52)$$

$$(C_{L_\alpha})_{\alpha > 180} = (C_{L_\alpha})_{180 - (\alpha - 180)} \qquad (53)$$

7. Convective Heating

a. Laminar

$$q_S = \frac{K_L}{(d/2)^{1/2}} \quad \rho_a^{1/2} \left(\frac{V}{10^4}\right)^{b_L} \qquad (54)$$

where,

$$K_L = (1.1 + 0.075M) \times 10^4 \times \left[\frac{d}{2V} \left(\frac{du}{ds}\right)_S\right]^{1/2} \qquad (55)$$

$$b_L = 3.909 - 0.0229M \qquad (56)$$

M = molecular weight

$\frac{d}{2V}\left(\frac{du}{ds}\right)_S$ = velocity gradient at stagnation point

b. Turbulent

$$q_T = K_T \times \rho_a^{0.8} \times \left(\frac{V}{10^4}\right)^{3.18} \qquad (57)$$

where,

$$K_T = [540000/(S^*)^{0.2}]\ (THF) \tag{58}$$

S^* = distance from stagnation to sonic point at zero angle of attack

THF = turbulent heating factor

$$Re^* = \frac{\rho_a}{\mu^*}\left(\frac{\rho_S}{\rho_a}\right)\left(\frac{\rho^*}{\rho_S}\right) u^*\ S^* \tag{59}$$

where,

ρ_S/ρ_a = density ratio at stagnation point

μ^* = $f(T^*)$ from built-in viscosity table

$$\rho^*/\rho_S = \left(\frac{2}{\gamma + 1}\right)^{\frac{1}{\gamma - 1}} \tag{60}$$

$$u^* = \left(\frac{2H}{\rho_S/\rho_a}\right)^{1/2} \tag{61}$$

$$H = (HM/RT_o)\ 24.4522 \times 10^6/M \tag{62}$$

$$T^* = 2\ T_S/(\gamma + 1) \tag{63}$$

T_S = temperature at stagnation point

$$\gamma = \frac{(\rho_S/\rho_a) + 1}{(\rho_S/\rho_a) - 1} \tag{64}$$

$$HM/RT_o = \frac{V^2\,M}{2RT_o} + \frac{M\,c_p\,Ta}{RT_o} \tag{65}$$

8. Nonequilibrium Radiation Heating

$$\Delta_{NE} = \frac{K_{NE} \times 10^{-6}}{\rho_a \left(\frac{V}{10^4}\right)^{4.3}} \tag{66}$$

$$\Delta_p = \frac{0.23 \times 10^{-6}}{\rho_a \left(\frac{V}{10^4}\right)^{3.3}} \tag{67}$$

$\Delta > \Delta_{NE}$

$$q_{RNE} = q_E \left[1 - \frac{1}{2}\frac{\Delta_p}{\Delta} - \frac{1}{2}\frac{\Delta_{NE}}{\Delta} + \frac{I_{NE}}{I_E}\frac{\Delta_{NE}}{2\Delta}\right] \tag{68}$$

$\Delta_p < \Delta < \Delta_{NE}$

$$q_{RNE} = q_E \left[1 - \frac{1}{2}\frac{\Delta_p}{\Delta} - \frac{1}{2}\frac{\Delta_{NE}}{\Delta} + \frac{I_{NE}}{I_E}\frac{\Delta_{NE}}{2\Delta} - \frac{1}{2}\frac{(\Delta_{NE} - \Delta)^2}{(\Delta_{NE} - \Delta_p)\Delta}\left(\frac{I_{NE}}{I} - 1\right)\right] \tag{69}$$

$\Delta < \Delta_p$

$$q_{RNE} = q_E \frac{1}{2}\frac{I_{NE}}{I_E}\frac{\Delta}{\Delta_p} \tag{70}$$

$$q_E = \frac{I_E \Delta}{2} \tag{71}$$

$I_E (\epsilon_1, N_1, T)$ → see Program 1883 (72)

9. Alternate Nonequilibrium Model

$$\frac{I_{NE}}{I_E} = \frac{\Delta}{\Delta_{NE}} \cdot \frac{DIRNE}{QE} \tag{73}$$

DIRNE (VIRNE) (74)

IV. IBM ROUTINES

A. PROGRAM FLOW

The program flow is illustrated in Figure 13.

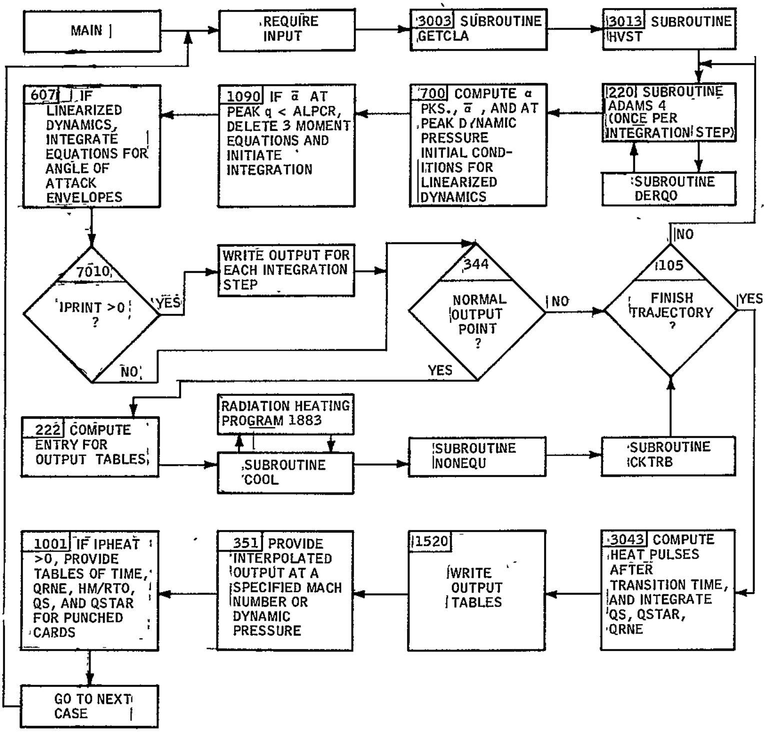


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Figure 13 FLOW DIAGRAM OF PROGRAM 1880

B. CØMMØN STORAGE

Much data are transferred between the main program and the subroutine DERQ0 which computes the values at time (t) of the eight possible differential equations being integrated. Many other tables are placed in CØMMØN storage to prevent an overlap of the loading tables and the program when Program 1880 is placed in core. CØMMØN data are as follows:

DERQ0

Name	Quantity	Source	Input or Output	Description
ZST	Z_{ST}	Main	Input	Stratosphere altitude. Used to compute atmospheric properties.
ZTH	Z_{TH}	Main	Input	Thermosphere altitude. Used to compute atmospheric properties.
RHØ	ρ	DERQ0	Output	Ambient density at trajectory time t.
ZTBL		Program Input	Input	Altitude table for tabular atmosphere.
TETBL		Program Input	Input	Temperature table for tabular atmosphere.
RØTBL		Program Input	Input	Density table for tabular atmosphere.
CD	C_D	Program Input	Input	Drag coefficient as a function of Mach number XMACH.
XMACH		Program Input	Input	Mach number table used with CD above.
XL1	L_1	Program Input	Input	Troposhere temperature gradient. Used to compute atmospheric properties.
GSL	G_{SL}	Program	Input	Sea level gravitational acceleration. Used to compute atmospheric properties and trajectory.

DERQ0

Name	Quantity	Source	Input or Output	Description
CPØR	$CP/_R$	Main	Input	Specific heat divided by gas constant. Used to compute atmospheric properties.
TST	T_{ST}	Program Input	Input	Stratospheric temperature. Used to compute atmospheric properties.
TSL	T_{SL}	Program Input	Input	Sea level temperature. Used to compute atmospheric properties.
RH ØSL	ρ_{SL}	Program Input	Input	Sea level density. Used to compute atmospheric properties.
RSL	R_{SL}	Program Input	Input	Planet radius. Used to compute atmospheric properties and trajectory.
XM	M	Main	Input	Mean molecular weight of atmosphere. Used to compute atmospheric properties.
AR	R	Main	Input	Gas constant. Used to compute atmospheric properties.
XL2	L_{TH}	Program Input	Input	Thermosphere temperature gradient. Used to compute atmospheric properties.
MVE		Program Input	Input	If = 1, parametric atmosphere if = 2, tabular.
XLØ	L_O	Main	Input	Troposphere temperature gradient. Used to compute atmospheric properties.
CSUBD	C_D	DERQ0	Output	Drag coefficient at trajectory time t.
C_L	C_L			No current use.

DERQ0

Name	Quantity	Source	Input or Output	Description
XMAC	M	DERQ0	Output	Mach number at trajectory time t.
SMA	a	DERQ0	Output	Ambient speed of sound at trajectory time t.
A	A	Main	Input	Vehicle area. Used to compute trajectory.
SMM	m	Program Input	Input	Mass of vehicle. Used to compute trajectory.
TEMP	T	DERQ0	Output	Ambient temperature at trajectory time t.
RØBAR	$\bar{\rho}$	Main	Input	Stratosphere density used to compute atmospheric properties.
RHØTH	$\bar{\rho}_{TH}$	Main	Input	Thermosphere density Used to compute atmospheric properties.
TABAL		Program Input	Input	Angle-of-attack table. Used as independent variable table for coefficients as functions of α and M to compute trajectory.
CNFA	C_N	Program Input	Input	C_N table as function of α and M to compute trajectory.
XCPFA	X_{cp}	Program Input	Input	X_{CP} table as function of α and M to compute trajectory.
CMQFA	C_{mq}	Program Input	Input	C_{mq} tables as function of α and M to compute trajectory.
CLAFM	C_{L_α}	Program Input	Input	C_{L_α} table as function of M to compute trajectory.
CMQFM	C_{mq}	Program Input	Input	C_{mq} table as function of M to compute trajectory.

DERQ0

Name	Quantity	Source	Input or Output	Description
CMAFM	C_{m_α}	Program Input	Input	C_{m_α} table as function of M to compute trajectory.
XCG0D	XCG/$_D$	Program Input	Input	XCG/D center of gravity. Used to compute trajectory.
ZIX	I_X	Program Input	Input	I_X moment of inertia. Used to compute trajectory.
ZIY	I_Y	Program Input	Input	I_Y moment of inertia. Used to compute trajectory.
D	d	Program Input	Input	Vehicle diameter. Used to compute trajectory.
N0EQD		Main	Input	Number of equations being integrated: 3 for particle trajectory; 8 for trajectory and dynamics.
ALDG	α'	DERQ0	Output	Angle of attack at trajectory time t.
P	P	Program Input	Input	Constant spin rate used to compute trajectory.
RTX	REY			Used to prevent loading table, program overlap.
HRT	HM/RT$_o$			Used to prevent loading table, program overlap.
QS	q_S			Used to prevent loading table, program overlap.
QT	q*			Used to prevent loading table, program overlap.
QR	q_R			Used to prevent loading table, program overlap.
TIME	t			Used to prevent loading table, program overlap.

DERQ0

Name	Quantity	Source	Input or Output	Description
XMBCH	M	Program Input	Input	Independent variable. Mach number table used to compute coefficients as a function of α and M for trajectory.
CXFA	C_X	Program Input	Input	C_X table as a function of α and M used to compute trajectory.
CLAFA	C_{L_α}	GETCLA	Input	C_{L_α} table as a function of α and M used to compute trajectory.
CMFA	C_m	Program Input	Input	C_M table as a function of α and M used to compute trajectory.
X0W	D/W			Drag force ratio.
EN0W	N/W			Normal force ratio.
XMAX		Main	Input	Largest value of XMBCH.
XMIN		Main	Input	Smallest value of XMBCH.
IXMAX		Main	Input	Index of XMAX in XMBCH.
IXMIN		Main	Input	Index of XMIN in XMBCH.
CMIN		Program Input	Input	If CMIN >O, use CMFA and CMC0D for C_M if CMIN $\leq$ O, use XCP0D for C_M.
CMC0D		Program Input	Input	Used to compute C_M for trajectory if CMIN > O.

C. SUBROUTINES

GETCLA	Variable Subroutine Input or output SOURCE	CNFA, C_N coefficient table Input Program Input	CXFA, C_X coefficient table Input Program Input	TABAL, α independent variable table Input Program Input	CLAFA, C_{L_α} coefficient table Output GETCLA

COOL	Variable Input or Output SOURCE	NXG, Atmos table number Input MAIN	XØ, $Ø_2$ mole fraction Input Program Input	XN, N_2 mole fraction Input Program Input	XC, $CØ_2$ mole fraction Input Program Input
XA, A mole fraction Input Program Input	IPRG, print sentionol Input Program Input	RHØ, ambient density Input DEREQ	VY, Vehicle velocity Input ADM4RK	QR1G, total equilibrium radiation Output GETN	ZNAM1, table of specie names Input MAIN
ZNAM2, table of radiation source names Input MAIN	ENTØT, stagnation enthalpy Input MAIN	RØRZ density ratio Output HEAT	DELØRC, table of Δ/RC Input Program Input	TSSZ Stagnation Temperature Output HEAT	TIM, Trajectory time Input ADM4RK
T1TBL, Zone 1 temperature table Input HVST	T2TBL, Zone 2 temperature table Input HVST	T3TBL, Zone 3 temperature table Input HVST	H1TBL, Zone 1 enthalpy table Input HVST	H2TBL, Zone 2 enthalpy table Input HVST	H3TBL, Zone 3 enthalpy table Input HVST
DENR, table of density ratios Input Program Input	D, vehicle diameter Input Program Input	DELDG, Δ detachment distance Output HEAT			

HEAT	Variable Subroutine Input or Output SØURCE	V, Velocity Input ADM4RK	RHØ, ambient density Input DEREQ	XN, N_2 mole fraction Input Program Input	XØ, Ø2 mole fraction Input Program Input
XC, $CØ_2$ mole fraction Input Program Input	XA, A mole fraction Input Program Input	NX atmosphere table numbers Input MAIN	P, Stagnation pressure Output HEAT	T, Stagnation temperature Output HEAT	Z, moles of gas mixture at T & P Output ZØNES
RHØST, density ratio ρ_s/ρ_∞ Output HEAT	QSUM-total radiation heating Output GETN	QI-component radiation heating Output GETN	X-moles of species in mixture of T&P Output ZØNES	HDHS dissociation energy ÷ enthalpy Output FINDH	HRT, enthalpy Output FINDH
DELØRC, table of Δ/RC Input Program Input	DUM-moles of O^+, N^+; C^+, e^- in Zone 2 Output ZØNES	ENTØT-stagnation enthalpy (HRT) Input MAIN	H1TBL, Zone 1 enthalpy table Input HVST	H2TBL Zone 2 enthalpy table Input HVST	H3TBL Zone 3 enthalpy table Input HVST
T1TBL, Zone 1 temperature table Input HVST	T2TBL, Zone 2 temperature table Input HVST	T3TBL, Zone 3 temperature table Input HVST	DENR, table of density ratio Input Program Input	D, vehicle diameter Input Program Input	DEL, Δ detachment distance Output HEAT

	Variable	RØRZ = Density ratio ρ_s/ρ_a	TSSZ stagnation temperature	TMPVS, temperature for viscosity	VISC, viscosity table
CKTRB	Subroutine Input or Output	Input	Input	Input	Input
ENTØT, stagnation enthalpy	DUMREY constant to compute Reynolds No	RØ (I), ambient density	SST, S* to compute Reynolds No	REYS, local Reynolds No	
Input	Input	Input	Output	Output	
MAIN	MAIN	MAIN	MAIN	CKTRB	

Calling sequences for ADAMS4 and DERQ0 are described in the section of special routines

Calling sequences for HVST, GETN, ZONES, GETK, FINDT, FINDH, and GETQ are the same as for those routines in the 1883 program description.

	Variable	DELDG, detachment distance	DSP, distance to peak nonequilibrium intensity	DNE nonequilibrium distance	XIRN, nonequilibrium intensity ratio
NONEQU	Subrouting Input or Output	Input	Input	Input	Input
	Source	HEAT	MAIN	MAIN	Program Input
QR(I), Equilibrium radiation heating	QRNE (I) non-equilibrium radiation heating				
Input	Output				
GETN	NØNEQU				

1. Subroutine DERQ0

Purpose: DERQ0 computes the atmospheric properties for the altitude at each time step of the numerical integration of the trajectory and dynamics differential equations, and provides the values of the derivatives of the differential equations for the succeeding integration step.

Method: The values of the dependent variables of the integration are contained in the array X of the calling sequence, at time = TIM, and the derivatives are computed and stored in the array DERX. All other data are passed through CØMMØN. The quantities in each X are: Velocity (V), flight path angle (γ), altitude (Z), pitch rate (Q), yaw rate (R), and the Euler angles (ψ, θ, ϕ). .

Knowing the altitude at time TIM, DERQ0 first computes the atmosphere temperature TEMP and density RHØ corresponding to that altitude. It does this with tables (MVE = 2, Statements 10 and 12) or from a parametric representation (MVE = 1, Statements 20 to 70). By the execution of Statement 93 the Mach number and speed of sound (XMAC and SMA) are calculated, as well as the value of dz/dt.

After Statement 92 the number of equations (NOEQD) is tested, and if this is 8 the remaining trajectory and dynamics derivatives must be evaluated using coefficients that are functions of angle of attack and Mach number. If NØEQD = 3, only the two remaining particle trajectory derivatives (dv/dt, $d\gamma/dt$) are evaluated using a drag coefficient as a function of MACH number (XMACH) only, and the RETURN before Statement 99 returns control to ADAMS4 so that the integration may be continued. If all eight derivatives must be evaluated, transfer is made to Statement 99 and by Statement 1000 the angle of attack at time TIM is computed from the Euler angles. Statements from 1000 to 1019 compute the aerodynamic coefficients by double interpolation in angle of attack (through ARTLU and ALPHA) and Mach number. Tests are first made (before 1000 or before 1001), and if the Mach number is lower (higher) than the lowest (highest) value in XMBCH. In addition, for values of ALPHA above 180 a transform is made to the value of the coefficient in the range between 0 and 180. The values of the derivatives are computed between Statements 1019 and 9999.

2. Subroutine CØØL

Purpose: Subroutine CØØL accepts data from the trajectory calculation in such form as is suitable for the radiation heating calculation, initiates the heating calculation, and returns radiation and gas dynamic data to the main program. If IPRQRD is ≥ 1.0, CØØL also causes data to be printed out each time it is called.

Method: Subroutine CØØL is analogous to the main program of Program 1883 (see 1883 description). The program flow for 1880 described above contains the logical position of the subroutine and, in fact, the "radiation heating Program 1883" division reflects the logical flow of Program 1883 (call HEAT, and so forth). If the sentinel IPRQRD is ≥ 1.0, subroutine CØØL will provide the normal 1883 output each time it is called, along with the trajectory time for identification.

3. Subroutine NØNEQU

Purpose: To compute the value of the nonequilibrium radiation heating for each time recorded on the output tables.

Method: Immediately before NØNEQU is called for some TIME entry, the equilibrium radiation heating calculation (subroutine CØØL, et al) has provided the equilibrium radiation and the detachment distance (QR (I)and DELDG). Given the distance to peak nonequilibrium intensity and the nonequilibrium density (computed in the main program as DSP and DNE, plus the input factor IRNE, the nonequilibrium radiation is computed from one of three relations (Reference 1, p. 104.Equation (78)) which relation is used to compute QRNE at time TIM, depending on the relative magnitude of DELDG, DNE, and DSP.

4. Subroutine CKTRB

Purpose: Subroutine CKTRB computes the local Reynolds number at the sonic point each time the equilibrium radiation calculation is successfully performed during the trajectory.

Method: Using output from the equilibrium radiation calculation, density ratio, stagnation temperature, and stagnation enthalpy, plus the ambient density, viscosity (known as a function of temperature), and S* from SSØD in the program input, the Subroutine CKTRB evaluates the local Reynold's number at the sonic point from a straight-forward algebraic solution.

5. Subroutine HEAT

Purpose: See 1883 description

Method: The method used by HEAT in Program 1880 is the same as in 1883 with the following changes. HEAT no longer calls the subroutine HVST, but has the output from that subroutine given to it by subroutine CØØL, which receives it from the 1880 main program which calls HVST once for each trajectory. HEAT does not compute the stagnation enthalpy, but receives it via CØØL from the trajectory calculation. Also the detachment distance is not supplied by direct input or the correlation in b/a and inverse density ratio, but from a direct correlation between detachment distance and density ratio supplied as program input (tables DEL0RC and TABDR in the input).

6. Subroutine GETN

Purpose: See 1883 description

Method: Same as in 1883, but the effective emissivities and detachment distance are deleted from the program output.

Subroutines HVST, GETK, GETQ, FINDH, FINDT, and Z0NES are the same as in Program 1883.

7. Subroutine GETCLA

Purpose: GETCLA will compute a table of C_L from the input tables C_N and C_X.

Method: Subroutine GETCLA computes the coefficient C_{L_α} by a linear approximation of the derivatives which depend upon tables of C_N and C_X. A value of C_{L_α} is computed for each of 5 Mach numbers and 19 angles of attack in the loop ending at Statement 1005.

8. Subroutine INTRP

Purpose: To interpolate trajectory data at a specified Mach number or dynamic pressure, and print the results.

Method: Linear interpolation.

D. MAIN PROGRAM

Purpose: The purpose of the main program is to acquire input, provide for the integration of the trajectory and vehicle dynamics equations (done by ADAMS4), exercise suitable options during the course of the trajectory calculations (depending on the value of certain input quantities), provide for the calculation and storage of all quantities which appear in the output tables, and provide output from the calculation.

Method: To easily follow the logical flow of the main program, one must remember two facts. First, the integration of the trajectory equations is arranged under normal operating procedure so that ADAMS4 returns control to the main program after each integration step. The size of this time interval depends only upon the behavior of the differential equations and the accuracy requirements. Second, since these time steps are usually rather small, to provide output for each step would be quite time consuming. Therefore, only some integration data appear on the output tables and the points selected depend upon the rates of change of physical quantities of interest to the user. For example, if the altitude is changing rapidly, finer resolution is shown on the output for the time span in which this occurs. All output points selected are stored on tables which are printed after the entire trajectory has been calculated.

The maximum number of lines of output is 150, and it is solely the responsibility of the problem submitter to assure (by judicious selection of values for VTST, GTST, ZTST, QTST, and DELMAC) that these tables are not exceeded. All statements before 500 either specify variables, or define preset input or tables. ZNAM1 and ZNAM2 are arrays of Hollerith names which define species and radiation contributors for the radiation heating block. The tables TMPVS and VISC define viscosity as a function of temperature. TBSUM is the sum of $O_2 + CO_2$ for each of the eleven atmospheric tables of enthalpy and temperature (see main description).

After Statement 500, sentinels are initialized for each case, and data is read in through the Namelist array INPUT. The values of the highest and lowest Mach numbers in the array XMBCH have been computed by Statement 3003, and subroutine GETCLA is called to provide a table of values for C_L for the tables of C_N and C_X. Following the call GETCLA, the modes of certain input variables are changed, the moments of inertia computed from the radii of gyration, S* computed, and by Statement 3018 the appropriate tables for the atmosphere being run have been selected by the calculation of NXG (i.e. the tables whose sum of O_2 and CO_2 mole fractions is closest to the sum of the input XO and XC). Call HVST obtains these enthalpy and temperature tables for use by the radiation heating calculation. Diagnostic tests are performed before Statement 3048 to assure that the sum of the mole fractions is $1. \pm .001$, and that $XN \geq .001$. By Statement 24, further initialization has been completed, constants computed for the theorized dynamic calculation, and the quantities which determine output points defined from the input. The statements immediately following 24 define atmospheric properties and constants for the computation of the convective heat pulses. The heat pulses which appear in the output tables are computed only at output points (not for every integration time step), since the pulses QS, QSTAR, and QRNE all depend upon the density ratio computed by the radiation heating calculation, and it is prohibitively expensive to compute the radiation for each integration step. However, the selection of an output point itself depends upon the rate of change of the stagnation point convective heating. For this reason an approximate heat pulse is computed and integrated by the program so that output points may be selected. The quantities XKL, QS1, QS2, and SMQS are used for this pulse. Then the initial values for the eight differential equations are defined, along with other parameters used by the predictor-corrector integration routine ADAMS4.

The statements between 220, CALL ADAMS4 and the computed GØ TØ numbered 105 toward the end of the program form a logical loop completed for each time step of the trajectory calculation until the vehicles trajectory has been entirely computed (either until impact or t = TSTØP). Immediately after the enthalpy (ENTØT), velocity (VY), and dynamic pressure (DYNPR) are computed, the sentinel NITWIT (preset to 0 after Statement 500) is checked. If NITWIT is > 0, this means that the linearized dynamic calculations were not done because the angle-of-attack envelope at peak dynamic pressure was > ALPCR, and the five dynamics equations are to be integrated until impact unless the dynamic pressure becomes larger than a quantity proportional to CDRØP. When NITWIT > 0, this quantity is computed and tested against the dynamic pressure for each time step (Statement 367). If larger than the dynamic pressure, only the first three (particle trajectory) differential equations are integrated; all remaining angle-of-attack envelope values (ALENV) are set equal to the last angle-of-attack envelope computed (DØ615) and no further angles of attack are computed (ILATE= 1, I2BIG = 1).

At Statement 368, the current value of the dynamic pressure is tested against the value computed for the previous time step. If it is smaller, the last value of the dynamic pressure in the output tables (QD(I)) is taken as the peak dynamic pressure, and the values of all variables at TIME (I) are used to compute all quantities of interest at peak dynamic pressure, including initial values of the integrals and constants of interest in the linearized dynamic calculations (GM10, PHI10, PHI0GM, PSI10, TMIG1). ILATE, preset to 0, is set equal to 1 to delete any further testing for peak dynamic pressure.

Statements 601 to 605 complete the consideration of data for angle-of-attack calculation dependent upon the integration of the (last) five dynamics differential equations. Since only the value of the angle of attack at time (TIM) is known for each time step, additional calculations are necessary to compute the value of the angle-of-attack envelope at time t. The angle of attack at TIM is ALDG, and the previously computed value is AOLD. If the angle of attack has been increasing (IPK = 2), but the current ALDG < AØLD, then a peak is defined (PKNEW at TALNEW), and with a knowledge of the previously defined peak (PKØLD at TALØLD), an angle-of-attack envelope value for some output point such that TALØLD $\leq$ TIME(JPAL) $\leq$ TALNEW may be computed by linear interpolation (Statement 805). Here, JPAL is the number of envelope values already computed +1. The statements between 3055 and 807 serve only to compute, as a function of angle of attack and Mach number, the coefficients necessary in the calculation of N/W (ENØW). If ILATE > 1 (first computation for angle of attack after peak dynamic pressure), the statements following 606 are executed to compute quantities for the linearized dynamics which depend on the angle-of-attack envelope at peak dynamic pressure. If this envelope value is less than the input ALPCR, the dynamics differential equations are deleted, the integration reinitialized (Statement 1090), and ISKIP (preset to 0) is set to 1. The ISKIP value deletes all consideration of the angle of attack from the dynamics differential equations by skipping the statements between 700 and 605. If ALPCR is too small (no linearized dynamic option), the eight differential equations are retained, ISKIP is set to 0, ILATE is set to 0, and NITWIT (see discussion of CDRØP above) is set to 1 (Statement 613). Statement 605 ends the angle-of-attack envelope portion, except for the linearized calculation.

If NPASS = 1, only the initial conditions of the integration have been computed, and the convective heat pulse used only for the determination of an output point is initialized (see the statements following 302). A transfer is made into the portion of the main program which generates the output tables (Statements 222 to 105), thus making the initial conditions the first line of the tabular program output. If NPASS = 2 for each time step, the integrals for the linearized dynamics and the output-determining heat pulse are integrated for each time step by the trapezoidal method (Statements 320 to 338). If I2BIG > 0, the linearized dynamic integrals are not computed since the sentinel indicates that the angle-of-attack envelope computed by the linearized method is unreasonably large. If ISKIP $\leq$ 0, the angle-of-attack envelope is being computed from the 5 dynamics differential equations, and the linearized dynamics integrals are not evaluated. The statements between 7010 and 7011 provide output for each time step (IPRINT $\geq$ 1).

After 7011 are ten tests used to select the time steps which appear in the output tables. The criteria for an output point are as follows: TIM = TZERØ (initial point), TIM $\geq$ TSTØP (maximum value of independent variable TIM), X (3) $\leq$ ZSTØP (impact), Mach number $\leq$ 5 and the difference from the last output line (XMØ) $\geq$ DMK; only if the approximate heat pulse is greater than 1 Btu/ft^2-sec, do the following tests determine an output point, velocity difference from last output velocity $\geq$ VTEST, flight path angle (γ) difference from last output point $\geq$ GTEST, altitude difference from last output point $\geq$ ZTEST, approximate convective heat pulse integral difference from last output point $\geq$ QSTST. Statement 222 begins the calculation of the output table for TIME (I) = TIM, where I is the line number in the output tables.

The statements to 358 compute a Mach number index for use at the end of the program in interpolating data at some input value of Mach number (PRTMAC). QDY (I) is computed, and the statements to 1076 compute the interpolation index if a specified dynamic pressure (QDYPRT) is to be used instead of the Mach number. Next the γ, Z, ρ, t, and Mach tables are filled, plus the natural frequency (FRNAT). If the dynamics differential equations have been deleted at peak dynamic pressure (NITWIT = 0, ISKIP = 1), and the linearized integrals are not too large (TGMIG $\leq$ 15, I2BIG $\leq$ 0), the linearized dynamics integrals are evaluated and the angle-of-attack envelope and N/W based on that envelope value are computed by Statement 8005. I2BIG is set = 1 if the angle-of-attack envelope value from the linearized calculation is $\geq$ 90 degrees.

Next the Reynolds number RTX(I) and enthalpy HRT(I) are calculated, along with the nonequilibrium distance (DNE) and distance to peak nonequilibrium intensity (DSP). If the velocity is greater than VSTØPQ(VSD), the dynamic pressure is $\geq$ 1, and I = 1 (first output line) transfer is made to Statement 1999, for the equilibrium radiation heating calculation, the computation of the nonequilibrium radiation by subroutine NONEQU, the computation of the stagnation point convective heating (dependent upon the density ratio RØRZ computed with the radiation heating) and the call of CKTRB to see if the local Reynolds number REYS is > REYT. If REYS > REYT, transition has occurred, and the time for transition is stored as TIMTR. A transfer is made out of the radiation heating block to Statement 1997. If the velocity > VSTØPQ, dynamic pressure > 1, and I > 1, transfer is made to Statement 2002. If IQRGO = 1, TIMØD is calculated and IQRGØ = 2. The equilibrium and nonequilibrium radiation is computed by CØØL and NONEQU, the stagnation convective heating is calculated, and the same calculation done for REYS to check for transition. On occasion the radiation heating calculation fails to find a solution (NØ VALID SØLN. in output). This is recognized by the fact that the equilibrium radiation from CØØL, QRIG, has the value 0. When this happens, the index MINUS is incremented for each such case and as soon as a valid solution is given linear interpolations are done to compute the appropriate values of laminar and turbulent convective heating and equilibrium radiation heating (Statements 2007 to 2009). The nonequilibrium radiation is then based on the interpolated value of the equilibrium radiation when NØNEQU is called (after Statement 3052). These interpolations are thought reasonable because of the fact that experience indicates NØ VALID SØLN. generally occurs away from peak heating and in areas where the radiation heating is quite small. The interpolation requires the continuous updating of TIMØD for the interpolation (Statement 2009). If 149 lines of output have occurred, an attempt is made to eliminate all addition points from the output, except for impact (Statement 8001). This does not invariably work. Statement 105 ends the integration loop (see ADAMS4 description).

Except for the case DELTA-T TØØ/SMALL (Statement 130), the output tables from the entire trajectory are now printed with appropriate headings (Statements 1520 to 1660). First, however, all values of X/W (XØW (I)), and the values of laminar and, if applicable, turbulent heating, which occur after the last time CØØL was called, are computed in the loop ending 3043. The heating integrals are also computed in this loop by a trapezoidal approximation. The reason for the QSTAR and SQS calculation is that the restrictions V>VSTØPQ or dynamic pressure > 1 usually deletes the radiation heating before impact in order to save machine time calculating low radiation. The aerodynamic heating, however, depends upon the density ratio computed in the radiation block and hence the approximation is that this density ratio is constant between the last time radiation heating is computed and the impact time.

The values of the heating integrals are printed after Statement 400, and if interpolations are asked for at a specific Mach number (or dynamic pressure), the interpolations are completed and the answers written out in subroutine INTRP. The transition time is noted between 3060 and 3063, and indication of the deletion of the five dynamics differential equations is provided by Statement 3057 if such deletion occurred.

IF IPHEAT > 1.0 punched cards are provided on Tape 7 which includes tables of TIME, QS, QSTAR, HM/RTØ, and QRNE suitable for direct use in the heat shield calculation.

A transfer is then made to Statement 500, to begin the next case.

E. SIGNIFICANT EQUATIONS

1. MAIN

a. Molecular Weight

$$M = XM = 28 \cdot XN + 32 \cdot X\text{Ø} + 44 \cdot XC + 40 \cdot XA \qquad (24)$$

b. Specific Heat

$$CP/R = CP\text{Ø}R = 3.5\,(XN + X\text{Ø}) + 4 \cdot XC + 2\ 5 \cdot XA)/XM$$

c. Velocity Exponent for QS (I)

$$b_{LAM} = BLAM = 3.909 - 0.0299 \cdot XM$$

d. Stagnation Enthalpy

$$HM/RT_o = ENT0T = V^2/\left(64.4.778. \cdot \frac{1.987 \cdot 454 \cdot 273.16}{252 \cdot XM}\right) + \frac{XM \cdot CP0R}{273.16} \cdot TEMP \quad (298)$$

e. Dynamic Pressure

$$q_d = DYNPR = \frac{1}{2} \rho V^2 \quad (700)$$

f. Ballistic Coefficient

M/C_DA = $EM0CDA = SMM/(C_{DD} \cdot A)$, C_{DD} = drag coefficient at peak q_d

g. Normal Force, when Coefficients = F (α, M)

$$N/W = EN0W\ (I) = C_N \cdot Q_{DY}\ (I) \cdot A/(32.16 \cdot SMM),\ C_N \text{ from CNFA} \quad (3039)$$

Q_{DY} (I) = i^{th} dynamic pressure in output table

h. Normal Force when Coefficients = F (M)

$$N/W = EN0W\ (I) = (C_{LAD} + C_{DD}) \cdot ALENV\ (I) \cdot QDY(I) \cdot A/(57.3 \cdot 32.16 \cdot SMM) \quad (8007)$$

C_{LAD} and C_{DD} = C_{L_α} and C_D at same MACH number, (ALENV (I) = i^{th} angle-of-attack envelope in output table).

i. Natural Frequency

$$FREQ = FRNAT\ (I). = \frac{1}{2\pi} (-CMAD \cdot Q_{DY}\ (I) \cdot A \cdot D/ZIY)^{1/2} \quad (1076)$$

CMAD = C_{m_α} at same Mach number, ZIY = moment of inertia.

j. Ambient Reynolds Number

REY = RTX (I). RH0 · V (I) · D/VIS, VIS = viscosity at temperature TEMP (8005)

k. Axial Force

$X/W = X0W\ (I) = C_{DD} \cdot Q_{DY}\ (I) \cdot A/(32.16\ SMM)$ where $C_{DD} = C_D$ at same Mach number

l. Stagnation Point Convective Heating

$$Q_S = Q_S(I) = \left\{ \frac{VLG}{\frac{1}{2} D} \right\}^{1/2} \cdot (1.1 + 0.075 \quad XM) \quad 10^4 \cdot \left(\frac{V}{10^4} \right)^{BLAM} \cdot \quad (RH\emptyset)^{ALAM} \quad (3041)$$

VLG = velocity gradient evaluated at same density ratio

m. Convective Sonic Point Heating

$$Q_{STAR} = Q_T(I) = Q_S(I) \text{ if laminar}$$

$$Q_{STAR} = \frac{5.4 \times 10^5 \; THF}{((SSTAR/D) \cdot D)^{0.2}} \cdot (RHO)^{ATRB} \left(\frac{V}{10^4} \right)^{BTRB} \quad \text{if turbulent} \qquad (3054)$$

Linearized dynamics - no spin

n. Angle-of-Attack Envelope - no spin

$$ALENV(I) = \frac{ENVPQ \quad (-CMAPK \cdot PKDYN)^{1/4}}{((-CMAD \cdot Q_{DY}(I))^{1/4}} \cdot EXPF \frac{1}{2} \int_{t_o}^{t_i} \frac{\rho A}{2SMM} \left(- CLA + \frac{1}{2} \frac{CMQ}{SIGMA} \right) \quad V \cdot dt$$

where ENVPQ, - CMAPK, and PKDYN are the angle-of-attack envelope, C_m, and $1/2 \ \rho V^2$ at peak dynamic pressure, CMAD and QDY (I) are the $C_m = f(M)$ and $1/2 \ \rho V^2$ at the i^{th} time in the output table, and the exponential argument is integrated trapezodially with $CMQ = C_{m_q} = f(M)$ and $SIGMA = ZIY/SMMD^2$ t_o is the trajectory time at the beginning of the linearized calculation, t_i is the i^{th} time in the output table, where $t_i > t_o$.

o. Linearized Dynamics, Spin Correction

Angle-of-attack envelope, spin:

p. Angle of Attack, Spin

$$\bar{\alpha} = ALENV(I) = \frac{1}{2} (\bar{\alpha})_{NO\ SPIN} [DUM \cdot EXPF \quad -\frac{1}{2} TGMIG \quad + DUM \quad EXPF \quad \frac{1}{2} TGMI \quad (8007)$$

$$\mathrm{TGMIG} = \int_{t_o}^{t_i} \frac{-\pi \dfrac{\text{RHØ} \cdot \mathrm{A} \cdot \mathrm{V}}{4\mathrm{SMM}} \cdot \dfrac{\mathrm{ZIX}}{\mathrm{ZIY}} \cdot \left(\mathrm{CLA} + \dfrac{\mathrm{CMQ}}{2 \cdot \mathrm{SIGMA}}\right)}{\left\{ \dfrac{\text{RHØ} \cdot \mathrm{A} \cdot \mathrm{V}^2}{2 \cdot \mathrm{SMM} \cdot \mathrm{D}} \cdot \left(\dfrac{-\mathrm{CMA}}{\mathrm{SIGMA}}\right) + \dfrac{\pi^2}{4} \left(\dfrac{\mathrm{ZIX}}{\mathrm{ZIY}}\right)^2 \right\}^{1/2}} \, dt$$

$$\mathrm{DUM} = \left\{ \left[\frac{\dfrac{\text{RHØPK} \cdot \mathrm{A} \cdot \mathrm{VYPK}^2}{2 \cdot \mathrm{SMM} \quad \mathrm{D}} \cdot \left(\dfrac{-\mathrm{CMA}}{\mathrm{SIGMA}}\right) + \dfrac{\pi^2}{4} \left(\dfrac{\mathrm{ZIX}}{\mathrm{ZIY}}\right)^2}{\dfrac{\text{RHØ} \cdot \mathrm{A} \quad \mathrm{VYPK}^2}{2 \cdot \mathrm{SMM} \cdot \mathrm{D}}} \right] \left[\frac{\dfrac{\text{RHØ} \cdot \mathrm{A} \cdot \mathrm{V}^2}{2 \cdot \mathrm{SMM} \cdot \mathrm{D}} \cdot \left(\dfrac{-\mathrm{CMAD}}{\mathrm{SIGMA}}\right)}{\dfrac{\text{RHØ} \cdot \mathrm{A} \cdot \mathrm{V}^2}{2 \cdot \mathrm{SMM} \cdot \mathrm{D}} \left(\dfrac{-\mathrm{CMAD}}{\mathrm{SIGMA}}\right) + \dfrac{\pi^2}{4} \left(\dfrac{\mathrm{ZIX}}{\mathrm{ZIY}}\right)^2} \right] \right\}^{\frac{1}{4}}$$

For the integral TGMIG, RHØ, V, CLA, CMQ, CMA, are the density, velocity, C_{L_α}, C_{m_q}, C_{m_α} (evaluated as f(M)) for each time $\mathrm{SIGMA} = \dfrac{\mathrm{ZIY}}{\mathrm{SMM} \cdot \mathrm{D}^2}$. For DUM, RHOPK, VYPK, CMA are the density velocity, and C_{m_α} evaluated at peak dynamic pressure. RHO, V, CMAD are these quantities evaluated at the i^{th} time in the output table, $t_i > t_o$ where t_o is the trajectory time at the start of the linearized calculation.

q. Atmosphere Constants

$$L_O = \mathrm{XLO} = -\mathrm{XL1} \cdot \mathrm{GSL/CP}$$

$$Z_{ST} = Z_{ST} = (\mathrm{TST} - \mathrm{TSL})/\mathrm{XLO}$$

$$\rho_{th} = \text{RHØTH} = \mathrm{PTH} \cdot \mathrm{XM/(AR} \cdot \mathrm{TST)}$$

$$\rho\mathrm{ST} = \text{RHØST} = \frac{\left(\dfrac{\text{RHØSL} \quad \mathrm{TSL}}{\mathrm{TST}}\right)}{e^{\left\{\dfrac{\mathrm{XM} \quad \mathrm{GSL}}{\mathrm{AR} \; (\mathrm{TSL} - \mathrm{XLO} \quad \mathrm{RSL})} \left(\dfrac{\mathrm{ZST} \quad \mathrm{RSL}}{\mathrm{RSL} + \mathrm{ZST}}\right) + \mathrm{XLO} - \mathrm{RSL}^2 \; \ln\left(\left[\dfrac{\mathrm{RSL} \; (\mathrm{TSL} + \mathrm{XLO} \quad \mathrm{ZST})}{\mathrm{TSL} \; (\mathrm{RSL} + \mathrm{ZST})}\right] \dfrac{1}{\mathrm{TSL} - \mathrm{XLO} \quad \mathrm{RSL}}\right)\right\}}} \qquad (24)$$

$$\bar{\rho} = \mathrm{ROBAR} = \text{RHØST} \cdot e^{\left[\dfrac{\mathrm{XM} \cdot \mathrm{GSL} \cdot \mathrm{RSL} \cdot \mathrm{ZST}}{\mathrm{AR} \cdot \mathrm{TST} \cdot (\mathrm{RSL} + \mathrm{ZST})}\right]}$$

$$Z_{TH} = \text{ZTH} = \ln \frac{\text{RØBAR}}{\text{RHØTH}} \cdot \frac{\text{AR} \cdot \text{TST} \cdot \text{RSL}}{\left[\text{XM} \cdot \text{GSL} \cdot \text{RSL} - \ln \left(\frac{\text{RØBAR}}{\text{RHØTH}}\right) \cdot \text{AR} \quad \text{TST}\right]}$$

2. DERQ0

Atmosphere

$\text{Z} \leq \text{ZST}$

$\text{T} = \text{TEMP} = \text{TSL} + \text{XLO} \cdot \text{Z}$

$$\rho = \text{RHØ} = \frac{\frac{\text{RHØSL} \quad \text{TSL}}{\text{TEMP}}}{e^{\left\{\frac{\text{XM} \quad \text{GSL}}{\text{AR} \quad (\text{TSL} - \text{XLO} \quad \text{RSL})} \left(\frac{\text{Z} \quad \text{RSL}}{\text{RSL} + \text{Z}} + \text{XLO} \quad \text{RSL}^2 \ln \left[\frac{\text{RSL} \ (\text{TSL} + \text{XLO} \quad \text{Z})}{\text{TSL} \ (\text{RSL} + \text{Z})}\right] \frac{1}{\text{TSL} - \text{XLO} \quad \text{RSL}}\right)\right\}}} \qquad (32)$$

$\text{ZST} < \text{Z} \leq \text{ZTH}$

$\text{T} = \text{TEMP} = \text{TST}$

$$\rho = \text{RHØ} = \text{RØBAR} / e^{\left[\frac{\text{XM} \cdot \text{GSL} \cdot \text{RSL} \cdot \text{Z}}{\text{AR} \cdot \text{TST} \cdot (\text{RSL} + \text{Z})}\right]}$$

$\text{Z} > \text{ZTH}$

$\text{T} = \text{TEMP} = \text{TSL} + \text{XL2} \ (\text{Z} - \text{ZTH})$

$$\rho = \text{RHØ} = \frac{\frac{\text{RHØTH} \quad \text{TST}}{\text{TEMP}}}{e^{\left\{\frac{\text{XM} \quad \text{GSL}}{\text{AR} \ (\text{TST} - \text{XL2} \quad (\text{RSL} + \text{ZTH}))} \left(\frac{\text{Z} - \text{ZTH} \quad \text{RSL}^2}{(\text{RSL} + \text{Z})(\text{RSL} + \text{ZTH})}\right) + \text{XL2} \quad \text{RSL}^2 \ln \left[\frac{\text{TST} + \text{XL2}(\text{Z} - \text{ZTH})}{(\text{RSL} + \text{Z})(\text{RSL} + \text{ZTH})}\right] \frac{1}{\text{TST} - \text{XL2}(\text{RSL} + \text{ZTH})}\right\}}} \qquad (62)$$

$$a = \text{SMA} = \left[\frac{\text{AR} \quad \text{TEMP} \cdot \text{CPØR}}{\text{XM} \quad \text{CPØR} - 1.}\right]^{1/2}$$

$$M = \text{XMAC} \quad \text{V/SMA}$$

$$\left.\begin{aligned}
& V, \gamma, Z, Q, R, \psi, \theta, \phi = X\,(1-8) \text{ respectively} \\
& \frac{dZ}{dt} = \text{DERX(3)} = V \cdot \sin(\gamma) \\
& \frac{dV}{dt} = \text{DERX(1)} = \frac{1}{\text{SMM}} \left[-\text{CSUBD} \; \frac{1}{2} \; \text{RHØ} \quad V^2 \quad A - \text{SMM} \cdot \text{GSL} \left(\frac{\text{RSL}}{\text{RSL} + Z}\right)^2 \cdot \sin(\gamma)\right] \\
& \qquad \text{CSUBD} = \text{Drag coeff. } f(M) \\
& \frac{d\gamma}{dt} = \text{DERX(2)} = \frac{1}{\text{SMM} \quad V} \left[\frac{\text{SMM} \cdot \cos(\gamma) \quad V^2}{\text{RSL} + Z} - \text{SMM} \quad \text{GSL} \left(\frac{\text{RSL}}{\text{RSL} + Z}\right)^2 \cdot \cos(\gamma)\right] \\
& \qquad \text{particle trajectory, } C_D = f(M) \text{ only}
\end{aligned}\right\} \text{particle trajectory}$$

$$\sin(\alpha) = \text{SAL} = \sin(\theta) \quad \cos(\psi) \cdot \cos(\phi) + \sin(\psi) \cdot \sin(\phi)$$

$$\sin(\beta) = \text{SBE} = \sin(\psi) \quad \cos(\phi) - \sin(\theta) \quad \cos(\psi) \cdot \sin(\phi)$$

$$\sin(\alpha') = \text{SALPHA} = [\sin^2(\psi) + (\cos(\psi) \sin(\theta))^2]^{1/2}$$

$$\cos(\alpha') = \text{CALPHA} = \cos(\theta) \quad \cos(\psi)$$

$$\alpha' = \text{ALPHA} = \tan^{-1} \left(\frac{\text{SALPHA}}{\text{CALPHA}}\right)$$

$$\left.\begin{aligned}
& \frac{dV}{dt} = \text{DERX(1)} = \frac{dV}{dt} \text{ above, but CSUBD} = \text{CX} \quad \text{CALPHA} + \text{CN} \quad \text{SALPHA}, \\
& \text{CX and CN} = f(\alpha', M) \\
& \frac{d\gamma}{dt} = \text{DERX(3)} = \frac{1}{\text{SMM} \cdot V} \left[\frac{\text{SMM} \cdot \cos(\gamma) \quad V^2}{\text{RSL} + Z} + \text{CL} \, \frac{\sin(\theta)}{\sin(\alpha')} \, \frac{A \cdot \text{RHØ} \quad V^2}{2} - \text{SMM} \quad \text{GSL} \left(\frac{\text{RSL}}{\text{RSL} + Z}\right)^2 \cos(\gamma)\right.
\end{aligned}\right\} \begin{array}{l}\text{trajectory} \\ \text{with} \\ \text{vehicle} \\ \text{dynamics} \\ \text{from three} \\ \text{moment} \\ \text{equations}\end{array}$$

$$\begin{aligned}\frac{dQ}{dt} = \text{DERX}(4) = \Bigg\{ & \frac{1}{2}\ \text{RH}\O \cdot V^2\ \ A \cdot D \left[\frac{\text{CM}, \cdot \text{SAL}}{\text{SALPHA}} + \frac{D \cdot \text{CMQ} \cdot Q}{2 \cdot V} - \frac{Q\ \ \text{ZIY} \cdot \text{CLA}}{\text{SMM} \cdot V \cdot D} - \text{CX}\ \ \text{ZCG}\O\text{D}\right] \\ & + (\text{ZIY} - \text{ZIX})\ \ P \cdot R + \text{SPINER}\ \ \text{SBE} - P \cdot \text{ZIX}\ \ \text{GD}\O\text{TT}\ \cdot \\ & [\sin(\psi)\ \sin(\theta) \cos(\phi) - \cos(\psi) \cdot \sin(\phi)] \Bigg\} \cdot \left(\frac{1}{\text{ZIY}}\right)\end{aligned}$$

$$\begin{aligned}\frac{dR}{dt} = \text{DERX}(5) = \Bigg\{ & \frac{1}{2} \text{RH}\O \cdot V^2 \cdot A \cdot D \left[\frac{\text{CM} \cdot \text{SBE}}{\text{SALPHA}} + \frac{D\ \ \text{CMQ}\ \ R}{2 \cdot V} - \frac{R \cdot \text{ZIY} \cdot \text{CLA}}{\text{SMM} \cdot V\ \ D}\right] \\ & + (\text{ZIX} - \text{ZIY}) \cdot P\ \ Q - \text{SPINER} \cdot \text{SAL} + P \cdot \text{ZIX} \cdot \text{GD}\O\text{TT}\ \cdot \\ & [\cos(\psi)\ \ \cos(\phi) + \sin(\psi)\ \sin(\theta)\ \sin(\phi)] \Bigg\}\ \ \frac{1}{\text{ZIY}}\end{aligned}$$

where,

$$\text{SPINER} = \frac{-P \cdot \text{ZIX}\ \ \text{RH}\O\ \ V\ \ A \cdot [\text{CN} \cdot \text{CALPHA} - \text{CX} \cdot \text{SALPHA}]}{2 \cdot \text{SMM} \cdot \text{SALPHA}} \qquad (8001)$$

and,

$$\text{GD}\O\text{TT} = -\frac{\text{GSL}}{V} \cdot \left(\frac{\text{RSL}}{\text{RSL} + Z}\right)^2 \cdot \cos(\gamma)$$

$$\frac{d\psi}{dt} = \text{DERX}(6) = \frac{R \cdot \cos(\phi) + Q \cdot \sin(\phi)}{\cos(\theta)}$$

$$\frac{d\theta}{dt} = \text{DERX}(7) = Q\ \ \cos(\phi) - R \cdot \sin(\phi)$$

$$\frac{d\phi}{dt} = \text{DERX}(8) = P + \text{DERX}(6) \cdot \sin(\theta)$$

3. <u>CØØL</u> - (No Significant Equations)

4. <u>NØNEQU</u>

DELDG < DSP

$$\text{QRNE} = \frac{1}{2} \cdot \text{QR} \cdot \text{XIRN} \left(\frac{\text{DELDG}}{\text{DSP}}\right) .$$

DSP $\leq$ DELDG $\leq$ DNE

$$\mathrm{QRNE} = \mathrm{QR}\left(1 - \frac{1}{2}\,\frac{\mathrm{DSP}}{\mathrm{DELDG}} - \frac{1}{2}\,\frac{\mathrm{DNE}}{\mathrm{DELDG}} + \mathrm{XIRN}\,\frac{\mathrm{DNE}}{2\ \mathrm{DELDG}} - \frac{1}{2}\,\frac{1}{\mathrm{DELDG}}\left(\frac{(\mathrm{DNE}-\mathrm{DELDG})^2}{(\mathrm{DNE}-\mathrm{DSP})}\right)(\mathrm{XIRN}-1.)\right) \quad (3)$$

DNE < DELDG

$$\mathrm{QRNE} = \mathrm{QR}\left(1 - \frac{1}{2}\,\frac{\mathrm{DSP}}{\mathrm{DELDG}} - \frac{1}{2}\,\frac{\mathrm{DNE}}{\mathrm{DELDG}} + \mathrm{XIRN}\,\frac{\mathrm{DNE}}{2\ \mathrm{DELDG}}\right) \qquad (4)$$

5. CKTRB

$$\mathrm{REYS} = \frac{\mathrm{R0}}{\mathrm{VIS}} \cdot \mathrm{R0RZ} \cdot \mathrm{R0S0R0}\ \ \mathrm{SST} \cdot \left(\frac{2\ \mathrm{ENT0T}\ \ 24\ \ 4522\ \ 10^6}{\mathrm{R0RZ}\ \ \mathrm{XM}}\right)^{1/2}$$

R0 = ambient density, R0RZ from radiation calculation, SSTOS* from input,

ENT0T = stagnation enthalpy, XM = molecular weight.

γ = GAMMA = (R0RZ + 1)/(R0RZ − 1)

$$\rho_S/\rho = \mathrm{R0S0R0} = \left(\frac{2}{\mathrm{GAMMA}+1}\right)^{1/\mathrm{GAMMA}\ -\ 1}$$

VIS = viscosity at temperature $T^* = \mathrm{TSTR} = \left(\frac{2}{\mathrm{GAMMA}+1}\right) \cdot \mathrm{TSSZ}$, TSSZ = stagnation temperature

GETCLA

$$C_{L_\alpha}(\alpha, M) = 5\ 73\,\{2\ C_L(\alpha+10, M) - \frac{3}{2}\,C_L(\alpha, M) - \frac{1}{2}\,C_L(\alpha+20, M)\} \qquad (1007)$$

$$C_L = \mathrm{CN} \cdot \cos(\alpha) - \mathrm{CX}\sin(\alpha)$$

6. HEAT

Same as 1883, but inverse density ratio, b/a correlation for detachment distance replaced by (input) detachment distancedensity ratio correlation in table look-up after Statement 502. GETH, HVST, GETK, GETQ, FINDH, FINDT, Z0NES - Same as 1883

V. REFERENCES

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PROGRAM 1881

PROGRAM
1881

ILLUSTRATIONS

TABLES

AERODYNAMIC COEFFICIENTS PROGRAM (1881)

CONTENTS

I. INTRODUCTION

A. GENERAL DESCRIPTION

This program computes the aerodynamic coefficients of axisymmetric shapes as a function of angle of attack utilizing impact (Newtonian) theory. In addition, radii of gyration are computed based on uniform densities forward and rearward of the specified center-of-gravity location. The general inputs required include:

1. Shape geometry,
2. Mass and center-of-gravity location, and
3. Desired angle of attack range.

Option is provided for determining the center-of-gravity location based on specified minimum values of the static margin and static moment coefficient derivative.

Configurations possible are bodies of revolution containing up to 10 sections of various geometries, including spherical segments, cones, tori, cylinders, and an optional section which may be a tension shape or a general shape input by coordinates. A typical shape containing 10 basic sections is illustrated in Figure 1. Figure 2 shows the alternate geometry for the tension shell and the general shape.

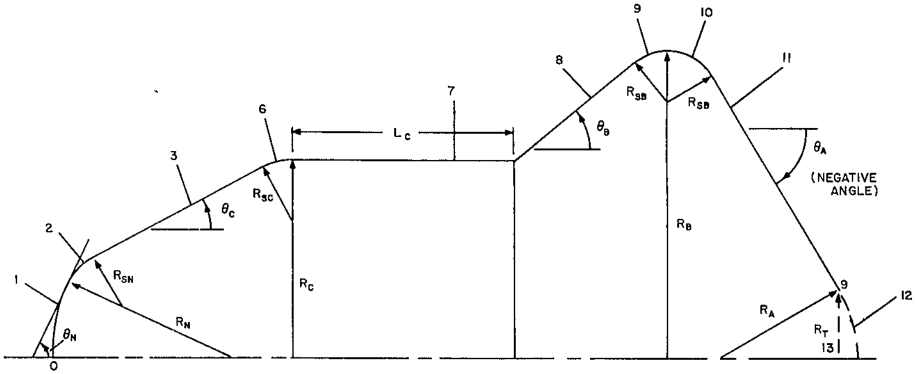
The program output includes the axial, drag, lift, and normal force coefficients, the static and pitch damping moment coefficients, the lift curve slope, and the center of pressure. The aerodynamic coefficient data generated are sufficient to facilitate the inputs to Program 1880. The lift curve slope is utilized in Program 1880, but it is not necessary as an input to that program as it is computed from the axial and normal force coefficients.

B. CALCULATION MODEL

1. Newtonian Coefficients

Using the coordinate system shown in Figure 3, consider an arbitrary surface in three dimensional space ($g = g(x, y, z) = 0$) which is continuous in the first derivative in the region of interest. The unit vector which is normal to the surface at any point, P, and which is positive into the surface is given by

$$\bar{n} = - \bar{\nabla} g / |\bar{\nabla} g| .$$

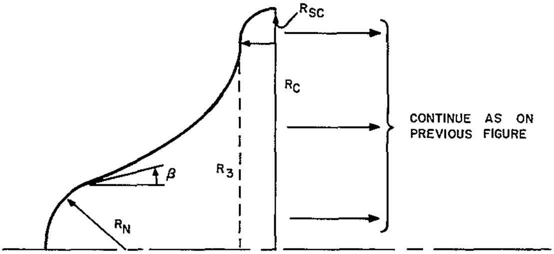


SECTION	
1	NOSE SPHERE
2	R_{SN} TORUS
3	CONE (SEE FIGURE 2 FOR ADDITIONAL OPTIONS)
6	R_{SC} TORUS
7	CYLINDER
8	FLARE
9	FORE R_{SB} TORUS
10	AFT R_{SB} TORUS
11	AFT CONE
12	AFT SPHERE (R_A)
13	BASE (R_T)

65 11627

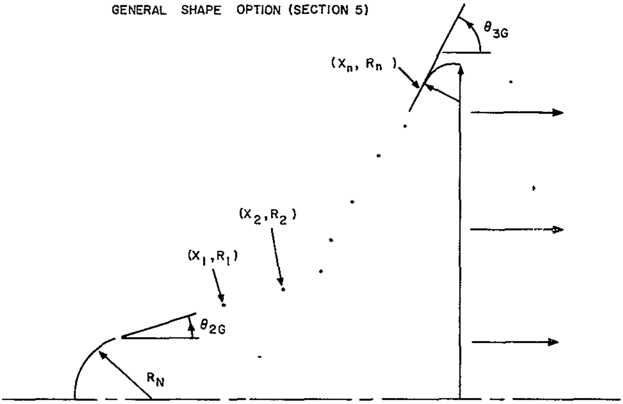
Figure 1 VEHICLE SHAPE PARAMETERS

TENSION SHELL OPTION (SECTION 4)



β - TENSION SHELL INPUT PARAMETER
R_3 - BASE RADIUS OF TENSION SHELL (NOT INPUT)

GENERAL SHAPE OPTION (SECTION 5)



$\theta_{2G}, \theta_{3G}, X, R$ - GENERAL SHAPE INPUT PARAMETERS
$n \leq 25$

65-11628

Figure 2 TENSION SHELL AND GENERAL SHAPE GEOMETRIES

Denote the component of the relative wind vector, $\overline{V}$ that lies along $\vec{n}$ as $\overline{V}_n$, the normal velocity vector. Hence,

$$\overline{V}_n = (\overline{V} \cdot \bar{n})\bar{n} .$$

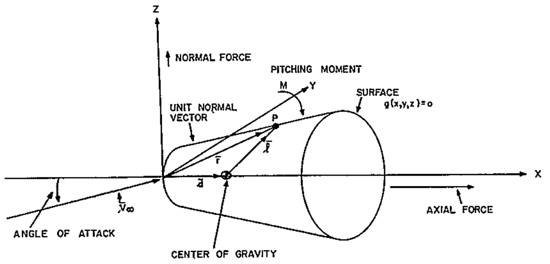


Figure 3 COORDINATE SYSTEM FOR CALCULATION MODEL

The Newtonian pressure approximation, used herein is then given by,

$$C_p = 2\left(\frac{|\overline{V}_n|}{|\overline{V}_\infty|}\right)^2 = 2\left(\frac{\overline{V}}{V} \cdot \bar{n}\right)^2 ;$$

where,

$$V = |\overline{V}_\infty| .$$

Defining $d\overline{C}_F$ as the element of the vector force coefficient acting normal to the surface at point P and $\overline{C}_F$ as the sum of all such elements.

$$d\,\overline{C}_F = \frac{C_p\, d\overline{S}}{A} \quad \text{, (A is the reference area.)}$$

$$\overline{C}_F = \frac{1}{A} \oiint_S C_p\, d\overline{S} = \frac{2}{A} \oiint_S \left(\frac{\overline{V}}{V} \cdot \bar{n}\right)^2 d\overline{S},$$

and, inasmuch as

$$d\bar{S} = \bar{n}\,dS,$$

$$\bar{C}_F = \frac{2}{A} \iint_S \left(\frac{\bar{V}}{V} \quad \bar{n}\right)^2 \bar{n}\,dS .$$

It follows that the aerodynamic normal and axial force coefficients are found from:

$C_X = \bar{\imath} \cdot \bar{C}_F$, and

$C_N = \bar{k} \cdot \bar{C}_F$, respectively.

We define a position vector $\bar{r}$ as the vector extending from the origin to the point P. The moment vector arm, $\bar{l}$ is defined as that vector extending from the center of gravity of the vehicle to the point P. Thus,

$$\bar{l} = \bar{r} - \bar{d},$$

where $\bar{d}$ is the vector position of the center of gravity.

The differential moment about the center of gravity is found from:

$$d\,\bar{C}_M = \frac{\bar{l} \times d\,\bar{C}_F}{D} = \frac{\bar{l} \times C_p\,d\bar{S}}{AD} = \frac{C_p}{AD}\ \bar{l} \times d\bar{S} .$$

Integrating,

$$\bar{C}_M = \frac{2}{AD} \oiint_S \left(\frac{\bar{V}}{V} \quad \bar{n}\right)^2 \bar{l} \times d\bar{S},$$

which may be evaluated as

$$\bar{C}_M = \frac{2}{AD} \oiint_S \left(\frac{\bar{V}}{V} \cdot \bar{n}\right)^2 (\bar{l} \times \bar{n})\,dS.$$

The aerodynamic pitching moment coefficient is found from:

$$C_m = \bar{\jmath} \cdot \bar{C}_M$$

The velocity at point P consists of two parts, one part from the velocity of the vehicle and one part from the rotation of the vehicle about its center of gravity. Hence,

$$\bar{V} = \bar{V}_\infty - \bar{\omega} \times \bar{l} .$$

where $\bar{\omega}$ is the total vector angular rate of the body about its center of gravity.

Developed expressions for the forces and moments on conic section are readily available, e.g., see References 1 through 3.

The computer program treats all sections, except the spherical nosecap section, as consisting of a series of conical frustra. The effects of shadowing of the incident flow are included to ensure that the local pressure coefficient is never less than zero (negative).

2. Radii of Gyration

A simplified method for estimating the radii of gyration is included in the program by considering the vehicle to be of uniform density fore and aft of the center of gravity as depicted in Figure 4. Specifying the desired center-of-gravity location and the total vehicle mass, then by elementary volume considerations, the relative densities fore and aft of the center of gravity can be determined and then the pitch and roll radii of gyration can be computed.

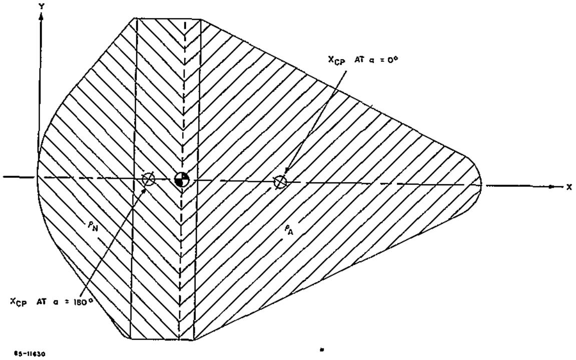


Figure 4 RADIUS OF GYRATION MODEL

3. Center of Pressure

The integration of the pressure forces over the complete surface of the vehicle yields the component forces on the vehicle and the line of action of the resultant force. Location of the center of gravity on the line of action eliminates any moments on the body arising due to aerodynamic forces, in which case the body is neutrally stable. The intercept of the line of action and the body longitudinal axis is designated as the center of pressure. Restricting the forces and moments to the static values, i.e., $\overline{\omega} = 0$, and with the center of gravity on the axis, the center of pressure as given in the output (XCP) is then defined as

$$\frac{X_{CP}}{D} = \frac{-(C_m)_o}{C_N}$$

where $(C_m)_o$ is the pitching moment evaluated about the nose of the vehicle At zero angle of attack,

$$\frac{X_{CP}}{D} = \lim_{\alpha \to o} \frac{(-C_m)_o}{C_N} = \frac{-C_{m_\alpha}}{C_{N_\alpha}} .$$

The reference length (D) is taken as equal to $(2\ R_c)$ throughout all the programs.

4 Moment Transfer

The center of pressure is independent of the center-of-gravity location but the moment coefficients must be modified if the center-of-gravity location is changed. Program 1880 provides for automatic static moment transfer, however, to transfer the damping moment coefficient, Program 1881 must be rerun for the new center-of-gravity position.

5. Pitch Damping Moment Coefficient

The pitch damping moment coefficient C_{m_q} is based on the normalized pitch rate qD/2V and is evaluated as $\left(\frac{qD}{2V}\right) \to 0$, i.e.,

$$C_{m_q} \equiv \lim_{\left(\frac{qD}{2V}\right) \to 0} \frac{\partial C_m}{\partial \left(\frac{qD}{2V}\right)} .$$

C. PROGRAM LIMITATIONS

Program limitations are listed below:

1. Coefficients are based on the Newtonian pressure distribution, with the assumption that each section of the body has self-shadowing, but does not cast shadows on other sections.

2. Radii of gyration are based on uniform densities fore and aft of the center of gravity, the ratio of these densities being determined by the specified center-of-gravity location.

3. The effect of an off-axis center-of-gravity location can be accounted for in the coefficient calculation, but is not reflected in the radii of gyration.

4. Configurations are limited to axisymmetric shapes composed of spherical segments, cones, cylinders, tori, and an optional section which may be a tension shell or a general shape specified by up to 25 consecutive points in rectangular coordinates.

5. The Newtonian flow approximation assumes that the normal component of momentum is lost, while the tangential component is unchanged. All viscous forces and base pressures are neglected.

Comparisons have been made[1] between Newtonian predictions and hypersonic experimental aerodynamic characteristics for various sharp and blunt bodies of revolution.

In general, the theory was found to agree quite well with experimental results for sharp nose cones and for configurations having large blunted noses and steep surface slopes. However, agreement between theory and experiment generally is poor for the more slender ($\theta_c < 20$ degrees) slightly blunted conic bodies. Real flow phenomena, such as viscous effects, sharp corner effects, gas composition, gas kinetics, and heat transfer are all neglected by Newtonian theory and may, in some cases, have a sizable effect on the aerodynamic characteristics of the configuration and the adequacy of the theoretical predictions.

The agreement between theory and experiment can be improved by using the actual stagnation pressure coefficient behind the normal shock rather than the Newtonian value of two (2). The stagnation pressure coefficient can be estimated by the following relation:

$$C_P = \frac{\gamma + 3}{\gamma + 1} \left[1 - \frac{2}{\gamma + 3} \quad \frac{1}{M^2_a} \right]$$

where γ is the ratio of specific heats (C_p / C_V).

6. The tension shell equations contained in Program 1881 are derived in Reference 4, and correspond to the case of zero hoop stress and a Newtonian pressure distribution. A comparison of the numerical integration results for the shape coordinates with the results of Reference 4 are given in Table I below.

TABLE I

TENSION SHELL CHECK

Shape		Length/Base Radius	
A^2	β	Ref. 4	1881*
0.5	62.50	0.343	0.343
1.2	33.50	0.939	0.943
1.6	22.835	1.413	1.417

*NDIV = 20.0

II. USAGE

A. INPUT DEFINITIONS

Name	Preset Value	Symbol	Parameter	Units
A1, A1L A2, A2L A3, A3L	0., ___ 0., ___ 0., ___		First and last values of angle of attack for each range of printout, these are all used only when the printout requirements differ for each range of angle of attack.	degrees
BETA	0.	β	Initial angle for third section in case of tension shell.	degrees
CASE			Identification number for case.	
CMAG(1)	0.	$C_{m_{\alpha 0}}$	Minimum pitching moment derivative at $\alpha = 0$ degrees.	per radian
CMAG(2)	0.	$C_{m_{\alpha 180}}$	Minimum pitching moment derivative at $\alpha = 180$ degrees.	per radian
DA1 DA2 DA3	0. 0. 0.		Intervals of angle of attack for which printout is desired; three ranges can be requested if data are needed more finely over a specific angle of attack range. Hence, the interval of printout is specified jointly with the range of angle of attack for which the printout frequency is desired.	degrees
DATE			Date identification number.	
DERDEL	.005		Interval of independent variable used to evaluate derivatives.	
GS0	0.		This symbol is input 1.0 when the third section is a general shape; otherwise, need not be input.	

LC	0.	L_C	Length of cylinder	feet
MASS	0.	m	Mass of vehicle	slugs
M2	10		Number of straight-line segments into which the second, fourth, seventh, eighth, and tenth sections (curved sections) are to be divided for computational purposes.	
M4	10			
M7	10			
M8	10			
M10	10			
MEM0			Identification number for computer run.	
NDIV	20		Increments of radius for which points are determined on tension shell.	
NPGS0	0.		Number of input points when third section is a general shape (includes last point but omits first point; max 25 points).	
RA	0.	R_A	Aft body radius.	feet
RB	0.	R_B	Flare radius.	feet
RC	0.	R_C	Cylinder radius.	feet
RINP		r	Ordinates of input points in case of general shape (third section).	
RN	0.	RN	Nose radius.	feet
RSB	0.	R_{SB}	Toroidal radius (adjacent to flare cone).	feet
RSC	0.	R_{SC}	Toroidal radius (adjacent to cone).	feet

RSN	0.	R_{SN}	Toroidal radius (adjacent to nose).	feet
RT	0.	R_T	Aft cone base radius.	feet
SM	0.	SM	Minimum static margin at zero angle of attack.	feet
TH2G	0.		Initial angle when third section is a general shape.	degrees
TH3G	0.		Final angle when third section is a general shape.	degrees
THA	0.	θ_A	Aft cone angle.	degrees
THB	0.	θ_B	Flare section angle.	degrees
THC	0.	θ_C	Cone angle.	degrees
THN	0.	θ_N	Complement of nose angle.	degrees
XCG	0.	X_{CG}	Center of gravity position measured from nose.	feet
XINP	0.	x	Abcissas of input points in case of general shape (third section).	
ZCG	0.	Z_{CG}	Center of gravity position for cases where center of gravity is not on the axis	feet

B. INPUT PROCEDURES

Input procedures are listed below

1. R_c must always be specified. Aerodynamic coefficients are based on the reference length, $D = 2R_c$

2. Contour angles (θ) are measured relative to free stream, progressing aft of the nose. Positive values indicate increasing body radius, negative values, decreasing radius (e.g., θ_A is negative).

3 Sections may be omitted provided the starting point of each section is compatible with the final point of the previous section. The first and last points on the body must be on the axis.

4. If several cases are run on a single memo, only changed inputs need be specified (inputs which are not repeated must be set = 0)

5. The tension shell option is specified by inputing RN, BETA, RC, and RSC the defining parameters of the tension shell as shown in Figure 2.

6. In the general shape option (GSØ = 1.0), up to 25 points may be specified along the desired contour. In addition, the initial slope, TH2G (which defines the final point on the preceding arc) and the final slope, TH3G, must be specified.

7. The center of mass may optionally be determined by specifying restraints on the stability at 0- and 180-degree angles of attack. The program checks the computed XCG to ensure a single, stable trim point from 0- to 180-degree angles of attack. This option is activated by specifying XCG = 0, and inputting the restraints on SM, CMAG (1), and CMAG (2)

8. The length and mass units of inputs called for in the definitions are feet and slugs. However, any consistent system of units may be employed with corresponding changes in the units of the outputs.

9. For shapes with flat bases, a value of R_T must be specified if $\theta_A = -90$.

10. An input form is provided on page 17 for the user. All the information shown is keypunched, provided the variable is specified. All numerical values have decimal points.

11. A brief bibliography of experimental measurements of aerodynamic coefficients is provided at the end of the text. These data can be used to improve the theoretical values obtained from Program 1881 where applicable.

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C. OUTPUT DEFINITIONS

External Name	Internal Name	Symbol	Parameter	Units
ALPHA	ALPHA		Angle of attack.	degrees
CD	CD(1)	C_D	Drag coefficient as a function of angle of attack.	
CL	CL(1)	C_L	Lift coefficients as a function of angle of attack.	
CL/CD	CL(1)/CD(1)	CL/CD	Lift/Drag ratio as a function of angle of attack.	
CLA	CLA	C_L	Derivative of lift coefficient	per radian
CM	CM1	C_m	Pitching moment coefficient as a function of angle of attack.	
CMQ	CMQ	C_{m_q}	Damping coefficient.	per radian
CN	CN1	C_N	Coefficient of normal force as a function of angle of attack	
CX	CX1	C_X	Coefficient of axial force as a function of angle of attack.	
R	R	r	Ordinates of all points computed along the body surface.	feet
RGX/D	RGXDD		Radius of gyration about roll axis as a fraction of diameter	
RGY/D	RGYDD		Radius of gyration about pitch axis as a fraction of diameter.	
RH0A	RH0A	ρ_A	Density of vehicle aft of center-of-gravity position.	slug/ft^3

RH0N	RH0N	ρ_N	Density of vehicle forward of center-of-gravity position.	slug/ft^3
X	X	x	Abcissas of all points computed along the body surface.	feet
XCG	GX		Center-of-gravity position measured from nose.	feet
XCG/D	XCGDD	X_{CG}/D	Center-of-gravity distance as a fraction of capsule diameter.	
XCP/D	XCPDD	X_{CP}/D	Center-of-pressure distance as a fraction of capsule diameter.	

D. SAMPLE PROBLEM

1. Statement of Problem

Determine the Newtonian coefficients and estimated radii of gyration for a blunt cone configuration. The vehicle parameters, range of angle of attack, and XCG location are to be prescribed as input. The final plot of the configuration, as performed automatically, is shown in Figure 5.

2. Computer Input Form

The computer input form containing all the necessary input data to be keypunched is shown on page 18. All the input on this form is written with decimals.

3. Output

The output is given on page 19. The data keypunched is shown in the output and should be verified with the input form. An array of vehicle coordinates (X, R) are given which are useful for drawing the configuration; the first coordinates given correspond to the last point on the nose cap, which is spherical.

The coefficient data has two rows for each angle of attack; the first row corresponds to the XCG at the nose and the second row provides the moment data for the XCG specified. Following the coefficient data, are the densities fore and aft of the XCG necessary to yield the desired XCG location, and also the desired radii of gyration are given. A plot of the vehicle coordinates can be obtained, as shown on page 16 ; a Stromberg Carlson 4020 plotter was used for this purpose.

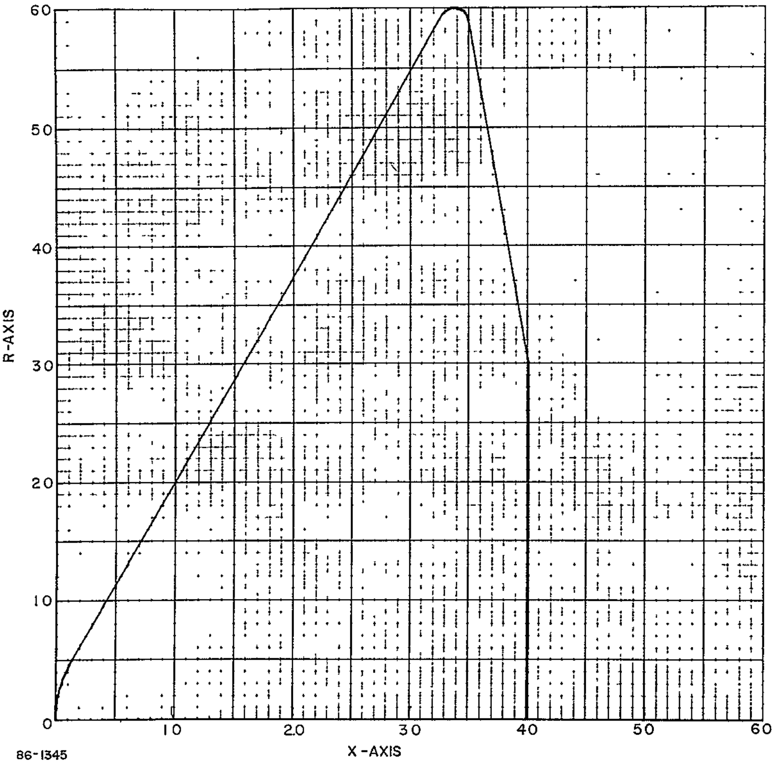

Figure 5 PLOT OF VEHICLE COORDINATES

RAD 2-0963
5 63

DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO 1881	PROGRAMMER A. Picado
	TITLE Newtonian Program for Bodies of Revolution	

MEMO NO	SECTION NO	WORK ORDER NO	(E240 USE ONLY)	REQUESTED BY	EXT	EST TIME	PAGE 1 OF 1 PAGES

$INPUT

DATE = ________, MEM0 = ________, CASE = ________,
BETA = ________, RA = ________, TH2G = ________,
CMAG(1) = ________, RB = ________, TH3G = ________,
CMAG(2) = ________, RC = ________, THA = ________,
DERDEL = ________, RN = ________, THB = ________,
GS0 = ________, RSB = ________, THC = ________,
LC = ________, RSC = ________, THN = ________,
MASS = ________, RSN = ________, XCG = ________,
NDIV = ________, RT = ________, ZCG = ________,
NPGS0 = ________, SM = ________,

A1 = ________, A1L = ________, DA1 = ________,
A2 = ________, A2L = ________, DA2 = ________,
A3 = ________, A3L = ________, DA3 = ________,
M2= ________, M4= ________, M7= ________, M8= ________, M10= ________,

RINP(1) = ________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
XINP(1) = ________, ________, ________, ________, ________,
________, ________, ________, ________, ________,

$

SC 4020 plots No. of frames ________

RAD 2 0963
5 63

DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO 1881				PROGRAMMER A. Picado		
	TITLE Newtonian Program for Bodies of Revolution						
MEMO NO PL-163	SECTION NO K420	WORK ORDER NO W305-050-0000	(E240 USE ONLY)	REQUESTED BY P. Levine	EXT 2996	EST TIME	PAGE 1 OF 1 PAGES

$INPUT

DATE = ______, MEMØ = ______, CASE = 1.,

BETA = ______, RA = ______, TH2G = ______,

CMAG(1) = ______, RB = ______, TH3G = ______,

CMAG(2) = ______, RC = 6.0, THA = -80.0,

DERDEL = ______, RN = 1.0, THB = ______,

GSØ = ______, RSB = 0.12, THC = 60.0,

LC = ______, RSC = 0.12, THN = 60.0,

MASS = 1.0, RSN = ______, XCG = 3.0,

NDIV = ______, RT = 3.0, ZCG = ______,

NPGSØ = ______, SM = ______,

A1 = 0.0, A1L = 180.0, DA1 = 10.0,

A2 = ______, A2L = ______, DA2 = ______,

A3 = ______, A3L = ______, DA3 = ______,

M2= ______, M4= ______, M7= ______, M8 = ______, M10= ______,

RINP(1) = ______, ______, ______, ______, ______,
______, ______, ______, ______, ______,

XINP(1) = ______, ______, ______, ______, ______,
______, ______, ______, ______, ______,

$

SC 4020 plots No. of frames ______

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$DATA                                                        12/01/64
                                                                        1881        FORTRAN IV             3/22/66

                    IBLDR                                        12/01/64

                          * MEMORY MAP *

SYSTEM                                  00000 THRU  02717
FILE BLOCK ORIGIN                       02720
FILES         1.      UNIT05
              2.      UNIT06
              3.      UNIT16
FILE LIST ORIGIN                        02764
PRE-EXECUTION INITIALIZATION            02772
CALL ON OBJECT PROGRAM                  03023
OBJECT PROGRAM                          03030 THRU  46571

      DECK  ORIGIN        CONTROL SECTIONS  (/NAME/=NON 0 LENGTH, (LOC)=DELETED, **NOT REFERENCED)

   1. 1881    03030       ......  14001 *
   2. SCALIN  14026       CALINT  14214
   3. SCPLOT  14264       CPLOT   15212
   4. .LXCON  15251       .LXSTR  15251 *   .LXSTP  15255     .LXOUT  15323     .LXRTN  15335     IBEXIT  15335 *
                          .LXCAL  15340 *   .LXERR  15340     .DBCLS  15522 *   .LXARG  15671     .IO     15714 *
                          .CLSE   15722     .LFBL   15723 *   .LUNB   15724     .DFOUT  15725
   5. .IODEF  15731       .DEFIN  15731     .ATTAC  15735 *   .CLOSE  15737     .OPEN   15741     .READ   15743
                          .WRITE  15745     .BSR    15755 *   .READR  15765     .RELES  15767 *   .LAREA  16000
                          .LFBLK  16016     .LTSX   16021 *   .AREA1  16033     .LUNBL  16041     .ENTRY  16045
                          .GOA    16100     .GO     16104     .DERR   16120     .NOPXI  16121     .COMXI  16123
                          .EX34   16145
   6. .LXSL   16152       .LXSEL  16152     LXCSEL  16153     .LXTST  16156 *   .LXOVL  16216 *   .LXRCT  16227 *
                          .LXIND  16276 *   .LXDIS  16301 *   .LXFLG  16302 *   .LTCH   16303
   7. .FPTRP  16311       .FFPT.  16311 *   .FPOUT  16440     .FPARG  16446     /.COUNT/ 16450 *  OVFLOW  16514 *
   8. .ERAS.  16521       E.1     16521     E.2     16522     E.3     16523     E.4     16524
   9. .XCC.   16525       CC.1    16525     CC.2    16526     CC.3    16527     CC.4    16530
  10. XIT     16531       EXIT    16531     .EXIT.  16531 *
  11. FXEM    16532       .FXEM.  16532     .FXOUT  17067     .FXARG  17075     /.OPTW./ 17151
  12. FOUT    17162       .FOUT.  17162
  13. FCNV    17524       .FCON.  17524     .FCNV.  17547     .ENDFS  17562     .CNVSW  17564     .FOX1   17570
                          .FDX2   17571     .DBC    17573     .DBC8   17714     .DBC9   17717     .DBC10  17724
                          .DBC20  17752     .DDSW   17762     .DDFIX  17771     .FIXSW  17777     .DOBC   20054
                          .DDRS1  20326     .DDRS2  20330     .D1     20333     .D2     20335     .FERR2  20422 *
                          .ANPT   20456     .ONPT   20473     .LNTP   20547     .AOUT   20616     .DFLT   20634
                          .FLT    20770     .DEXPN  21060     .EXD    21061     .HOUT   21217     .INTG   21261
                          .LOUT   21377     .OOUT   21416     .XCF    21447     .TEST   22154     .KOUNT  22157
                          .LIST   22162     .DONE   22173     .OUTBF  22237     .BUF    22265     .OSTO   22266
                          .WIDTH  22267     .GAIN   22270     .GAIN1  22271     .FBDBF  22301     .DDDFL  22324
                          .ODFLG  22325     .MOD    22326     .PEX    22327     .FEXP   22330     .DIG    22331
  14. FIOS    22351       .FIOS.  22351     .FSEL.  22511     .FILR.  22515     .FRTB.  22524 *   .FRTD.  22531
                          .FILL.  22534     .FCLS   22536 *   .FOPN   22542 *   .REDF.  22546 *   .FOUT.  22711
                          .REED   22717 *   .BIN    22720 *   .FCT    22721     .FCKSZ  22723 *
  15. FIOH    23005       .FIOH.  23005     .FFIL.  23574     .FRTN.  23621 *
  16. FWRD    24006       .FWRD.  24006
  17. FWRU    24032       .FWRU.  24032
  18. FWRO    24056       .FWRO.  24056     .FREST  24361 *
  19. FRDU    24463       .FRDU.  24463
  20. UN05    24524       .UN05.  24524
  21. UN06    24525       .UN06.  24525     .BUFSZ  24526
  22. FIOU    24531       .FIOU.  24531     .CTUIO  25204     .NMLST  25227     .NAME.  26332     .INTAR  26333
  23. JASIN   26756       ASINR   27036     ASIN    27045 *   ASIND   27054 *
  24. JACOS   27063       ACOSR   27143 *   ACOS    27152     ACOSD   27161 *
```

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              IBLDR                                            12/01/64

 25. JTNQR    27170     ATANQR  27246     ATANQ   27255 *   ATANQD  27264 *
 26. JRSIM    27273     ARSIMP  27334
 27. FLOG     27365     ALOG10  27365     ALOG    27367
 28. FSCN     27526     COS     27526     SIN     27530
 29. FSQR     27737     SQRT    27737
 30. FATN     30044     ATAN2   30044     ATAN    30046 *
 31. FXP2     30252     .XP2.   30252
 32. .IOCS    30370     .L(0)   30370     .MONSW  30410     .TEOR   30457     .DEFI.  30537     .JOINX  30603 *
                        .CLOS.  30622     .ATTC.  30635     .SH1    31047 *   .SH9    31111 *   .OPEN.  31132
                        .OP4    31160 *   .OP7    31211 *   .OP9.2  31225 *   .RLSE.  31277     .RER2.  31277
                        .READ.  31300     .RER1.  31323     .WRIT.  31325     .MYT1A  31513 *   .EOFEX  31574 *
                        .FEEIT  31644     .GTIOX  31665     .RW7    32003 *   .RE7    32422 *   .ENDTR  33063
                        .SEL59  33065 *   .BSR.   33476     .EOTOF  33623     .ETOF3  33631 *   .SWITC  33660
                        .TCHEX  34161     .BASIO  34164 *
 33. .IOCSM   34165
 34. IDV      34165     IDV    (34165)
 35. PLOT..   34205     PLOT.. (34205)    (4020)  34216 *   CIPE..  34223 *   PLTND   34224 *   NOFRV   34234 *
                        BIGV    34304 *   SMALLV  34306 *   PAGE40  34313     PAGE41  34330     ID4G    34424
                        4OUT    34626 *
 36. UN16     35064     .UN16.  35064
 37. SCPOOL   35065     Z..PTA  35065     .XXSYY  35066     XXXX..  35067     YYYY..  35070     AX..    35071
                        AY..    35072 *   BX..    35073     BY..    35074 *   ML..    35075     MR..    35076 *
                        MB..    35077     MT..    35100 *   0.0     35101     WIDE..  35103     HIGH..  35104 *
                        ....YY  35107     .XX.YY  35110 *   ...S..  35111 *   HOLD..  35112     CAMV..  35113
                        YTOP..  35114 *   YREG..  35115 *
 38. CAMRAV   35116     CAMRAV (35116)    SC1..   35143 *   SC2..   35144 *   SBC..   35145 *
 39. FRAMEV   35151     FRAMEV (35151)    FRAMEV (35151)    RESETV  35212 *   BUMP..  35221 *   STOP..  35222
 40. BRITEV   35230     BRITEV (35230)    FAINTV  35232 *
 41. XSCALQ   35262     XSCALV  35273     YSCALV  35277     NXV     35412     NYV     35416     IXV     35455 *
                        IYV     35457 *   SCERRV  35462     SERSAV  35467 *   SERREV  35474 *   UXV     35503 *
                        UYV     35507 *   SCLSAV  35520 *   RESCLV  35532 *
 42. XMODQ    35602     XMODV   35602     YMODV   35602
 43. SMXYV    35616     SMXYV  (35616)    MSXYV   35623
 44. DXDYV    35630     DXDYV  (35630)
 45. GRIDIV   36417     GRIDIV (36417)
 46. LINEV    37325     LINEV  (37325)    GRIDXY  37540
 47. LINRV    37566     LINRV  (37566)
 48. NONLNV   40400     NONLNV (40400)
 49. SETGIV   41010     SETGIV (41010)    SETGOV  41014
 50. SETMIV   41020     SETMIV (41020)    SETMOV  41027
 51. HOLDIV   41036     HOLDIV (41036)    HOLDOV  41041
 52. ERMRKV   41044     ERMRKV (41044)
 53. ERRNLV   41056     ERRNLV (41056)
 54. ERRLNV   41242     ERRLNV (41242)
 55. APLOTV   41415     APLOTV (41415)
 56. PLOTV    41702     PLOTV  (41702)
 57. PRINTV   41721     PRINTV (41721)
 58. STOPTV   42031     STOPTV (42031)
 59. LABLV    42036     LABLV  (42036)
 60. HOLLV    42336     HOLLV  (42336)
 61. BNBCDQ   42363     BNBCDV  42363     BINBCD  42363 *
 62. RITE2Q   42604     RITSTV  42604 *   RITXYV  42627 *   RITE2V  42641
 63. VCHARV   43062     VCHARV (43062)    VCHX..  43313 *   VCHY..  43314 *   CHSIZV  43315     RTSIZV  43321
 64. TABL1Q   43327     TABL1V  43646
 65. AICRT    43650     AICRT3  46136
 66. SORTV    46445     SORT    46536

              IBLDR                                            12/01/64

 I/O BUFFERS                                 46572 THRU  77723

 UNUSED CORE                                 77724 THRU  77777
```

```
$INPUT
RN     =        0.10000000E 01,
DA2    =        0.00000000E-38,
A3     =        0.00000000E-38,
A3L    =       -0.00000000E-19,
DA3    =        0.00000000E-38,
A1     =        0.00000000E-38,
A1L    =        0.18000000E 03,
DA1    =        0.10000000E 02,
A2     =        0.00000000E-38,
A2L    =       -0.00000000E-19,
MEMO   =       -0.00000000E-19,
CASF   =        0.10000000E 01,
DATE   =       -0.00000000E-19,
THN    =        0.60000000E 02,
RSN    =        0.00000000E-38,
THC    =        0.60000000E 02,
PSC    =        0.12000000E 00,
PC     =        0.60000000E 01,
MASS   =        0.10000000E 01,
THP    =        0.00000000E-38,
RP     =        0.00000000E-38,
RSP    =        0.12000000E 00,
THA    =       -0.90000000E 02,
RT     =        0.30000000E 01,
RA     =        0.00000000E-38,
SM     =        0.00000000E-38,
CMAG   =        0.00000000E-38,     0.00000000E-38,
M2     =                  10,
M4     =                  10,
M7     =                  10,

M8     =                  10,
LC     =        0.00000000E-38,
M10    =                  10,
XCG    =        0.30000000E 01,
ZCG    =        0.00000000E-38,
DERDEL =        0.50000000E-02,
BETA   =        0.00000000E-38,
GSO    =        0.00000000E-38,
XINP   =       -0.00000000E-19,    -0.00000000E-19,    -0.00000000E-19,    -0.00000000E-19,    -0.00000000E-19,
               -0.00000000E-19,    -0.00000000E-19,    -0.00000000E-19,    -0.00000000E-19,    -0.00000000E-19,
               -0.00000000E-19,    -0.00000000E-19,    -0.00000000E-19,    -0.00000000E-19,    -0.00000000E-19,
               -0.00000000E-19,    -0.00000000E-19,    -0.00000000E-19,    -0.00000000E-19,    -0.00000000E-19,
               -0.00000000E-19,    -0.00000000E-19,    -0.00000000E-19,    -0.00000000E-19,    -0.00000000E-19,
RINP   =       -0.00000000E-19,    -0.00000000E-19,    -0.00000000E-19,    -0.00000000E-19,    -0.00000000E-19,
               -0.00000000E-19,    -0.00000000E-19,    -0.00000000E-19,    -0.00000000E-19,    -0.00000000E-19,
               -0.00000000E-19,    -0.00000000E-19,    -0.00000000E-19,    -0.00000000E-19,    -0.00000000E-19,
               -0.00000000E-19,    -0.00000000E-19,    -0.00000000E-19,    -0.00000000E-19,    -0.00000000E-19,
               -0.00000000E-19,    -0.00000000E-19,    -0.00000000E-19,    -0.00000000E-19,    -0.00000000E-19,
TH2G   =        0.00000000E-38,
TH3G   =        0.00000000E-38,
NPGSO  =                   0,
NDIV   =                  20,
$ END
```

```
PROGRAM 1881     MEMO= -0.00      CASE=  1.00      DATE= -0.00

         X                     R
          0.13397460            0.50000001
          3.27474007            5.94000000
          3.28160107            5.95053422
          3.28950572            5.96029562
          3.29838744            5.96917737
          3.30814886            5.97708201
          3.31868309            5.98392302
          3.32987469            5.98962539
          3.34160107            5.99412674
          3.35373369            5.99737769
          3.36613968            5.99934262
          3.37868309            5.99999994
          3.39538383            5.99883211
          3.41175956            5.99535131
          3.42749149            5.98962539
          3.44227238            5.98176569
          3.45581758            5.97192526
          3.46786046            5.96029556
          3.47816759            5.94710308
          3.48653835            5.93260443
          3.49280986            5.91708195
          3.49686000            5.90083772
          4.00835592            3.00000000
          4.00835592            0.00000000


ALPHA  XCC      CN       CX       CM       CMO      CLA      CL       CD       CL/CD     XCP/D

  0    0.00    0.0000   1.4884   0.0000  -0.6424  -0.9768  -0.0000   1.4884  -0.0000    0.7469
       3.00                      0.0000  -0.3243

 10    0.00    0.0875   1.4512  -0.0654  -0.6328  -0.8946  -0.1658   1.4444  -0.1148    0.7467
       3.00                     -0.0435  -0.3193

 20    0.00    0.1648   1.3442  -0.1229  -0.6043  -0.6729  -0.3048   1.3195  -0.2310    0.7458
       3.00                     -0.0817  -0.3047

 30    0.00    0.2229   1.1801  -0.1658  -0.5577  -0.3663  -0.3970   1.1334  -0.3503    0.7441
       3.00                     -0.1101  -0.2810

 40    0.00    0.2550   0.9785  -0.1890  -0.4947  -0.0494  -0.4337   0.9135  -0.4748    0.7413
       3.00                     -0.1253  -0.2489

 50    0.00    0.2575   0.7637  -0.1897  -0.4172   0.2033  -0.4195   0.6882  -0.6095    0.7367
       3.00                     -0.1254  -0.2096

 60    0.00    0.2306   0.5612  -0.1680  -0.3277   0.3373  -0.3707   0.4803  -0.7718    0.7286
       3.00                     -0.1104  -0.1645

 70    0.00    0.1824   0.3863  -0.1301  -0.2689   0.4692  -0.3006   0.3035  -0.9904    0.7133
       3.00                     -0.0845  -0.1352

 80    0.00    0.1295   0.2378  -0.0885  -0.2199   0.5334  -0.2117   0.1689  -1.2538    0.6836
       3.00                     -0.0562  -0.1114

 90    0.00    0.0837   0.1105  -0.0479  -0.1908   0.6431  -0.1105   0.0837  -1.3202    0.5724
       3.00                     -0.0270  -0.1160

100    0.00    0.0540  -0.0369  -0.0085  -0.2298   0.9426   0.0269   0.0596   0.4523    0.1583
       3.00                      0.0050  -0.1929

110    0.00    0.0404  -0.2428   0.0203  -0.2884   1.1671   0.2143   0.1210   1.7718   -0.5019
       3.00                      0.0304  -0.2959

120    0.00    0.0393  -0.5058   0.0346  -0.3563   1.1355   0.4184   0.2869   1.4584   -0.8806
       3.00                      0.0444  -0.3993

130    0.00    0.0400  -0.8164   0.0406  -0.4539   0.8760   0.5997   0.5554   1.0798   -1.0168
       3.00                      0.0506  -0.5115

140    0.00    0.0374  -1.1462   0.0414  -0.5385   0.3084   0.7081   0.9021   0.7850   -1.1066
       3.00                      0.0507  -0.6087

150    0.00    0.0315  -1.4558   0.0367  -0.6072  -0.4296   0.7006   1.2765   0.5488   -1.1658
       3.00                      0.0446  -0.6878

160    0.00    0.0228  -1.7080   0.0274  -0.6580  -1.1520   0.5627   1.6128   0.3489   -1.2032
       3.00                      0.0331  -0.7461

170    0.00    0.0120  -1.8775   0.0146  -0.6891  -1.6736   0.3134   1.8462   0.1697   -1.2240
       3.00                      0.0176  -0.7819

180    0.00    0.0000  -1.9297   0.0000  -0.6996  -1.8599   0.0000   1.9297   0.0000   -1.2296
       3.00                      0.0000  -0.7940

RHO N=  0.00356    RHO A=  0.00755    XCG=  3.00000    XCG/D=  0.25000    RGX/D=  0.29978    RGY/D=  0.22102
```

```
  2663 LINES OUTPUT.
      $IBSYS
      $PAUSE
      OPFR. ACTION PAUSE

      ..CONTINUING

      $PAUSE
      OPFR. ACTION PAUSE

      ..CONTINUING

      $IBSYS
000000000000Q0000080001I-0101GQ0000080001F000000IBSYST-00001000006400700000000 )
     1 LINES OUTPUT THIS JOB.
```

III. COMPUTATIONS

A. BLOCK DIAGRAM

A block diagram illustrating the information flow within the Program 1881 is given in Figure 6.

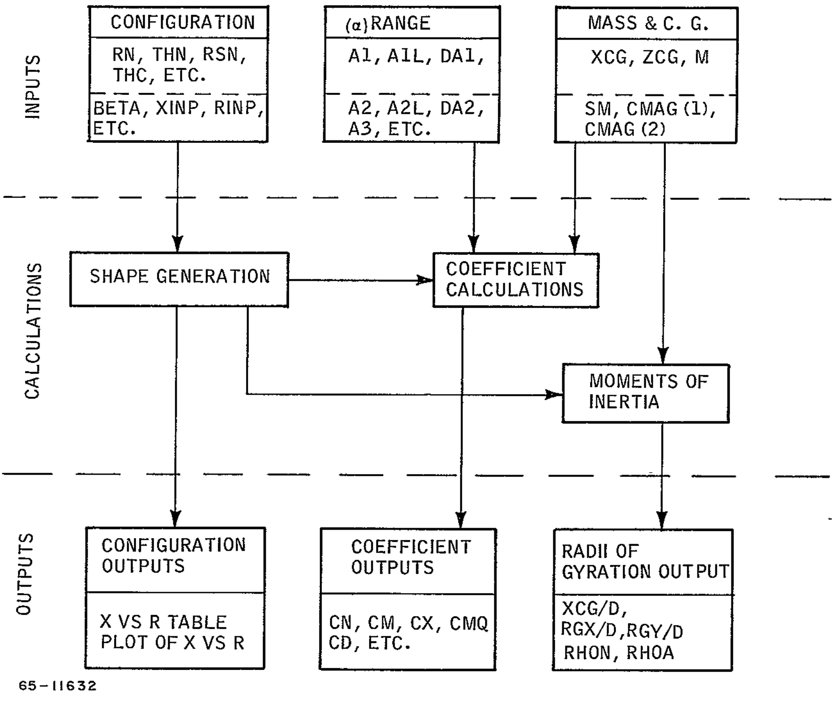

Figure 6 BLOCK DIAGRAM OF PROGRAM 1881

B. SYMBOLS

$A_i(x)$	function defined by equation (10)
$B_i(x)$	function defined by equation (11)
C_D	drag coefficient
C_L	lift coefficient
C_m	moment coefficient (based on characteristic radius R_c and characteristic length d)
C_{m_α}	$(\partial C_m/\partial \alpha)$
C_{m_q}	$(\partial C_m/\partial Q)$
C_N	coefficient of force normal to body
C_x	coefficient of force along body axis
d	characteristic length, diameter (feet) = $2 R_c$
dQ	increment in Q used to compute derivatives (radians) $dQ = 0.005$
$d\alpha$	increment in α used to compute derivatives (radians) $d\alpha = 0.005$
$G_i(x)$	function defined by equation 12
L_c	length of cylindrical section
M	vehicle mass
q	angular pitch speed (rad/sec)
Q	pitching speed parameter: $Q = qd/2V$ (radians)
R_B	radius of flare
R_c	characteristic radius (cylinder radius, usually)
R_N	radius of spherical nose cap
R_{SB}	toroidal radius between flare and aftcone
R_{SC}	toroidal radius following cone
R_{SN}	toroidal radius following nose cap
R_T	radius of truncated afterbody
SM	static margin
V_A	volume rear of c. g. position
V_N	volume forward of c. g. position
x	axial coordinate; nose is located at $x = 0$
X_f	length of body
X_{CG}	distance of center of gravity from nose
X_{CP}	distance of center of pressure from nose
Z_{CG}	offset distance of center of gravity
$Z_i(x)$	function defined by equation (14)
α	angle of attack
β	slope at start of tension shell

ρ_A	density aft of c g. position
ρ_N	density forward of c.g. position
θ	body contour slope
θ_A	slope of aftcone
θ_B	slope of flare
θ_C	slope of cone
θ_N	slope at end of nose cap
θ_{2G}	slope at start of general shape
θ_{3G}	slope at end of general shape
θ_{3T}	slope at end of tension shell
ω_i	Function defined by Equation (15)

Subscripts

$i = 0$ denotes moments taken about the nose

$i = g$ denotes moments taken about the center of gravity

C. EQUATIONS

1. Coefficient Calculation

a Newtonian Coefficients

$$C_{N_i} = -\frac{2}{\pi R_c^2}\int_0^{X_f}\left[-A_i(x)\cos\omega_i^* + B_i(x)\left(\frac{\omega_i^*}{2} - \frac{1}{4}\sin 2\,\omega_i^* + \frac{\pi}{4}\right)\right. \tag{1}$$

$$\left. - \frac{2}{3}\,G_i(x)\cos\omega_i^*\,(\sin^2\omega_i^* + 2)\right] r(x)\,dx$$

$$C_{X_i} = \frac{2}{\pi R_c^2}\int_0^{X_f}\left[A_i(x)\left(\omega_i^* + \frac{\pi}{2}\right) - B_i(x)\cos\omega_i^*\right. \tag{2}$$

$$\left. + 2G_i(x)\left(\frac{\omega_i^*}{2} - \frac{1}{4}\sin 2\,\omega_i^* + \frac{\pi}{4}\right)\right] r(x)\tan\theta\,dx$$

$$
\begin{aligned}
C_{m_i} = \frac{2}{\pi R_c^{\,2}} \int_o^{x_f} \Bigg[& -A_i(x)\,\frac{Z_i}{l}\,\sin\theta\left(\omega_i^{\,*} + \frac{\pi}{2}\right) - A_i(x)\,K_i(x) \qquad (3) \\
& - B_i(x)\,\frac{Z_i}{l}\,\sin\theta \Bigg)\cos\omega_i^{\,*} + \left(B_i(x)\,K_i(x) - 2\,G_i(x)\,\frac{Z_i}{l}\,\sin\theta\right) \\
& \left(\frac{\omega_i^{\,*}}{2} - \frac{1}{4}\,\sin 2\,\omega_i^{\,*} + \frac{\pi}{4}\right) - \frac{2}{3}\,G_i(x)\,K_i(x)\,\cos\omega_i^{\,*}\Bigg(\sin^2\omega_i^{\,*} \\
& + 2\Bigg)\Bigg]\frac{r(x)}{\cos\theta}\,dx
\end{aligned}
$$

$$C_{L_i} = -\,C_{X_i}\,\sin\alpha + C_{N_i}\,\cos\alpha \tag{4}$$

$$C_{D_i} = C_{X_i}\,\cos\alpha + C_{N_i}\,\sin\alpha \tag{5}$$

$$X_{CP}/d = -\,C_{m_o}/C_{N_o} \tag{6}$$

$$C_{m_{\alpha_i}} = \frac{\partial C_{m_i}}{\partial\alpha} = \frac{C_{m_i}(\alpha + d\alpha, Q) - C_{m_i}(\alpha, Q)}{d\alpha} \tag{7}$$

$$C_{L_{\alpha_i}} = \frac{\partial C_{L_i}}{\partial\alpha} = \frac{C_{L_i}(\alpha + d\alpha, Q) - C_{L_i}(\alpha, Q)}{d\alpha} \tag{8}$$

$$C_{m_{qi}} = \frac{\partial C_{m_i}}{\partial Q} = \frac{C_{m_i}(\alpha, Q + dQ) - C_{m_i}(\alpha, Q)}{d\,Q} \tag{9}$$

b. Auxiliary Equations

$$A_i(x) = 2\,\sin^2\theta\,\cos\alpha\left(\cos\alpha + 2\,Q\,\frac{Z_i}{l}\right) \tag{10}$$

$$B_i(x) = -2 \sin \theta \left[\cos \theta \sin 2\alpha + 2Q \left(K_i(x) \cos \alpha + \frac{Z_i}{l} \cos\theta \sin \alpha \right) \right] \tag{11}$$

$$G_i(x) = \cos \theta \sin \alpha \left(\cos \theta \sin \alpha + 2Q\, K_i(x) \right) \tag{12}$$

$$K_i(x) = \frac{r(x)}{l} \sin \theta + \frac{x - x_i}{l} \cos \theta \tag{13}$$

$$Z_i = \begin{array}{l} 0 \text{ IF } i = 0 \\ Z_g \text{ IF } i = g \end{array} \tag{14}$$

$$\omega_i^* = \begin{cases} \text{ARC} \sin \left(\dfrac{\sin \theta \cos \alpha}{\cos \theta \sin \alpha} \right) \text{ IF } \left| \dfrac{\sin \theta \cos \alpha}{\cos \theta \sin \alpha} \right| \leq 1 \\ \pi/2 \text{ If } \cos \theta \sin \alpha = 0 \text{ and } \sin\theta \cos \alpha \geq 0 \\ -\pi/2 \text{ If } \cos \theta \sin \alpha = 0 \text{ and } \sin \theta \cos \alpha < 0 \\ \pi/2 \text{ If } \dfrac{\sin \theta \cos \alpha}{\cos \theta \sin \alpha} > 1 \\ -\pi/2 \text{ If } \dfrac{\sin \theta \cos \alpha}{\cos \theta \sin \alpha} < -1 \end{cases} \tag{15}$$

c. Center of Gravity Determination

1) C_{m_α} Criteria

$$\left(X_{CG} \right)_{\alpha = 0} = \frac{d}{C_{N_\alpha}} \left[\left(C_{m_\alpha} \right)_{\text{spec.}} - \left(C_{m_\alpha} \right)_{i = 0} \right]_{\alpha = 0} \tag{16}$$

$$\left(X_{CG} \right)_{\alpha = 180} = \frac{d}{C_{N_\alpha}} \left[\left(C_{m_\alpha} \right)_{\text{spec.}} - \left(C_{m_\alpha} \right)_{i = 0} \right]_{\alpha = 180} \tag{17}$$

2) <u>Static Margin Criteria</u>

$$\text{At } \alpha = 0, \; X_{CG} = X_{CP} - SM$$

$$\text{At } 0 < \alpha \leq 180, \; X_{CG} \leq X_{CP}$$

2. Moments of Inertia

a. Density Distribution

$$X_{CG} = \left[\frac{\displaystyle\int_0^{X_{CG}} xr^2 dx + \frac{\rho_A}{\rho_N} \int_{X_{CG}}^{X_f} xr^2 \, dx}{\displaystyle\int_0^{X_{CG}} r^2 \, dx + \frac{\rho_A}{\rho_N} \int_{X_{CG}}^{X_f} r^2 \, dx} \right] \tag{18}$$

$$M = \rho_N \left(V_N + \frac{\rho_A}{\rho_N} V_A \right) \tag{19}$$

where,

$$V_N = \pi \int_0^{X_{CG}} r^2 dx \tag{20}$$

$$V_A = \pi \int_{X_{CG}}^{X_f} r^2 \, dx \tag{21}$$

b. Moments of Inertia

$$I_y = \pi \rho_N \left[\int_0^{X_{CG}} x^2 r^2 \, dx + \frac{\rho_A}{\rho_N} \int_{X_{CG}}^{X_f} x^2 r^2 \, dx + \frac{1}{4} \int_0^{X_{CG}} r^4 \, dx \right.$$

$$\left. + \frac{\rho_A}{4 \rho_N} \int_{X_{CG}}^{X_f} r^4 \, dx \right] - M \, X_{CG}^2 \tag{22}$$

$$I_x = \frac{\pi \rho_N}{2} \left[\int_0^{X_{CG}} r^4 \, dx + \frac{\rho_A}{\rho_N} \int_{X_{CG}}^{X_f} r^4 \, dx \right] \tag{23}$$

IV. IBM ROUTINES

A. PROGRAM FLOW

A flow diagram of Program 1881 is shown as Figure 7.

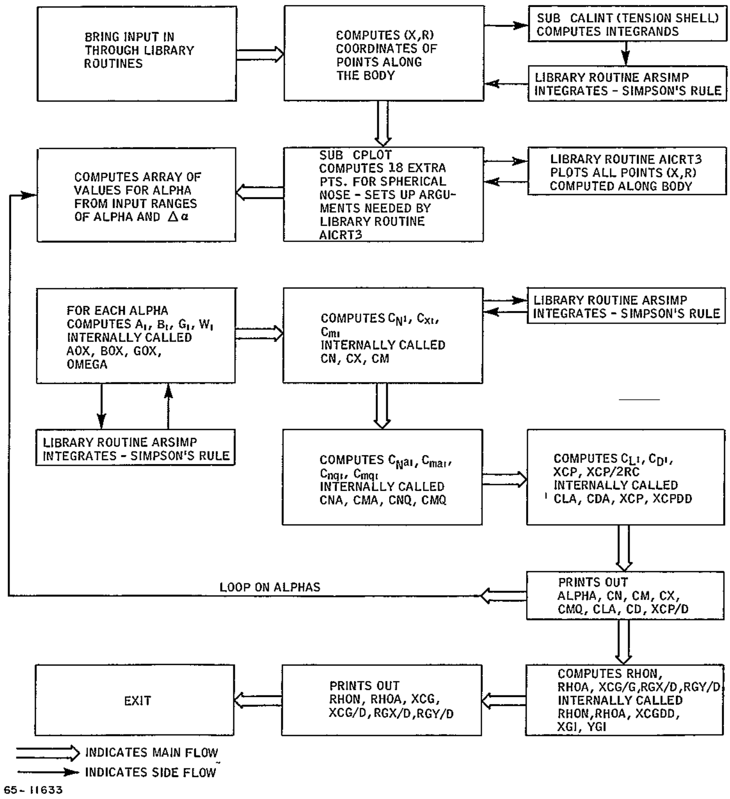

Figure 7 FLOW DIAGRAM OF PROGRAM 1881

B. SUBROUTINES

	VARIABLE	THR	DELR	R3	RK	SBETAR	CBETAR	RJ	Q000FL
CALINT	SUBROUTINE INPUT OR OUTPUT	INPUT	INPUT	INPUT	INPUT	INPUT	INPUT	OUTPUT	OUTPUT
	SOURCE	INPUT	MAIN	MAIN	MAIN	MAIN	MAIN		

	VARIABLE	X	R	L	T	RN	THETAN	RAD
CPLØT	SUBROUTINE INPUT OR OUTPUT	INPUT	INPUT	INPUT	INPUT	INPUT	INPUT	INPUT
	SOURCE	MAIN	MAIN	MAIN	INPUT	INPUT	MAIN	MAIN

1. Subroutine CALINT

a. Purpose

This subroutine is used in the case of the tension shell (third section) to compute the integrands Q000FL required to apply Simpson's Rule in subroutine ARSIMP.

b. Method

Starting with initial angle BETA at the first point of the section, other points along the section for each DELR increment in the radius are computed. The section is subdivided into NDIV portions. To compute the abcissa X of the righthand point of each of these portions, an integration is performed over each portion. Thirty-two (32) intervals are considered for each portion and, therefore, a loop is set up to compute the integrands Q000FL at 33 points. For each of these points the ordinate RJ is computed in the same loop. The last computed RJ for each portion is the ordinate of the point corresponding to that portion.

2. Subroutine CPL0T

a. Purpose

To set up the array of points (X, R) to be plotted by library routine AICRT3.

b. Method

In MAIN, the first point computed is the end point of the first section. Therefore, for the purpose of plotting the whole body, compute 18 extra points in the first section of CPL0T. These extra points are then incorporated into the X and R arrays of points computed in MAIN. CPL0T also computes the maximum values XU and YU for X and R from the respective arrays and chooses the greater of the two to establish the scale of the plot.

All the variables in the calling sequence of library routine AICRT3 are set to the proper values and the total array of points XPT (abcissas) and RPT (ordinates) are then plotted on the 4020.

3. Main Program

a. Purpose

The main program computes the array of coordinates (X, R) along the body, defines table of alphas to be considered, performs preliminary computations for the integration procedures, sets up the main logical flow of the problem and performs the final computations to obtain the aerodynamic coefficients.

b. Method

The program first sets the values of all preset input, then reads in the data through the Namelist array INPUT.

After converting all input angles to radians and finding the values of their sines and cosines, the program proceeds to compute the coordinates (X, R) of the points considered for each section. The first point to be computed is the intersection of the nose radius with the body surface, i. e., the end point of the first section (Statement No. 302). All curved sections (except the first) are subdivided into the prescribed input number, M2, M4, M7, M8, and M10. If these are not input, the program will use the preset values. The third section may have one of the three different shapes, i.e., general, tension, or conic shape.

In the general shape (Statement No. 9141), the points along the section are input (XINP, RINP) and are merely incorporated in the (X, R) arrays of coordinates for the whole body.

In the case of the tension shape (Statement No. 486), the initial angle BETA is input and the program computes the points determined by the input number of divisions NDIV. The angle θ along the section lies between BETA $\leq \theta \leq 90$ degrees and for the last point on the section $\theta = 90$ degrees. The number of divisions is preset to 20. For each subdivision a point (X, R) will be computed. The ordinate R is obtained by adding an increment ΔR to the R of the previous point. Each ΔX is obtained by integrating over the respective subdivision (Loop on Statement No. 5533). For integration purposes in each subdivision, 32 intervals (or 33 auxiliary points) are considered. The integrands Q000FL are computed in subroutine CALINT. Then library routine ARSIMP integrates using Simpson's Rule.

The ordinate R is, for each subdivision, the value RJ computed in CALINT. In the case of a conic shape (Statement No. 484), only the end point is computed. The remaining sections are handled by straightforward application of the given formulas. For RSB $\neq 0$ (internally RSCB), the program assumes that both toroidal sections 10 and 9 are given.

Symbol L represents the number of points whose coordinates were computed along the body. These L points plus 18 extra points on the nose computed by subroutine CPLØT will be plotted (R versus X) by library routine AICRT3, using the first available tape on channel A.

Arrays X(1-L) and R(1-L) are then printed out (Statement No. 4999) and the program proceeds by forming the angle of attack table for the 3 possible ranges using the input A1, A2, A3, A1L, A2L, A3L and the input increments DA1, DA2, DA3 (Statements between Statement Nos. 13 and 20).

A loop on ALPHAS (Statement number 1003) is set up comprising most of the rest of the program, i.e., for each ALPHA a set of force and moment coefficients (C_{N_i}, C_{X_i}, C_{m_i}, C_{L_i}, C_{D_i}, $(L/D)_i$, Xcp and the corresponding derivatives $C_{N_{a_i}}$, $C_{m_{a_i}}$, $C_{N_{q_i}}$ and $C_{m_{q_i}}$ are computed.

The loop on ALPHAS is the outermost of a nest of loops which are completed as follows loop for subscript Ø and XG (Statement number 345), loop to compute numerically the derivatives CNA, CMA, CNQ, and CMQ (DØ 91 MM - 1, 3), loop for the integration of body sections L(Statement number 2774)(the body is subdivided into a number of portions equal to the number of computed points), and loop for computation of integrands (DØ 50 M = 1, J) (each of the L sections is further subdivided into a maximum of 9 intervals before Simpson's Rule (subroutine ARSIMP) is applied).

After exiting from this nest of loops, (after Statement No. 389) ρ_N (internally RHØN), ρ_A (internally RHØA), XCG/D (internally XCGDD), RGX/D, RGY/D are computed.

Within the ALPHA loop, the program prints out for each ALPHA the coefficients CN, CM, CX, CMQ, CLA, CD, CL/CD, and XCP/D (immediately after Statement No. 370).

Outside this loop, at the very end of the program, the quantities RHØN, RHØA, XCG, XCG/D, RGX/D, and RGY/D are printed out.

C. SIGNIFICANT EQUATIONS

1. Main Program — Statement Number*

Section 1 (NØSE): $X(1) = RN \cdot [1 - \cos(\text{THETAN})]$

$$R(1) = \sqrt{X(1) \cdot [2RN - X(1)]}$$ 302

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* The statement numbers are provided to assist in locating the equations in the program listing as the equations noted appear in the immediate vicinity of these statement numbers.

Section 2 (TØRØIDAL):

$$X(J) = X(1) + RS \cdot \left\{ \cos(THETAN) - \sin\left\{ XJ \quad \frac{[90 - (THETAN + THETAC)]}{XM2} \right\} \right\}$$

where, XJ = 1, . . . , XM2

$$R(J) = R(1) + RS \cdot \left\{ \cos\left\{ XJ \quad \left[\frac{90 - (THETAN + THETAC)}{XM2} \right] \right\} - \sin(THETAN) \right\} \qquad 303$$

Section 3 (CØNIC):

$$R(K) = RC - RSCA\,[1 - \cos(THETAC)]$$

$$X(K) = X(K-1) + [R(K) - R(K-1)]\ \frac{\cos(THETAC)}{\sin(THETAC)}\ , \qquad 306$$

Section 4 (TØRØIDAL):

$$X(J) = X(K) + RSCA\,[\sin(THETAC) - \sin(TJ)]$$

$$R(J) = R(K) + RSCA\,[\cos(TJ) - \cos(THETAC)]$$

where,

$$TJ = \frac{(XJ \cdot TM4)}{RAD}$$

and, $TM4 = THETAC/M4$ 325

Section 5 (CYLINDRICAL):

$$X(K) = X(K-1) + DX1$$

$$R(K) = RC \qquad 312$$

Section 6 (CØNIC):

$$R(K) = RB - RSCB\,[1 - \cos(FTHETA)]$$

$$X(K) = X(K-1) + (R(K) - RC) \cdot \frac{\cos(FTHETA)}{\sin(FTHETA)} \qquad 314$$

Section 7 (TØRØIDAL):

$$X(J) = X(K) + RSCB\ [\sin(FTHETA) - \sin(TJ)]$$

$$R(J) = R(K) + RSCB \cdot [\cos(TJ) - \cos(FTHETA)]$$

where, $TJ = XJ \cdot \dfrac{FTHETA}{M7}\ /RAD$ 317

Section 8 (TØRØIDAL):

$$X(J) = X(K) + RSCB \cdot \sin(TJ)$$

$$R(J) = RB - RSCB \cdot [1 - \cos(TJ)]$$

$$\text{where, } TJ = XJ \cdot \frac{THETAA}{M8} / RAD \qquad 317$$

Section 9 (CØNIC)·

$$R(K) = RA$$

$$X(K) = X(K-1) + [R(K-1) - R(K)] \cdot \frac{\cos(THETAA)}{\sin(THETAA)} \qquad 321$$

Section 10 (SPHERICAL):

$$X(J) = X(K) + RSA \cdot [\sin(TJ) - \sin(THETAA)].$$

$$R(J) = R(K) - RSA \cdot [\cos(THETAA) - \cos(TJ)]$$

$$\text{where, } TJ + [XJ \cdot (90 - THETAA)/M10 + THETAA]/RAD \qquad 326$$

$$B\O X = -2\sin(THETA) \left\{ \cos(THETA) \cdot \sin 2ALPHA + 2ZAQ \left[XK \cdot \cos(ALPHA) + + \frac{ZZ(II)}{SL} \cdot \cos(THETA) \quad \sin(ALPHA) \right] \right\}$$

$$\text{where, } ZK = RX(M) \cdot \frac{\sin(THETA)}{SL} + (XZ(M) - ZX) \cdot \frac{\cos(THETA)}{SL} \qquad 48$$

$$A\O X = 2\sin^2(THETA \cdot \cos(ALPHA) \cdot \left[\cos(ALPHA) + 2ZAQ \cdot \frac{ZZ(II)}{SL} \right] \qquad 48$$

$$G\O X = \cos(THETA) \quad \sin(ALPHA) \quad [\cos(THETA) \cdot \sin(ALPHA) + 2ZAQ \cdot ZK] \qquad 48$$

$$CN(M) = \left[-A\O X \quad \cos(\O MEGA) + B\O X \quad \O Z - 2G\O X \cdot \cos(\O MEGA) \cdot \frac{(\sin^2(\O MEGA)+2)}{3} \right] \cdot RX(M) \qquad 48$$

$$\text{where, } \O Z = 5\ \O MEGA - .25\sin(2\O MEGA) + .78539816$$

$$RX(M) = \sqrt{2RN \quad XZ(M) - XZ(M)^2}$$

$$CX(M) = [A\O X \cdot (OMEGA + 1\ 5707963) - B\O X \ \cos(\O MEGA) + 2 \cdot \O Z \cdot G\O X] \cdot RX(M) \frac{\sin(THETA)}{\cos(THETA)} \qquad 48$$

$$\begin{aligned}\mathrm{CM(M)} = \Big\{ &- \mathrm{AOX} \cdot \mathrm{ZZ(II)} \quad \sin(\mathrm{THETA}) \cdot (\mathrm{OMEGA} + 1\ 5707963) - \\ &- [\mathrm{AOX} \cdot \mathrm{ZK} \cdot \mathrm{SL} - \mathrm{BOX} \cdot \mathrm{ZZ(II)} \cdot \sin(\mathrm{THETA})] \cdot \cos(\mathrm{OMEGA}) + \\ &+ [\mathrm{BOX} \quad \mathrm{ZK} \quad \mathrm{SL} - 2\,\mathrm{GOX} \quad \mathrm{ZZ(II)} \cdot \sin(\mathrm{THETA})] \cdot \mathrm{OZ} - \\ &- 2\,\frac{\mathrm{GOX}}{3} \cdot \mathrm{ZK} \cdot \mathrm{SL} \quad \cos(\mathrm{OMEGA})[\sin^2(\mathrm{OMEGA}) + 2]\Big\} \cdot \frac{\mathrm{RX(M)}}{\cos(\mathrm{THETA})} \qquad 48\end{aligned}$$

$$\mathrm{CD(MM)} = \mathrm{CX1} \cdot \cos(\mathrm{ALPHA}) + \mathrm{CN1} \cdot \sin(\mathrm{ALPHA}) \qquad 48$$

$$\mathrm{CL(MM)} = \mathrm{CX1} \quad \sin(\mathrm{ALPHA}) + \mathrm{CN1} \cdot \cos(\mathrm{ALPHA}) \qquad 93$$

$$\mathrm{CNA} = \frac{(\mathrm{CN3} - \mathrm{CN1})}{\mathrm{DDL}} \qquad 352$$

$$\mathrm{CMA} = \frac{(\mathrm{CM3} - \mathrm{CM1})}{\mathrm{DDL}}$$

$$\mathrm{CNQ} = \frac{(\mathrm{CN2} - \mathrm{CN1})}{\mathrm{DDL}}$$

$$\mathrm{CMQ} = 2 \quad \frac{(\mathrm{CM2} - \mathrm{CM1})}{\mathrm{DDL}}$$

$$\mathrm{XCP} = - \mathrm{SL} \cdot \frac{\mathrm{CM1}}{\mathrm{CN1}} \qquad 920$$

2. Subroutine CALINT

$$\mathrm{THR} = \mathrm{THR} \quad \mathrm{DELR} * \mathrm{DERIN}$$

$$\mathrm{RJ} = \mathrm{RJ} \quad \mathrm{DELR}$$

where, $\mathrm{COTM} = (\mathrm{COTT} \quad \mathrm{COTTM1})/2.$

$$\mathrm{ALOGBE} = \mathrm{LOG}\left[\frac{1 + \cos(\mathrm{BETAG})}{\sin(\mathrm{BETAR})}\right]$$

$$\mathrm{DERVR1} = \left\{\frac{\mathrm{RK}^2 - \mathrm{R3}^2}{\mathrm{ALOGBE}} \cdot \frac{\sin(\mathrm{THR})}{1 + \cos(\mathrm{THR})} \cdot \left[- 1 - \frac{(1 + \cos(\mathrm{THR})) \quad \cos(\mathrm{THR})}{\sin^2(\mathrm{THR})}\right]\right\}$$

$$\mathrm{DERIN} = \mathrm{RJ}/(0.5 * \mathrm{DERVR1})$$

3. <u>Subroutine CPLØT</u>

$$\mathrm{ANGL} = (\mathrm{XK} \cdot \mathrm{DIVTHN})/\mathrm{RAD}$$

where, $\mathrm{DIVTHN} = \mathrm{THETAN}/18.$

and, $\mathrm{XK} = 1, \ldots 18$

$$\mathrm{XPT(I)} = \mathrm{RN} \cdot [1 - \cos(\mathrm{ANGL})]$$ 60

$$\mathrm{RPT\ (I)} = \mathrm{RN} \quad \sin(\mathrm{ANGL})$$

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PROGRAM 1882

PROGRAM
1882

SUBSYSTEM WEIGHTS PROGRAM (1882)

CONTENTS

ILLUSTRATIONS

I. INTRODUCTION

A. GENERAL DESCRIPTION

The purpose of this program is to determine the component system weights for an axisymmetric entry vehicle. The program has four distinct segments within which exists a number of options. The four segments are as follows

1. Heat Shield and Structural Shell -- The inboard profile coordinates of the vehicle are generated based on body input parameters. The moments of inertia, center of gravity, area and weight of each section of the vehicle are then computed. The weights are based upon specified unit weights for the heat shield and structure of each section.

2. Descent System -- The descent system weight computation is based on specified deployment and impact conditions. Three options exist (a) a two chute; (b) a single-chute, or (c) a drogue-chute retrorocket system.

3. Impact Attenuation System -- The amount of crushup weight is computed so as to assure a soft landing within impact velocity and acceleration limits. Three options exist as to the landed package configuration: (a) spherical; (b) lenticular; or (c) conical. The latter option utilizes a spherical segment of crushup and assumes preferred impact orientation. All of the options yield the geometric dimensions of the crushup and payload.

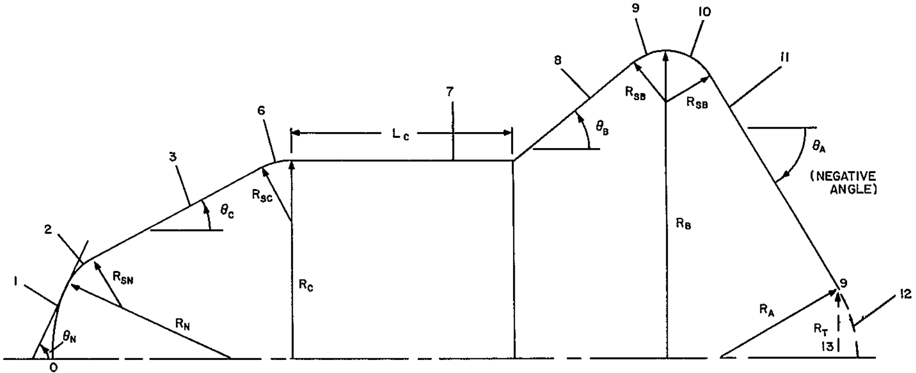
4. Packaging Design -- This portion of the program packages the landed package and descent system components within the inboard profile limits of the vehicle. A minimum overall specified center of gravity must be satisfied. With the overall vehicle center-of-gravity position established, the moments of inertia are then computed for the entire capsule. The internal structural weight of the lander is also computed in this portion of the program.

B. CALCULATION MODEL

The calculation model for each of the four segments of Program 1882 is as follows:

1. Heat Shield and Structural Shell

a. The evolved body coordinates of the vehicle reflect the bond line profile of the heat shield and structure shell. The heat shield and structural unit area weights are input for each vehicle section. The vehicle sections are identified parametically as shown in Figures 1 and 2.

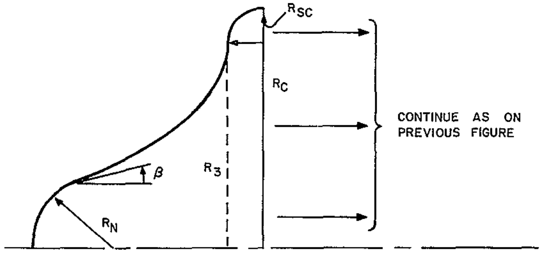


SECTION
1 NOSE SPHERE
2 R_{SN} TORUS
3 CONE (SEE FIGURE 2 FOR ADDITIONAL OPTIONS)
6 R_{SC} TORUS
7 CYLINDER
8 FLARE
9 FORE R_{SB} TORUS
10 AFT R_{SB} TORUS
11 AFT CONE
12 AFT SPHERE (R_A)
13 BASE (R_T)

65-11627

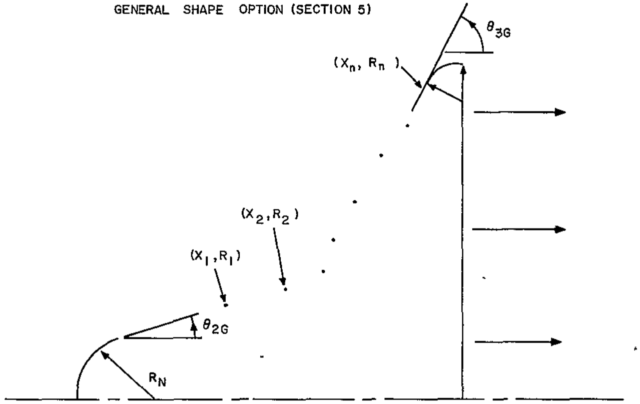
Figure 1 VEHICLE SHAPE PARAMETERS

TENSION SHELL OPTION (SECTION 4)



β - TENSION SHELL INPUT PARAMETER
R_3 - BASE RADIUS OF TENSION SHELL (NOT INPUT)

GENERAL SHAPE OPTION (SECTION 5)



θ_{2G}, θ_{3G}, X, R - GENERAL SHAPE INPUT PARAMETERS
$n \leq 25$

65-11628

Figure 2 TENSION SHELL AND GENERAL SHAPE GEOMETRIES

b. The inertia, center of gravity, and area equations are based on a derivation assuming the heat shield and structure thickness to be small and uniform.

2. Descent System

a. The model atmosphere generated consists of a troposphere and stratosphere. Equations for the thermosphere are not utilized since it is reasonable to assume that chute deployment will always occur at an altitude well below the thermosphere region.

b. The equations of motion utilized in the trajectories are the two degree of freedom equations neglecting the centripetal acceleration and lift terms.

c. The drogue chute descent calculation assumes that the chute opens instantaneously, and hence does not account for the loss in altitude due to the filling time. This is a reasonable assumption since drogue chutes are usually fairly small in diameter with filling times in the order of 0.05 second. The drogue chute is sized by the requirement of achieving a prescribed Mach number at a prescribed altitude.

d. The main chute descent accounts for the loss in altitude due to chute opening and assumes constant velocity during filling. Subsonic chutes (Mach 0.8) in the order of 60 feet diameter would result in filling times of about 1.5 seconds, and hence incur an altitude loss of about 800 to 1000 feet.

e. Terminal descent velocity is assumed for the calculation of the main chute canopy size.

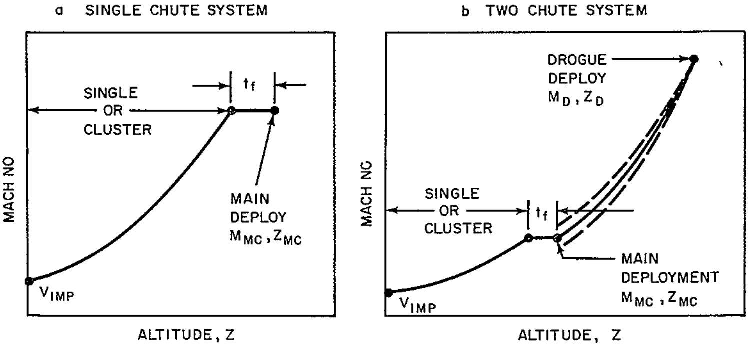
f. All trajectory calculations account for the correct vehicle and chute drag components where applicable.

g. Jettisoning of heat shield, structure, and drogue system weights are accounted for in the trajectory calculations where applicable.

h. A cluster of chutes is employed if the required diameter of a single main chute exceeds the maximum specified value DMCMAX.

i. The descent system options are depicted in Figure 3.

j. The parachute weight model (see below) accounts for materials, dynamic pressure and size.



c DROGUE-RETRO SYSTEM

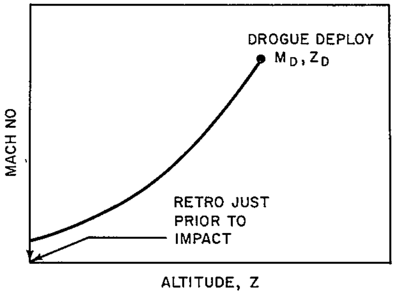


Figure 3 DESCENT SYSTEM OPTIONS

Parachute Weight Model

Materials (K)

Dynamic Pressure (q)

$$\boxed{W_T = K \left[\frac{d^3}{18.6} \quad \frac{q}{65} \right]}$$

Diameter (d)

3. Impact Attenuation System

a. The equations utilized are based on the analysis of Reference 1 which accounts for the variation of mass during the crush-up stroke and for materials with anisotropic properties.

b. Equations derived are for the particular case where the crushable material is in the shape of a spherical segment.

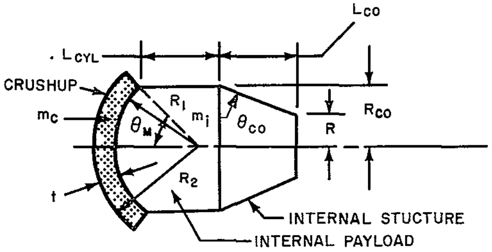
c. Crushing is assumed to start at the initial contact point and then the surface of crushing moves upward into the material during impact. Hence, at any time the mass below this surface has already been brought to rest such that the mass being decelerated is a variable with time.

d. The crushable material is assumed to be rigid and perfectly plastic, deforming at constant stress up to the total usable strain.

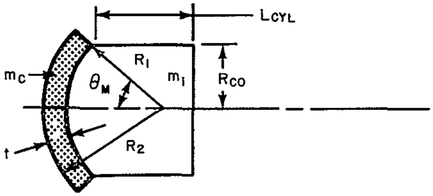
e. The conical and lenticular options which utilize a spherical segment of crushup assume preferred orientation upon impact, such that the resultant deceleration vector passes through the center of gravity of the landed package.

f. The impact surface is considered to be flat, smooth and infinitely rigid.

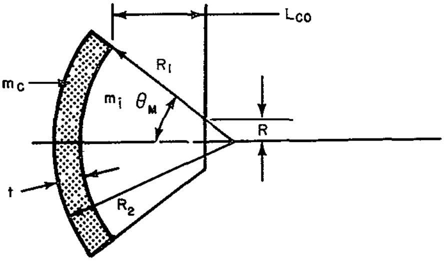
g. Landed package geometries are shown in Figure 4.



4a. CONE-CYLINDER SHAPE LANDER



4b. CYLINDER SHAPE LANDER



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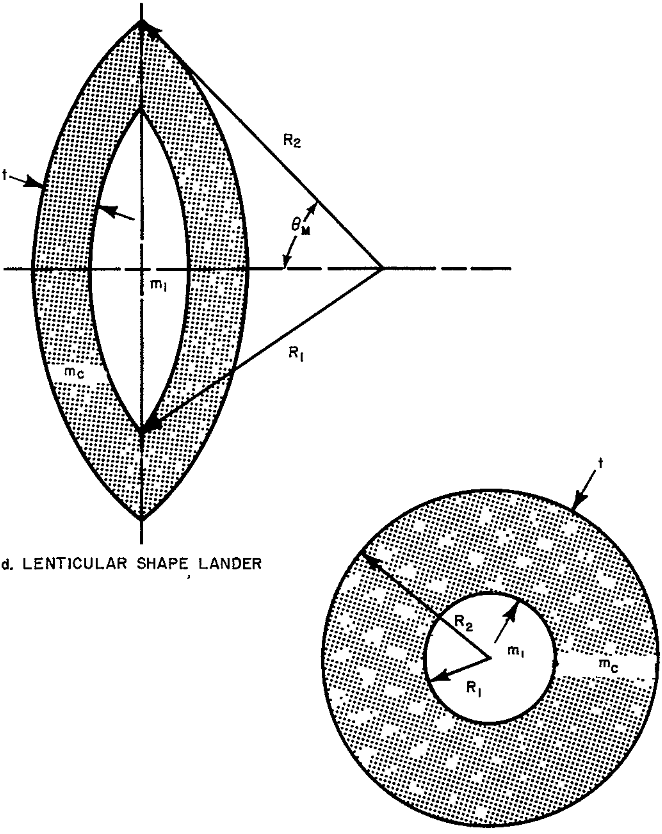
4c CONE SHAPE LANDER

Figure 4 LANDED PACKAGE GEOMETRIES



4d. LENTICULAR SHAPE LANDER

4e. SPHERE SHAPE LANDER

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Figure 4 LANDED PACKAGE GEOMETRIES (Concl'd)

4 Lander Packaging Design

a. The thickness of the heat shield and structure is accounted for in the lander packaging by adding the thickness to the outer dimension of the landed package.

b. The internal payload is packaged with uniform density.

c. A symmetrical cylindrical ring, placed at the maximum radius of the landed package, is utilized for parachute packaging as shown in Figure 5.

d. The landed package is located as far forward in the vehicle as possible as shown in Figure 5.

C. LIMITATIONS

Limitations of Program 1882 are listed below:

1. The heat shield and structure must be of uniform unit weight and/or thickness for each section.

2. Parachute designs (drogue and/or main) do not account for reefing; however, the chute drag coefficients can be arranged so as to simulate reefing.

3. The parachute design does not include fabric heating effects which often result in Mach number deployment limitations for various fabrics.

4. The parachute design does not include stability considerations and/or losses in performance due to angle of attack or Reynolds number effects.

5. The retrorocket system design is based on a single-impulse system.

6. The impact crush-up design assumes homogeneous materials.

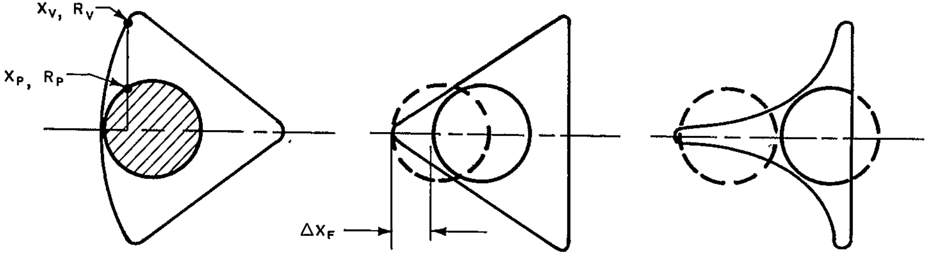
7. Only spherical segments of crushup can be utilized for the impact geometry.

8. The impact attenuation analysis assumes that crushing takes place only in the plane of the impact surface, that the payload is rigidly attached and that crushing cannot take place at an inner crushup surface and proceed outward.

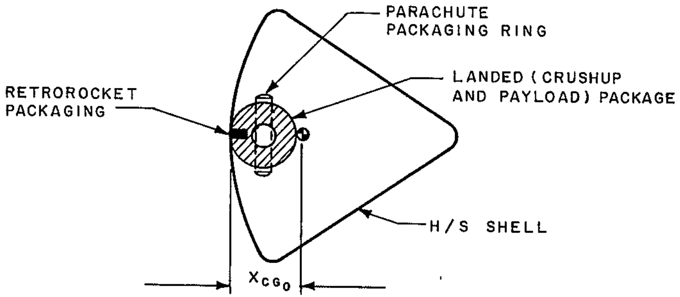
CONSTRAINTS.

1 LANDER GEOMETRY $R_V(X) > R_P(X)$

2 $X_{CG_{OVERALL}} < X_{CG_{SPECIFIED}}$



5a. LOCATION OF LANDED PACKAGE



5b. PARACHUTE AND ROCKET LOCATIONS

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Figure 5 PACKAGING MODEL

II. PROGRAM USAGE

A. INPUT DEFINITIONS

Name	Preset Value	Symbol	Parameter	Units
ALPHA		α	Empirically determined constant relating crushing stress and density.	--
AO		a_o	Empirically determined constant describing anisotropy of crushable material.	--
A1		a_1	Empirically determined constant describing anisotropy of crushable material.	--
A2		a_2	Empirically determined constant describing anisotropy of crushable material.	--
A3		a_3	Empirically determined constant describing anisotropy of crushable material.	--
BETA	0.	β	Tangent angle at beginning of tension shell.	degrees
CDD		C_{DD}	Table of drogue chute drag coefficients, Mach number dependent.	--
CDMC		C_{DMC}	Table of main chute drag coefficients, Mach number dependent.	--
CDV		C_{DV}	Table of entry vehicle drag coefficients, Mach number dependent.	--
DELTA	0.01		Integration Δt.	seconds
DELMIT	1.E-5		Smallest allowable Δt.	seconds

Name	Preset Value	Symbol	Parameter	Units
DESSYS			Input sentinel to designate type of descent system.	--
DDMIN			Minimum drogue chute diameter.	feet
DLVFAC		ΔV	Velocity increment in rocket design.	ft/sec
DMCMAX	100.		Maximum main chute diameter.	feet
DMCMIN			Minimum main chute diameter.	feet
DNBND	1.E-3, 1.E-6, 1.E-2		Lower bounds on trajectory integration (velocity, angle, altitude).	--
DRVEL	50.		Velocity interval for printout of drogue chute trajectory.	--
EF		E	Modulus of elasticity.	psi
EPSILN		ϵ	Total usable strain.	--
EPS1	1.E-3		Convergence factor for y/R_2.	--
EPS3	1.E-3		Convergence factor for R_{CO}.	--
FACTØR	0.2		Factor by which to change Δt.	--
FALR		L_1	Temperature gradient in troposphere expressed as a fraction of the adiabatic lapse rate.	--
FREQ	0.5		Interval for exiting from integration routine.	--
FREQ2	2.		Time interval for exiting from ADAMS4 during main chute trajectory.	--
FREQ3	2.		Time interval for exiting from ADAMS4 during drogue-retro-rocket trajectory.	--

Name	Preset Value	Symbol	Parameter	Units
GAMD		γ_D	Flight path angle at drogue chute deployment.	degrees
GAMMC		γ_{MC}	Flight path angle at main chute deployment.	degrees
GIMP		γ_{imp}	Maximum allowable impact acceleration.	Earth g
GSL		g_{SL}	Gravitational acceleration at planet surface.	ft/sec^2
IMPSYS			Input sentinel to designate type of impact system.	--
ISP		I_{SP}	Required specific impulse of retrorocket.	lb-sec/lb
IYR2	0.4		Initial guess for Y/R2	--
JET			Input sentinel to indicate when jettisoning of heat shield and structure occurs.	--
LC	0.	L_C	Cylinder body section length.	feet
LC0RC0	0.	L_{CO}/R_{CO}	Ratio of cone length to cylinder radius (internal geometry).	--
LCYRC0	0.	L_{CYL}/R_{CO}	Ratio of cylinder length to cylinder radius (internal geometry).	--
LRDR		L_R/D_R	Ratio of retrorocket length to diameter.	--
MACD		M_D	Drogue chute deployment Mach number.	--
MACH			Table of Mach numbers.	--
MACMC		M_{MC}	Main chute deployment Mach number.	--
MCVEL	50.		Velocity interval for printout of main chute trajectory.	ft/sec

Name	Preset Value	Symbol	Parameter	Units
MR		M.R.	Mass-fuel ratio of retrorocket.	--
NRINGS	0.		Number of rings.	--
PSI		ψ	Empirically determined constant relating crushing stress and density.	--
RA	0.	R_A	Radius of rear spherical cap.	feet
RB	0.	R_B	Flare radius.	feet
RC	0.	R_C	Reference vehicle radius.	feet
RCHUTE		ρ_{CHUTE}	Packaging density of the parachute system.	lb/ft^3
RH0CM		$\rho_{C_{MAX}}$	Maximum allowable crushup density.	$slug/ft^3$
RH0CMI		$\rho_{C_{MIN}}$	Minimum allowable crushup density.	$slug/ft^3$
RH0F		ρ_{fs}	Density of internal structural face sheet.	lb/ft^3
RH0I		ρ_i	Packaging density of the internal payload.	$slug/ft^3$
RH0R0C		ρ_R	Density of retrorocket.	lb/ft^3
RH0SL		ρ_{SL}	Density of the atmosphere at planet surface.	$slug/ft^3$
RN	0.	R_N	Nose cap radius.	feet
RR	0.	r	Ordinates for general shape.	feet
RSB	0.	R_{SB}	Toroidal radius from flare to afterbody sections.	feet
RSC	0.	R_{SC}	Toroidal radius following cone section.	feet

Name	Preset Value	Symbol	Parameter	Units
RSN	0.	R_{SN}	Toroidal radius following nose cap section.	feet
RT	0.	R_T	Base radius of truncated afterbody.	feet
SECTN	0.		Ordered array of vehicle sections. Each element is a number between 1 and 13.	--
SIGCYF		σ_{cy}	Yield stress of the internal structural face sheet.	psi
STRFAC	1.		Structural weight factor.	--
TFMIN		t_{fmin}	Minimum allowable face sheet thickness.	inches
THA	0.	θ_A	Aftcone section body angle (negative).	degrees
THB	0.	θ_B	Flare section body angle.	degrees
THC	0.	θ_C	Cone section body angle.	degrees
THC0	0.	θ_{CO}	Cone angle of the internal payload.	degrees
THM		θ_M	Angle subtended by the crushable material segment.	degrees
THN	0.	θ_N	Tangent angle at end of nose radius.	degrees
THS		$t_{H/S}$	Thickness of heat shield and structure combined.	feet
TH2G	0.	θ_{2G}	Tangent angle at beginning of general shape.	degrees
TH3G	0.	θ_{3G}	Tangent angle at end of general shape.	degrees
TN		n	Empirically determined exponent describing anisotropy of crushable material.	--

Name	Preset Value	Symbol	Parameter	Units
TSL		T_{SL}	Atmospheric temperature at planet surface.	^{o}K
TST		T_{ST}	Atmospheric temperature in the stratosphere.	^{o}K
TZERO	0.	T_o	Initial time for trajectory.	seconds
UPBND	0.01, 1.E-5 0.1		Upper bounds for trajectory integration (velocity, angle, altitude).	--
VELW		V_W	Horizontal velocity component used in impact attenuation analysis.	ft/sec
VIMP		V_{IMP}	Design impact velocity for retrorocket system. (Vertical and horizontal components included).	ft/sec
VV		V_V	Design vertical descent velocity for chute system.	ft/sec
WE		W_e	Total capsule entry weight.	pounds
WHSD			Array of corresponding heat shield weights.	--
WRING			Array of weights of rings.	--
WSTR			Array of corresponding structure weights.	--
XA		X_A	Mole fraction of Argon in the atmosphere.	--
XC		X_C	Mole fraction of CO_2 in the atmosphere.	--
XCGMIN		$X_{CG_{MIN}}$	Minimum overall CG requirement.	feet
XD		X_D	Dynamic opening shock load factor on drogue chute.	--

Name	Preset Value	Symbol	Parameter	Units
XMC		X_{MC}	Dynamic opening shock load factor on main chute.	--
XN		X_N	Mole fraction of N_2 in the atmosphere.	--
XØ		X_o	Mole fraction of O_2 in the atmosphere.	--
XRING			Array of x-coordinates specifying location of rings.	--
XX		X	Abcissas for general shape.	feet
ZD		Z_D	Drogue chute deployment altitude.	feet
ZMC		Z_{MC}	Main chute deployment altitude.	feet

B. INPUT PROCEDURES

1. Heat Shield and Structural Shell

a. The body sections are specified in the array SECTN in the order in which they appear on the vehicle. The specification for each section is an integer between 1. and 13., the correspondence being as follows:

NUMBER	SECTION	INPUT REQUIRED
1.	NOSE SPHERE	RN, THN
2.	TORUS	RSN
3.	CONE	THC
4.	TENSION SHELL	BETA
5.	GENERAL SHAPE	TH2G, TH3G, X, R
6.	TORUS	RSC, RC
7.	CYLINDER	LC
8.	FLARE	THB
9.	TORUS	RSB

NUMBER	SECTION	INPUT REQUIRED
10.	TORUS	RSB
11.	AFTCONE	THA
12.	AFTSPHERE	RA
13.	BASE	RT

The nose sphere must always be the first section, i.e. SECTN (1) = 1. A vehicle consisting of a nose sphere, cone, aftcone, and base would be specified as SECTN = 1., 3., 11., 13. The individual sections are depicted in Figures 1 and 2.

b. Body Section 6 can be omitted or included only together with Sections 3, 4, and 5.

c. Body Section 9 can be omitted or included only together with Section 8.

d. The body radius R_c must always be specified

e. The body angle input θ_A(THA) describing the aftcone section must be input with a minus sign to be consistent with the coordinate system.

f. For the tension shell β(BETA) and R_{sc}(RSC) must be specified

g. For the general shape the initial and final body angles θ_{2G} (TH2G), and the approximate x and r coordinates of that section must be specified A maximum of 25 and a minimum of 3 points can be specified.

h. If the Section 2 is deleted, then the initial angles β (BETA), θ (THC), and θ_{2G} (TH2G) must be equal to the nose cap section body angle θ^c_N (THN).

i. For any of the body sections specified, all of the corresponding utilized body parameters must also be specified, i.e. as an example, if the aftcone section is specified, then θ_A (THA), R_A (RA), and R_{SB} (RSB) must also be specified. The body parameter R_B (RB) need not be specified unless a flare section is used.

j. For each body section specified, there must be a corresponding unit heat shield and structure weight. These are specified in the arrays WHSD and WSTR in the same order as the section appears in SECTN.

k A total vehicle entry weight W_e (WE) must always be input

l. A set of computer input forms are provided for the user. All the data shown on the form is keypunched when the variable is supplied

2. Descent System

a. Each of the three options are individually specified by utilizing the sentinel DESSYS:

1) Two-chute drogue-main option DESSYS = 1.

2) Single-chute main option DESSYS = 2.

3) Drogue-retrorocket option DESSYS = 3.

b. When to jettison the heat shield and structure in the two chute drogue-main system and single chute system is specified by the sentinel JET:

1) Jettisoning at main chute deployment JET = 1.

2) Jettisoning just prior to impact JET = 2.

c. Drag coefficients of the vehicle (CDV), drogue chute (CDD), and the main chute (CDMC) are input as a function of Mach number. As an example:

MACH = 0.0, 3.0, 5.0

CDV = 1.0, 1.5, 1.6

CDD = 0.7, 0.8, 0.9

CDMC = 0.6, 0.6, 0.6 .

d. The parameters used for calculating the atmosphere and/or trajectory are input for all options. These parameters list nine and are GSL, TSL, TST, RHØSL, FALR, XN, XØ, XC, and XA.

e. The main chute trajectory for DESSYS Options 1. and 2. is calculated based on a required vertical input descent velocity (VV). The horizontal wind velocity component, however, is not accounted for.

f. The retrorocket system is designed on a specified input velocity (VIMP). Horizontal wind velocity can be accounted for by the input (VELW). The input (VV) is not an input for this option.

g. The minimum size drogue chute input DDMIN must be specified for the drogue-main option and the drogue-retro option. There is no requirement as to how small or how big this input should be. Note however, if a smaller drogue is actually required (in the drogue-main option), the minimum input value is utilized.

h. The minimum drogue diameter input DDMIN is the actual size of the drogue chute for the drogue-retrorocket option. There is no iteration involved in this option.

i. The minimum size main chute input DMCMIN must be specified for the drogue-main option and the single main chute option. There is no requirement as to how small this input should be. Note however, if a smaller main chute is actually required (for either option), the minimum input value is utilized.

j. The maximum size main chute input DMCMAX must be specified for the drogue-main option and the single main option. If the first pass design requires a chute which exceeds DMCMAX, then a cluster of chutes will automatically be employed. Note, DMCMAX must be greater than DMCMIN.

k. Additional specific inputs to be specified for the retrorocket are as follows· ISP, MR, RHØRØC, VIMP, VELW, LRDR, and DLVFAC.

l. Parachute data suitable for input are given in References 2 and 3.

3. Impact Attenuation System

a. Each of the two options are individually specified by utilizing the sentinel IMPSYS:

1) Lenticular option IMPSYS = 1.

2) Cone-cylinder option IMPSYS = 2.

b. A sphere can be utilized as the lander in the lenticular option by specifying θ_M (THM) as 90 degrees.

c. The cone portion of the internal payload can be deleted in the cone-cylinder option by specifying L_{co}/R_{co} (LCØRCØ) as zero.

d. The cylinder portion of the internal payload can be deleted in the cone-cylinder option by specifying L_{cyl}/R_{co} (LCYRC0) as zero.

e. If it is desired to neglect the anistropy of the crushable material, merely set a_o (A0), a_2 (A2), and a_3 (A3) equal to zero.

f. The specified input value of θ_M (THM) cannot exceed 90 degrees.

g. The specified input value of L_{co}/R_{co} (LC0RC0) must be equal to or less than cot θ_{co}.

h. The inputs for the crushing stress PSI and ALPHA, relate the stress to the density as

$$S_m = [(\text{ALPHA})\, \rho_c]^{1/\text{PSI}}$$

where(S_m) is the maximum crushing stress, (ρ_c) is the density in slug-ft^3, and ALPHA and PSI are empirical constants. A summary of crushup data[1] is given in Figure 6, from which the following correlations for ALPHA and PSI occur:

MATERIAL	ALPHA	PSI
Al Honeycomb	2090	0.554
Plastic Foams	3980	0.662
Balsa Wood	1.65×10^{10}	1.81

4. Lander Packaging Design

a. Additional required inputs for the lander packaging design are as follows: THS, XCGMIN, RCHUTE, EF, RH0F, TFMIN, and SIGCYF.

C. OUTPUT DEFINITIONS

External Name	Internal Name	Symbol	Parameter	Units
AD	AD	A_D	Area of drogue chute.	ft^2
ALT	Z	Z	Altitude.	feet

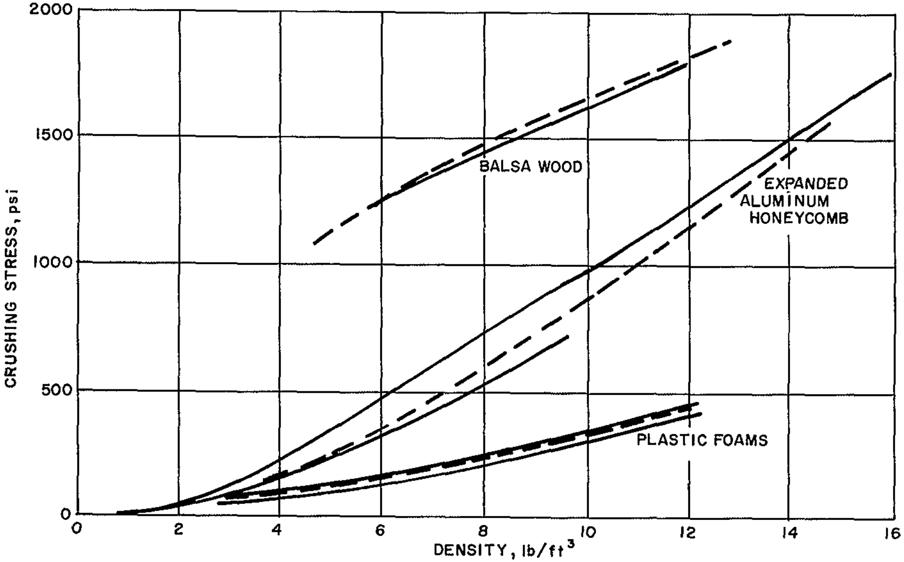

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Figure 6 CRUSHING STRENGTH OF IMPACT MATERIALS

External Name	Internal Name	Symbol	Parameter	Units
AMC	AMC	A_{MC}	Main chute area.	ft^2
AREA	AREA	A	Area.	ft^2
DELXF		Δx_f	Distance between vehicle nose and payload nose.	feet
DD	DI	D_D	Diameter of drogue chute.	feet
DMC	DMC	D_{MC}	Diameter of main chute.	feet
DR	DR	D_R	Diameter of retrorocket.	feet
GAMMA	GAM	γ	Flight path angle.	degrees
GPEAK	PGCALC		Maximum value from PGCAL array.	g
GPEAKS	PGCAL		Array of impact acceleration values.	g
IX	RØLL	I_x	Moment of inertia about the x-axis.	$slug\text{-}ft^2$
IXTØTCG			Roll moment of inertia of the entire vehicle about the c.g.	$slug\text{-}ft^2$
IY	PITCH	I_y	Moment of inertia about the y-axis.	$slug\text{-}ft^2$
IYTØTCG			Pitch moment of inertia of the entire vehicle about the c.g.	$slug\text{-}ft^2$
LCØ		L_{co}	Length in the internal payload cone.	feet
LCYL		L_{cyl}	Length in the internal payload cylinder.	feet
LR	XLR	L_R	Length of retrorocket.	feet

External Name	Internal Name	Symbol	Parameter	Units
MACH	XMAC	M	Mach number.	--
MC		m_c	Mass of the crushable material.	slugs
MI		m_i	Mass of the internal payload.	slugs
PD	PD	P_D	Opening shock load on drogue chute.	pounds
PMC	PMC	P_{MC}	Opening shock load on main chute.	pounds
R	R	r	Ordinates of all points computed along the body surface.	feet
R		R	Small radius of the internal payload cone.	feet
R1		R_1	Inner radius of the crushup segment.	feet
R2		R_2	Outer radius of the crushup segment.	feet
RC0			Internal payload cylinder radius.	feet
RH0C		ρ_c	Density of the crushable material utilized.	slug/ft^3
S		S_m	Maximum crushing stress.	lb/ft^2
SECTI0N			Section specification number.	--
T	T	t_o	Total time of descent system trajectory.	seconds
T		t_c	Thickness of crushup material.	feet

External Name	Internal Name	Symbol	Parameter	Units
TD	T	t_D	Total time on the drogue chute.	seconds
TF	TF		Main chute filling time.	seconds
TIME	T		Time.	seconds
T(INS)			Thickness of the internal structure face sheet.	inches
VEL	V	V	Velocity.	ft/sec
VFINAL	VFINAL	V_o	Final resultant descent velocity for the drogue retro system.	ft/sec
W(LBS)			Itemized section weights of the internal structure.	pounds
W INTERNAL STRUCTURE			Total weight of the internal structure.	pounds
WD	WD	W_D	Drogue chute system weight.	pounds
WF	WF	W_F	Final weight for sizing retro system.	pounds
WHS	WHS		Unit weight heat shield factor times area.	pounds
WI	WI	W_{11}	Initial weight for sizing retro system.	pounds
WL	WL	W_L	Landed weight.	pounds
WMC	WMC	W_{MC}	Main chute system weight.	pounds
WST	WST		Unit weight structure (includes weight factor)	pounds

External Name	Internal Name	Symbol	Parameter	Units
WR	WR	w_{RR}	Entry weight less heat shield and structure weight.	pounds
WR0C	WR0C	w_R	Retrorocket system weight.	pounds
WHST0T	WHST0T		Total heat shield weight.	pounds
WSTT0T	WSTT0T		Total structural shell weight.	pounds
WSTRAPS	WSTRAP	w_{STRAPS}	$0.05(w_D + w_{MC})$.	pounds
X	X	x	Abscissas of all points computed along the body surface.	feet
XCGH/S	XCGH/S		C.g. position of the heat shield and structural shell.	feet
XCG	XCG	$\bar{x}_{NN}$	Centroid of each section from the nose of the vehicle.	feet
XCG0		x_{CG_o}	Total vehicle center of gravity measured from vehicle nose.	feet
YDD/G	PGCALC	$\dot{y}_{imp}$	Peak impact acceleration.	g
Y/R2 VALUES	YR2	y/R_2	Nondimensional parameter.	

D. SAMPLE PROBLEM

1. Statement of Problem

Determine the residual weight for the blunt cone configuration used in the sample problems of Programs 1880, 1881, 1884, and 1886.

The descent system is to utilize a single main chute system. The chute is to be deployed at Mach 1.2 at an altitude of 21451. feet and a flight path angle of -35.19 degrees. The heat shield and structure is to be jettisoned at its deployment. Vertical impact velocity is to be 60 ft/sec.

The lander geometry is to be a spherical shape utilizing balsa wood as the crushable material. The horizontal wind velocity is 30 ft/sec and the maximum impact acceleration is not to exceed 1000 g. The balsa density cannot exceed 0.4 slug/ft^3 or be less than 0.1 slug/ft^3.

The internal payload is to have a packaging density of 1.5 slug/ft^3, and the parachute system packaging density is 35 lb/ft^3. Internal structure is to be constructed of aluminum face sheet with a minimum thickness of 0.010 inch. Final design is to have a maximum center of gravity position of 3.75 feet.

2. Input Form

The input data required is shown on the following pages. Decimals are used for all input and all the variable names are keypunched wherever an input quantity is given. An additional unused input form is provided in the following page for the program user.

3. Output

The output is shown on the following pages. The keypunched data are listed and should be verified with the input form.

The vehicle coordinates (X,R) are provided for use in drawing the configuration. Detailed section data are given regarding the surface area, heat shield weight, structure weight, moments of inertia, and center of gravity. The coordinates refer to the exterior of the structural shell and are used to evaluate all the weights by considering that the thicknesses of the structure and heat shield are small with respect to the size of the vehicle.

The heat shield and structural weights for the individual sections are totaled and the remaining weight (WR) is given. The overall center of gravity of the heat shield and structure is also given.

The trajectories during descent on the drogue and main chutes are given, including velocity, Mach number, flight path angle, altitude, and density. The parachute designs are given in terms of their area, diameter, and weight. Other pertinent information is given, including the parachute filling time, opening shock load, and the dynamic pressure at chute deployment. The number of clustered chutes required for the main system is also given, as well as the estimated parachute harness weight and the landed weight (WL).

The impact attenuator design results indicate the density of the attenuator material, the peak deceleration, the crush up stroke and history of deceleration versus stroke. The size of the impact attenuator, the mass of crush-up, and the residual mass are determined. Details of the internal structure are also provided.

The overall vehicle center of gravity and moments of inertia are finally determined and given as output.

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5 63

DIGITAL COMPUTER INPUT REQUEST FORM

PROBLEM NO 1882

PROGRAMMER

TITLE Packaging and Moments of Inertia

MEMO NO	SECTION NO	WORK ORDER NO	(E240 USE ONLY)	REQUESTED BY	EXT	EST TIME	PAGE 1 OF 3 PAGES

$INPUT

ALPHA = ______,
A0 = ______,
A1 = ______,
A2 = ______,
A3 = ______,
BETA = ______,
DELTA = ______,
DELMIT = ______,
DLVFAC = ______,
DESSYS = ______,
DDMIN = ______,
DMCMIN = ______,
DMCMAX = ______,
DRVEL = ______,
EF = ______,
EPSILN = ______,
EPS1 = ______,
EPS3 = ______,
FACTØR = ______,
FALR = ______,
FREQ = ______,
FREQ2 = ______,
FREQ3 = ______,
GAMD = ______,
GAMMC = ______,
GIMP = ______,
GSL = ______,
IMPSYS = ______,

ISP = ______,
IYR2 = ______,
JET = ______,
LC = ______,
LCØRCØ = ______,
LCYRCØ = ______,
LRDR = ______,
MACD = ______,
MACMC = ______,
MCVEL = ______,
MR = ______,
PSI = ______,
RA = ______,
RB = ______,
RC = ______,
RCHUTE = ______,
RHØCM = ______,
RHØCMI = ______,
RHØF = ______,
RHØI = ______,
RHØRØC = ______,
RHØSL = ______,
RN = ______,
RSB = ______,
RSC = ______,
RSN = ______,
RT = ______,
SIGCYF = ______,

STRFAC = ______,
TFMIN = ______,
THA = ______,
THB = ______,
THC = ______,
THCØ = ______,
THM = ______,
THN = ______,
THS = ______,
TH2G = ______,
TH3G = ______,
TN = ______,
TSL = ______,
TST = ______,
TZERØ = ______,
VELW = ______,
VIMP = ______,
VV = ______,
WE = ______,
XA = ______,
XC = ______,
XCGMIN = ______,
XD = ______,
XMC = ______,
XN = ______,
XØ = ______,
ZD = ______,
ZMC = ______,

RAD 2-0964
5 63

DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO 1882	MEMO NO	SECTION NO	CONTINUATION SHEET PAGE 2 OF 3 PAGES

NRINGS = ______,

DNBND = ______, ______, ______,

UPBND = ______, ______, ______,

SECTN = ______, ______, ______, ______, ______, ______, ______, ______, ______, ______,

WHSD = ______, ______, ______, ______, ______, ______, ______, ______, ______, ______,

WRING = ______, ______, ______, ______, ______, ______, ______, ______, ______, ______,

WSTR = ______, ______, ______, ______, ______, ______, ______, ______, ______, ______,

XRING = ______, ______, ______, ______, ______, ______, ______, ______, ______, ______,

RR = ______, ______, ______, ______, ______, ______, ______, ______, ______, ______,
______, ______, ______, ______, ______, ______, ______, ______, ______, ______,
______, ______, ______, ______, ______,

XX = ______, ______, ______, ______, ______, ______, ______, ______, ______, ______,
______, ______, ______, ______, ______, ______, ______, ______, ______, ______,
______, ______, ______, ______, ______,

CDD = ______, ______, ______, ______, ______, ______, ______, ______, ______, ______,
______, ______, ______, ______, ______, ______, ______, ______, ______, ______,
______, ______, ______, ______, ______, ______, ______, ______, ______, ______,
______, ______, ______, ______, ______, ______, ______, ______, ______, ______,
______, ______, ______, ______, ______, ______, ______, ______, ______, ______,

CDMC = ______, ______, ______, ______, ______, ______, ______, ______, ______, ______,
______, ______, ______, ______, ______, ______, ______, ______, ______, ______,
______, ______, ______, ______, ______, ______, ______, ______, ______, ______,
______, ______, ______, ______, ______, ______, ______, ______, ______, ______,
______, ______, ______, ______, ______, ______, ______, ______, ______, ______,

RAD 2 0964
5-63

DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO. 1882	MEMO NO	SECTION NO	CONTINUATION SHEET PAGE 3 OF 3 PAGES

CDV = ______, ______, ______, ______, ______, ______, ______, ______, ______, ______,
______, ______, ______, ______, ______, ______, ______, ______, ______, ______,
______, ______, ______, ______, ______, ______, ______, ______, ______, ______,
______, ______, ______, ______, ______, ______, ______, ______, ______, ______,
______, ______, ______, ______, ______, ______, ______, ______, ______, ______,

MACH = ______, ______, ______, ______, ______, ______, ______, ______, ______, ______,
______, ______, ______, ______, ______, ______, ______, ______, ______, ______,
______, ______, ______, ______, ______, ______, ______, ______, ______, ______,
______, ______, ______, ______, ______, ______, ______, ______, ______, ______,
______, ______, ______, ______, ______, ______, ______, ______, ______, ______,

$

RE-ORDER No. 66-447

RAD 2-0063
5-63

DIGITAL COMPUTER INPUT REQUEST FORM		PROBLEM NO 1882			PROGRAMMER		
		TITLE Packaging and Moments of Inertia					
MEMO NO	SECTION NO	WORK ORDER NO	(E240 USE ONLY)	REQUESTED BY	EXT	EST TIME	
	K420	W305-050-0005		P. Levine	2996		PAGE 1 OF 3 PAGES

$INPUT

ALPHA = 1.65E10,
A0 = 1.0,
A1 = ,
A2 = ,
A3 = ,
BETA = 0.,
DELTA = .01,
DELMIT = 1.E-5,
DLVFAC = ,
DESSYS = 2.0,
DDMIN = ,
DMCMIN = 10.0,
DMCMAX = 80.0,
DRVEL = 50.0,
EF = 1.0E7,
EPSILN = 0.75,
EPS1 = .001,
EPS3 = .001,
FACTØR = .2,
FALR = 1.11367,
FREQ = .5,
FREQ2 = 2.,
FREQ3 = 2.,
GAMD = ,
GAMMC = -35.19,
GIMP = 1000.0,
GSL = 12.3,
IMPSYS = 1.0,

ISP = ,
IYR2 = 0.4,
JET = 1.0,
LC = 0.,
LCØRCØ = ,
LCYRCØ = ,
LRDR = ,
MACD = ,
MACMC = 1.2,
MCVEL = 50.,
MR = ,
PSI = 1.81,
RA = 0.,
RB = 0.,
RC = 7.5,
RCHUTE = 35.0,
RHØCM = 0.40,
RHØCMI = 0.1,
RHØF = 172.,
RHØI = 1.5,
RHØRØC = ,
RHØSL = 2.56E-5,
RN = 1.25,
RSB = 0.15,
RSC = 0.15,
RSN = 0.,
RT = 3.75,
SIGCYF = 6.0E4,

STRFAC = 1.5,
TFMIN = 0.010,
THA = -80.,
THB = ,
THC = 60.0,
THCØ = ,
THM = 90.0,
THN = 60.0,
THS = 0.2,
TH2G = 0.,
TH3G = 0.,
TN = 2.1,
TSL = 200.0,
TST = 100.0,
TZERØ = ,
VELW = 30.0,
VIMP = ,
VV = 60.0,
WE = 1850.,
XA = 0.,
XC = .999,
XCGMIN = 3.75,
XD = ,
XMC = 1.8,
XN = .001,
XØ = 0.,
ZD = ,
ZMC = 21451.,

RAD 2-0964
5 63

DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO 1882	MEMO NO	SECTION NO	CONTINUATION SHEET PAGE 2 OF 3 PAGES

NRINGS = _____,
DNBND = _____, _____, _____,
UPBND = _____, _____, _____,
SECTN = 1.0, 3.0, 6.0, 10.0, 11.0, 13.0, _____, _____, _____, _____,
WHSD = 1.0, .94, .94, .94; _____, _____, _____, _____, _____, _____,
WRING = _____, _____, _____, _____, _____, _____, _____, _____, _____, _____,
WSTR = .507, .526, .526, .526, .405, .414, _____, _____, _____, _____,
XRING = _____, _____, _____, _____, _____, _____, _____, _____, _____, _____,

RR = _____, _____, _____, _____, _____, _____, _____, _____, _____, _____,
_____, _____, _____, _____, _____, _____, _____, _____, _____, _____,
_____, _____, _____, _____, _____,

XX = _____, _____, _____, _____, _____, _____, _____, _____, _____, _____,
_____, _____, _____, _____, _____, _____, _____, _____, _____, _____,
_____, _____, _____, _____, _____,

CDD = _____, _____, _____, _____, _____, _____, _____, _____, _____, _____,
_____, _____, _____, _____, _____, _____, _____, _____, _____, _____,
_____, _____, _____, _____, _____, _____, _____, _____, _____, _____,
_____, _____, _____, _____, _____, _____, _____, _____, _____, _____,
_____, _____, _____, _____, _____, _____, _____, _____, _____, _____,

CDMC = 0.8, 0.8, 1.0, 1.0, 1.0, _____, _____, _____, _____, _____,
_____, _____, _____, _____, _____, _____, _____, _____, _____, _____,
_____, _____, _____, _____, _____, _____, _____, _____, _____, _____,
_____, _____, _____, _____, _____, _____, _____, _____, _____, _____,
_____, _____, _____, _____, _____, _____, _____, _____, _____, _____,

RAD 2-0964
5-63

DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO	MEMO NO	SECTION NO	CONTINUATION SHEET
	1882			PAGE 3 OF 3 PAGES

CDV = 1.0, 1.0, 1.2, 1.5, 1.5, ____, ____, ____, ____, ____,
____, ____, ____, ____, ____, ____, ____, ____, ____, ____,
____, ____, ____, ____, ____, ____, ____, ____, ____, ____,
____, ____, ____, ____, ____, ____, ____, ____, ____, ____,
____, ____, ____, ____, ____, ____, ____, ____, ____, ____,

MACH = 0.0, 0.7, 1.0, 2.0, 6.0, ____, ____, ____, ____, ____,
____, ____, ____, ____, ____, ____, ____, ____, ____, ____,
____, ____, ____, ____, ____, ____, ____, ____, ____, ____,
____, ____, ____, ____, ____, ____, ____, ____, ____, ____,
____, ____, ____, ____, ____, ____, ____, ____, ____, ____,

$

```
                                                                               12/01/64

  $IBLDR S2BLK                                                      12/01/64    S2BL0000
  $IBLDR S3BLK                                                      12/01/64    S3BL0000
  $IBLDR SARTLU                                                     12/01/64    SART0000
  $IBLDR SRP346                                                     12/01/64    SRP30000
  $IBLDR SGENSH                                                     12/01/64    SGEN0000
  $IBLDR STENSH                                                     12/01/64    STEN0000
  $IBLDR SFINDR                                                     12/01/64    SFIN0000
  $IBLDR SDERQ2                                                     12/01/64    SDER0000
  $IBLDR SADAMS                                                     12/01/64    SADA0000
  $IBLDR SPEAK                                                      12/01/64    SPEA0000
  $IBLDR SR2B3                                                      12/01/64    SR2B0000
  $IBLDR SBL3IN                                                     12/01/64    SBL30000
  $IBLDR SR2B34                                                     12/01/64    SR2B0000
  $IBLDR SATMOS                                                     12/01/64    SATM0000
  $DATA

            IBLDR                                                              12/01/64


                          * MEMORY MAP *

  SYSTEM                                        00000 THRU  02717
  FILE BLOCK ORIGIN                             02720
  FILES        1.       UNIT05
               2.       UNIT06
  FILE LIST ORIGIN                              02750
  PRE-EXECUTION INITIALIZATION                  02754
  CALL ON OBJECT PROGRAM                        02777
  OBJECT PROGRAM                                03004 THRU  60547

      DECK  ORIGIN       CONTROL SECTIONS  (/NAME/=NON 0 LENGTH, (LOC)=DELETED, *=NOT REFERENCED)

   1. 1882    03004     ///     /(77434)    ......  12246 *
   2. S2BLK   12262     ///     /(77434)    BLOCK2  16265
   3. S3BLK   16766      BLOCK3  25624
   4. SARTLU  26462      ARTLU   27204
   5. SRP346  27355      RP3467  27757
   6. SGENSH  30027      GENSHP  30437
   7. STENSH  30545      TENSHL  31367
   8. SFINDR  31533      FINDRV  32505
   9. SDERQ2  32704     ///     /(77434)    DERQ2   33253
  10. SADAMS  33305      ADAMS4  36450
  11. SPEAK   36610      PEAK    37055
  12. SR2B3   37140      R2B3    37343
  13. SBL3IN  37402      BL3INT  40031
  14. SR2B34  40141      R2B34   40724
  15. SATMOS  41112      ATMOS   41374
  16. .LXCON  41505     .LXSTR   41505 *   .LXSTP  41511     .LXOUT   41557     .LXRTN  41571     IBEXIT  41571 *
                        .LXCAL   41574 *   .LXERR  41574     .DBCLS   41756 *   .LXARG  42125     .LO     42150 *
                        .CLSF    42156     .LFBL   42157 *   .LUNB    42150     .DFOUT  42161
  17. .IODEF  42165     .DEFIN   42165     .ATTAC  42171 *   .CLOSE   42173     .OPEN   42175     .READ   42177
                        .WRITE   42201     .BSR    42211 *   .READR   42221     .RELES  42223 *   .CAREA  42234
                        .LFBLK   42252     .LTSX   42255 *   .AREA1   42257     .LUNBL  42275     .ENTRY  42301
                        .GOA     42334     .GO     42340     .DERR    42354     .NOPXI  42355     .COMXI  42357
                        .EX34    42401
  18. .LXSL   42406     .LXSEL   42406     LXCSEL  42407     .LXTST   42412 *   .LXOVL  42452 *   .LXRCT  42463 *
                        .LXIND   42532 *   .LXDIS  42535 *   .LXFLG   42536 *   .LTCH   42537
  19. .FPTRP  42545     .FFPT.   42545 *   .FPOUT  42674     .FPARG   42702    /.COUNT/ 42704 *   OVFLOW  42750 *
  20. .ERAS.  42755     E.1      42755     E.2     42756     E.3      42757     E.4     42760
  21. .XCC.   42761     CC.1     42761     CC.2    42762     CC.3     42763     CC.4    42764
  22. XIT     42765     EXIT     42765      EXIT.  42765 *
  23. FXEM    42766     .FXEM.   42766     .FXOUT  43323     .FXARG   43331    /.OPTW./ 43405
  24. FOUT    43416     .FOUT.   43416
  25. FCNV    43760     .FCON.   43760     .FCNV.  44003     .ENDFS   44016     .CNVSW  44020     .FDX1   44024
                        .FDX2    44025     .DBC    44027     .DBC8    44150     .DBC9   44153     .DBC10  44160
                         DBC20   44206      DDSW   44216     .DDFIX   44225     .FIXSW  44233     .DDBC   44310
                        .DDRS1   44552     .DDRS2  44564     .D1      44557     .D2     44571     .FERR2  44656 *
                        .ANPT    44712     .ONPT   44727     .LNTP    45003     .AOUT   45052     .DFLT   45070
                        .FLT     45224     .DEXPN  45314     .FXD     45315     .HOUT   45445     .INTG   45515
                        .LOUT    45633     .OOUT   45652     .XCF     45703     .TEST   46410     .KOUNT  46413
                        .LIST    46416     .DONE   46427     .OUTBF   46473     .BJF    46521     .QSTO   46522
                        .WIDTH   46523     .GAIN   46524     .GAIN1   46525     .FBDBF  46535     .DDDFL  46560
                        .DOFLG   46561      MQD    46562     .PEX     46553      FEXP   46564     .DIG    46565
  26. FIOS    46605     .FIOS.   46605     .FSEL.  46745     .FILR.   46751     .FRTB.  46760 *   .FRTD.  46765
                        .FILL.   46770     .FCLS   46772 *   .FOPN    46776 *   REOF    47002 *   .TOUT.  47145
```

```
                             .REED   47153 *   .BIN    47154 *   .FCT    47155     .FCKSZ  47157 *
  27. FIOH      47241        .FIOH.  47241     .FFIL.  50030     .FRTN.  50055 *
  28. FWRD      50242        .FWRD.  50242
  29. FWRU      50266        .FWRU.  50266
  30. FWRD      50312        .FWRD.  50312     .FREST  50615 *
  31. FRDU      50717        .FRDU.  50717
  32. UN05      50760        .UN05.  50760
  33. UN06      50761        .UN06.  50761     .BUFS7  50762
  34. FIOU      50765        .FIOU.  50765     .CTUIO  51440     .NMLST  51453     .NAME.  52566     .INTAP  52567
  35. JASIN     53212        ASINR   53272 *   ASIN    53301     ASIND   53310 *
  36. JACOS     53317        ACOSR   53377 *   ACOS    53406     ACOSD   53415 *
  37. JTNOR     53424        ATANOR  53502     ATANQ   53511 *   ATANQD  53520 *
  38. JRSIM     53527        ARSIMP  53570
  39. FLOG      53621        ALOG10  53621 *   ALOG    53623
  40. FXPF      53762        EXP     53762
  41. FSCN      54102        COS     54102     SIN     54104
  42. FSOR      54313        SORT    54313
  43. FATN      54420        ATAN2   54420     ATAN    54422 *
  44. FXP3      54626        .XP3.   54626
  45. .IOCS     54753        .L(0)   54753     .MONSW  54773     .TEOR   55042     .DEFI.  55122     .JOINX  55166 *
                             .CLOS.  55205     .ATTC.  55220     .SH1    55432 *   .SH9    55474 *   .OPEN.  55515
                             .OP4    55543 *   .OP7    55574 *   .OP9.2  55610 *   .RLSE.  55662     .RFR2.  55662
                             .READ.  55663     .RERI.  55706     .WRIT.  55710     .MNT1A  56076 *   .EOFFX  56157 *
                             .FFFIT  56227     .GTIOX  56250     .RW7    56356 *   .RE7    57005 *   .ENDTR  57446
                             .SELS9  57450 *   .BSR.   60061     .FOTOF  60206     .ETOF3  60214 *   .SWITC  60243
                             .TCHEX  60544     .BASIO  60547 *
  46. .IOCSM    60550
  47. //        77434

 I/O BUFFERS                            60550 THRU  77333

 UNUSED CORF                            77334 THRU  77433

 $INPUT

 SECTN  =          0.10000000F 01,      0.30000000F 01,      0.60000000E 01,      0.10000000E 02,      0.11000000F 02,
                   0.13000000E 02,      0.00000000E-38,      0.00000000E-38,      0.00000000E-38,      0.00000000E-38,

 RN     =          0.12500000F 01,

 RSN    =          0.00000000E-38,

 RSC    =          0.15000000E 00,

 RSB    =          0.15000000E 00,

 RA     =          0.00000000E-38,

 THN    =          0.60000000E 02,

 THC    =          0.60000000E 02,

 THB    =          0.00000000F-38,

 THA    =         -0.80000000F 02,

 XX     =          0.00000000F-38,      0.00000000E-38,      0.00000000E-38,      0.00000000E-38,      0.00000000E-38,
                   0.00000000E-38,      0.00000000E-38,      0.00000000E-38,      0.00000000E-38,      0.00000000E-38,
                   0.00000000E-38,      0.00000000E-38,      0.00000000E-38,      0.00000000E-38,      0.00000000F-38,
                   0.00000000E-38,      0.00000000F-38,      0.00000000E-38,      0.00000000E-38,      0.00000000E-38,
                   0.00000000E-38,      0.00000000E-38,      0.00000000E-38,      0.00000000E-38,      0.00000000F-38,

 RR     =          0.00000000E-38,      0.00000000E-38,      0.00000000E-38,      0.00000000F-38,      0.00000000E-38,
                   0.00000000F-38,      0.00000000F-38,      0.00000000E-38,      0.00000000E-38,      0.00000000E-38,
                   0.00000000E-38,      0.00000000E-38,      0.00000000E-38,      0.00000000E-38,      0.00000000E-38,
                   0.00000000E-38,      0.00000000E-38,      0.00000000E-38,      0.00000000E-38,      0.00000000E-38,
                   0.00000000F-38,      0.00000000E-38,      0.00000000E-38,      0.00000000E-38,      0.00000000E-38,

 LC     =          0.00000000E-38,

 RB     =          0.00000000E-38,

 RC     =          0.75000000E 01,

 RT     =          0.37500000F 01,

 BETA   =          0.00000000F-38,

 TH2G   =          0.00000000F-38,

 TH3G   =          0.00000000E-38,

 WHSD   =          0.10000000E 01,      0.94000000E 00,      0.94000000E 00,      0.94000000F 00,      0.00000000E-38,
                   0.00000000E-38,     -0.00000000F-19,     -0.00000000E-19,     -0.00000000F-19,     -0.00000000F-19,

 WSTR   =          0.50700000E 00,      0.52600000E 00,      0.57600000E 00,      0.52600000E 00,      0.40500000E 00,
                   0.41400000F 00,     -0.00000000F-19,     -0.00000000E-19,     -0.00000000E-19,     -0.00000000E-19,

 STRFAC =          0.15000000E 01,

 WE     =          0.18500000F 04,

 JET    =          0.10000000E 01,
```

```
MACD   =        -0.00000000E-19,

ZD     =        -0.00000000E-19,

GAMD   =        -0.00000000E-19,

CDD    =        -0.04046848E-26,   -0.04046847E-26,    0.20699710E-24,   -0.00007880E-26,    0.20780487E-24,
                 0.49963344E 00,   -0.00007880E-26,    0.00080777E-23,   -0.00000020E-26,    0.20780487E-24,
                 0.49938931E 00,    0.33135625E-23,   -0.70535401E-37,    0.10164460E-19,    0.00012614E-25,
                 0.13585490E-19,    0.00114795E-38,   -0.47019780E-37,    0.00114797E-38,   -0.70529706E-37,
                 0.00028629E-38,    0.00000036E-26,    0.04144116E-23,    0.00000565E-38,    0.16181135E-25,
                 0.00007878E-26,    0.31554578E-29,    0.10359927E-24,   -0.00000362E-36,    0.04417637E-27,
                 0.47111610E-37,    0.00028638E-38,    0.00080780E-24,    0.00028622E-38,    0.13579004E-19,
                -0.70535401E-37,    0.13578998E-19,   -0.33167972E-23,    0.18844881E-36,    0.00000023E-38,
                 0.16940659E-20,    0.00007877E-26,    0.10359941E-24,    0.13578997E-19,    0.33167983E-23,
                 0.00031515E-26,    0.00172032E-19,   -0.33103371E-23,   -0.20687583E-23,    0.00000565E-38,

XD     =        -0.00000000E-19,

MACHC  =         0.12000000E 01,

ZMC    =         0.21451000E 05,

CDMC   =         0.80000000E 00,    0.80000000E 00,    0.10000000E 01,    0.10000000E 01,    0.10000000E 01,
                 0.18844998E-36,    0.16181135E-25,    0.00080781E-24,    0.12621977E-27,    0.41439810E-24,
                 0.00028630E-38,    0.00000000E-38,    0.00000000E-38,   -0.00000000E-37,    0.03673420E-38,
                -0.11513579E 24,    0.00000000E-37,    0.26864381E-14,   -0.00119114E-19,   -0.06095238E 02,
                -0.06095238E 02,    0.21079701E-35,   -0.17220459E-27,   -0.94603335E-26,   -0.89297371E 06,
                 0.00000000E-38,    0.00000000E-38,    0.00000000E-38,    0.00000000E-38,    0.00000000E-38,
                 0.00000000E-38,   -0.00000030E 19,    0.00010474E 10,   -0.00121962E-38,   -0.01483510E-19,
                 0.00000036E-19,    0.00000036E-19,    0.00000000E-38,    0.00000000E-38,    0.00000000E-38,
                 0.00000000E-38,    0.00000000E-38,    0.00000000E-38,    0.00000000E-38,    0.00000000E-38,
                 0.00000000E-38,    0.00000000E-38,    0.00000000E-38,    0.00000000E-38,    0.00000000E-38,

XMC    =         0.18000000E 01,

CDV    =         0.10000000E 01,    0.10000000E 01,    0.12000000E 01,    0.15000000E 01,    0.15000000E 01,
                -0.35764838E-37,   -0.00047903E-31,   -0.04046816E-26,    0.08279875E-23,    0.00007851E-26,
                -0.47025514E-37,    0.00007853E-26,    0.10359898E-24,    0.00005131E-24,   -0.00008056E-23,
                 0.49841258E 00,    0.13571695E-19,    0.13579000E-19,    0.00031515E-26,    0.00028615E-38,
                 0.00015777E-26,   -0.00001985F-31,    0.08312195E-23,    0.33119475E-23,    0.33135631E-23,
                 0.12943596E-25,    0.13565698E-19,    0.20687562E-23,    0.33881318E-20,    0.13559145E-19,
                 0.13571696E-19,   -0.00061630E-29,    0.04176292E-23,   -0.00007860E-26,    0.00080777E-23,
                -0.00015777E-26,   -0.00048089E-31,   -0.00000001E-20,    0.00028605E-38,   -0.00585335F 19,
                 0.00007878E-26,    0.31554578E-29,    0.00018313E-36,    0.04143971E-23,    0.00317302E 00,
                 0.49938915E 00,    0.00018313E-36,    0.03388132E-19,   -0.00048091E-31,   -0.00018310E-36,

GSL    =         0.12300000E 02,

VV     =         0.60000000E 02,

DESSYS =         0.20000000E 01,

XN     =         0.10000000E-02,

XO     =         0.00000000E-38,

XC     =         0.99900000E 00,

XA     =         0.00000000E-38,
```

```
TSL    =         0.20000000E 03,
TST    =         0.10000000E 03,
RHOSL  =         0.25600000E-04,
FALR   =         0.11136700E 01,
ISP    =        -0.00000000E-19,
MR     =        -0.00000000F-19,
RHORDC =        -0.00000000E-19,
VIMP   =        -0.00000000E-19,
LRDR   =        -0.00000000E-19,
DIVFAC =        -0.00000000F-19,
TZERO  =         0.00000000F-38,
DELTA  =         0.10000000E-01,
UPBND  =         0.10000000F-01,     0.10000000E-04,     0.10000000E 00,
DNBND  =         0.10000000E-02,     0.10000000E-05,     0.10000000E-01,
FREQ   =         0.50000000E 00,
FACTOR =         0.20000000E 00,
DELMIT =         0.10000000E-04,
DMCMAX =         0.80000000F 02,
MACH   =         0.00000000F-38,     0.70000000E 00,     0.10000000E 01,     0.20000000E 01,     0.60000000E 01,
                 0.00000986E-38,     0.33167918E-23,     0.33135606E-23,     0.33119474E-23,     0.00000110E-26,
                 0.10359951E-24,     0.00000281E-24,     0.16168513E-25,    -0.00091620E 19,    -0.00063110E-26,
                 0.00078537E-38,     0.18844866E-36,    -0.00000023E-38,     0.00063110F-26,     0.00028536E-38,
                 0.00007877E-26,     0.10380148E-24,     0.18844856E-36,    -0.00000023F-38,     0.00063110E-26,
                 0.00028541E-38,     0.10339781E-24,     0.00007888E-26,     0.10340039E-24,     0.13584931E-19,
                 0.13572358E-19,     0.33947493E-20,    -0.00030652E-29,     0.03975120E-29,     0.04136187F-23,
                 0.11858461F-19,    -0.00000001E-20,     0.01588642E-19,     0.26645677E-14,     0.33167960E-23,
                -0.00007328E-35,     0.04417637E-27,     0.00032080E-26,     0.00028619E-38,     0.00031514F-26,
                 0.00028579E-38,     0.12943596E-25,     0.00015777E-26,     0.04143971F-23,    -0.35276303F-37,
GAMMC  =        -0.35190000E 02,
DDMIN  =        -0.00000000E-19,
DRVEL  =         0.50000000E 02,
MCVEL  =         0.50000000E 07,
FREQ2  =         0.20000000E 01,
FRFQ3  =         0.20000000E 01,
DMCMIN =         0.10000000E 02,
```

```
RHOT    =          0.15000000E 01,
RHOCM   =          0.40000000E 00,
RHOCMI  =          0.10000000E 00,
ALPHA   =          0.16500000E 11,
PSI     =          0.18100000E 01,
EPSILN  =          0.75000000E 00,
THN     =          0.90000000E 02,
VELW    =          0.30000000E 02,
GIMP    =          0.10000000E 04,
IMPSYS  =          0.10000000E 01,
LCORCO  =          0.00000000E-38,
LCYRCO  =          0.00000000E-38,
THCO    =          0.00000000E-38,
A0      =          0.10000000E 01,
A1      =         -0.00000000E-19,
A2      =         -0.00000000E-19,
A3      =         -0.00000000E-19,
EPS1    =          0.10000000E-02,
EPS3    =          0.10000000E-02,
TN      =          0.21000000E 01,
IYR2    =          0.40000000E 00,
EF      =          0.10000000E 08,
RHOF    =          0.17200000E 03,
TFMIN   =          0.10000000E-01,
SIGCYF  =          0.60000000E 05,
THS     =          0.20000000E 00,
XCGMIN  =          0.37500000E 01,
RCHUTE  =          0.35000000E 02,
NRINGS  =                 0,
XRING   =         -0.00000000E-19,  -0.00000000E-19,  -0.00000000E-19,  -0.00000000E-19,  -0.00000000E-19,
                  -0.00000000E-19,  -0.00000000E-19,  -0.00000000E-19,  -0.00000000E-19,  -0.00000000E-19,

WRING   =         -0.00000000E-19,  -0.00000000E-19,  -0.00000000E-19,  -0.00000000E-19,  -0.00000000E-19,
                  -0.00000000E-19,  -0.00000000E-19,  -0.00000000E-19,  -0.00000000E-19,  -0.00000000E-19,

$ END
```

```
         X COORDINATES          R COORDINATES

           0.0000E-39             0.0000E-39
           1.0694E-02             1.6316E-01
           4.2593F-02             3.2352E-01
           9.5151E-02             4.7835E-01
  X1 =     1.6747E-01 R1 =        6.2500E-01
  X3 =     4.0934F 00 R3 =        7.4250E 00
           4.1173E 00             7.4561E 00
           4.1484E 00             7.4799E 00
           4.1845E 00             7.4949E 00
  X4 =     4.2234E 00 R4 =        7.5000E 00
           4.2747E 00             7.4910E 00
           4.3198E 00             7.4649E 00
           4.3533F 00             7.4250E 00
  X8 =     4.3711E 00 R8 =        7.3760E 00
  X9 =     5.0104E 00 R9 =        3.7500E 00
           5.0104F 00             2.8125E 00
           5.0104E 00             1.8750E 00
           5.0104E 00             9.3750E-01
 X10 =     5.0104F 00 R10 =       0.0000E-39

  SECTION        APEA              WHS               WST              IX               IY               XCG
                  FT2              (LBS)             (LBS)                    (SLUG-FT2)                  (FT)

      1      1.3153E 00        1.3153E 00        1.0003E 00       1.4395E-02       7.8704E-03       8.3734E-02
      3      1.9857E 02        1.8666E 02        1.5668E 02       2.9628E 02       2.4116E 02       2.6832E 00
      6      7.3766E 00        6.9340E 00        5.8201E 00       2.2147E 01       1.7904F 01       4.1518E 00
     10      9.8114E 00        9.2227E 00        7.7412E 00       2.9316E 01       2.4463E 01       4.3119E 00
     11      1.2870E 02        0.0000E-39        7.8184E 01       8.3201E 01       9.6954E 01       4.6560E 00
     13      4.4179F 01        0.0000E-39        2.7435E 01       5.9963E 00       2.4408E 01       5.0104E 00

  TOTAL HEAT SHIELD - STRUCTURE RESULTS

   WHSTOT =      2.0413F 02       WR =       1.3690E 03
   WSTTOT =      2.7686E 02   XCGH/S =       3.2205E 00

              TIME               VEL              MACH             GAMMA             ALT              RHO

UNDRFLOW AT 27146 IN MO

UNDRFLOW AT 27150 IN MO

UNDRFLOW AT 27151 IN MO

UNDRFLOW AT 27154 IN MO

UNDRFLOW AT 27156 IN MO
CLUSTER OF      5. CHUTES REQUIRED.

           3.7475F 00        1.8440E 02        2.740E-01      -3.9029E 01       1.96498E 04       1.6025E-05
           5.7475F 00        1.1333E 02        1.682E-01      -4.6467E 01       1.94596E 04       1.6105E-05
           2.2175E 02        6.3248E 01        8.756E-02      -9.0000E 01       4.57416E 03       2.3124E-05
           2.9596F 02        6.0096E 01        8.158E-02      -9.0000E 01       0.00000E-39       2.5660E-05

AMC =  3.5497574E 03 DMC =  6.7228651E 01 WMC =  1.3603889E 02 PMC =  1.2505330E 05 WL =  1.2261706E 03 T =  2.9596168E 02
 TF =  1.7475145F 00 OMC =  4.8928737E 00 WSTRAPS =  6.8019444F 00
```

```
RHOC=  4.0000E-01      GPEAK=  6.0878E 02      Y/R2=  1.0284E-01

GPEAKS          Y/R2 VALUES

  -0.0000E-39     0.0000E-39

   7.4598E 01     1.0284E-02

   1.4601E 02     2.0568E-02

   2.1430E 02     3.0852E-02

   2.7950E 02     4.1136E-02

   3.4168E 02     5.1420E-02

   4.0087E 02     6.1704E-02

   4.5714E 02     7.1988E-02

   5.1051E 02     8.2271E-02

   5.6105E 02     9.2555E-02

   6.0878E 02     1.0284E-01

SPHERE OPTION

R2 =  2.0177003E 00 T =  2.7666522E-01 S =  2.6617195E 05 MI =  3.3159080E 01
MC =  4.9207532E 00 YDD/G =  6.0877760E 02 RHOC =  4.0000000E-01
TF =     5.1174E-03LESS THAN     1.0000E-02 MINIMUM GAUGE FACE SHEET.

  XCGO =     2.4522E 00  DELXF =     1.6633E-01  XTOTCG =     4.9699E 02  YTOTCG =     3.2226E 02
INTERNAL STRUCTURE DESIGN

                       AREA(FT2)             T(INS)              W(LBS)

SPHERE
                       3.8091E 01            1.0000E-02          5.4597E 00

W INTERNAL STRUCTURE =   5.4597E 00
```

III. COMPUTATIONS

In the following pages are presented block diagrams illustrating the operation of each portion of Program 1882 and the engineering equations which are solved.

The block diagrams and engineering write-ups are broken down into the four portions of the program, namely; heat shield and structural shell, descent system, impact attenuation system, and the lander packaging design. Symbols used precede the equations.

A. BLOCK DIAGRAM

A block diagram of Program 1882 is shown below as Figure 7.

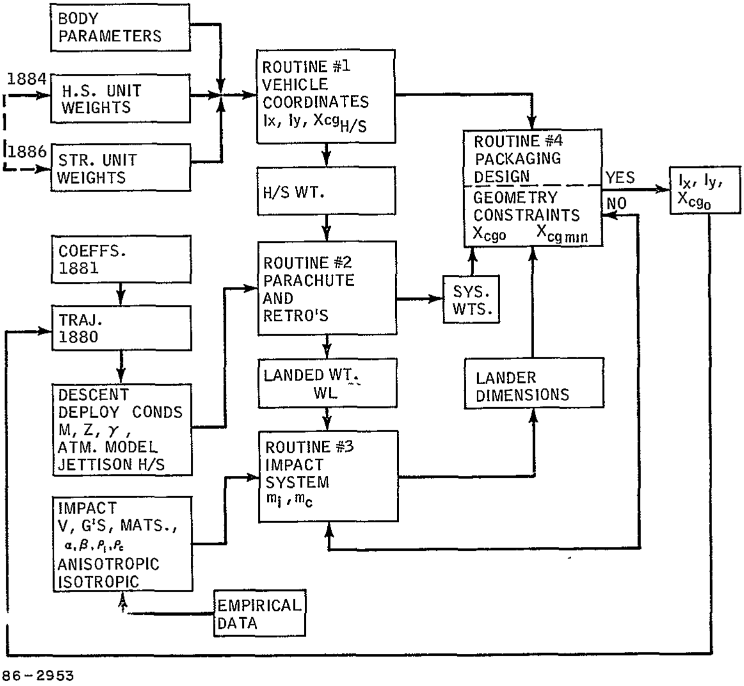

Figure 7 BLOCK DIAGRAM OF PROGRAM 1882

B. SYMBOLS

a_o, a_1, a_2, a_3	Coefficients of the $S(\theta)$ equation in the anisotropic crush-up analysis
A	Area, ft^2
a	Speed of sound, ft/sec
C_D	Drag coefficient
C_p	Specific heat at constant pressure, Btu/lb
d	Diameter, feet
D	Drag force, pounds
E	Modulus of elasticity, psi
g	Acceleration due to gravity, ft/sec^2
I_{sp}	Required specific impulse of retrorocket system, lb-sec/lb
I_x	Roll moment of inertia, slug-ft^2
I_y	Pitch moment of inertia, slug-ft^2
L_1	Temperature gradient in the troposphere expressed as a function of the adiabatic lapse rate
L_c	Length of cylindrical vehicle section, feet
L_{co}	Length of internal cone, feet
L_{cyl}	Length of internal cylinder, feet
L_o	Temperature gradient in the troposphere, °K/ft
L_R	Length of a retrorocket, feet
m	Mass, slugs
M	Mach number
M	Molecular weight
MR	Mass-fuel ratio of retrorocket

N	Exponent of the $S(\theta)$ equation in the anisotropic crushup analysis
n	Number of chutes in a cluster
P	Opening parachute shock load, pounds
q	Dynamic pressure, lb/ft^2
r	Vehicle ordinate dimension, feet
R	Universal gas constant, 89,516 ft^2/sec^2 - mole - ^oK
R_1	Inner radius of lander payload package, feet
R_2	Outer radius of lander payload package, feet
R_A	Aft spherical body radius, feet
R_B	Flare body radius, feet
R_C	Vehicle cylinder body radius, feet
R_{CO}	Radius of internal cone and/or cylinder, feet
R_N	Spherical nose cap radius, feet
R_{SB}	Toroidal radius adjacent to the flare cone section, feet
R_{SC}	Toroidal radius adjacent to the cone section, feet
R_{SN}	Toroidal radius adjacent to the spherical nose cap section, feet
R_T	Aft cone base radius, feet
S	Crushing stress of impact material, lb/ft^2
t_{fs}	Internal structure face sheet thickness, inches
t_c	Thickness of the crushable material, feet
t_{cc}	Thickness of the parachute packaging ring, feet
T	Temperature, ^oK

V_{imp}	Design impact velocity for the retrorocket system (vertical and horizontal component included), ft/sec
V_o	Total resultant impact velocity, ft/sec
V_v	Design vertical descent velocity for chute systems, ft/sec
V_w	Horizontal velocity component, ft/sec
w	Unit weight, lb/ft^2
W	Weight, pounds
W_e	Total vehicle entry weight, pounds
W_{RR}	Entry weight less the total heat shield and structure weight, pounds
x	Vehicle abcissa dimension, feet
$\bar{X}$	Centroidal distance as measured from the vehicle nose, feet
X_A	Mole fraction of argon in the atmosphere
X_C	Mole fraction of CO_2 in the atmosphere
X_D	Dynamic opening shock load factor on the drogue chute
X_{MC}	Dynamic opening shock load factor on the main chute
X_N	Mole fraction of N_2 in the atmosphere
X_O	Mole fraction of O_2 in the atmosphere
ΔX	Distance between vehicle nose and lander nose, feet
y	Crushup stroke coordinate, feet
Z	Altitude, feet
α	Curve fit constant relating crushing stress and density
β	Initial body angle in the tension shell section, degrees
γ	Flight path angle (positive in climb), degrees

ϵ	Total usable strain
θ_{2G}	Initial body angle of the general shape section, degrees
θ_{3G}	Final body angle of the general shape section, degrees
θ_A	Aft cone section body angle, degrees
θ_B	Flare section body angle, degrees
θ_C	Cone section body angle, degrees
θ_{CO}	Internal lander cone angle, degrees
θ_M	Angle subtended by the crushable material segment, degrees
θ_N	Complement of nose cap angle, degrees
ρ	Density, slug/ft^3
σ	Yield strength of face sheet, psi
ψ	Curve fit constant relating crushing stress and density

Subscripts:

1,2,3, etc.	Designated points on the vehicle surface
c	Crushup
cl	Parachute cluster
c.g.	Center of gravity
D	Drogue parachute conditions
f	Final utilized value
fs	Face sheet (internal structure)
HS	Heat shield
H/S	Heat shield and structure

i	Internal lander (payload and crushup)
ii	Initial weight just prior to retrorocket ignition
imp	Impact conditions
m	Maximum
MC	Main chute conditions
R	Retrorocket conditions
SL	Sea level conditions
ST	Stratosphere conditions
STR	External structure
susp	Suspended weight on chute system
v	Vehicle profile
vert	Vertical component
w	Wind component
$\oplus$	Earth conditions

C. ENGINEERING EQUATIONS

1. Heat Shield and Structural Shell System

There are 13 possible body sections which exist for the overall general shape. The x and r coordinates can be evolved for any shape via equations which are provided. These coordinates are evolved from input body parameters.

For the tension shell option, the x and r coordinate equations are provided, and for the general shape option the x and r coordinates are specified as inputs.

With the body coordinates in hand for the desired vehicle shape, the area, centroid, moments of inertia, and weight of each section are then calculated.

The final calculation in this portion of the program is to establish the center of gravity of the heat shield and structural shell.

2. Shape Generation Equations

a. SECTIØN 1. Spherical Nose Cap

Coordinates	Formula	Independent Variable Limits
x_o	$x_o = 0$	$\theta_o = 90^\circ$
$x_o \rightarrow x_1$	$x = R_N(1 - \sin\theta)$	$\theta_1 = \theta_N$
x_1	$x_1 = R_N(1 - \sin\theta_N)$	$\theta_o \leq \theta \leq \theta_1$
r_o	$r_o = 0$	
$r_o \rightarrow r_1$	$r = R_N \cos\theta$	
r_1	$r_1 = R_N \cos\theta_N$	

b. SECTIØN 2. Torus

$x_1 \rightarrow x_2$	$x = x_1 + R_{SN}(\sin\theta_N - \sin\theta)$
x_2	$x_2 = x_1 + R_{SN}(\sin\theta_N - \sin\theta_2)$
$r_1 \rightarrow r_2$	$r = r_1 + R_{SN}(\cos\theta - \cos\theta_N)$
r_2	$r_2 = r_1 + R_{SN}(\cos\theta_2 - \cos\theta_N)$

θ_2 depends on which option is utilized:

SECTIØN 3.	$\theta_2 = \theta_c$
SECTIØN 4.	$\theta_2 = \beta$
SECTIØN 5.	$\theta_2 = \theta_{2G}$

c. SECTIØN 3.

$x_2 \rightarrow x_3$	$x = x_2 + (r - r_2)\cot\theta_c$	$r_2 \leq r \leq r_3$
x_3	$x_3 = x_2 + (r_3 - r_2)\cot\theta_c$	
$r_2 \rightarrow r_3$	$r = r$	
r_3	$r_3 = R_C - R_{SC}(1 - \cos\theta_c)$	

d. SECTIØN 4.

$$r = \left[r_3^2 + (r_2^2 - r_3^2) \frac{\ln \left(\frac{1 + \cos \theta}{\sin \theta} \right)}{\ln \frac{1 + \cos \beta}{\sin \beta}} \right]^{1/2} \qquad \beta \leq \theta \leq 90° \tag{1}$$

$$x = x_2 + \int_{r_2}^{r} \cot \theta \, dr \tag{2}$$

$$r_3 = R_C - R_{SC} \tag{3}$$

e. SECTIØN 5.

Table of x and r coordinates (maximum of 25 points)

First pair of coordinates are x_2, r_2

Last pair of coordinates are x_3, r_3

Also specify θ_{2G} and θ_{3G}

$$x_2 = x_1 + R_{SN} (\sin \theta_N - \sin \theta_{2G}) \tag{4}$$

$$r_2 = r_1 + R_{SN} (\cos \theta_{2G} - \cos \theta_N) \tag{5}$$

$$x_3 = x_2 + (r_3 - r_2) \cos \theta_{2G} \tag{6}$$

$$r_3 = R_C - R_{SC} (1 - \cos \theta_{2G}) \tag{7}$$

f. SECTIØN 6.

$x_3 \rightarrow x_4$ $\quad x = x_3 + R_{SC} (\sin \theta_3 - \sin \theta)$ (8)

x_4 $\quad x_4 = x_3 + R_{SC} \sin \theta_3$ $\quad \theta_3 \leq \theta \leq 0°$ (9)

$r_3 \rightarrow r_4$ $\quad r = r_3 + R_{SC} (\cos \theta - \cos \theta_3)$ (10)

r_4 $\quad r_4 = R_C$ (11)

θ_3 depends on which option section (2-3) utilizes, i.e:

SECTIØN 3. $\quad \theta_3 = \theta_c$

SECTIØN 4. $\quad \theta_3 = 90°$

SECTIØN 5. $\quad \theta_3 = \theta_{3G}$

g. SECTIØN 7.

$x_4 \to x_5$ $\quad x = x \quad x_4 \leq x \leq (x_4 + L_c)$ (12)

x_5 $\quad x_5 = x_4 + L_c$ (13)

$r_4 \to r_5$ $\quad r = R_C$ (14)

r_5 $\quad r_5 = R_C$ (15)

h. SECTIØN 8.

$x_5 \to x_6$ $\quad x = x_5 + (r - R_C) \cot \theta_B \quad r_5 \leq r \leq r_6$ (16)

x_6 $\quad x_6 = x_5 + (r_6 - R_C) \cot \theta_B$ (17)

$r_5 \to r_6$ $\quad r = r$ (18)

r_6 $\quad r_6 = R_B - R_{SB} (1 - \cos \theta_B)$ (19)

i. SECTIØN 9.

$x_6 \to x_7$ $\quad x = x_6 + R_{SB} (\sin \theta_B - \sin \theta) \quad \theta_B \leq \theta \leq 0^\circ$ (20)

x_7 $\quad x_7 = x_6 + R_{SB} \sin \theta_B$ (21)

$r_6 \to r_7$ $\quad r = r_6 + R_{SB} (\cos \theta - \cos \theta_B)$ (22)

r_7 $\quad r_7 = R_B$ (23)

j. SECTIØN 10.

$x_7 \to x_8$ $\quad x = x_7 - R_{SB} \sin \theta \quad 0^\circ \leq \theta \leq \theta_A$ (24)

x_9 $\quad x_8 = x_7 - R_{SB} \sin \theta_A$ (25)

$r_7 \to r_8$ $\quad r = R_B - R_{SB} (1 - \cos \theta)$ (26)

r_8 $\quad r_8 = R_B - R_{SB} (1 - \cos \theta_A)$ (27)

k. SECTIØN 11.

$x_8 \to x_9$ $\quad x = x_8 + (r - r_8) \cot \theta_A \quad r_9 \leq r \leq r_8$ (28)

x_9 $\quad x_9 = x_8 + (r_9 - r_8) \cot \theta_A$ (29)

$$r_8 \rightarrow r_9 \qquad r = r \tag{30}$$

$$r_9 \qquad r_9 = R_A \cot \theta_A \tag{31}$$

l. SECTIØN 12.

$$x_9 \rightarrow x_{10} \qquad x = x_9 + R_A (\sin \theta_A - \sin \theta) \qquad \theta_A \leq \theta \leq -90° \tag{32}$$

$$x_{10} \qquad x_{10} = x_9 + R_A (\sin \theta_A + 1) \tag{33}$$

$$r_9 \rightarrow r_{10} \qquad r = R_A \cos \theta \tag{34}$$

$$r_{10} \qquad r_{10} = 0 \tag{35}$$

m. SECTIØN 13.

$$x_9 \rightarrow x_{10} \qquad x = x_9 \qquad 0 \leq r \leq R_T \tag{36}$$

$$x_{10} \qquad x_{10} = x_9 \tag{37}$$

$$r_9 \rightarrow r_{10} \qquad r = R_T - r \tag{38}$$

$$r_{10} \qquad r_{10} = 0 \tag{39}$$

3. Shape and Body Parameter Logic

a. The nose cap, SECTIØN 1. cannot be omitted.

b. If the R_{SN} torus, SECTIØN 2. is omitted, then:

$\theta_2 = \theta_N$

$x_2 = x_1$

$r_2 = r_1$

c. When SECTIØNS 3., 4., 5., and SECTIØN 6. are omitted,

$x_2 = x_4$

$r_2 = r_4$

d. If the cylinder, SECTIØN 7. is omitted, then:

$$x_5 = x_4$$

$$r_5 = r_4$$

e. SECTIØN 8. and SECTIØN 9. can be omitted together only in which event:

$$x_7 = x_6 = x_5$$

$$r_7 = r_6 = r_5 \quad .$$

f. If SECTIØN 10. is omitted:

$$x_8 = x_7$$

$$r_8 = r_7 \quad .$$

g. If SECTIØN 11. is omitted, then:

$$x_8 = x_9$$

$$r_8 = r_9 \quad .$$

h. Either the aft sphere, SECTIØN 12. or the base, SECTIØN 13. has to be specified. Both can not be simultaneously present or deleted.

Listed below are the equations for the surface area, centroid, and moments of inertia of each section. The centroid and moments of inertia are measured about the nose of the vehicle.

a. SECTIØN 1.

1) Area

$$A = 2\pi R_N^2 \left(1 - \sin\theta_N\right) \tag{40}$$

2) Centroid

$$\bar{X} = \frac{\pi R_N^3}{A} \left[2\left(1 - \sin\theta_N\right) - \cos^2\theta_N\right] \tag{41}$$

3) Roll moment of inertia

$$I_x = \frac{2\pi\, w_{01}\, R_N^4}{3 g_\oplus} \left[2 - \sin\theta_N(\cos^2\theta_N + 2)\right] \tag{42}$$

4) Pitch moment of inertia

$$I_y = \frac{2\pi \, w_{01} \, R_N^4}{3 g_\oplus} \left[1 - 3 \sin\theta_N + 3 \sin^2\theta_N - \sin^3 \theta_N\right] + \frac{I_x}{2} \tag{43}$$

where w_{01} is the sum of the unit heat shield and structure (the structure includes the weight factor STRFAC)

b. SECTION 2.

1) Area

$$A = 2\pi R_{SN} \left[\frac{R_{SN} \cos \theta_N}{57.3} (\theta_N - \theta_2) + R_{SN} (\sin \theta_N - \sin \theta_2) + \frac{R_{SN} \cos\theta_N (\theta_2 - \theta_N)}{57\ 3} \right] \tag{44}$$

2) Centroid

$$\bar{X} = \frac{2\pi R_{SN}}{A} \left[\frac{A_{12} B_{12}}{57.3} (\theta_N - \theta_2) + B_{12} R_{SN} (\sin \theta_N - \sin \theta_2) + A_{12} R_{SN} (\cos \theta_N - \cos \theta_2) - \frac{R_{SN}^2}{2} (\sin^2 \theta_N - \sin^2 \theta_2) \right] \tag{45}$$

3) Roll moment of inertia

$$I_x = \frac{2\pi \, w_{12} \, R_{SN}}{g_\oplus} \left[\frac{A_{12}^3 (\theta_N - \theta_2)}{57.3} + 3 A_{12}^2 R_{SN} (\sin\theta_N - \sin\theta_2) + \frac{3}{2} A_{12} R_{SN}^2 \left(\frac{\theta_N - \theta_2}{57.3} + \frac{\sin 2\theta_N - \sin 2\theta_2}{2} \right) + \frac{R_{SN}^3}{3} \left\{ \sin\theta_N (\cos^2 \theta_N + 2) - \sin\theta_2 (\cos^2 \theta_2 + 2) \right\} \right] \tag{46}$$

4) Pitch moment of inertia

$$I_y = \frac{2\pi w_{12}}{g_\oplus} R_{SN} \left[\frac{A_{12} B_{12}^2 (\theta_N - \theta_2)}{57.3} + 2A_{12} B_{12} R_{SN} (\cos\theta_N - \cos\theta_2) \right.$$

$$+ \frac{A_{12} R_{SN}^2}{2} \left(\frac{\theta_N - \theta_2}{57.3} - \frac{\sin 2\theta_N - \sin 2\theta_2}{2} \right) + B_{12}^2 R_{SN} (\sin\theta_N - \sin\theta_2)$$

$$\left. - B_{12} R_{SN}^2 (\sin^2\theta_N - \sin^2\theta_2) + \frac{R_{SN}^2}{3} (\sin^3\theta_N - \sin^3\theta_2) \right] + \frac{I_x}{2}$$

where,

$$A_{12} = r_1 - R_{SN} \cos\theta_N$$

$$B_{12} = x_1 + R_{SN} \sin\theta_N$$

and θ_2 depends on which option is utilized:

SECTIØN 3. $\theta_2 = \theta_c$

SECTIØN 4. $\theta_2 = \beta$

SECTIØN 5. $\theta_2 = \theta_{2G}$

c. SECTIØN 3.

1) Area

$$A = \frac{\pi}{\sin\theta_c} (r_3^2 - r_2^2) \tag{48}$$

2) Centroid

$$\bar{X} = \frac{\pi}{A \sin\theta_c} \left[[A_{23} (r_3^2 - r_2^2)] + \frac{2\cot\theta_c}{3} (r_3^3 - r_2^3) \right] \tag{49}$$

3) Roll moment of inertia

$$I_x = \frac{\pi w_{23}}{2 g_\oplus \sin\theta_c} (r_3^4 - r_2^4) \tag{50}$$

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4) <u>Pitch moment of inertia</u>

$$I_y = \frac{\pi\, w_{23}}{g_\oplus \sin\theta_c} \left[A_{23}^2 (r_3^2 - r_2^2) + \frac{4\, A_{23}}{3} \cot\theta_c\, (r_3^3 - r_2^2) + \frac{\cot^2\theta_c}{2} (r_3^4 - r_2^4) \right] + \frac{I_x}{2} \qquad (51)$$

where,

$$A_{23} = x_2 - r_2 \cot\theta_c$$

d. SECTION 4. and 5.

1) <u>Area</u>

$$A = 2\pi \int \frac{r\, dx}{\cos\theta} \qquad (52)$$

2) <u>Centroid</u>

$$\bar{X} = \frac{2\pi}{A} \int \frac{r\, x\, dx}{\cos\theta} \qquad (53)$$

3) <u>Roll moment of inertia</u>

$$I_x = \frac{2\pi\, w_{23}}{g_\oplus} \int \frac{r^3\, dx}{\cos\theta} \qquad (54)$$

4) <u>Pitch moment of inertia</u>

$$I_y = \frac{2\pi\, w_{23}}{g_\oplus} \int \frac{r\, x^2\, dx}{\cos\theta} + \frac{I_x}{2} \qquad (55)$$

SECTION 5. $\theta_{2G} \leq \theta \leq \theta_{3G}$

SECTION 4. $\beta \leq \theta \leq 90°$

e. SECTIØN 6.

1) Area

$$A = 2\pi R_{SC} \left[\frac{r_3 \theta_3}{57.3} + R_{SC} \left(\sin \theta_3 - \frac{\theta_3 \cos \theta_3}{57.3} \right) \right] \tag{56}$$

2) Centroid

$$\bar{X} = \frac{2\pi R_{SC}}{A} \left[\frac{A_{34} B_{34} \theta_3}{57.3} + B_{34} R_{SC} \sin \theta_3 + A_{34} R_{SC} (\cos \theta_3 - 1) - \frac{R_{SC}^2}{2} (\sin^2 \theta_3) \right] \tag{57}$$

3) Roll moment of inertia

$$I_x = \frac{2\pi w_{34} R_{SC}}{g_{\oplus}} \left[\frac{A_{34}^3 \theta_3}{57.3} + 3 A_{34}^2 R_{SC} \sin \theta_3 + \frac{3}{2} A_{34} R_{SC}^2 \left(\frac{\theta_3}{57.3} + \frac{\sin 2\theta_3}{2} \right) + \frac{R_{SC}^3}{3} \sin \theta_3 (\cos^2 \theta_3 + 2) \right]$$

4) Pitch moment of inertia

$$I_y = \frac{2\pi w_{34} R_{SC}}{g_{\oplus}} \left[\frac{A_{34} B_{34}^2 \theta_3}{57.3} + 2A_{34} B_{34} R_{SC} (\cos \theta_3 - 1) + \frac{A_{34} R_{SC}^2}{2} \left(\frac{\theta_3}{57.3} - \frac{\sin 2\theta_3}{2} \right) + B_{34}^2 R_{SC} \sin \theta_3 - B_{34} R_{SC}^2 \sin^2 \theta_3 + \frac{R_{SC}^3}{3} \sin^3 \theta_3 \right] + \frac{I_x}{2} \tag{59}$$

where,

$A_{34} = r_3 - R_{SC} \cos \theta_3$

$B_{34} = x_3 + R_{SC} \sin \theta_3$

and θ_3 depends on which option section 2-3 utilizes:

SECTIØN 3. $\theta_3 = \theta_C$

SECTIØN 4. $\theta_3 = 90°$

SECTIØN 5. $\theta_3 = \theta_{3G}$

f. SECTIØN 7.

1) Area

$$A = 2\pi R_C L_c \tag{60}$$

2) Centroid

$$\bar{X} = x_4 + \frac{L_c}{2} \tag{61}$$

3) Roll moment of inertia

$$I_x = \frac{2\pi w_{45} R_C^3}{g_\oplus} (x_5 - x_4) \tag{62}$$

4) Pitch moment of inertia

$$I_y = \frac{2\pi w_{45} R_C}{g_\oplus} (x_5^3 - x_4^3) + \frac{I_x}{2} \tag{63}$$

g. SECTIØN 8.

1) Area

$$A = \frac{\pi}{\sin \theta_B} (r_6^2 - r_5^2) \tag{64}$$

2) Centroid

$$\bar{X} = \frac{\pi}{A \sin \theta_B} \left[A_{56} (r_6^2 - r_5^2) + \frac{2 \cot \theta_B}{3} (r_6^3 - r_5^3) \right] \tag{65}$$

3) Roll moment of inertia

$$I_x = \frac{\pi w_{56}}{2 g_\oplus \sin \theta_B} (r_6^4 - r_5^4) \tag{66}$$

4) Pitch moment of inertia

$$I_y = \frac{\pi\, w_{56}}{g_\oplus \sin\theta_B}\left[A_{56}^2\,(r_6^2 - r_5^2) + \frac{4A_{56}}{3}\cot\theta_B\,(r_6^3 - r_5^3) + \frac{1}{2}\cot^2\theta_B\,(r_6^4 - r_5^4)\right] + \frac{I_x}{2} \qquad (67)$$

where,

$$A_{56} = x_5 - R_C \cot\theta_B$$

h. SECTIØN 9.

The area, centroid and inertia equations for this section are identical to SECTIØN 6. with the following changes:

x_3 is replaced by x_6

R_{SC} is replaced by R_{SB}

θ_3 is replaced by θ_B (for all options)

r_3 is replaced by r_6

i. SECTIØN 10.

1) Area

$$A = 2\pi R_{SB}\left[R_{SB}\left(\frac{\theta_A}{57.3} - \sin\theta_A\right) - \frac{R_B\,\theta_A}{57.3}\right] \qquad (68)$$

2) Centroid

$$\bar{x} = \frac{2\pi R_{SB}}{A}\left[\frac{R_{SB}}{2}\sin^2\theta_A - \frac{A_{78}\,B_{78}\,\theta_A}{57.3} - B_{78}\,R_{SB}\sin\theta_A - A_{78}\,R_{SB}\,(\cos\theta_A - 1)\right] \qquad (69)$$

3) Roll moment of inertia

$$I_x = -\frac{2\pi\, w_{78}\, R_{SB}}{g_\oplus}\left[\frac{A_{78}^3\,\theta_A}{(57.3)} + 3A_{78}^2\,R_{SB}\sin\theta_A + \frac{3}{2}A_{78}\,R_{SB}^2\left(\frac{\theta_A}{57.3} + \frac{\sin 2\theta_A}{2}\right) + \frac{R_{SB}^3}{3}\sin\theta_A\,(\cos^2\theta_A + 2)\right] \qquad (70)$$

4) Pitch moment of inertia

$$I_y = -\frac{2\pi w_{78}\ R_{SB}}{g_\oplus}\left[\frac{A_{78}\,B_{78}^{\ 2}\,\theta_A}{57.3} + 2\,A_{78}\,B_{78}\,R_{SB}\,(\cos\theta_A - 1) + \frac{A_{78}\,R_{SB}^{\ 2}}{2}\left(\frac{\theta_A}{57.3} - \frac{\sin 2\theta_A}{2}\right) + B_{78}^2\ R_{SB}\ \sin\theta_A - B_{78}\,R_{SB}^{\ 2}\,(\sin^2\theta_A) + \frac{R_{SB}^{\ 3}}{3}\ \sin^3\ \theta_A\right] + \frac{I_x}{2} \qquad (71)$$

where,

$$A_{78} = R_B - R_{SB}$$

$$B_{78} = x_7$$

j. SECTION 11.

1) Area

$$A = \frac{\pi}{\sin\theta_A}\ (r_9^{\ 2} - r_8^{\ 2}) \qquad (72)$$

2) Centroid

$$\bar{X} = \frac{\pi}{A\,\sin\theta_A}\left[A_{89}\,(r_9^{\ 2} - r_8^{\ 2}) + \frac{2\cot\theta_A}{3}\ (r_9^{\ 3} - r_8^{\ 3})\right] \qquad (73)$$

3) Roll moment of inertia

$$I_x = \frac{\pi\ w_{89}}{2\,g_\oplus\,\sin\theta_A}\ (r_9^{\ 4} - r_8^{\ 4}) \qquad (74)$$

4) Pitch Moment of inertia

$$I_y = \frac{\pi\ w_{89}}{g_\oplus\,\sin\theta_A}\left[A_{89}^{\ 2}\,(r_9^{\ 2} - r_8^{\ 2}) + \frac{4\,A_{89}}{3}\ \cot\theta_A\,(r_9^{\ 3} - r_8^{\ 3}) + \frac{\cot^2\ \theta_A}{2}\ (r_9^{\ 4} - r_8^{\ 4})\right] + \frac{I_x}{2} \qquad (75)$$

where,

$$A_{89} = x_8 - r_8 \cot \theta_A$$

k. SECTION 12.

1) <u>Area</u>

$$A = 2\pi R_A^2 (\sin \theta_A + 1) \tag{76}$$

2) <u>Centroid</u>

$$\bar{X} = \frac{2\pi R_A}{A} \left[A_{910} R_A (\sin \theta_A + 1) + \frac{R_A^2}{2} (1 - \sin^2 \theta_A) \right] \tag{77}$$

3) <u>Roll moment of inertia</u>

$$I_x = \frac{2\pi w_{910} R_A^4}{3g_\oplus} [\sin \theta_A (\cos^2 \theta_A + 2) + 2] \tag{78}$$

4) <u>Pitch moment of inertia</u>

$$I_y = \frac{2\pi w_{910} R_A^2}{g_\oplus} \left[A_{910}^2 (\sin \theta_A + 1) + A_{910} R_A (1 - \sin^2 \theta_A) + \frac{R_A^2}{3} (\sin^3 \theta_A + 1) \right] + \frac{I_x}{2} \tag{79}$$

where,

$$A_{910} = x_9 + R_A \sin \theta_A$$

l. SECTION 13.

1) <u>Area</u>

$$A = \pi R_T^2 \tag{80}$$

2) <u>Centroid</u>

$$\bar{X} = x_{10} \tag{81}$$

3) <u>Roll moment of inertia</u>

$$I_x = \frac{\pi \, w_{910} \, R_T^4}{2 g_\oplus} \tag{82}$$

4) <u>Pitch moment of inertia</u>

$$I_y = \frac{\pi \, w_{910} \, X_{10}^2 \, R_T^2}{g_\oplus} + \frac{I_x}{2} \tag{83}$$

The weight of each section of the vehicle is calculated in the following manner:

Example:

SECTIØN 1.

$W_{HS} = w_{01_{HS}} \, A$ pound

$W_{STR} = (w_{01_{STR}} \, A) \, (STRFAC)$ pound

$W_{RR} = W_e - \sum (W_{HS} + W_{STR})$ pound

The center of gravity of the heat shield and structural shell is calculated, with respect to the nose of the vehicle, by the following expression:

$$X_{CG_{H/S}} = \frac{W_{01} \, \bar{X}_{01} + W_{12} \, \bar{X}_{12} + \text{----------} \, W_{910} \, \bar{X}_{910}}{W_{01} + W_{12} + \text{-----} \, W_{910}} \tag{84}$$

4. <u>Descent System</u>

The descent system portion of this program consists of three options, as shown in Figure 3; namely:

a. Option One -- Two Chute System

1) <u>Drogue chute</u>

Chute diameter $\geq$ specified minimum diameter

2) <u>Main chute</u>

a) Single chute diameter $\geq$ specified minimum diameter

b) Cluster of n chutes if the diameter of a single chute $\geq$ maximum input diameter.

b. Option Two -- Single Chute System

1) Main chute

a) Single chute diameter $\geq$ specified minimum diameter

b) Cluster of n chutes if the diameter of a single chute $\geq$ maximum input diameter.

c. Option Three -- Drogue Chute - Retrorocket System

1) Drogue chute

Specified chute diameter

2) Retrorocket

Sized on required ΔV

5. Atmosphere Equations

To solve the equations of motion utilized in each of the descent system options, a model atmosphere relating the atmospheric density and speed of sound as a function of altitude must be generated. The model atmosphere will consist of a troposphere and stratosphere. Equations are not generated for the thermosphere since it is assumed that chute deployment conditions will always be well below the thermosphere region. The inputs required to establish the atmosphere are sea-level temperature, stratosphere temperature, the temperature gradient in the troposphere expressed as a fraction of adiabatic lapse rate, the acceleration of gravity at sea level, the mole fraction of the concentrations of oxygen, nitrogen, carbon dioxide, and argon in the atmosphere, and the sea-level density. Nine quantities are used to specify the atmosphere. The atmosphere is assumed to be in hydrostatic equilibrium.

a. Troposphere

$$M = 28\,X_N + 32\,X_O + 44\,X_C + 40\,X_A \qquad (85)$$

$$R = 89{,}516$$

$$C_p = \frac{R}{M}\,(3.5\,X_N + 3.5\,X_O + 4.0\,X_C + 2.5\,X_A) \qquad (86)$$

$$L_o = -L_1 \left(\frac{g_{SL}}{C_p}\right) \tag{87}$$

$$Z_{ST} = \frac{T_{ST} - T_{SL}}{L_o} \tag{88}$$

$$\rho = \rho_{SL} \left(1 + \frac{L_o Z}{T_{SL}}\right)^{-\left(1 + \frac{Mg_{SL}}{RL_o}\right)} \tag{89}$$

$$T = T_{SL} + L_o Z \tag{90}$$

$$a = \sqrt{\frac{C_p T}{\frac{C_p M}{R} - 1}} \tag{91}$$

b. Stratosphere $Z > Z_{ST}$

$$a = \sqrt{\frac{C_p T_{ST}}{\frac{C_p M}{R} - 1}} \tag{92}$$

$$\rho_{ST} = \rho_{SL} \left(\frac{T_{ST}}{T_{SL}}\right)^{-\left(1 + \frac{Mg_{SL}}{RL_o}\right)} \tag{93}$$

$$\rho = \rho_{ST}\, e^{-\frac{Mg_{SL}}{RT_{ST}} (Z - Z_{ST})} \tag{94}$$

6. Equations of Motion

For purposes of short-range parachute trajectories, the two-degree-of-freedom equations of motion are utilized neglecting the centripetal acceleration and lift component of the vehicle. The equations are as follows:

$$m\dot{V} = -D - mg_{SL} \sin\gamma \tag{95}$$

$$V\dot{\gamma} = -g_{SL} \cos\gamma \tag{96}$$

$$\dot{Z} = +V \sin\gamma \tag{97}$$

a. Two Chute System - Option 1

1) Drogue chute

It is desired to deploy a drogue chute at some specified Mach number (M_D) and altitude (Z_D) so as to have the vehicle decelerate to a specified set of main chute deployment conditions of Mach number (M_{MC}) and altitude (Z_{MC}). The intent is to determine the drogue chute canopy area which will satisfy these end conditions (see Figure 3b).

To start the drogue chute trajectory, a minimum specified diameter chute is used in the drag component:

$$D = \frac{1}{2} (C_D A)_{eff} \, \rho(Z) \, V^2(Z) \tag{98}$$

where,

$$(C_D A)_{eff} = (C_D A)_v + (C_D A)_D \tag{99}$$

$$m = \frac{W_e}{g_\oplus} \tag{100}$$

and,

$$A_V = \pi R_C^2 \tag{101}$$

If the minimum specified drogue chute diameter satisfies the main chute deployment conditions such that the main chute deployment Mach number (M_{MC}) is reached at a higher altitude than the specified deployment altitude (Z_{MC}), then the drogue is allowed to decelerate to the specified deployment altitude (Z_{MC}) and some new somewhat lower Mach number. In this case the design drogue chute diameter is the minimum specified value and the main-chute descent commences at the specified deployment altitude (Z_{MC}) with the newly established Mach number.

If the minimum specified drogue chute diameter does not satisfy the deployment conditions of the main chute, then increasing drogue chute areas (A_D) are used until the end conditions are satisfied within ± 500 feet of the specified main chute deployment altitude (Z_{MC}).

a) Drogue Diameter

$$d_D = \sqrt{\frac{4A_D}{\pi}} \tag{102}$$

b) Drogue Weight

$$W_D = 0.11 \left[\frac{d_D}{18.6} \quad \frac{q_D}{65}\right] A_D \qquad \left[\begin{array}{l}\text{Curve fit from}\\ \text{Reference 3}\end{array}\right]$$

c) Opening Drogue Shock Load

$$P_D = X_D \; q_D \; (C_D A)_D \qquad \left[\text{Reference 2}\right] \tag{103}$$

where,

$$q_D = 1/2 \; \rho_D \; V_D^2 \tag{104}$$

2) Main chute

The main chute canopy area is sized such that the suspended package decelerates to a specified vertical descent velocity (see Figure 3b). Terminal descent velocity is assumed such that

$$A_{MC} = \frac{2 \, g_{SL} \; m_{susp}}{\rho_{SL} \; C_{D_{MC}} \; V_{vert}^2} \tag{105}$$

The calculated main chute canopy diameter must be ≥ a minimum specified diameter. If the calculated diameter is less than the minimum specified value, then the specified diameter is utilized. In the above equation m_{susp} is dependent upon when the heat shield and structure is jettisoned from the vehicle. There are two options; namely,

a) Jettison at main chute deployment

$$m_{susp} = \frac{W_{RR} - W_D}{g_\oplus} \tag{106}$$

b) Jettison just prior to impact

$$m_{susp} = \frac{W_e - W_D}{g_\oplus} \tag{107}$$

Main Chute Diameter

$$d_{MC} = \sqrt{\frac{4A_{MC}}{\pi}} \quad . \tag{108}$$

b. Main Chute Cluster Option

If the diameter of the main chute exceeds the maximum specified diameter, then a cluster of n chutes are employed so as to reduce the size of each chute to less than the maximum allowable value. The area of each chute in the cluster is defined as:

$$A_{MC} = \frac{2\, g_{SL}\, m_{susp}}{n\, \rho_{SL}\, C_{D_{cl}}\, V_{vert}^2} \tag{109}$$

where n is the number of chutes in the cluster and $C_{D_{cl}}$ the drag coefficient of each chute in the cluster.

$$C_{D_{cl}} = C_{D_{MC}} (0.95 - 0.03\, n) \qquad \text{[Reference 2]} \tag{110}$$

The diameter of each chute in the cluster is

$$d_{cl} = \sqrt{\frac{4A_{MC}}{\pi}} \quad , \tag{111}$$

hence n should be increased until this diameter ≤ the maximum specified diameter.

The number of chutes n is increased in odd increments, i. e., n equal to 3, 5, 7, . . . 15.

The weight of the clustered main chute system is:

$$W_{MC_{cl}} = \frac{0.013\, q_{MC}\, A_{MC}}{10} (0.98 + 0.045\, n)\, n \tag{112}$$

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c. Main Chute Descent Trajectory

With the area of the main chute canopy established via either a single chute or cluster, the actual main chute descent trajectory can be determined from the equations of motion. In general, because of the large size of the main chute, the filling time and/or loss in altitude has to be accounted for before the trajectory commences.

The main chute filling time is expressed as:

$$t_f = d_{MC} \left(0.05 - 3.0 \times 10^{-5} V_{MC}\right) \qquad \left[\text{Reference } 2\right] \quad (113)$$

Assuming no change in velocity during inflation, the loss in altitude is:

$$\Delta Z_f = V_{MC} \, t_f \; ;$$

hence the main chute trajectory commences at γ_{MC}, V_{MC}, and $(Z_{MC} - \Delta Z_f)$. The mass (m) used in the equations of motion is m_{susp} and is dependent upon when the heat shield and structure are jettisoned.

1) Jettison at Main Chute Deployment

$$m_{susp} = \frac{W_{RR} - W_D}{g_\oplus} \qquad (114)$$

$$(C_D A)_{eff} = (C_D A)_{MC} \qquad (115)$$

2) Jettison Just Prior to Impact

$$m_{susp} = \frac{W_e - W_D}{g_\oplus} \qquad (116)$$

$$(C_D A)_{eff} = (C_D A)_v + (C_D A)_{MC} \; . \qquad (117)$$

Note that if the cluster option is utilized, then $C_{D_{MC}}$ is replaced by $(n)\, C_{D_{c1}}$.

3) Single Main Chute Weight

$$W_{MC} = \frac{0.013 \, q_{MC} \, A_{MC}}{10} \qquad (118)$$

4) Opening Main Chute Shock Load (Single or Cluster)

$$P_{MC} = X_{MC} \, q_{MC} \, (C_D A)_{MC} \qquad (119)$$

where,

$$q_{MC} = \frac{1}{2} \rho_{MC} V_{MC}^2 \quad (120)$$

5) Landed Impact Weight (Crushup, Payload and Internal Structure)

$$W_L = W_{RR} - W_D - W_{MC} - W_{STRAPS} \quad (121)$$

where,

$$W_{STRAPS} = 0.05 (W_D + W_{MC}) \ .$$

d. Single Chute System-Option 2

It is desired to deploy a main chute at a specified Mach number (M_{MC}) and altitude (Z_{MC}) so as to decelerate the package to a specified impact velocity at zero altitude. This option is identical to the main chute portion of Option 1, including clusters.

e. Drogue Retrorocket System-Option 3

Option 3 consists of a specified drogue chute diameter and a retrorocket. The intent is to deploy the drogue chute at specified deployment Mach number (M_D) and altitude (Z_D) conditions. The drogue is allowed to decelerate down to impact and the drogue chute impact velocity (V_D) is obtained via the equations of motion and/or descent trajectory. The retrorocket is then sized on the ΔV which exists between the resultant of the drogue impact velocity (V_D) and horizontal wind velocity (V_W), and the required specified impact velocity (V_{imp}) .

1) Resultant Velocity at Retro Ignition

$$V_R = \sqrt{V_D^2 + V_W^2} \quad (122)$$

2) Required Rocket ΔV

$$\Delta V = V_R - V_{imp} \quad (123)$$

3) Retrorocket Weight (Structure and Fuel)

$$W_R = \frac{W_{i1} - W_{final}}{MR} \quad (124)$$

where,

$$W_{final} = W_{11}\, e^{\left(-\frac{\Delta V}{I_{sp}\, g_{e}}\right)} \tag{125}$$

4) Initial Weight Prior to Retro Ignition

$$W_{11} = W_E - W_D - W_{HS} - W_{STR} - W_{STRAPS} \tag{126}$$

5) Drogue Chute Weight

$$W_D = 0.11 \left[\frac{d_D\, q_D}{18.6\ (65)}\right] A_D \tag{127}$$

6) Strap Weight

$$W_{STRAPS} = 0.05\ W_D \tag{128}$$

7) Rocket Volume

$$V_{OL_R} = \frac{W_R}{\rho_R} = \pi\, d_R^{\,3} \left(\frac{L_R}{d_R}\right) \tag{129}$$

8) Rocket Diameter

$$d_R = \left(\frac{W_R\, d_R}{\pi\, \rho_R L_R}\right)^{1/3} \tag{130}$$

9) Landed Impact Weight (Crushup, Payload, and Internal Structure)

$$W_L = W_{11} - W_R \tag{131}$$

10) Opening Drogue Shock Load

$$P_D = X_D\, q_D\ (C_D\, A)_D \tag{132}$$

where,

$$q_D = \frac{1}{2}\ \rho_D\ V_D^{\,2} \tag{133}$$

Since the retrorocket system has some inherent ΔV error, it should be accounted for so as to ascertain a correct resultant impact velocity which is required in the impact attenuation system.

11) Final Resultant Impact Velocity

$$V_o = V_{imp} \left(1 + \Delta V_{error} \right) \tag{134}$$

7. Impact Attenuation System

This portion of the program is the impact dynamics of the lander package using crushable material. The intent is to determine the weight and geometric dimensions of the crushable material and residual payload.

The equations presented herein are based on an analysis which accounts for the variation of mass during the crushup stroke and for materials with anisotropic properties.[1] The equations have been derived for the particular case where the crushable material is in the shape of a spherical segment.

There are two options for the type lander configuration and three special cases therein·

a. Option One - Lenticular Shape

1) Lenticular (see Figure 4d).

2) Sphere -- The sphere is a special case of the lenticular with θ_M set equal to 90 degrees (see Figure 4e).

b. Option Two - Spherical Segment Cone-Cylinder Shape

1) Cone-Cylinder --A spherical segment of crushup ($\theta_M \leq 90$ degrees) with a cone and cylinder payload package (see Figure 4a).

2) Cylinder -- A special case of the cone-cylinder with the exception that the cone portion of the payload is deleted (see Figure 4b).

3) Cone --A special case of the cone-cylinder with the exception that the cylinder portion is deleted (see Figure 4c).

a. Lenticular - Option One

This option is capable of handling either a lenticular or spherical shape lander. The sphere portion of the option is utilized by setting θ_M equal to 90 degrees whereas the lenticular utilizes a θ_M of anything between 0 and 90 degrees (see Figures 4d and 4e).

1) Geometry Expression

$$R_2 = \left[\frac{3\,(m_i + m_c)}{2\pi\,[\rho_i K_1^2\ K_2 + \rho_c \{(1 - \cos\theta_M)^2 (2 + \cos\theta_M) - K_1^2 K_2\}]} \right]^{1/3} \tag{135}$$

where,

$$m_i + m_c = \frac{W_L}{g_\oplus}$$

$$K_1 = \left(1 - \frac{y_m}{\epsilon R_2} - \cos\theta_M\right)$$

$$K_2 = \left(2 - \frac{2y_m}{\epsilon R_2} + \cos\theta_M\right)$$

2) Internal Payload and Mass

$$m_i = \frac{2\pi}{3}\ (\rho_i\ R_2^3\ K_1^2\ K_2) \tag{136}$$

3) Crushup Mass

$$m_C = \frac{2\pi}{3}\ \rho_c\ R_2^3\ [(1 - \cos\theta_M)^2 (2 + \cos\theta_M) - K_1^2\ K_2] \tag{137}$$

4) Maximum Crushing Stress

$$S_m = (\alpha\ \rho_c)^{1/\psi} \tag{138}$$

5) Crushup Thickness

$$t_C = \left(\frac{y_m}{R_2}\right) \frac{R_2}{\epsilon} \tag{139}$$

6) Velocity Expression

$$\frac{V_o^2\,(m_i + m_c)}{4\pi S_m R_2^3} = \int_o^{y_m/R_2} \frac{\left(1 - \frac{y}{\epsilon R_2}\right)^2 \left[I\left(\frac{y}{R_2}\right)\right] d\left(\frac{y}{R_2}\right)}{\left[1 - \frac{\rho_c \pi R_2^3}{m_i + m_c}\left\{\left(\frac{y}{\epsilon R_2}\right)^2 - \frac{1}{3}\left(\frac{y}{\epsilon R_2}\right)^3\right\}\right]} \tag{140}$$

where,

$$V_o = (V_v^2 + V_w^2)^{1/2}$$

$$u = 1 - \frac{y}{\epsilon R_2}$$

$$I\left(\frac{y}{R_2}\right) = \frac{a_o}{(N-2)}\left[1 - u^{N-2}\right] + \frac{a_1}{2}\,\frac{(1-u^2)}{(u^2)}$$

$$+ \frac{a_2}{2u}\left[\frac{\cos^{-1} u}{u} - \sqrt{1-u^2}\right]$$

$$+ \frac{a_3}{2}\left[\frac{(\cos^{-1} u)^2}{u^2} - 2\,\frac{(\cos^{-1} u)}{u}\sqrt{1-u^2} - 2 \ln u\right]$$

The constants a_0, a_1, a_2, a_3, and N are empirically determined and are used to describe the materials anistropy, i. e. the variation of crushing stress with the direction of loading (see Reference 1).

$$S(\theta) = a_o \cos^N \theta + a_1 + a_2\,\theta + a_3\,\theta^2$$

7) Acceleration Expression

$$G_{imp} = \frac{2\pi S_m R_2^2}{(m_i + m_c)\,g_\oplus}\left[\frac{\left(1 - \frac{y}{\epsilon R_2}\right)^2 \left[I\left(\frac{y}{R_2}\right)\right]}{\left[1 - \frac{\rho_c \pi R_2^3}{m_i + m_c}\left\{\left(\frac{y}{\epsilon R_2}\right)^2 - \frac{1}{3}\left(\frac{y}{\epsilon R_2}\right)^3\right\}\right]}\right] \tag{141}$$

b. Cone-Cylinder-Option Two

This option is capable of utilizing a cone-cylinder, a cone, and a cylinder as the lander payload geometry (see Figures 4a, b, c). The special case of the cylinder is made possible by setting L_{co}/R_{co} equal to zero, whereas the special case of the cone is evolved by setting L_{cyl}/R_{co} equal to zero.

1) Geometry Expression

$$R_2 = \left[\frac{(m_1 + m_c) - \frac{\pi\rho_1}{3}\left(\frac{L_{CO}}{R_{CO}}\right) R_{co}^3 \{1 + K_3 + K_3^2\} - \frac{\pi\rho_1}{3}\left(\frac{R_{CO}}{\sin\theta_M} - \frac{R_{CO}}{\tan\theta_M}\right)^2 \left(\frac{2R_{CO}}{\sin\theta_M} + \frac{R_{CO}}{\tan\theta_M}\right) - \pi\rho_1 R_{CO}^3 \left(\frac{L_{cyl}}{R_{CO}}\right)}{\frac{2\pi}{3}\rho_c (1 - \cos\theta_M)} + \frac{R_{CO}^3}{\sin^3\theta_M} \right]^{1/3} \qquad (142)$$

where,

$$K_3 = 1 - \frac{L_{CO}}{R_{CO}\tan\theta_{CO}}$$

2) Internal Payload Mass

$$m_1 = \frac{\pi\rho_1 L_{CO}}{3}(R_{CO}^2 + R_{CO}R + R^2) + \frac{\pi\rho_1}{3}\left(R_1 - \frac{R_{CO}}{\tan\theta_M}\right)^2 \left(2R_1 + \frac{R_{CO}}{\tan\theta_M}\right) + \pi\rho_1 R_{CO}^2 L_{cyl} \qquad (143)$$

where,

$$R_1 = \frac{R_{CO}}{\sin\theta_M}$$

$$R = R_{CO} K_3$$

and,

$$\frac{y_m}{R_2} = \epsilon\left(1 - \frac{R_{CO}}{R_2 \sin\theta_M}\right)$$

3) Crushup Mass

$$m_c = \frac{2\pi \rho_c}{3} (1 - \cos \theta_M)(R_2^3 - R_1^3) \quad (144)$$

Note that the velocity and acceleration equations are identical as those utilized in the lenticular option.

4) Cylinder Length

$$L_{cyl} = \left(\frac{L_{cyl}}{R_{CO}} \right) R_{CO} \quad (145)$$

5) Cone Length

$$L_{CO} = \left(\frac{L_{CO}}{R_{CO}} \right) R_{CO} \quad (146)$$

8. Engineering Logic

In order to satisfy the geometry constraints of the lander, the impact velocity, and impact G simultaneously, iteration is required between specified values of the crushup density, i.e. $\rho_{c\ min}$ and $\rho_{c\ max}$. Both the lenticular option and the cone-cylinder option are started by using $\rho_{c\ max}$ and then satisfying the geometry and velocity expressions. With these two expressions satisfied, the acceleration equation is checked to see that $G_{peak} \leq G_{specified}$. If this requirement is not satisfied, then ρ_c is decreased by increments towards $\rho_{c\ min}$ until $G_{peak} \leq G_{specified}$. If at $\rho_{c\ min}$, G_{peak} is still greater than $G_{specified}$, then these are the values used, i.e., $\rho_{c_{min}}$ and the associated G and geometry. The method of solution is depicted by a flow diagram in Figure 8.

9. Lander Packaging Design

The intent in this portion of the program is to package the lander (payload and crushup) and descent system within the vehicle such that it both fits within the inboard profile of the vehicle and also satisfies a minimum center of gravity constraint. To include the thickness of the heat shield and structure in the packaging design it is necessary to redefine the lander outer radius as:

$$R_2' = R_2 + t_{H/S} \quad (147)$$

where $t_{H/S}$ is the thickness in feet.

The design is started by placing the lander at the nose of the vehicle, i.e. $\Delta x = 0$; if the constraints are not met, then the lander is moved aft a given Δx until design is made possible. The geometry constraints are cited below

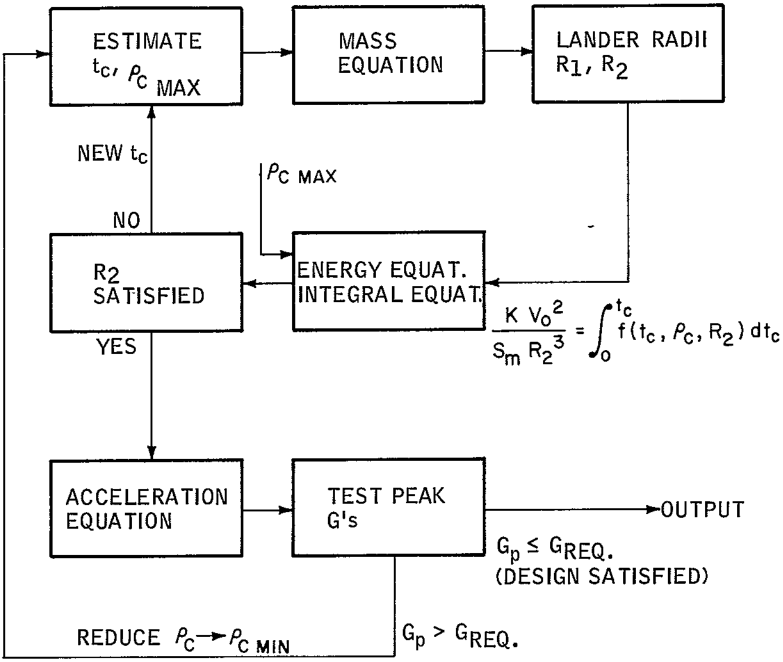
(DOUBLE ITERATION ON t_c AND ρ_c)

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Figure 8 METHOD OF SOLUTION OF IMPACT ATTENUATOR DESIGN

a. Lenticular Option

$$2 R_2' (1 - \cos \theta_M) < X_{V_{final}} - \Delta X$$

$$R_2' \sin \theta_M \leq R_C$$

b. Cone-Cylinder Option

$$\left(R_2' - \frac{R_{CO}}{\tan \theta_M} + L_{cyl} + L_{CO} \right) \leq X_{V_{final}} - \Delta X$$

$$R_2' \sin \theta_M \leq R_C$$

If the above geometry constraints are not satisfied, then return to the impact attenuation system and increase ρ_C to $\rho_{C_{max}}$ and find new, smaller lander dimensions. With these new dimensions, check the geometry constraints again.

If $\rho_{C_{max}}$ were already utilized in the impact attenuation system, then stop the problem realizing that packaging is impossible for the given design constraints.

Once the overall geometry constraints are satisfied, one can proceed to check the x and r coordinates of the lander (x_p and r_p) against the inboard profile coordinates x_v and r_v (see Figure 5). An overall logic diagram is shown in Figure 9, depicting the manner in which the packaging is done.

a. Lenticular (Sphere) Option

$$x_p = R_2' (1 - \cos \theta) + \Delta X , \quad r_p = R_2' \sin \theta \qquad 0 < \theta \leq \theta_M \tag{148}$$

$$x_p = R_2' (1 - 2 \cos \theta_M + \cos \theta) + \Delta X , \quad r_p = R_2' \sin \theta \quad \theta_M \leq \theta < 0 \tag{149}$$

b. Cone-Cylinder Option

$$x_p = R_2' (1 - \cos \theta) + \Delta X \qquad r_p = R_2' \sin \theta \quad 0 \leq \theta \leq \theta_M \tag{150}$$

$$x_p = R_2' (1 - \cos \theta_M) + t \cos \theta_M + \Delta X + L \quad r_p = R_{CO} \quad 0 \leq L \leq L_{cyl} \tag{151}$$

$$x_p = R_2' (1 - \cos \theta_M) + t \cos \theta_M + L_{cyl} + \Delta X + L , \; r_p = R_{CO} - \frac{L}{R_{CO - R}} \quad 0 \leq L \leq L_{CO} \tag{152}$$

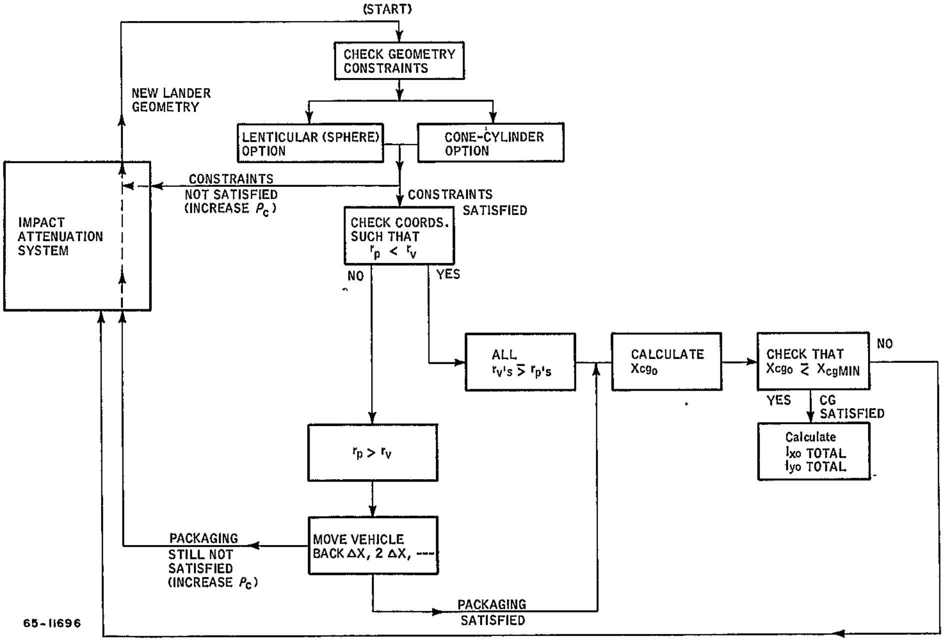

Figure 9 PACKAGING LOGIC DIAGRAM

Vehicle Coordinate Logic -- Solve for x_p from the given equations and then determine which body section x_p occurs. With this established, go to that section and find r_v noting that r_p must be equal to or smaller than r_v.

1) SECTIØN 1.0

$$r_v = R_N \cos\theta \tag{153}$$

where,

$$\theta = \arc\sin\left(\frac{R_N - x_p}{R_N}\right)$$

2) SECTIØN 2.

$$r_v = r_1 + R_{SN}\,(\cos\theta - \cos\theta_N) \tag{154}$$

where,

$$\theta = \arc\sin\left(\frac{R_{SN}\sin\theta_N - x_p + x_1}{R_{SN}}\right)$$

3) SECTIØN 3.

$$r_v = \frac{x_p + r_2 \cot\theta_c - x_2}{\cot\theta_c} \tag{155}$$

4) SECTIØN 4. and 5.

Linear extrapolation is used for both of these options.

5) SECTIØN 6.

$$r_v = r_3 + R_{SC}\,(\cos\theta - \cos\theta_3) \tag{156}$$

where,

$$\theta = \arc\sin\left(\frac{x_3 + R_{SC}\sin\theta_3 - x_p}{R_{SC}}\right)$$

and,

a) SECTIØN 3.

$$\theta_3 = \theta_C$$

$$r_3 = R_C - R_{SC} \ (1 - \cos \theta_C)$$

$$x_3 = x_2 + (r_3 - r_2) \ \cot \theta_c$$

b) SECTIØN 4.

$$\theta_3 = 90 \text{ degrees}$$

$$r_3 = R_C - R_{SC}$$

X_3 is the last point in this section.

c) SECTIØN 5.

$$\theta_3 = \theta_{3G}$$

r_3 and x_3 are the last values of the input tables.

6) SECTIØN 7.

$r_v = R_C$ for all x_p's in this section.

7) SECTIØN 8.

$$r_v = \frac{x_p + R_C \cot \theta_B - x_5}{\cot \theta_B} \tag{157}$$

8) SECTIØN 9.

$$r_v = r_6 + R_{SB} \ (\cos \theta - \cos \theta_B) \tag{158}$$

where,

$$\theta = \arcsin \left(\frac{x_6 + R_{SB} \sin \theta_B - x_p}{R_{SB}} \right)$$

9) SECTIØN 10.

$$r_v = R_B - R_{SB} \ (1 - \cos \theta) \tag{159}$$

where,

$$\theta = \arc\sin\left(\frac{x_7 - x_p}{R_{SB}}\right)$$

10) SECTION 11.

$$r_v = \frac{x_p + r_8 \cot\theta_A - x_8}{\cot\theta_A} \tag{160}$$

11) SECTION 12.

$$r_v = R_A \cos\theta \tag{161}$$

where,

$$\theta = \arc\sin \frac{x_9 + R_A \sin\theta_A - x_p}{R_A}$$

12) SECTION 13.

$$r_v = 0 \tag{162}$$

If for a limiting value of ΔX, the lander still cannot fit within the inboard profile of the vehicle, then the design must return to the impact attenuation system and increase ρ_C to $\rho_{C_{max}}$ so as to assure a smaller dimensional lander which may or may not fit into the vehicle.

If the lander is finally positioned within the vehicle, the overall center of gravity position must be found such as to check the requirement that

$$\text{c.g.}_{\text{ overall}} \leq \text{c.g.}_{\text{ specified}}$$

Overall Vehicle Center of Gravity

a. Lenticular (sphere) Option

$$X_{CG_o} = \frac{[1.05\,(W_D + W_{MC}) + W_c + W_I]\,[\Delta X_f + R_2\,(1 - \cos\theta_M)] + W_{H/S}\,X_{CG_{H/S}} + W_R\left(\Delta X_f + \frac{L_R}{2}\right)}{W_e} \tag{163}$$

b. Cone Cylinder Option

$$X_{CG_o} = \frac{W_{H/S}\ X_{CG_{H/S}} + W_R \left(\Delta X_f + \frac{L_R}{2}\right) + W_c\ (\Delta X_f + X_{CGC}) + W_i\ (\Delta X_f + t + X_{CG_i}) + 1.05\,(W_D + W_{MC}) \left(\Delta X_f + t \cos\theta_M + \frac{R_2}{10}\right)}{W_e}$$

where,

$$X_{CGC} = \frac{\left[R_2\ (R_2^3 - R_1^3)\ (1 - \cos\theta_M) - \left(\frac{3\ R_2^4 - R_1^4}{8}\right) \sin^2\theta_M\right]}{(R_2^3 - R_1^3)\ (1 - \cos\theta_M)} \tag{164}$$

where,

$$X_{CGi} = \frac{W_{CAP}\ X_{CAP} + W_{cyl}\left(h + \frac{L_{cyl}}{2}\right) + W_{cone}\ (h + L_{cyl} + X_{cone})}{(W_{CAP} + W_{cyl} + W_{cone})}$$

$$W_{CAP} = \frac{\pi h^2 \rho_1}{3}\ (3R_1 - h)\, g_\oplus$$

$$W_{cyl} = \pi \rho_1\ R_{CO}^2\ L_{cyl}\ g_\oplus$$

$$W_{cone} = \frac{\pi\, \rho_1\, L_{CO}}{3}\ (R_{CO}^2 + R_{CO}\, R + R^2)\, g_\oplus$$

$$X_{CAP} = \frac{\pi}{V_{CAP}} \left(\frac{2\, h^3\, R_1}{3} - \frac{h^4}{4}\right)$$

$$V_{CAP} = \frac{\pi\, h^2}{3}\ (3R_1 - h)$$

$$X_{cone} = \frac{L_{CO}\left(R_{CO} - \frac{2\, L_{co}}{3 \tan\theta_{CO}}\right)}{2R_{CO} - \frac{L_{co}}{\tan\theta_{CO}}}$$

$$h = R_1\ (1 - \cos\theta_M)$$

If $x_{cg_{overall}} > x_{cg_{specified}}$, then the design returns to the impact attenuation system and increases ρ_c to $\rho_{c_{max}}$. If $\rho_{c_{max}}$ was already utilized, then packaging is impossible for the given design constraints. If the center of gravity constraint is satisfied, i. e. $X_{CG_O} \leq X_{CG_{specified}}$,

then the moments of inertia of the entire vehicle about the overall center of gravity can be established.

Total Moments of Intertia

1) <u>Lenticular (sphere) option</u>

$$I_{x_{TOT/X_{CG_O}}} = \sum I_{x_{H/S}} + \frac{1}{2}\,\frac{W_R}{g_\oplus}\left(\frac{D_R}{2}\right)^2 + \frac{4\pi}{15}\,\rho_{c_f}\,(R_2{}^5 - R_1{}^5)\,[2 - \cos\theta_M\,(\sin^2\theta_M + 2)]$$

$$+ \pi\rho_1\left(\frac{4}{3}R_1{}^2\,h^3 - R_1\,h^4 + \frac{h^5}{5}\right) + \frac{1.05\,(W_D + W_{MC})}{2\,g_\oplus}\,[(R_2 + t_{cc})^2 - R_2{}^2] \tag{165}$$

where,

$$t_{cc} = \frac{0.80\,(W_D + W_{MC})}{P_{chute}\,R_2{}^2}$$

$$I_{y_{TOT/X_{CG_O}}} = \sum I_{y_{H/S}} + \frac{W_{H/S}}{g_\oplus}\left[\left(X_{CG_O} - X_{CG_{H/S}}\right)^2 - X_{CG_{H/S}}{}^2\right]$$

$$+ \frac{W_R}{g_\oplus}\left(\frac{L_R{}^2}{12} + \frac{D_R{}^2}{16}\right) + \frac{W_R}{g_\oplus}\left(X_{CG_O} - \Delta X_f - \frac{L_R}{2}\right)^2 \tag{166}$$

$$+ \frac{4\pi}{3}\,\rho_{c_f}\,R_2{}^2\,(R_2{}^3 - R_1{}^3)\,(1 - \cos\theta_M) - \pi R_2\,\rho_{c_f}\,(R_2{}^4 - R_1{}^4)\,\sin^2\theta_M$$

$$+ \frac{4\pi}{15}\,\rho_{c_f}\,(R_2{}^5 - R_1{}^5)\,(1 - \cos^3\theta_M) + \frac{2\pi}{15}\,\rho_{c_f}\,(R_2{}^5 - R_1{}^5)\,[2 - \cos\theta_M(\sin^2\theta_M + 2)]$$

$$- 2\rho_{c_f}\,V_s\,\bar{X}_s^2 + 2\,\rho_{c_f}\,V_s\,[R_2\,(1 - \cos\theta_M) - \bar{X}_s]^2$$

$$+ \frac{W_c + W_1 + 1.05\,(W_D + W_{MC})}{g_\oplus} \left[X_{CG_O} - \Delta X_f - R_2\,(1 - \cos\theta_M)\right]^2$$

$$+ \pi\rho_1\left(R_1\,h^4 - \frac{2h^5}{5}\right) + \frac{\pi\rho_1}{2}\left(\frac{4}{3}\,R_1^{\,2}\,h^3 - R_1\,h^4 + \frac{h^5}{5}\right) - 2\rho_1\,V_{CAP}\,X_{CAP}^{\,2}$$

$$+ 2\rho_1\,V_{CAP}\,(h - X_{CAP})^2 + \frac{1\;05\,(W_D + W_{MC})}{g_\oplus}\left[\frac{R_2^{\,2}}{300} + \frac{(R_2 + t_{cc})^2}{4}\right]$$

where,

$$V_S = \frac{2\pi}{3}\,(1 - \cos\theta_m)\,(R_2^{\,3} - R_1^{\,3})$$

$$\bar{X}_S = \frac{2\pi}{V_S}\left[\frac{R_2\,(R_2^{\,3} - R_1^{\,3})}{3}\,(1 - \cos\theta_M) - \frac{(R_2^{\,4} - R_1^{\,4})}{8}\,\sin^2\theta_M\right]$$

b. Cone-cylinder option

$$I_{x_{TOT/X_{CG_O}}} = \sum I_{x_{H/S}} + \frac{1}{2}\,\frac{W_R}{g_\oplus}\left(\frac{D_R}{2}\right)^2 + \frac{2\pi\rho_{c_f}}{15}\,(R_2^{\,5} - R_1^{\,5})\left[2 - \cos\theta_M(\sin^2\theta_M + 2)\right] \tag{167}$$

$$+ \frac{\pi\rho_i}{2}\left[\frac{4}{3}\,R_1^{\,2}\,h^3 - R_1\,h^4 + \frac{h^5}{5}\right] + \frac{W_{cyl}}{2\,g_\oplus}\,R_{CO}^{\,2}$$

$$+ \frac{3}{10}\,\rho_i\,\frac{\pi L_{co}}{3}\,(R_{CO}^{\,2} + R_{CO}R + R^2)\left(\frac{R_{CO}^{\,5} - R^5}{R_{CO}^{\,3} - R^3}\right) + \frac{1\;05}{2}\,\frac{(W_D + W_{MC})}{g_\oplus}\left[(R_2 + t_{cc})^2 - R_2^{\,2}\right]$$

$$I_{y_{TOT/X_{CG_O}}} = \sum I_{y_{H/S}} + \left(\frac{W_{H/S}}{g_\oplus}\right)\left[(X_{CG_O} - X_{CG_{H/S}})^2 - X_{CG_{H/S}}^{\,2}\right] \tag{168}$$

$$+ \frac{W_R}{g_\oplus}\left[\frac{L_R^{\,2}}{12} + \frac{D_R^{\,2}}{16}\right] + \frac{W_R}{g_\oplus}\left[X_{CG_O} - \Delta X_f - \frac{L_R}{2}\right]^2$$

$$+ \frac{2\pi}{3}\,\rho_{c_f}\,R_2^{\,2}\,(R_2^{\,3} - R_1^{\,3})\,(1 - \cos\theta_M) - \frac{\pi R_2\,\rho_{c_f}}{2}\,(R_2^{\,4} - R_1^{\,4})\,\sin^2\theta_M$$

$$+ \frac{2\pi}{15}\,\rho_{c_f}\,(R_2^{\,5} - R_1^{\,5})\,(1 - \cos^3\theta_M) + \frac{\pi}{15}\,\rho_{c_f}\,(R_2^{\,5} - R_1^{\,5})\left[2 - \cos\theta_M(\sin^2\theta_M + 2)\right.$$

$$- \rho_{c_f} V_S \bar{X}_S^2 + \frac{2\pi}{3} \rho_{c_f} (1 - \cos\theta_M)(R_2^3 - R_1^3)(X_{CG_O} - \Delta X_f - \bar{X}_S)^2$$

$$+ \pi\rho_1 \left[\frac{R_1 h^4}{2} - \frac{h^5}{5}\right] + \frac{\pi}{4}\rho_1 \left[\frac{4}{3} R_1^2 h^3 - R_1 h^4 + \frac{h^5}{5}\right] - \rho_1 V_{CAP} \bar{X}_{CAP}^2$$

$$+ \frac{W_{CAP}}{g_\oplus} (X_{CG_O} - \Delta X_f - t_c - \bar{X}_{CAP})^2 + \frac{W_{cyl}}{g_\oplus} \left[\frac{L_{cyl}^2}{12} + \frac{R_{CO}^2}{4}\right]$$

$$+ \frac{W_{cyl}}{g_\oplus} \left(X_{CG_O} - \Delta X_f - t_c - h - \frac{L_{cyl}}{2}\right) +$$

$$+ \frac{W_{cone}}{g_\oplus} \left[\frac{L_{co}^2}{10} \left\{\frac{R_{CO}^2 + 3R_{CO} R + 6R^2}{R_{CO}^2 + R_{CO} R + R^2}\right\} + \frac{3}{20} \left\{\frac{R_{CO}^5 - R^5}{R_{CO}^3 - R^3}\right\}\right]$$

$$- \frac{W_{cone}}{g_\oplus} (X_{cone})^2 + \frac{W_{cone}}{g_\oplus} (X_{CG_O} - \Delta X_f - t_c - h - L_{cyl} - \bar{X}_{cone})^2$$

$$+ \frac{1.05 (W_{MC} + W_D)}{g_\oplus} \left[\frac{R_2^2}{300} + \frac{(R_2 + t_{cc})^2}{4}\right] + \frac{1.05 (W_{MC} + W_D)}{g_\oplus} \left[X_{CG_O} - \Delta X_f - R_2(1 - \cos\theta_M) - \frac{R_2}{10}\right]^2$$

10. Internal Structure

The internal structure consists of a cap or spherical segment, a cylinder, and a cone for all possible lander geometrics. The cap is designed for a buckling mode of failure assuming the maximum stress to be that applied to the crushup during impact. The cylinder is also designed for a buckling mode of failure and assumes the internal payload in the cylinder to be reacted at one end. The cone is designed by assuming it reacts the parachute opening shock load in tension.

a. Lenticular (Sphere) Option

1) Face sheet thickness

$$t_{fs} = 0.117 \left(\frac{S_m}{144 E_{fs}}\right)^{3/7} (1 - \cos\theta_M)^{1/7} R_1 \qquad (169)$$

t_{fs} must be $\geq$ than a minimum gage face sheet $t_{f_{min}}$

2) Area

$$A = 4\pi R_1^{2}(1-\cos\theta_M) \tag{170}$$

3) Internal structure weight

$$W = \frac{\rho_{fs}\ A\ t_{fs}}{12} \tag{171}$$

b. Cone-Cylinder Option

1) CAP

$$A_{CAP} = 2\pi R_1^{2}(1-\cos\theta_M) \tag{172}$$

$$t_{fs_{CAP}} = 0.117\left(\frac{S_m}{144\ E_{fs}}\right)^{3/7}(1-\cos\theta_M)^{1/7}\ R_1 \tag{173}$$

$$W_{CAP} = \frac{\rho_{fs}\ A_{CAP}\ t_{f_{CAP}}}{12} \tag{174}$$

2) Cylinder

$$A_{cyl} = 2\pi\ R_{CO}\ L_{cyl} \tag{175}$$

$$t_{fs_{cyl}} = \left(\frac{y_m\ W_{i\,cyl}\ L_{cyl}^{2}}{546\ R_{CO}\ E_{fs}}\right)^{1/3} . \tag{176}$$

$$W_{cyl} = \frac{\rho_{fs}\ A_{cyl}\ t_{fs_{cyl}}}{12} \tag{177}$$

where,

$$W_{i\,cyl} = W_i\left[\frac{\pi R_{CO}^{2}\ L_{cyl}}{\frac{2\pi R_1^{3}}{3}(1-\cos\theta_M)+\pi R_{CO}^{2}\ L_{cyl}+\frac{\pi L_{co}}{3}(R_{CO}^{2}+R_{CO}R+R^{2})}\right]$$

3) Cone

$$A_{CO} = \pi (R_{CO} + R) [L_{co}^2 + (R_{CO} - R)^2]^{1/2} + \pi R^2 \tag{178}$$

$$t_{fs_{CO}} = \frac{P_{MC}}{2\pi R_{CO} \sigma_{cy}} \tag{179}$$

$$W_{CO} = \frac{A_{CO} \rho_{fs} t_{fs_{co}}}{12} \tag{180}$$

If the drogue-retrorocket option is used in the descent system then

$$t_{fs_{CO}} = \frac{P_D}{2\pi R_{CO} \sigma_{cy}} \tag{181}$$

The total internal structural weight is the sum of the components; namely,

$$W = W_{CAP} + W_{cyl} + W_{CO}. \tag{182}$$

IV. IBM PROGRAM ROUTINES

A. PROGRAM FLOW

1. Descent System

The program flow for the descent system is shown in Figure 10.

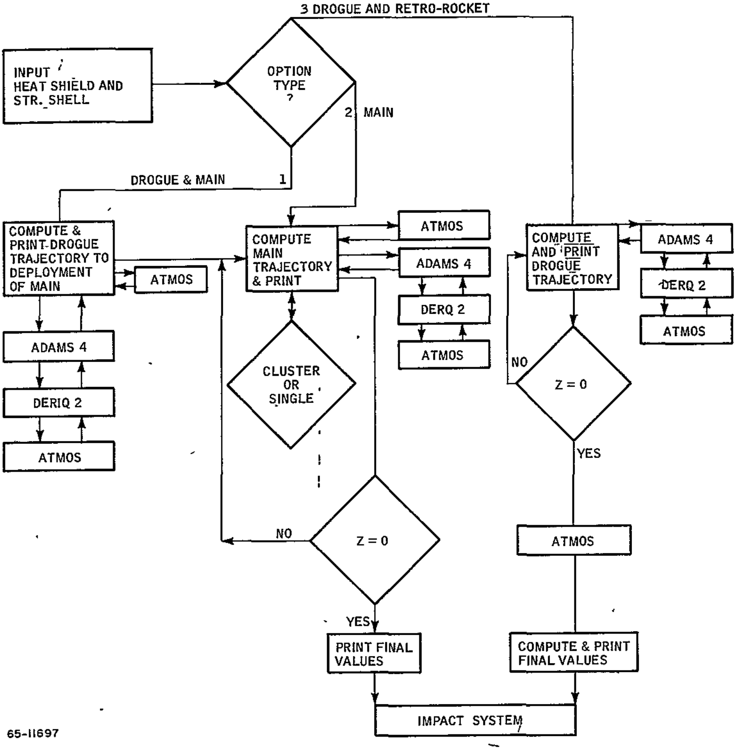

Figure 10 PROGRAM FLOW FOR DESCENT SYSTEM

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2. Impact Attenuation System

The program flow for the impact attenuation is shown in Figure 11.

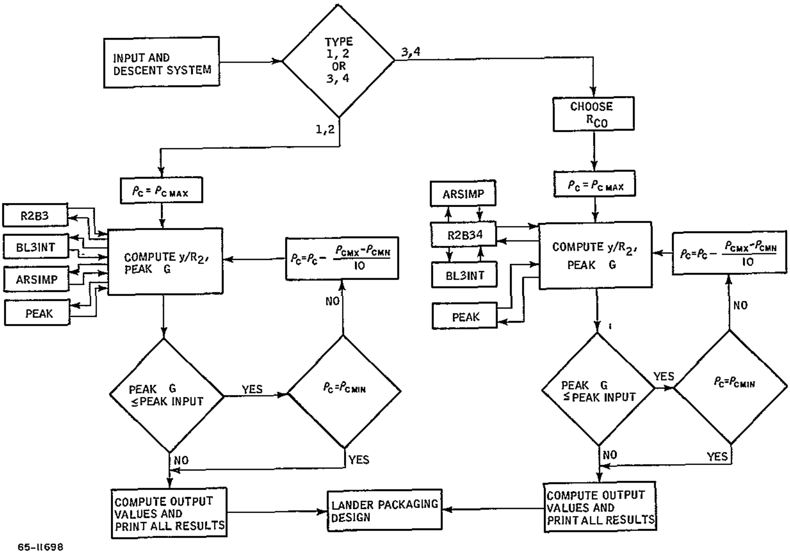
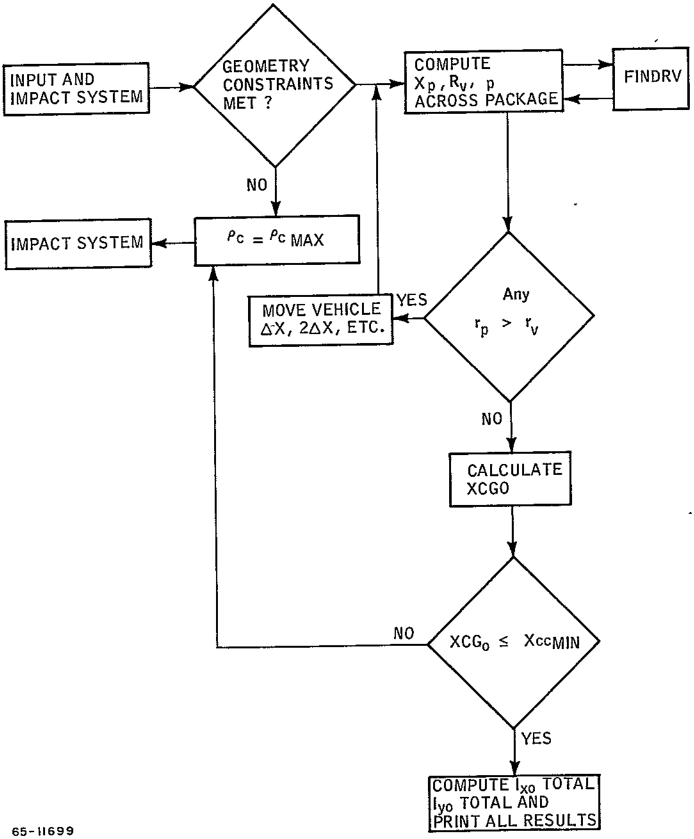


Figure 11 PROGRAM FLOW FOR IMPACT ATTENUATION SYSTEM

3. Lander Packaging Design

The program flow for the lander packaging system is shown in Figure 12.



65-11699

Figure 12 PROGRAM FLOW FOR LANDER PACKAGING SYSTEM

B. COMMON STORAGE

Name	Quantity	Source	Input or Output	Description
AD	A_D	Main	Output	Drogue chute area.
AMC	A_{MC}	Main	Output	Main chute area.
AS	a	ATMØS	Output	Speed of sound.
AV	A_v	DERQZ		Area of vehicle.
CDD	C_{DD}	Input	Input	Table.
CDDD	C_{DD} value	ATMØS	Output	Interpolated value at XMAC.
CDM	C_{DMC} value	ATMØS	Output	Interpolated value at XMAC.
CDMC	C_{DMC}	Input	Input	Table.
CDV	C_{DV}	Input	Input	Table.
CDVV	C_{DV} value	ATMØS	Output	Interpolated value at XMAC.
DV	D_v	Main		Diameter of vehicle.
FALR	L_1	Input		Temperature gradient in troposphere expressed as a fraction of adiabatic lapse rate.
G	G_{SL}	Input		Gravitational acceleration at planet surface.
IJET	JET	Input		Input sentinal.
IISYS	DESSYS	Input		Input sentinal.
MACH	M	Input		Table of Mach numbers.

Name	Quantity	Source	Input or Output	Description
PI	π	Main		
RH0	ρ	ATM0S	Output	Density.
RH0SL	ρ_{SL}	Input		Density of atmosphere at planet surface.
TSL	T_{SL}	Input		Atmospheric temperature at planet surface.
TST	T_{ST}	Input		Atmospheric temperature in stratosphere.
V	V	Main	Output	Velocity.
WD	W_D	BL0CK2	Output	Drogue chute weight.
WE	We	Input		Total entry weight.
WR	WR	Main	Output	WE - WHST0T - WSTT0T.
XA	X_A	Input		Mole fraction of Argon in atmosphere.
XC	X_C	Input		Mole fraction of CO_2 in atmosphere.
XMAC	M	ATM0S	Output	Mach number.
XN	X_N	Input		Mole fraction of N_2 in atmosphere.
XZER0	X_O	Input		Mole fraction of O_2 in atmosphere.

C. SUBROUTINES

Calling Sequences and Definitions

ATMØS	Variable Input or Output Source	AS Output ATMØS	CDD Input Main	CDDD Output ATMØS	CDM Output ATMØS
CDMC Input Main	CDV Input Main	CDVV Output ATMØS	FALR Input Main	G Input Main	RHØ Output ATMØS
RHØSL Input Main	TSL Input Main	TST Input Main	V Input Main	XA Input Main	XC Input Main
XMAC Output ATMØS	XN Input Main	XZERØ Input Main	Z Input Main		

ADAMS4

(See the writeup of ADAMS4 under the section SPECIAL SUBROUTINES.)

ARSIMP

(See the writeup of ARSIMP in the section SPECIAL SUBROUTINES.)

BLOCK2	Variable Input or Output Source	AMVEL Input Input	BEL Input Input	CDD Input Input	CDMC Input Input
CDV Input Input	DD Output BLOCK2	DELMIT Input Input	DLVFAC Input Input	DMCFAC Input Input	DMCMIN Input Input
DMIN Input Input	DNBND Input Input	DR Output BLØCK2	DRVEL Input Input	DV Input Main	FACTØR Input Input

BL0CK2 (Continued)	Variable Input or Output Source	FALR Input Input	FREQ Input Input	FREQ2 Input Input	FREQ3 Input Input
G Input Input	GAMMAD Input Input	GAMMC Input Input	IG00FX Output	IJET Input Input	IISYS Input Input
PD Output BL0CK2	PMC Output BL0CK2	RH0R Input Input	RH0SL Input Input	TSL Input Input	TST Input Input
TZER0 Input Input	UPBND Input Input	VIMP Input Input	VFINAL Output BL0CK2	VW Input Input	W Input Main
WD Output BL0CK2	WE Input Input	WL Output BL0CK2	WMC Output BL0CK2	WR Input Main	WR0C Output BL0CK2
WWHS Input Main	WWSTR Input Main	XA Input Input	XC Input Input	XD Input Input	XISP Input Input
XLRDR Input Input	XL Input Input	XMACH Input Input	XMC Input Input	XMD Input Input	XMMC Input Input
XMR Input Input	XN Input Input	XZER0 Input Input	ZD Input Input	ZMC Input Input	

BLØCK3	Variable Input or Output Source	ALPHA Input	A0, A1, A2, A3 Input Input	BETA Input Main	CTH1, CTH2, CTH3, CTH6, CTH9 Input Main
CTHM Output Main	DIAM Input	DR Input BLØCK2	EF Input Input	EPS1, EPS3 Input Input	ETA Input Input
GS Input Impact	IBLK3 Output	IGØØFX Output	IISYS Input Input	P Input Main	PD Input BLØCK2
PMC Input BLØCK2	PSI Input Input	Q Input Main	R3, R12, R34, R67 Input Main	RA, RB, RC Input Main	RCHUTE Input Input
RHØF Input Input	RHØI Input Input	RHØMN Input Input	RHØMX Input Input	RØ Output BLØCK3	SIGCYF Input Input
STH1, STH2 STH3, STH6, STH9 Input Input	STHM Output Main	SYSIMC Input	TFMIN Input Input	THC Input Main	THETAM Input Input
THETCØ Input Input	THS Input	TTCØ Output Main	TTHM Output	VFINAL Input Main	VV Input Main
VW Input Main	WC Output BLØCK3	WD Input BLØCK2	WE Input Input	WHSTØT Input Main	WI Output BLØCK3
WMC Input BLØCK2	WRØC Input BLØCK2	WSTTØT Input Main	X3 Input	XCGHS Input Main	XCGMIN Input
XIRDR Input	XITØT Input	XLCRC Input Input	XLCYRC Input Input	XN Input Input	YIR2 Input
YITØT Input					

BL3INT	Variable Input or Output Source	A0, A1, A2, A3 Input Input	DYR2 Input Main	ETA Input Input	FUNC Output BL3INT
GSTAR Input Main	GUNC Output BL3INT	HSYS Input Main	PI Input Main	RHØC Input Main	RØFX Input Main
SM Input Main	SMIMC Input Main	VFINAL Output BL3INT	VV Input Main	VW Input Main	WW4 Output BL3INT
WW5 Output BL3INT	XN Input Input	YR2I Output BL3INT			

DERQZ	Variable Input or Output Source	DERN Output DERQZ	K Input ADAMS4	NPAR Input	NZ Input
PAR Input	T Input Main	VALUE Input ADAMS4			

FINDRV	Variable Input or Output Source	BETA Input Main	CTH1, CTH2, CTH3, CTH6, CTH9 Input Main	I Output FINDRV	P Input Main
Q Input Main	R01, R3, R12 R34, R67 Input Main	RA, RB, RC Input Main	RV Output FINDRV	STH1, STH2, STH3, STH6, STH9, Input Main	THC Input Main
X3 Input	XP Input Main				

GENSHP										
Variable	AREAG	NX	PG	RGEN	RØLLG	THET2G	THET3G	WLB	XCGG	XGEN
Input or Output	Output	Output	Output	Input	Output	Input	Input	Input	Output	Input
Source	GENSHP	GENSHP	GENSHP	Input	GENSHP	Input	Input	Main	GENSHP	Input

PEAK													
Variable	DYR2	ETA	GSTAR	PI	PGGAL	PGGALC	R3BLK3	RHØC	SM	SMIMC	YR2	YR2I	YR2P
Input or Output	Input	Input	Input	Input	Output	Output	Input	Input	Input	Input	Input	Input	Output
Source	Main	Input	Main	Main	PEAK	PEAK	Main	Main	Main	Main	Input	Main	PEAK

R2B3							
Variable	CTHM	ETA	PI	R2BLK3	RHØC	RHØI	SMIMC
Input or Output	Input	Input	Input	Output	Input	Input	Input
Source	Main	Input	Main	R2B3	Main	Input	Main

R2B34	Variable Input or Output Source	A0, A1, A2 A3, Input Input	CTHM Input Main	DRY2 Output R3B34	EPS3 Input
ETA Input Input	GSTAR Input Main	HSYS Input Main	PI Input Main	RCØ Input Main	RHØC Input Main
RHØI Input Input	RØFX Output R2B34	SM Input Main	SMIMC Input Main	STHM Input Main	TTCØ Input Main
VFINAL Input Main	VV Input Main	VW Input Main	XLCRC Input	XLCYRC Input	XN Input Input
YR2I Output					

RP3467	Variable Input or Output Source	PIT3 Output RP3467	RØL3 Output RP3467	RR Input Main	RRR Input Main
THH Input Main	W Input Main	XX Input Main			

TENSHL	Variable Input or Output Source	AREAT Output TENSHL	BETA Input Input	CTH2 Input Main	PITT Output TENSHL
RC Input Input	R3 Output TENSHL	R34 Input Input	RØLLT Output TENSHL	RT2 Input Main	RTEN Output TENSHL
STH2 Input Main	THETA3 Input TENSHL	WLB Input Main	XCGT Output TENSHL	XT2 Input Main	XTEN Output TENSHL

1. GENSHP

a. Purpose

This subroutine computes the surface area, centroid from the nose, and moments of inertia for the general shape.

b. Method

The trapezoidal rule is used, with as many as 25 input values for the coordinates XGEN and RGEN. The number of XGEN and RGEN values are counted.

2. TENSHL

a. Purpose

This subroutine computes the surface area, centroid from the nose and moments of inertia for the tension shell.

b. Method

A set of five ordinate values between R2 and R3 are computed corresponding to five abscissas and the trapezoidal rule is utilized.

3. RP3467

a. Purpose

This subroutine computes the moments of inertia of Sections 6 and 9.

b. Method

The given equations are utilized with the input variables for Sections 6 and 9.

4. BLØCK2

a. Purpose

This subroutine performs a trajectory calculation with three options, a drogue and main chute or cluster, a main chute or cluster, or a drogue chute with a retrorocket.

b. Method

First the program checks which of these three options mentioned above are to be used, and presets initial conditions, including those for the derivative equations. In the drogue chute trajectory, the minimum diameter is used first and the Mach number is repeatedly checked unitl the time it becomes $\leq$ MACD input. If the corresponding altitude is above ZMC, the program continues with this size drogue chute and prints the trajectory down to ZMC, where it switches to the main chute logic If this altitude is below ZMC, an equation is used to calculate the next drogue chute area. If the altitude is zero, AD is increased by 1.5 (Statement 250) and the program begins again This process of checking the Mach number MACMC against the altitude ZMC is repeated. When again the altutide is tested and it is not within 100 feet of ZMC, the present drogue area is multiplied by ZMC/S at Statement 249 Eventually an area will be found where MACMC occurs within 100 feet of ZMC. Then the trajectory is recalculated, and printed out at intervals specified by DRVEL, the change in velocity Output values for the drogue trajectory are also computed and printed before starting the main chute trajectory.

For the main chute portion, first the area is calculated. Then, if the diameter is less than DMCMIN, the minimum main chute size is used If the diameter is greater than DMCMAX, a cluster of three to fifteen chutes is used. (The number is increased from three to fifteen by intervals of two until a diameter less than DMCMAX is found (See DØ LØØP at Statement 351)). Then the program calculates the filling time for the main chute or cluster, and the initial conditions for the main chute trajectory. The trajectory printout proceeds at intervals of MCVEL changes in velocity until impact. Then final output quantities describing the main chute are calculated and printed

For the drogue-retrorocket option, a trajectory is computed utilizing a specified drogue chute size diameter DDMIN. The program prints out at intervals of DRVEL in velocity from ZD (drogue deployment altitude) to impact The impact velocity on the drogue VD is then taken with a specified horizontal wind velocity VW and the resultant velocity VR is evolved. The required retrorocket ΔV is the difference between the required specified impact velocity VIMP and the resultant velocity VR. With the ΔV established, the sizing of the rocket system commences, i.e diameter, length, and weight.

5. DERQZ

a. Purpose

This subroutine computes the values of the derivatives of velocity, flight path angle, and altitude for the trajectory.

b. Method

Subroutine ATMØS is called to obtain C_D values from which the drag is calculated. The value of the suspended weight Msusp is calculated depending on when the heat shield and structure is to be jettisoned

6. ATMØS

a. Purpose

This subroutine computes the density RHØ and speed of sound AS variations with altitude Z.

b. Method

Initially, Z_{ST} is calculated and compared with the altitude Z in the calling sequence. Then, depending on whether Z is greater or less than Z_{ST}, one or two sets of equations are used to compute the density RHØ and the speed of sound AS.

7. BLØCK3

a. Purpose

This subroutine determines the crushup density (ρ_c) required to absorb the impact energy.

b. Method

First the program determines whether to use the lenticular (sphere) option or the cone-cylinder option. For the lenticular option, the program starts with $\rho_c = \rho_{cmax}$. Then Subroutine R2B3 is called to get R_2^3 . Next BL3INT is called, then ARSIMP. If the y/R2 value is good enough, the program calls PEAK, otherwise it uses a Newton-Raphson approximation to converge on y/R2. The chosen PGCALC is compared with the input GIMP until PGCALC is less than GIMP. If it is not, ρ_c is reduced by $(\rho_{cmax} - \rho_{cmin})/10$ and the loop starting at Statement 822 continues. If no satisfactory values are found before ρ_{cmin}, is reached, the program continues with the values it has at that time to calculate output equations. Then it goes on to the lander packaging design.

If the cone-cylinder option is used, the iteration starts with $\rho_c = \rho_{cmax}$. Then Subroutine R2B34 is called with a starting value of R_{co}. Next PEAK is called to determine if PGCALC is less than GIMP. If it is, the program computes output equations and goes on to the packaging design. If PGCALC is still too large, ρ_c is reduced by $(\rho_{cmax} - \rho_{cmin})/10$ and the iteration continues from Statement 726. If ρ_{cmin} is reached without a satisfactory PGCALC, the program continues with the ρ_{cmin} value and calculates the output equations and continues on to the packaging design.

Geometry constraints are checked at 901 or 902 depending on which option was used in the impact system, the lenticular (sphere) or cone-cylinder. For the lenticular (sphere) option an array of θ_M values is set up and each x_p and r_p is calculated. Subroutine FINDRV is then called to get r_v. All r_p values must be less than the corresponding r_v values If not, the package must be moved back a distance of 0 025 R_2 along the vehicle axis until a position is found where all the r_p values are acceptable If no such position can be found, the program returns to the impact system with ρ_c equal to $\rho_{c\ max}$

If all the geometry constraints are satisfied, then the overall X_{CGO} is calculated and tested against X_{CGmin}. If X_{CGO} is less than X_{CGmin}, the program continues; otherwise it goes back to the impact system with ρ_c equal to ρ_{cmax}. With X_{CGO} satisfied, the overall moments of inertia are calculated and finally, the internal structural weight.

8. R2B3

a. Purpose

Subroutine R2B3 calculates the value of R2 for the lenticular and sphere option.

b. Method

The program evaluates the expressions for R2, using the values of ρ_c from BLØCK3.

9. BL3INT

a. Purpose

Subroutine BL3INT evaluates the integrand of Equation (140) in preparation for integration by Simpson's Rule.

b. Method

The expressions for the integrand of Equation 140 is evaluated at 11 points between 0 and y_m/R_2.

10. PEAK

a. Purpose

This subroutine determines the maximum value of G during impact.

b. Method

Eleven (11) values of G corresponding to $0 \leq y/R_2 \leq y_m/R_2$ are computed and the maximum of these values is chosen as PGCALC, the output of the routine.

11. R2B34

a. Purpose

This subroutine computes the value of R_2 for the cone cylinder option.

b. Method

Subroutine R2B34 computes the value of R_2 for the cone-cylinder option and calls it RØFX. Then it calls Subroutine BL3INT to evaluate the expression within the velocity integral using this R2. Next R_2 is corrected by a Newton-Raphson approximation. This process is repeated until the R2 value gives a solution within EPS3.

12. FINDRV

a. Purpose

This subroutine determines whether the payload package fits within the vehicle envelope.

b. Method

This subroutine compares the X_p computed in the main program with the abscissas computed in the heat shield and structural shell system until it finds the section in which X falls. Then it calculates the ordinate r_v which will correspond to X_p from the equations in that section.

D. MAIN PROGRAM

The program first sets the values of any preset input, then reads the data into storage as specified by the namelist array INPUT.

After converting angle to radians and computing their sines and cosines, the program begins at Statement 20, computes five (x) and (r) values for the nose cap section which is required to be the first segment. Area, moments of inertia, and centroid from the nose are also calculated after the (x) and (r) values are written on the output tape.

The program then tests to see if the toroidal section following the nose is included. If it is not, starting at Statement 31, theta 2 is set equal to theta 1, and x2 and r2 are set equal to xl and rl If the section is included, five (x) and (r) values are computed and written on the output tape. Then the moments of inertia and centroid from the nose are computed.

Next, at Statements 21 and 28, the program determines which, if any, of the three options (3., 4 , and 5.) for Section 23 is to be used. If none are included, theta 4 is set equal to theta 0, and r4 and x4 are set equal to r2 and x2 Section 34, a toroidal section, has to be included if Section 23 is used.

If the tension shell option is used, five (x) and (r) points are computed and written on the output tape The area, moments of inertia, and centroid from the nose are also calculated. All of these calculations use the trapezoidal rule and subroutine TENSHL, and occur between Statements 34 and 44.

For the general shape option, as many as 25 points may be used to describe the curve. The program proceeds in steps similar to those used for the tension shell, but with subroutine GENERL, between Statements 44 and 42

For the conic section, two (x) and (r) values are computed and written out, followed by area, moments of inertia, and centroid from the nose calculations, between Statements 42 and 52

Then, from Statements 52 to 22, Section 34, is handled a toroidal shape, with five (x) and (r) values which are written on the output tape. Next the area, moments of inertia, and centroid from the nose are calculated. The moments of inertia are calculated in Subroutine RP3467.

Section 45, if included, is a cylinder described by two points. If it is not used, x5 and r5 are set equal to x4 and r4 If used, the two (x) and (r) values are computed and written out. Then the area, moments of inertia, and centroid from the nose are calculated, (Statements 45 to 46).

Section 56, a flared section, is described by two points. If it is not used, x6 and x7 are set equal to x5, and r6 and r7 are set equal to r5. After the two (x) and (r) values are written on the output tape, the area, moments of inertia, and centroid from the nose are calculated. If section 56 is used, section 67 a toroidal segment must be included Five (x) and (r) values are written on the output tape, then the area and centroid from the nose are calculated The moments of inertia are computed in subroutine RP3467. These computations occur between Statements 46 and 24

If section 78, a toroidal section, is not included, x8 is set equal to x7 and r8 is set equal to r7 If used, five (x) and (r) values are computed and written on the output tape. Then the area, moments of inertia and centroid from the nose are calculated, (Statements 24 to 25).

Section 89, if used, is a cone described by two points If it is not included x9 is set equal to x8 and r9 is set equal to r8. When this section is used, two values of (x) and (r) are written on tape, and then the area, moments of inertia, and centroid from the nose are computed, (Statements 25 to 53).

There are two options, 12. and 13 , for the final section, one of which must be used. The first is a cap described by five (x) and (r) values which are written on the output tape. Then the area, moments of inertia, and centroid from the nose are calculated. The other option is a two point base section. Two values of (x) and (r) are written on the output tape, and then the area, moments of inertia and centroid from the nose are calculated. (Statements 51 to 40).

Next, output values for the total heat shield and structure weights, WHS and WST, for each section are calculated. If one or more rings is to be added to the vehicle, the appropriate moments of inertia are computed and printed Then the total vehicle shield and structure weights called WHSTØT and WSTTØT, are calculated along with the vehicle center of gravity XCGHS and moments of inertia RØLLT and PITCHT. Depending on which sections have been included, a tabular printout of section number, area, WHS, WST, and moments of inertia is provided, followed by values of WHSTØT, WSTTØT, XCGHS, and WR, the entry weight less heat shield and structure weights. If WR is found to be less than or equal to zero, work on the present case is terminated, a transfer to Statement 1000 being made for consideration of the next case. If WR is greater than 0, subroutines BLØCK2 and BLØCK3 are called to carry out the rest of the computations for the case Then the transfer to 1000 is made.

E. SIGNIFICANT EQUATIONS

1. MAIN

The programmed expressions for surface areas, center of gravity, moments of inertia, and weight, are very straightforward, and only the case of Section 2 is given here as an example.

Subroutines GENSHP and TENSHL perform similar calculations for the general and tension shell shapes.

$$A = AREA\ (2) = 2.\cdot \pi \cdot R12 \cdot (R01 \cdot CTH1 \cdot (THETA1 - THETA2) + R12 \cdot (STH1 - STH2) + R12 \cdot CTH1 \cdot (THETA2 - THETA1)) \qquad \text{(Statement 1002)}$$

where,

$\mathrm{CTH1} = \cos\theta_1$ $\qquad$ $\mathrm{THETA1} = \theta_1$
$\mathrm{STH1} = \sin\theta_1$ $\qquad$ $\mathrm{THETA2} = \theta_2$
$\mathrm{STH2} = \theta_2$

$\mathrm{X} = \mathrm{XCG(2)} = \mathrm{WS1}\cdot(\mathrm{WS2} + \mathrm{WS3})$ (Statement 9210)
$\mathrm{WS1} = 2.\cdot\pi\cdot\mathrm{R12}/\mathrm{AREA(2)}$
$\mathrm{WS2} = \mathrm{A121}\cdot\mathrm{B12}\cdot(\mathrm{THETA1} - \mathrm{THETA2}) + \mathrm{B12}\cdot\mathrm{R12}\cdot(\mathrm{STH1} - \mathrm{STH2})$
$\mathrm{WS3} = \mathrm{A121}\cdot\mathrm{R12}\cdot(\mathrm{CTH1} - \mathrm{CTH2}) - \frac{(\mathrm{R12})^2}{2}\cdot((\mathrm{STH1})^2 - (\mathrm{STH2})^2)$

where,

$\mathrm{CTH2} = \cos\theta_2$
$\mathrm{WS1} = 2.\cdot\pi\cdot\mathrm{WLBS(2)}\cdot\mathrm{R12}/32.17$
$\mathrm{A121} = \mathrm{R1} - \mathrm{R12}\cdot\mathrm{CTH1}$
$\mathrm{B12} = \mathrm{X1} + \mathrm{R12}\cdot\mathrm{STH1}$
$\mathrm{WS2} = (\mathrm{A121})^3(\mathrm{THETA1} - \mathrm{THETA2}) + 3.\,(\mathrm{A121})^2\cdot\mathrm{R12}\cdot(\mathrm{STH1} - \mathrm{STH2})$
$\mathrm{WS3} = 3.\cdot\mathrm{A121}\cdot(\mathrm{R12})^2\cdot((\mathrm{THETA1} - \mathrm{THETA2})/2. - (\mathrm{SINF}\,(2.\cdot\mathrm{THETA2}))/4\ )$
$\mathrm{WS4} = \frac{(\mathrm{R12})^3}{3}\,.\,(\mathrm{STH1}\,.\,((\mathrm{CTH1})^2 + 2.\,) - \mathrm{STH2}\,.\,((\mathrm{CTH2})^2 \qquad))$
$\mathrm{R\varnothing LL(2)} = \mathrm{WS1}\cdot(\mathrm{WS2} + \mathrm{WS3} + \mathrm{WS4})$ (Statement 1002)

where,

$\mathrm{WLBS(2)} = \mathrm{WHS(2)} + \mathrm{WST(2)}\cdot\mathrm{STRFAC}$ (Statement 54)
$\mathrm{WS2} = \mathrm{A121}\cdot(\mathrm{B12})^2\cdot(\mathrm{THETA1} - \mathrm{THETA2}) + 2.\cdot\mathrm{A121}\cdot\mathrm{B12}\cdot\mathrm{R12}\cdot\mathrm{B12}\cdot\mathrm{R12}\cdot(\mathrm{CTH1} - \mathrm{CTH2})$

$\mathrm{WS3} = \mathrm{A121}\cdot(\mathrm{R12})^2\cdot((\mathrm{THETA1} - \mathrm{THETA2})/2. - (\mathrm{SINF}(2.\cdot\mathrm{THETA1}) - \mathrm{SINF}\,(2.\cdot\mathrm{THETA2}))/4\ ) + (\mathrm{B12})^2\cdot\mathrm{R12}\cdot(\mathrm{STH1} - \mathrm{STH2})$
$\mathrm{WS4} = \mathrm{B12}\cdot(\mathrm{R12})^2\cdot((\mathrm{STH1})^2 - (\mathrm{STH2})^2) - \frac{(\mathrm{R12})^3}{3}\cdot((\mathrm{STH1})^3 - (\mathrm{STH2})^3)$

$\mathrm{PITCH(2)} = \mathrm{WS1}\cdot(\mathrm{WS2} + \mathrm{WS3} - \mathrm{WS4}) + .5\cdot\mathrm{R\varnothing LL(2)}$ (Statement 9210)
$\mathrm{WHST\varnothing T} = \Sigma\ \mathrm{WHS(I)}$
$\mathrm{WSTT\varnothing T} = \Sigma\ \mathrm{WST(I)}$ (Statement 1016)

2. BLØCK2

$\mathrm{W_D} = \mathrm{WD} = .11\cdot\mathrm{DIAD}/18.6\cdot\mathrm{QD}/65.\cdot\mathrm{AD}$ (Statement 4444)
$\mathrm{P_D} = \mathrm{PD} = \mathrm{XD}\cdot\mathrm{QD}\cdot\mathrm{CDDGGI}\cdot\mathrm{AD}$

where,

CDDGGI is value from CDD table versus Mach

Amc = AMC = (2.· G ·SUSPM)/(RHØSL · CDM·(VV)^{2})(Statement 501)
C_D cluster = CDCL = CDM · (95 - .03 AN)

A_{mc} = area of each chute in a cluster = AMC = (2.· G ·SUSPM)/
(RHØSL · CDCL·(VV)^{2}·AN) (Statement 321)
W_{mc} cluster = WMC = .0013· QMC ·AMC·AN·(98 + .045·AN) (Statement 215)
t_f = TF = DMC·(05 - 3.E-5 · VMC) (Statement 214)
V_R = VR = SQRTF((VD)^{2} + (VW)^{2}) (Statement 406)
ΔV = DELV = VR - VIMP
W_f/W_i = WFWI = EXPF (-DELV/(XISP·GTHET)) (Statement 411)

3. DERQZ

$\dot{V}$ = DERN(1) = (-D-SM·G·SGAM)/SM (Statement 2)
$\dot{\gamma}$ = DERN(2) = (-G·CGAM)/V
$\dot{Z}$ = DERN(3) = V·SGAM

4. ATMØS

M = AM = 28.·XN + 32.·XZERØ + 44.·XC + 40.·XA
C_p = CP = R/AM·(3.5·(XN + XZERØ) + 4.·XC + 2.5·XA)
Lo = AL = -FALR·G/CP
ZST = ZST = (TST - TSL)/AL
T = TSL + AL·Z

Troposphere

FAC = -1. - AM·G/(R·AL)
ρ = RHØ = ((TSL + AL·Z)/(TSL)^{FAC})·RHØSL
FAC1 = CP·AM/R - 1. (Statement 4)
a = AS = SQRTF ((CP·T)/FAC1)

Stratosphere

ρST = RHØST = ((TST/(TSL)^{FAC})·RHØSL (Statement 2)
ρ = RHØ = RHØST·EXPF (-(AM·G)/(R·TST)·(Z - ZST)
a = AS = SQRTF ((CP·TST)/FAC1)

5. <u>BLØCK3</u>

$\mathrm{SMIMC} = \mathrm{WL}/32.2$

$\mathrm{Sm} = \mathrm{SM} = \mathrm{SBLK3} = (\mathrm{ALPHA} \cdot (\mathrm{RH\O C})^{(1./\mathrm{PSI})})$

$t = \mathrm{TBLK3} = \mathrm{YR2} \cdot \mathrm{R213}/\mathrm{ETA}$

$\mathrm{R213} = (\mathrm{R2BLK3})^{(1./3.)}$

$I(y/R_2)$

$\mathrm{WS1} = 1. - \mathrm{YR2}/\mathrm{ETA}$ (Statement 832)

$\mathrm{WS2} = 2. \cdot \pi/3. \cdot \mathrm{R2BLK3}$

$\mathrm{WS3} = (\mathrm{WSI} - (\mathrm{CTHM})^2) \cdot (2. \cdot \mathrm{WS1} + \mathrm{CTHM})$

$\mathrm{FMI} = \mathrm{RH\O I} \cdot \mathrm{WS2} \cdot \mathrm{WS3}$

$\mathrm{WS4} = (1. - (\mathrm{CTHM})^2) \cdot (2. + \mathrm{CTHM}) - \mathrm{WS3}$

$\mathrm{FMC} = \mathrm{RH\O C} \cdot \mathrm{WS2} \cdot \mathrm{WS4}$

$\mathrm{WS1} = \pi \cdot \mathrm{RH\O I} \cdot \mathrm{C\O P}/3. \cdot ((\mathrm{RC\O})^2 + \mathrm{RC\O} \cdot \mathrm{RWS} + (\mathrm{RWS})^2)$ (Statement 925)

$\mathrm{WS6} = \pi \cdot \mathrm{RH\O I}/3. \cdot (\mathrm{RP1} - \mathrm{RC\O}/(\mathrm{TTHM})^2) \cdot (2.\ \mathrm{RP1} + \mathrm{RC\O}/\mathrm{TTHM})$
$\quad + \pi \cdot \mathrm{RH\O I} \cdot (\mathrm{RC\O})^2 \cdot \mathrm{CYP}$

$\mathrm{FMI} = \mathrm{WS1} + \mathrm{WS6}$

$\mathrm{FMC} = 2. \cdot \pi \cdot (\mathrm{RH\O C}/3. \cdot (1. - \mathrm{CTHM}) \cdot \mathrm{R\O FX} - \mathrm{RC\O}/(\mathrm{STHM})^3)$

$\mathrm{WS3} = \mathrm{WHSSTT} \cdot \mathrm{XCGHS} + \mathrm{WR\O C} \cdot (\mathrm{DEL4} + \mathrm{XLR} \cdot .5)$ (Statement 987)

$\mathrm{WS1} = (1.05 \cdot (\mathrm{WD} + \mathrm{WMC}) + \mathrm{WC} + \mathrm{WI}) \cdot \mathrm{DEL4} + \mathrm{R2BK3} \cdot (1. - \mathrm{CTHM}))$ (Statement 988)

$\mathrm{XCG\O} = (\mathrm{WS1} + \mathrm{WS3})/\mathrm{WE}$ (Statement 991)

where,

$\mathrm{WHSSTT} = \mathrm{WHST\O T} + \mathrm{WST\,T\O T}$

$X_{CG_{CR}} = \mathrm{XCGCR} = 3. \cdot (\mathrm{R2BK3} \cdot \mathrm{WS1}/3. \cdot (1. - \mathrm{CTHM}) - ((\mathrm{R2BK3})^4$ (Statement 987)
$\quad - (\mathrm{R1BK3})^4) / 8. \cdot (\mathrm{STHM})^2)/((1 - \mathrm{CTHM}) \cdot \mathrm{WS1})$

$\mathrm{WS1} = (\mathrm{R2BK3})^3 - (\mathrm{R1BK3})^3$

$h = H = \mathrm{R1BK3} \cdot (1. - \mathrm{CTHM})$

$X_{CG_i} = \mathrm{XCGI} = (\mathrm{WCAP} \cdot \mathrm{XCAP} + \mathrm{WCYL} \cdot (H + \mathrm{XLCY} \cdot .5)$
$\quad + \mathrm{WC\O N} \cdot (H + \mathrm{XLCY} + \mathrm{XC\O N}))/\mathrm{WCAP} + \mathrm{WCYL} + \mathrm{WC\O N})$

$\mathrm{WCAP} = \mathrm{WS2} \cdot (H)^{2/3.}\ (3. \cdot \mathrm{R1BK3} - H)$

$\mathrm{WCYL} = \mathrm{WS2} \cdot (\mathrm{RC\O})^2 \cdot \mathrm{XLCY}$

$\mathrm{WC\O N} = \mathrm{WS2} \cdot \mathrm{XLC}/3. \cdot ((\mathrm{RC\O})^2 + \mathrm{RC\O} \cdot \mathrm{RBK3} + (\mathrm{RBK3})^2)$

$\mathrm{XC\O N} = \mathrm{XLC} \cdot (\mathrm{RC\O} - (2.\ \mathrm{XLC})/(3. \cdot \mathrm{TTC\O}))/(2. \cdot \mathrm{RC\O} - \mathrm{XLC}/\mathrm{TTC\O})$

$\mathrm{VCAP} = \pi \cdot (H)^{2/3.} \cdot (3. \cdot \mathrm{R1BK3} - H)$

$\mathrm{XCAP} = \pi / \mathrm{VCAP} \cdot (2./3 \cdot (H)^3 \cdot \mathrm{R1BK3} - .25 \cdot (H)^4)$

$\mathrm{WS2} = \mathrm{RH\O I} \cdot \pi$

Lenticular

$I_{x}\text{TØT/XCG}_{o}$

$\text{WS1} = \text{WRØC}/(2.\cdot\text{GSTAR})\cdot(.5\cdot(\text{DR})^{2})$ (Statement 990)

$\text{WS2} = 2.\cdot\pi/15.\cdot\text{RHØC}\cdot\text{WS10}\cdot(2. - \text{CTHM}((\text{STHM})^{2} + 2.))$

$\text{WS10} = (\text{R2BK3})^{5} - (\text{R1BK3})^{5}$

$\text{WS3} = \pi\cdot\text{RHØI}/2.\cdot(4./3.\cdot(\text{R1BK3})^{2}\cdot(\text{H})^{3} - \text{R1BK3}\cdot(\text{H})^{4} + (\text{H})^{5/5.})$

$\text{WS4} = 1.05/2.\cdot(\text{WD} + \text{WMC})/\text{GSTAR}\cdot((\text{R2BK3} + (\text{TC})^{2}) - (\text{R2BK3})^{2})$

$\text{XITØT} = \Sigma\ \text{RØLL(I)}$

$\text{XTØTCG} = \text{XITØT} + \text{WS1} + \text{WS2} + \text{WS2} + \text{WS3} + \text{WS3} + \text{WS4}$

$\text{TC} = (8\cdot(\text{WD} + \text{WMC}))/(\text{RCHUTE}\cdot(\text{R2BK3})^{2})$

Cone - Cylinder

$I_{x}\text{TØT/SCG}_{o}$

$\text{WS16} = .5\ \text{WCYL/GSTAR}\cdot(\text{RCØ})^{2} + .3\cdot\text{RHØI}\cdot\pi\cdot\text{XLC}/3.\cdot((\text{RCØ})^{2}$ (Statement 994)

$+ \text{RCØ}\cdot\text{RBK3} + (\text{RBK3})^{2}\ (((\text{RCØ})^{5} - (\text{RBK3})^{5})/((\text{RCØ})^{3} - (\text{RBK3})^{3}))$

$\text{XTØTCG} = \text{XITØT} + \text{WS1} + \text{WS2} + \text{WS3} + \text{WS16} + \text{WS4}$

Lenticular

$I_{y}\ \text{TØT/XCG}_{o}$

$\text{WS5} = \text{WHSTT/GSTAR}$ (Statement 990)

$\text{WS6} = (\text{XCGØ} - (\text{XCGHS})^{2}) - (\text{XCGHS})^{2}$

$\text{WS7} = \text{WRØC/GSTAR}\cdot(((\text{XLR})^{2})/12. + (\text{DR})^{2/16.}) + (\text{XCGØ} - \text{DEL4} -$

$(\text{XLR}/2.)^{2})$

$\text{WS8} = 2.\cdot\pi/3.\cdot\text{RHØC}\cdot(\text{R2BK3})^{2}\cdot\text{WS11}\cdot(1. - \text{CTHM}) - \pi\cdot\text{R2BK3}\cdot$

$\text{RHØC}/2.\cdot((\text{R2BK3})^{4} - (\text{R1BK3})^{4})\cdot(\text{STHM})^{2} + 2./15.\cdot\text{RHØC}\cdot$

$\pi\cdot\text{WS10}\cdot(1. - (\text{CTHM})^{3}) + \pi/15.\cdot\text{RHØC}\cdot\text{WS10}\cdot/(2. - \text{CTHM}\cdot$

$((\text{STHM})^{2} + 2.))$

$\text{WS11} = (\text{R2BK3})^{3} - (\text{R1BK3})^{3}$

$\text{VS} = 2.\cdot\pi/3.\cdot(1. - \text{CTHM})\cdot\text{WS11}$

$\text{XBARS} = 2\ \cdot\pi/\text{VS}\cdot(\text{R2BK3}\cdot\text{WS11}/3.\cdot(1. - \text{CTHM}) - ((\text{R2BK3})^{4}$

$- (\text{R1BK3})^{4})/8.\ (\text{STHM})^{2})$

$\text{WS9} = \text{RHØC}\cdot\text{VS}\cdot(\text{XBARS})^{2}$

WS12 = 1 05·(WMC + WD)/GSTAR· (R2BK3)$^{2/300.}$ + ((R2BK3 + TC))$^{2/4.}$)
WS13 = 2.·RHOC·VS·((R2BK3.·(1. - CTHM) - (XBARS))^{2}
WS14 = (WI + WC + 1.05·(WD + WMC))/GSTAR·((XCGO - DEL4
- R2BK3·(1. - CTHM)))^{2}
WS15 = 2.· (π·RHOI·(R1BK3·(H)$^{4/2.}$ - (H)$^{5/5.}$) + π·RHOI/4.
(4./3 ·(R1BK3)^{2}· (H)^{3} - R1BK3·(H)^{4} (H)$^{5/5.}$)) - 2.· RHOI·
VCAP·(XCAP)^{2} + 2.· RHOI·VCAP·((H-XCAP))^{2}
YITOT = Σ PITCH(I)
YTOTCG = YITOT + WS5· WS6 + WS7 + 2.·WS8 - 2.·WS9 + WS13
+ WS14 + WS15 + WS12

Cone - Cylinder

I_{y}TOT/XCG$_{o}$
WS17 = 2.·π/3 · RHOC·(1 CTHM)·((R2BK3)^{3} - (R1BK3)^{3})·((XCGO
- DEL4 - XBARS))^{2} (Statement 994)
WS19 = WCAP/GSTAR·((XCGO - DEL4 - TBK3 - XCAP))^{2} + WCYL/
GSTAR· (((XLCY)$^{2/12.}$ + (RCO)$^{2/4.}$(+ (XCGO - DEL4 - TBK3
- H - XLCY/2.))
WS18 = π·RHOI·(R1BK3·(H)$^{4/2.}$ - (H)$^{5/5.}$) + π/4.· RHOI·4./3 ·
(R1BK3)^{2}·(H)^{3} - R1BK3·(H)^{4} + (H)$^{5/5.}$·(- RHOI·VCAP·(XCAP)^{2}
WS20 = WCON/GSTAR· ((XLC)^{2}· .1·((RCO)^{2} + 3.· RCO·(RBK3)^{2})/
((RCO)^{2} + RCO·RBK3 + (RBK3)^{2})·.15· (((RCO)^{5} - (RBK)^{5})/
((RCO)^{3} - (RBK3)^{3}))
WS21 = WCON/GSTAR· (XCON)^{2} - ((XCGO - DEL4 - TBK3 - H -
XLCY - XCON))^{2})
WS22 = 1.05· (WMC + WD)/GSTAR· ((XCGO - DEL4 - R2BK3·(1. -
CTHM) - .1·R2BK3))^{2}
YTOTCG = YITOT + WS5·WS6·WS7 + WS8 - WS9 + WS17 + WS18
+ WS19 + WS20 - WS21 + WS12 + WS22

6. R2B3 (Lenticular Option Only)

WS1 = ((1. - YR2/ETA - CTHM))^{2}
WS2 = 2. -2.·YR2/ETA + CTHM
WS3 = RHOI·WS1·WS2
WS4 = RHOC·(((1. - CTHM))^{2}· (2. + CTHM) - WS1·WS2)
R2BLK3 = (3 · SMIMC)/(2.· π·(WS3 + WS4))

7. BL3INT

WS1 = SQRTF (1. - (U)^{2})/U
WS2 = ACØS (U) (Statement 3)
WS3 = (U)^{2}
WS4 = 0. or BØ / (XN-2.) (1. - (U)$^{(XN - 2)}$
YR2I(I) = WS4 + B1.. 5 (1. /WS3 -1.)+ B2.. .5 ·(WS2/WS3 - WS1)
+ B3 · .5· ((WS2)^{2}/(U)^{2} - 2. ·WS2·WS1 - 2.· LØGF(U)) (Statement 4)

where,

BØ = A0, B1 = A1, B2 = A2, B3 = A3
U = 1. - YR2P(I)/ETA
YR2P(I) = (I-1)·DYR2 (Statement 2)
Vo
VFINAL = SQRTF ((VV)^{2} + (VW)^{2})
WS1 = YR2P(I)/ETA
WS3 = RHØC π /SMIMC
WW4 = ((1. WS1))^{2} YR2I(I)
GUNC(I) = WS3 ((WS1)^{2} - (WS1)^{3}/3
WW5(I) = 1. - RØFX GUNC(I)

$$\int_{0} \mathrm{FUNC(I)} = \int_{0}^{Y_m/R_2} \mathrm{WW4\ (I)\ /WW5(I)}$$

8 PEAK

WS1 = YR2P(I)/ETA
WS2 = 2. π SM (R213)^{2}/(SMIMC GSTAR)
WS3 = RHØC π R2BLK3/SMIMG
WS4 = ((1. - WS1))^{2} YR2I(I)
WS5 = 1. - WS3 ((WS1)^{2} - (WS1)$^{3/3.}$)
PGCAL(I) = WS2 WS4/WS5 (Statement 817)

9. R2B34

YMR2 = ETA (1. - RCØ/(RØFX)$^{.33333333}$ STHM)
WS2 = 1. - XLCRC/TTCØ (Statement 5)
WS3 = 2. π/3. RHØC (1. - CTHM)
WS1 = SMIMC/WS3
WS4 = π/3. RHOI XLRC (1 + WS2 +(WS2)^{2})
WS5 = π RHØI/3. ((1./STHM - STHM))^{2} (2. 1STHM + CTHM/STHM)
WS6 = (WS4 - WS5 - π RHØI XLCYRC)/WS3
WS7 = WS6 + 1./(STHM)^{3}
RØFX = WS1 + WS7 (RCØ)^{3} (Statement 8)

V. REFERENCES

1. Cloutier, G. J., Dynamic Analysis of Crushable Material Impact Energy Absorbers, Avco/RAD Technical Report KHDR-15 (June 1965).
2. Performance of and Design Criteria for Deployable Aerodynamic Decelerators, Wright-Patterson Air Force Base Technical Report No. ASD-TR-61-579 (December 1963).
3. Turner, R. D., A Parachute Design Study for a Mars Entry Vehicle, Cook Electric Company, Report No. FR-3707B (September 1964).

PROGRAM 1883

RADIATION HEATING PROGRAM (1883)

CONTENTS

ILLUSTRATIONS

TABLES

I. INTRODUCTION

A. GENERAL DESCRIPTION

Program 1883 computes the equilibrium gas properties in the stagnation region behind a normal shock, and the associated radiative heating, given ambient conditions of density, temperature, and molecular composition of the atmosphere, the shock standoff distance and the flight velocity. The shock standoff distance can also be computed, provided sufficient body shape data are given, based on the correlation of standoff distance stored in the program.

B. CALCULATION MODEL

During hypervelocity entry, the state of the gas behind a bow wave can vary from a highly ionized state to a molecular and atomic state. Enumerating all the likely species to be encountered throughout entry to solve the thermodynamic state of the gas would require an equal number of equations to be solved simultaneously. The present approach is an approximate method which divides the thermodynamic states into 4 zones, wherein only a few major reactions govern the state of the gas result in simplified and more rapid solutions for the state conditions. For example, Figure 1 illustrates the variation in specie concentrations with temperature, and typical zone demarcation lines are indicated for initially pure CO_2 The zone division is performed automatically by testing enthalpy and pressure.

Assumptions include:

1. Rigid rotator molecules
2. Harmonic oscillators
3. Electronic energy states are not considered beyond 70, 000°K
4. The enthalpy of all molecules is taken as 0 at 0°K
5. Equilibrium thermodynamics apply
6. Only several major reactions govern the thermodynamic state at any time.

The calculation model is described in detail in Reference 1, and a summary is presented herein for completeness.

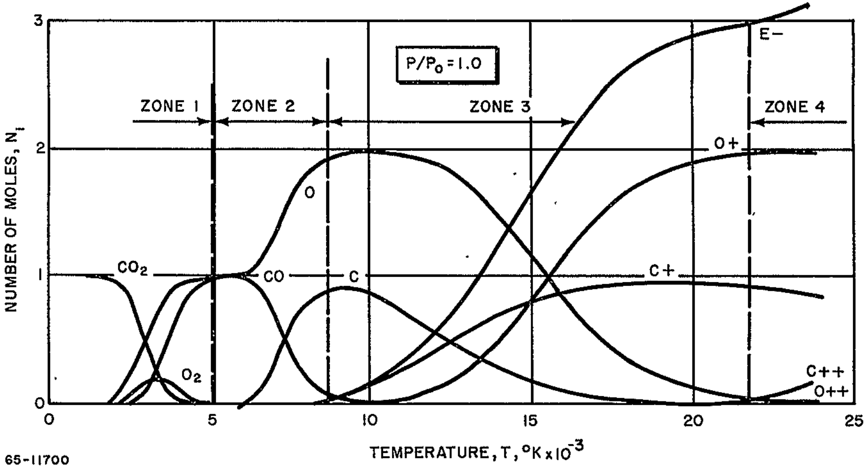


Figure 1 TYPICAL ZONE MODEL FOR PROGRAM 1883

1. Stagnation Point Conditions

During hypervelocity entry, the state of the gas behind a bow shock can vary from highly ionized to atomic and molecular states. Enumerating all the likely species to be encountered throughout entry would require an equal number of equations to be solved simultaneously. In general, a sufficient number of chemical reaction equations,

$$\sum a_i A_i \rightleftarrows \sum b_i B_i$$

(where A_i are the reactants, B_i the products, and a_i, b_i, the stoichiometric coefficients) must be formulated, such that taken together with the element and charge conservation equations, we are able to solve for the specie concentrations. The present program considers 19 species, 4 elements and electrons and hence there are 14 reaction equations and 5 conservation equations.

The elements considered are carbon, oxygen, nitrogen, and argon; however, the conservation relationships are utilized in terms of the molecular concentrations of nitrogen, carbon dioxide, oxygen, and argon as they appear in the atmosphere. The complete reaction matrix is given in Table I-13, page 46, of Reference 1.

The 14 reactions could be solved at each point along the trajectory using the method of the minimization of free energy, e. g. Reference 2, page 207. Since the reactions cover the whole range of species to be encountered, at any one time only a few of them will be important, which leads to the alternate method of solving a small number of concentration equations simultaneously. The latter approach, demonstrated by Hansen[3] for air, is utilized in the present program.

For each reaction, an equation involving an equilibrium constant is formulated:[2, 3]

$$K_p = \frac{\Pi [X(B_i)]^{b_i}}{\Pi [X(A_i)]^{a_i}} \left(\frac{P}{Z}\right)^{b_i - a_i}$$

where Z is the compressibility factor and represents the number of moles of gaseous products per mole of reactants, and $X(A_i)$ and $X(B_i)$ are the moles of reactants and products, respectively.

The equilibrium constants are, in turn, calculated from kinetic theory using spectroscopic and structural aspects of the individual molecules, atoms and ions.[2, 3]

The equilibrium constants are expressible as

$$\ln K_p = -\frac{\Delta E_0}{RT} + \sum b_i \ln Q_p(B_i) - \sum a_i \ln Q_p(A_i)$$

where $Q_p(A_i)$ and $Q_p(B_i)$ are the partition functions of the individual molecules, atoms, ions, and electrons, and ΔE_0 is the change in the zero point energy for the reaction. The expressions for the equilibrium constants and partition functions are given in Reference 1, Tables I-15 and I-18.

The partition functions and equilibrium constants are given in terms of pressure and temperature and hence the solution to the species concentrations is obtained for these two-state variables. During entry, sufficient trajectory data exist to compute the total enthalpy and to estimate the stagnation pressure closely, and hence an iterative solution of the specie concentrations is required to determine the temperature of the gas as well, such that the stagnation enthalpy is matched. The enthalpy of the gas given by:

$$\frac{HM}{RT_0} = \sum X_i \left(\frac{H_i M}{RT_0}\right)$$

must equal the stagnation enthalpy during flight:

$$\frac{HM}{RT_0} = \frac{V^2}{2}\,\frac{M}{RT_0} + \frac{h_a M}{RT_0}\,.$$

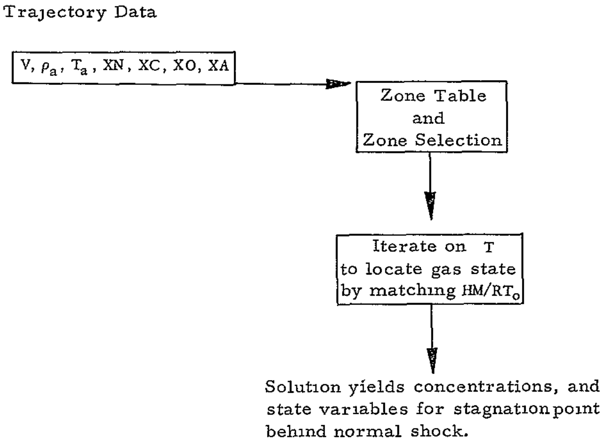
The stagnation pressure is approximated as:

$$P \cong \frac{\rho V^2}{2116}\,.$$

The velocity (V) is input in fps, the density$_o$ as RHØA in slug/ft^3, and the ambient temperature TA in degrees Kelvin(°K).

For the approach selected, of solving a limited number of key concentration relationships simultaneously, a priori knowledge is required of the relative importance of the reactions for various flight conditions. Hence, tabular data were computed and stored in the program as Table I-19 in Reference 1, which specifies zones of HM/RT_0 and P, where the number of simultaneous algebraic equations for the species concentrations can be optimized. The dominant reactions in each zone are discussed in Reference 1.

The general nature of the solution proceeds as follows



The radiation heating is computed for a parallel slab of gas at uniform stagnation temperature and pressure of thickness (Δ) DELTA. The heating is given by:

$$QR = \bar{\epsilon}\sigma T^4$$

where σ = the Stefan-Boltzmann constant. The calculated emissivity of the gas accounts for absorption, and is given as:

$$\bar{\epsilon} = 1 - 2E_3(\Sigma\tau_i)$$

where τ_i is the optical path length of each radiating specie,

$$\tau_i \approx 15\ 24 \frac{\epsilon_i}{L} \Delta$$

and $E_3(\tau)$ is defined as:

$$E_3(\tau) = \int_0^1 s e^{-\tau/s}\, ds\ .$$

Tabular values of $1 - 2E_3(\tau)$ are shown in Table I and are used in the computer program.

$$\frac{\epsilon_i}{L} = C_i \frac{N_i}{5\ 4 \times 10^{19}} \cdot \frac{e^{-T_i/T}}{(T \times 10^{-4})^{n_i}}$$

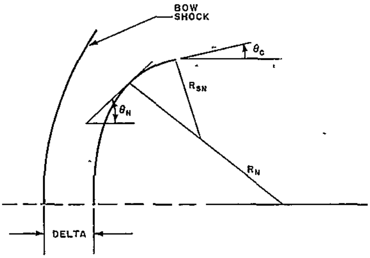
where N_i is the particle density of the radiating species.

The values of C_i, T_i, n_i for the corresponding species X_i are given in Table I-20 in Reference 1. A detailed discussion of the radiation heating model is given in Reference 1 also. The standoff distance (Δ) may be input, or the nose geometry can be input, in terms of RN, RSN, THN as shown in Figure 2 which utilizes the correlations of Reference 5 as shown in Figure 3.

2. Limitations

The limitations of the calculation model are discussed in Reference 1, page 49, from the point of view of the kinetic theory approximations.

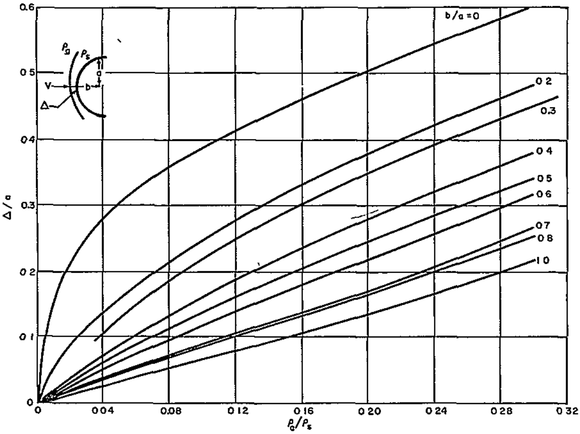
The flight speed range and atmosphere limits are governed by the range of species considered. Doubly ionized carbon, oxygen, and nitrogen ions



$$a = (R_N \cos\theta_N \quad + R_{SN}(1-\cos\theta_N)$$
$$b = R_N(1-\sin\theta_N) + R_{SN} \sin\theta_N$$

65-11701

Figure 2 CALCULATION MODEL 'FOR OPTION TO COMPUTE DELTA



65-11702

Figure 3 SHOCK DETACHMENT DISTANCE FOR OBLATE ELLIPSOIDS and singly ionized argon are considered in the extreme temperature range, hence, the calculable flight speed regime is higher for mixtures without argon. As the program was developed primarily for high-speed studies, its use for low-temperature work, corresponding to flight velocities below 8000 fps, is not recommended.

Because of the nature of the algebraic equations, several limitations arise in specifying concentrations; both the concentrations of argon and oxygen can be specified as zero, but the concentrations of CO_2 and N_2 should be greater than 10^{-3}.

The radiation model uses the parallel slab approximation and assumes an isothermal gas layer of uniform composition; hence, the results will tend to be conservative, especially at large radiative heating rates when the radiation heat loss approaches the energy content of the gas. This limit has been treated by Wick,[6] Yoshikawa and Chapman.[7]

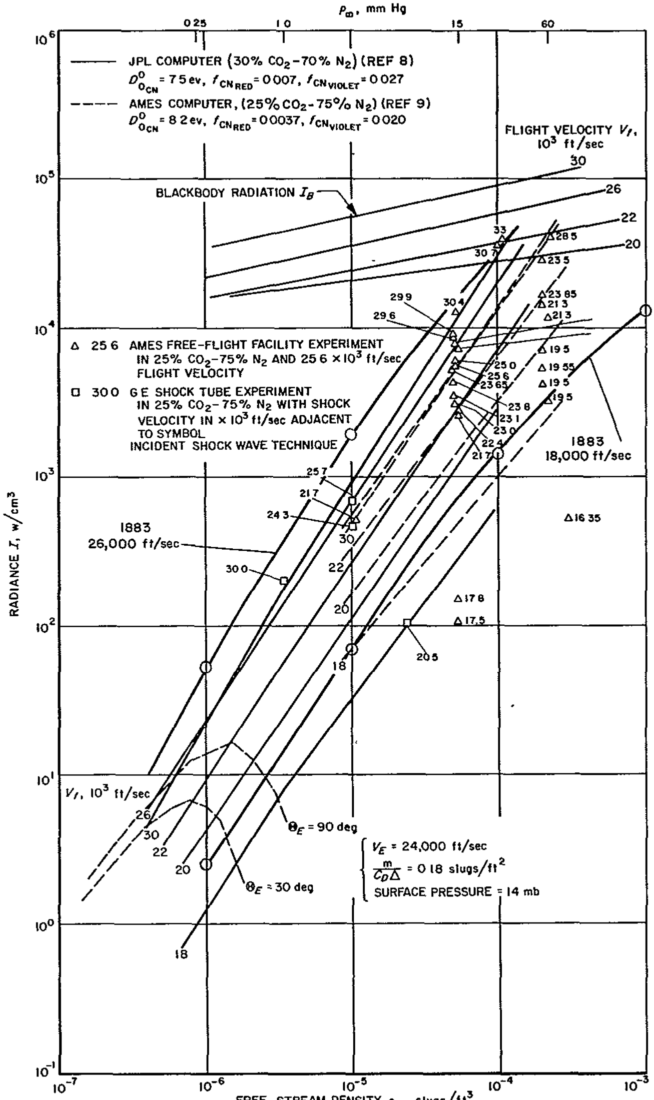
The limitations of the model to predict the standoff distance are discussed under Program 1880.

Comparative results obtained from Program 1883 with those obtained from JPL and Ames Programs are given in Figure 4.

TABLE I

TABULAR VALUES
OF $\bar{\epsilon}$

TAUTBL		EPSTBL ($\bar{\epsilon}$)	
(1)	0	(1)	0
(2)	0.01	(2)	0.02
(3)	0.05	(3)	0.092
(4)	0.1	(4)	0.168
(5)	0.2	(5)	0.298
(6)	0.3	(6)	0.400
(7)	0.4	(7)	0.486
(8)	0.5	(8)	0.558
(9)	0.6	(9)	0.618
(10)	0.7	(10)	0.668
(11)	0.8	(11)	0.712
(12)	0.9	(12)	0.750
(13)	1.0	(13)	0.782
(14)	1.1	(14)	0.810
(15)	1.2	(15)	0.834
(16)	1.3	(16)	0.854
(17)	1.4	(17)	0.872
(18)	1.5	(18)	0.888
(19)	1.6	(19)	0.900
(20)	1.7	(20)	0.912
(21)	1.8	(21)	0.923
(22)	1.9	(22)	0.932
(23)	2.0	(23)	0.939
(24)	2.5	(24)	0.967
(25)	3.0	(25)	0.982
(26)	3.5	(26)	0.990
(27)	4.0	(27)	0.994
(28)	6.0	(28)	0.999
(29)	10.0	(29)	1.00
(30)	1.0E + 10	(30)	1.00



86-3417

Figure 4 COMPARATIVE RESULTS FOR 30 PERCENT CO_2 - 70 PERCENT N_2

II. USAGE

A. INPUT DEFINITIONS

External Name	Preset Values	Symbol	Parameter	Units
ATMØS			A number of the form XX.XX for identification.	--
CASE			A number of the form XX.XX for identification.	--
DATE			A number of the form XX.XX for identification.	--
DELTA	0.	Δ	Shock detachment distance. If = 0, Δ is computed from a geometry correlation.	feet
MEMØ			A number of the form XX.XX for identification.	--
RC	0.		Cylinder radius.	feet
RHØA	0.	ρ_a	Ambient density.	slug/feet^3
RN	0.	R_N	Nose radius used for Δ correlation (see DELTA).	feet
RSN	0.	R_{SN}	Shoulder radius for Δ correlation (See DELTA).	feet
TA	0.	T_a	Ambient temperature.	°K
THN	0.	θ_N	Nose angle used for Δ correlation (See DELTA).	degrees
V	0.	V	Vehicle velocity.	ft/sec
VEHICL			A number of the form XX.XX for vehicle identification.	--
XA	0.	XA	Mole fraction of A in atmosphere.	--

External Name	Preset Values	Symbol	Parameter	Units
XC	0.	XC	Mole fraction of CO_2 in atmosphere.	----
XN	0.	XN	Mole fraction of N_2 atmosphere	----
XØ	0.	XØ	Mole fraction of $Ø_2$ atmosphere	----

B. INPUT PROCEDURES

The following procedures are to be observed when formulating inputs for Program 1883:

1. All data are numerical and may be written with decimal points.

2. Since all variables have been preset to 0., before the first case, only those which are to be non-zero must be input.

3. The concentrations of oxygen and argon may be equal to zero; however, the concentrations of nitrogen and carbon dioxide should not be less than 0.001.

4. Argon is included only in Zones 1 and 2 and hence, if the flight conditions are outside of these limits, one must ensure that the concentrations of oxygen, carbon dioxide, and nitrogen total unity.

5. A set of computer input forms are provided for the user. All the data shown on the form is keypunched when the variable is supplied.

C. OUTPUT DEFINITIONS

External Name	Preset Values	Symbol	Parameter	Units
ATMØS	ATMØS		Number of the form XX.XX used for identification of the atmosphere.	--
CASE	CASE		Number of the form XX.XX used for identification of the case.	--
DATE	DATE		Number of the form XX.XX used for identification of the problem run.	--
DELTA	DEL	Δ	Detachment distance.	feet
EPSILØN	EPBAR	$\bar{\epsilon}$	Total effective emissivity.	--

External Name	Internal Name	Symbol	Parameter	Units
EPSILON (I)	EPS	ϵ_1	Table of emissivities for each radiation source.	--
HD/HS	HDHS	H_D/H_S	Ratio of dissociation enthalpy to stagnation enthalpy.	---
HM/RTØ	HRT	HM/RT_o	Stagnation enthalpy ratio.	---
MEMØ	MEMØ		Number of the form XX.XX used for identification of the problem run.	---
QI	QI		Radiative heating contribution of each source.	Btu/ft^2-sec.
QR	QSUM		Total radiation heating at stagnation point.	Btu/ft^2-sec.
RHØS/RHØ	RHØST	ρ_S/ρ_a	Ratio of stagnation density to ambient density.	---
TS	T	T_S	Stagnation temperature.	°K
VEHICL	VEHICL		Number of the form XX.XX for vehicle identification.	--
X	X	X_i	Specie concentration.	moles
ZS	Z	Z	Total moles of species.	moles

1. Chemical Terms

Although conventional chemical symbols are utilized in the text and especially in writing chemical reactions, the symbols used in the program and occurring on the program printout sheets must include only captial letters without subscripts. The following table summarizes the nomenclature for all the species considered in the program:

Program Symbol	Chemical Symbol	Chemical Name
Ø	O	Atomic oxygen
Ø2	O_2	Molecular oxygen

Program Symbol	Chemical Symbol	Chemical Name
C	C	Atomic carbon
CØ2	CO_2	Carbon dioxide
CØ	CO	Carbon monoxide
N	N	Atomic nitrogen
N2	N_2	Molecular nitrogen
A	A	Argon (monatomic)
Ø+	O^+	Singly ionized atomic oxygen
Ø++	O^{++}	Doubly ionized atomic oxygen
C+	C^+	Singly ionized atomic carbon
C++	C^{++}	Doubly ionized atomic carbon
N+	N^+	Singly ionized atomic nitrogen
N++	N^{++}	Doubly ionized atomic nitrogen
N2+	N_2^+	Single ionized molecular nitrogen
A+	A^+	Singly ionized argon
CN	CN	Cyanogen
NØ	NO	Nitric oxide
E-	e^-	Electrons

D. SAMPLE PROBELM

1. Statement of Problem

Determine the radiation heating for a specified flight condition for a gas mixture of 51.2 percent nitrogen and 48.8 percent carbon dioxide.

2. Input Form

The input form containing the necessary data is shown on a following page. Case 1 typifies the input when the vehicle geometry is specified, and Case 2 is the optional input of specifying the shock stand off distance. All the variable names for which data are given should be keypunched.

3. Output Form

The output is shown on the following pages. The keypunched data are shown and should be compared with the input form. The emissivities of each specie contributing to the radiation are given as well as the total emissivity including self absorption (grey gas approximation).

The stagnation temperature, compressibility factor, shock density ratio, radiation heating, enthalpy, and dissociation energy are given. The concentrations of the individual constituents are given as well as the radiation contributions of the species considered.

E. DIAGNOSTICS

The number of messages are given in the printout reflecting the following program diagnostics.

1. NO VALID SOLUTION

The equilibrium gas dynamics (1883) solution was not able to obtain a solution with positive concentrations for all the species satisfying the elemental and charge conservation relationships. In this case, the data is linearly interpolated between the last and the next point for which a solution is found.

2. NOT CONVERGED IN 30 ITERATIONS

The equilibrium gas dynamics (1883) solution was unable to converge within 30 iterations to within 1 percent on the enthalpy; use the last value found.

RAD 2-0963
5 63

DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO 1883	PROGRAMMER D. Gillespie
	TITLE Radiation Heating Program	

MEMO NO	SECTION NO	WORK ORDER NO	(E240 USE ONLY)	REQUESTED BY	EXT	EST TIME	PAGE 1 OF 1 PAGES

```
$INPUT

DATE = ________, MEMØ =______, CASE =______, ATMØS = ______, VEHICL =________,

DELTA   =  __________,        RSN  =  __________,    XA  =  __________,
RC      =  __________,        TA   =  __________,    XC  =  __________,
RHØA    =  __________,        THN  =  __________,    XN  =  __________,
RN      =  __________,        V    =  __________,    XØ  =  __________,

$
```

RAD 2-0963
5 63

DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO 1883			PROGRAMMER D. Gillespie			
	TITLE Radiation Heating Program						
MEMO NO 1	SECTION NO K420	WORK ORDER NO W305-050-0005	(E240 USE ONLY)	REQUESTED BY P. Levine	EXT 2996	EST TIME	PAGE 1 OF 1 PAGES

$INPUT

DATE = ________, MEMØ= 1. , CASE = 1. , ATMØS = 3. , VEHICL= ________,

DELTA = ________, RSN = .6768, XA = ________,
RC = 6.7681, TA = 100., XC = .488,
RHØA = 1.21E-6, THN = 66.92, XN = .512,
RN = 16.2434, V = 19705., XØ = ________,

$

```
                IBLOR                                                    12/01/64

                        * MEMORY MAP *

  SYSTEM                                  00000 THRU  02717
  FILE BLOCK ORIGIN                       02720
  FILES          1.     UNIT05
                 2.     UNIT06
  FILE LIST ORIGIN                        02750
  PRE-EXECUTION INITIALIZATION            02754
  CALL ON OBJECT PROGRAM                  02777
  OBJECT PROGRAM                          03004 THRU  46035

       DECK  ORIGIN       CONTROL SECTIONS  (/NAME/=NON 0 LENGTH, (LOC)=DELETED, *=NOT REFERENCED)

    1. SAR2TL  03004      AR2TLU  03306
    2. 1883    03357      ......  04146 *
    3. SGETN1  04162      GETN1   06152
    4. SHVST1  06216      HVST1   12205
    5. SARTLU  13223      ARTLU   13435
    6. SHFAT1  13606      HEAT1   15754
    7. SFNDH1  16157      FINDH1_ 16516
    8. SGETQ1  16633      GETQ1   20707
    9. SGETK1  21031      GETK1   21363
   10. SFNDT1  21523      FINDT1  21754
   11. SZONS1  22070      ZONES1  25624
   12. .LXCON  25767      .LXSTR  25767 *   .LXSTP  25773     .LXOUT  26041     .LXRTN  26053     IBEXIT  26053 *
                          .LXCAL  26056 *   .LXERR  26056     .DBCLS  26240 *   .LXARG  26407     .LO     26432 *
                          .CLSF   26440     .LFBL   26441 *   .LUNB   26442     .DFOUT  26443
   13. .IODEF  26447      .DEFIN  26447     .ATTAC  26453 *   .CLOSE  26455     .OPEN   26457     .READ   26461
                          .WRITE  26463     .BSR    26473 *   .READR  26503     .RELES  26505 *   .LAREA  26516
                          .LFBLK  26534     .LTSX   26537 *   .AREA1  26551     .LUNBL  26557     .ENTRY  26563
                          .GJA    26616     .GO     26622     .DERR   26636     .NOPXI  26637     .CUMXI  26641
                          .EX34   26663
   14. .LXSL   26670      .LXSEL  26670     LXCSEL  26671     .LXTST  26674 *   .LXOVL  26734 *   .LXRCT  26745 *
                          .LXIND  27014 *   .LXDIS  27017 *   .LXFLG  27020 *   .LTCH   27021
   15. .FPTRP  27027      .FFPT.  27027 *   .FPOUT  27156     .FPARG  27164     /.COUNT/ 27166 *  OVFLOW  27232 *
   16. .ERAS.  27237      E.1     27237     E.2     27240     E.3     27241     E.4     27242
   17. .XCC.   27243      CC.1    27243     CC.2    27244     CC.3    27245     CC.4    27246
   18. XIT     27247      EXIT    27247     .EXIT.  27247 *
   19. FXEM    27250      .FXEM.  27250     .FXOUT  27605     .FXARG  27613     /.OPTW./ 27667
   20. FOUT    27700      .FOUT.  27700
   21. FCNV    30242      .FCBN.  30242     .FCNV.  30265     .ENDFS  30300     .CNVSW  30302     .FOX1   30306
                          .FOX2   30307     .DBC    30311     .DBC8   30432     .DBC9   30435     .DBC10  30442
                          .DBC20  30470     .DDSW   30500     .DDFIX  30507     .FIXSW  30515     .DDBC   30572
                          .DDRS1  31044     .DDRS2  31046     .D1     31051     .D2     31053     .FERR2  31140 *
                          .ANPT   31174     .DNPT   31211     .LNTP   31265     .AOUT   31334     .DFLT   31352
                          .FLT    31506     .DEXPN  31576     .FXD    31577     .HOUT   31727     .INTG   31777
                          .LOUT   32115     .DOUT   32134     .XCF    32165     .TEST   32672     .KOUNT  32675
                          .LIST   32700     .DONE   32711     .OUTBF  32755     .BUF    33003     .QSTO   33004
                          .WIDTH  33005     .GAIN   33006     .GAINI  33007     .FBDBF  33017     .DDDFL  33042
                          .DDFLG  33043     .MQD    33044     .PEX    33045     .FEXP   33046     .DIG    33047
   22. FIOS    33067      .FIOS.  33067     .FSEL.  33227     .FILR.  33233     .FRTB.  33242 *   .FRTD.  33247
                          .FILL.  33252     .FCLS   33254 *   .FOPN   33260 *   REOF    33264 *   .TOUT.  33427
                          .REED   33435 *   .BIN    33436 *   .FCT    33437     .FCKSZ  33441 *
   23. FIOH    33523      .FIOH.  33523     .FFIL.  34312     .FRTN.  34337 *
   24. FWRD    34524      .FWRD.  34524
   25. FWRU    34550      .FWRU.  34550
```

```
                    IBLDR                                                     12/01/64

     26. FWRD      34574      .FWRD.  34574      .FREST  35077 *
     27. FRDU      35201      .FRDU.  35201
     28. UN05      35242      .UN05.  35242
     29. UN06      35243      .UN06.  35243      .BUFSZ  35244
     30. FIOU      35247      .FIOU.  35247      .CTUIO  35722      .NMLST  35745      .NAME.  37050      .INTAP  37051
     31. JPLRT     37474      POLROT  40651
     32. JCDIV     40734      CONDIV  40775
     33. JPRT1     41033      POLRT1  41216
     34. FLOG      41315      ALOG10  41315 *    ALOG    41317
     35. FXPF      41456      EXP     41456
     36. FSCN      41576      COS     41576      SIN     41600
     37. FSQR      42007      SQRT    42007
     38. FXP3      42114      .XP3.   42114
     39. .IOCS     42241      .L(0)   42241      .MONSW  42261      .TEOR   42330      .DEFI.  42410      .JOINX  42454 *
                              .CLOS.  42473      .ATTC.  42506      .SH1    42720 *    .SH9    42762 *    .OPEN.  43003
                              .OP4    43031 *    .OP7    43062 *    .OP9.2  43076 *    .RLSE.  43150      .RER2.  43150
                              .READ.  43151      .RER1.  43174      .WRIT.  43176      .MNT1A  43364 *    .EOFEX  43445 *
                              .FEEIT  43515      .GTIOX  43536      .RW7    43654 *    .RE7    44273 *    .ENDTR  44734
                              .SEL59  44736 *    .BSR.   45347      .EOTOF  45474      .ETOF3  45502 *    .SWITC  45531
                              .TCHEX  46032      .BASIO  46035 *
     40. .IOCSM  46036

     I/O BUFFERS                        46036 THRU  77741

     UNUSED CORE                        77742 THRU  77777

     $INPUT
     V      =          0.19705000E 05,
     XN     =          0.51200000E 00,
     XO     =          0.00000000E-38,
     XA     =          0.00000000E-38,
     XC     =          0.48800000E 00,
     THN    =          0.66920000E 02,
     RN     =          0.16243400E 02,
     RC     =          0.67691000E 01,
     RHOA   =          0.12100000E-05,
     TA     =          0.10000000E 03,
     DELTA  =          0.00000000E-38,
     ATMOS  =          0.30000000E 01,
     VEHICL =          0.99900000E 01,
     RSN    =          0.67680000E 00,
     DATE   =          0.40100000E 01,
     MEMO   =          0.10000000E 01,
     CASE   =          0.10000000E 01,
     $ END
```

```
      DATE    4.01  CASE    1.00  MEMO    1.00  ATMOS    3.00  VEHICLE    9.99

        UNDRFLOW AT 40753 IN MQ

        UNDRFLOW AT 40763 IN AC AND MQ.

        UNDRFLOW AT 40763 IN MQ

        UNDRFLOW AT 40763 IN AC AND MQ.

        UNDRFLOW AT 40763 IN MQ

         EPSILON(I), I=1 TO 21

      1    8.79953E-06  2    7.14842E-05  3    3.60825E-09  4    0.00000E-39  5    6.99787E-04  6    0.00000E-39
      7    0.00000E-39  8    4.43364E-08  9    1.53081E-08 10    2.96127E-03 11    4.62941E-03 12    8.68609E-05
     13    1.20091E-06 14    1.15892E-06 15    2.31807E-07 16    5.56989E-30 17    3.82328E-26 18    6.93851E-22
     19    1.15973E-04 20    0.00000E-39 21    0.00000E-39

         EPSILON BAR =    8.57673E-03 DELTA =    9.92675E-01

                        TS                       ZS                RHOS/RHO            QR                HD/HS              HM/RTO

                 0.56528459E-04      0.16122614E-01      0.17042358E 02      0.44432617E 02     0.58907126E 00     0.28240456E 03

                        X(MOLAR CONC.)                             QI
         N2            0.39843028E 00          N2 1          0.45589495E-01
         CO2           0.00000000E-38          N2-2          0.37035265E 00
         CO            0.47152183E 00          N2            0.18693974E-04
         O2            0.00000000E-38          CO2 13        0.00000000E-38
         O             0.49955057E 00          CO            0.36255298E 01
         N             0.22135297E 00          O2 S-R        0.00000000E-38
         CN            0.85885380E-03          O2            0.00000000E-38
         NO            0.49276015E-02          O-            0.22970241E-03
         C             0.15619319E-01          N             0.79309766E-04
         O+            0.16934164E-04          CN RED        0.15342035E 02
         N+            0.53380483E-05          CN VIO        0.23984492E 02
         C+            0.87616135E-04          NO B-G        0.45001797E 00
         E-            0.11103584E-03          NO 16         0.62217899E-02
         N++           0 00000000E-38          NO -          0.60042313E-02
         O++           0.00000000E-38          C             0.12009694E-02
         C++           0.00000000E-38          O+            0.28857057E-25
         N2+           0.11474966E-05          N+            0.19808027E-21
         A             0.00000000E-38          C+            0.35947726E-17
         A+            0.00000000E-38          N2+           0.60084711E 00
                                               A-            0.00000000E-38
                                               A+            0.00000000E-38

      $INPUT

      V        =           0.19705000E 05,

      XN       =           0.51200000E 00,

      XO       =           0.00000000E-38,

      XA       =           0.00000000E-38,

      XC       =           0.48800000E 00,

      THN      =           0.66920000E 02,

      RN       =           0.16243400E 02,

      RC       =           0.67691000E 01,

      RHOA     =           0.12100000E-05,

      TA       =           0.10000000E 03,

      DELTA    =           0.10107000E 01,

      ATMOS    =           0.30000000E 01,

      VEHICL   =           0.99900000E 01,

      RSN      =           0.67680000E 00,

      DATE     =           0.40100000E 01,

      MEMO     =           0.10000000E 01,

      CASE     =           0.70000000E 01,

      $ END
```

```
 DATF    4.01  CASE    2.00  MEMO    1.00  ATMOS    3.00  VEHICLE    9.99

   EPSILON(I), I=1 TO 21

  1    8.95931F-06  2    7.27822E-05  3    3.67377E-09  4    0.00000E-39  5    7.12494E-04  6    0.00000E-39
  7    0.00000E-39  8    4.51415E-08  9    1.55861E-08 10    3.01504E-03 11    4.71347E-03 12    8.84382E-05
 13    1.22272E-06 14    1.17996E-06 15    2.36016E-07 16    5.67103E-30 17    3.89270E-26 18    7.06450E-22
 19    1.19079E-04 20    0.00000E-39 21    0.00000E-39

   EPSILON BAR =   8.73196E-03 DELTA =   1.01070E 00

            TS                    ZS                RHOS/RHO              QR                HD/HS               HM/RTO

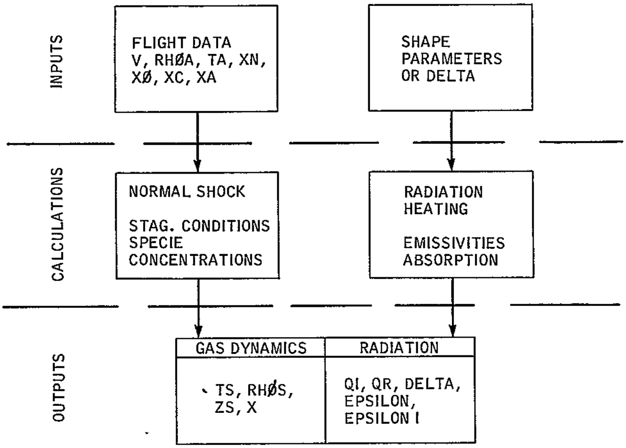
       0.56528459E-04       0.16122614E-01      0.17042358E-02      0.45239440E-02      0.58907126E 00      0.28240456E-03

               X(MOLAR CONC.)                               QI
  N2           0.39843028E 00          N2 1          0.46417324E-01
  CO2          0.00000000E-38          N2 2          0.37707764E 00
  CO           0.47152183E 00          N2            0.19033426E-04
  O2           0.00000000E-38          CO2 13        0.00000000E-38
  O            0.49955057E 00          CO            0.36913635E 01
  N            0.22135297E 00          O2 S-R        0.00000000E-38
  CN           0.85885380E-03          O2            0.00000000E-38
  NO           0.49276015E-02          O             0.23387343E-03
  C            0.15619319E-01          N             0.80749900E-04
  O+           0.16934164E-04          CN RED        0.15620621E-02
  N+           0.53380483E-05          CN VIO        0.24420011E 02
  C+           0.87616135E-04          NO B-G        0.45818955E 00
  E-           0.11103584E-03          NO 16         0.63347673E-02
  N++          0.00000000E-38          NO            0.61132581E-02
  O++          0.00000000E-38          C             0.12227770E-02
  C++          0.00000000E-38          O+            0.29381053E-25
  N2+          0.11474966E-05          N+            0.20167708E-21
  A            0.00000000E-38          C+            0.36600477E-17
  A+           0.00000000E-38          N2+           0.61175749E 00
                                       A             0.00000000E-38
                                       A+            0.00000000E-38
```

III. COMPUTATIONS

A. BLOCK DIAGRAM

The block diagram for Program 1883 is given in Figure 5.



65-11703

Figure 5 BLOCK DIAGRAM FOR PROGRAM 1883

B. SYMBOLS

E_o	zero point energy
H_i	total enthalpy of i^{th} specie, Btu/mole
H	total enthalpy, Btu/mole
K_{pi}	equilibrium constant for i^{th} reaction
M	mean molecular weight of atmosphere
N_i	number density of i^{th} specie, particles/cm^3

P	pressure, atmospheres
R	universal gas constant
QR	equilibrium radiative heating rate, Btu/ft^2-sec
T_a	atmospheric temperature, °K
T	temperature, °K
T_o	reference temperature, 273.16 °K
V	flight velocity, fps
X( )	molar concentration
XA, XC, XN, XO	molar concentrations of argon, carbon dioxide, nitrogen, and oxygen in atmosphere
Z	compressibility factor; number of moles of products per mole reactants
$\frac{\epsilon_i}{L}$	emissivity per unit thickness, cm^{-1}
τ_i	optical path length, feet
$\bar{\epsilon}$	emissivity, accounting for absorptivity (smeared out model)
ρ_a	atmospheric density, slug/ft^3

C. EQUATIONS

1. Basic Equations

a. Enthalpy

$$\frac{H_i M}{R T_o} = \frac{E_{oi}}{R T_o} + \frac{T^2}{T_o}\left(\frac{\partial \ln Q_i}{\partial T}\right)_P \tag{1}$$

$$\frac{HM}{R T_o} = \Sigma X_i \left(\frac{H_i M}{R T_o}\right) \tag{2}$$

b. Energy of Dissociation

$$\frac{H_D M}{R T_o} = \sum_i X_i \frac{E_{oi}}{R T_o} \tag{3}$$

c. Equilibrium Constants

The equilibrium constants for all the reactions used in the program are given as a function of (T, P) in Reference 1, Table I-15.

d. Partition Functions

The partition functions for all the species considered in the program are given as a function of (T, P) in Reference 1, Table I-18.

e. Zero Point Energies

The zero point energies used are given in Reference 1, Table I-14. It is important to note that the values for all molecules are zero.

2. Zone 1

a. Major Species

1) Six major species considered:

Six major species considered

X(N2), $X(CO_2)$, $X(O_2)$, X(A), X(CO), X(O)

b. Major Specie Reactions

$CO_2 \rightarrow CO + 1/2\, O_2$

$O_2 \rightarrow 2O$

c. Major Specie Conservation Equations

$$X(N_2) = XN \tag{4}$$

$$X(CO_2) = XC - X(CO) \tag{5}$$

$$X(O_2) = XO + (1/2)\, X(CO) - (1/2)\, X(CO) \tag{6}$$

$$X(A) = XA \tag{7}$$

d. Equilibrium Constants for Major Species Reactions

$$K_{P1} = \frac{[X(CO)]\sqrt{[X(O_2)]}\ \sqrt{P}}{[X(CO_2)]\ \sqrt{Z}} \tag{8}$$

$$K_{P2} = \frac{[X(O)]^2\ P}{[X(O_2)]\ Z} \tag{9}$$

Total moles: (10)

$$Z = \Sigma X_i = 1 + (1/2)\,X(CO) + (1/2)\,X(O)$$

e. General Solution

There can be as many as six major species governing the thermodynamic state of the gas. Hence, six equations are required to be solved (identified as Equations (4) through (9)). The auxiliary equation for the compressibility factor Z is given by Equation (10). Making use of Equations (5) and (6), and combining Equations (8) and (9), an explicit solution for the CO concentration can be found, namely,

X(CO) Polynomial

$$\sum_{i=1}^{4} C_i\, X(CO)^{4-i} = 0 \tag{11}$$

$$C_1 = K_{P1}\sqrt{K_{P2}}\left(\frac{K_{P1}}{\sqrt{K_{P2}}} - 1\right) - P$$

$$C_2 = K_{P1}\sqrt{K_{P2}}\left\{\frac{2K_{P1}}{\sqrt{K_{P2}}}(1 - XC) + XC - 1 - XO\right\} - 2PXO$$

$$C_3 = K_{P1}\sqrt{K_{P2}}\ XC\left\{XO + 1 + \frac{K_{P1}}{\sqrt{K_{P2}}}(XC - 4)\right\}$$

$$C_4 = 2(XC)^2 K_{P1}^2 \quad .$$

3. Zone 2

a. Major Species

Six major species are considered in Zone 2:

$X(N_2)$, $X(N)$, $X(A)$, $X(O)$, $X(C)$, and $X(CO)$.

b. Major Specie Reactions

$$N_2 \rightarrow 2N$$

$$CO \rightarrow C + O$$

c. Major Species Conservation Equations

$$X(N_2) = XN - (1/2)X(N) \tag{12}$$

$$X(CO) = XC - X(C) \tag{13}$$

$$X(O) = 2XO + XC + X(C) \tag{14}$$

$$X(A) = XA \tag{15}$$

d. Equilibrium Constants for Major Species Reactions

$$K_{P3} = \frac{[X(N)]^2 \; P}{X(N_2)\, Z} \tag{16}$$

$$K_{P4} = \frac{[X(C)]\,[X(O)] \; P}{X(CO)\, Z} \tag{17}$$

$$Z = 1 + XO + XC + \frac{X(N)}{2} + X(C) \tag{18}$$

e. Minor Species

A large number of minor concentrations are considered in Zone 2 because of their importance in the radiative heating calculations. Eight minor species are considered:

$X(CN)$, $X(NO)$, $X(N^+)$, $X(C^+)$, $X(O^+)$, $X(A^+)$, $X(N_2^+)$, and $X(e^-)$.

f. Minor Species Reactions

$N \rightarrow N^{+} + e^{-}$

$O \rightarrow O^{+} + e^{-}$

$C \rightarrow C^{+} + e^{-}$

$A \rightarrow A^{+} + e^{-}$

$N_2^{+} \rightarrow N^{+} + N$

$C + N \rightarrow CN$

$N + O \rightarrow NO .$

g. Minor Species Concentrations

$$X(O^{+}) = K_{P7} \frac{Z}{P} \frac{X(O)}{X(e^{-})} \tag{19}$$

$$X(N^{+}) = K_{P8} \frac{Z}{P} \frac{X(N)}{X(e^{-})} \tag{20}$$

$$X(C^{+}) = K_{P9} \frac{Z}{P} \frac{X(C)}{X(e^{-})} \tag{21}$$

$$X(N_2^{+}) = \frac{K_{P8}}{K_{P13}} \frac{[X(N)]^{2}}{X(e-)} \tag{22}$$

$$X(CN) = X(C)\,X(N)\,K_{P5} \frac{P}{Z} \tag{23}$$

$$X(NO) = X(N)\,X(O)\,K_{P6} \frac{P}{Z} \tag{24}$$

$$[X(e-)]^{2} = \frac{Z}{P} \quad X(O)\,K_{P7} + X(N)K_{P8} + X(C)K_{P9} + X(A)K_{P14} + \frac{K_{P8}}{K_{P13}} [X(N)]^{2} \tag{25}$$

h. General Solution

X(N) Polynomial (26)

$$\sum_{i=1}^{5} C_i \, X(N)^{5-i} = 0$$

$$C_1 = -\left(K_{P4}\right)\left(4P + K_{P3}\right) - 2P\left[2P - K_{P3}\right] - \frac{K^2_{P3}}{8}$$

$$C_2 = \frac{(K_{P3})\,(K_{P4}}{2}\,[XN - (1 + XC + XO + XC)] + \frac{K_{P3}}{8}\,[4P\,(2XN - 2 - XC)]$$

$$-\frac{K^2_{P3}}{8}\,(2 - 2XN + XC)$$

$$C_3 = (K_{P3})\,(K_{P4})\,\frac{XN}{2}\,(1 + XO + 2XC) + \frac{P}{2}\,(K_{P3})\,XN\,(2 + XC)$$

$$-\frac{K^2_{P3}}{8}\,[XN^2 - 2XN\,(2 + XC) + (1 + XC - XOXC - XO^2)]$$

$$C_4 = -\frac{K^2_{P3}}{8}\,[XN^2\,(2 + XC) - 2XN\,(1 + XC - XOXC - XO^2)]$$

$$C_5 = -\frac{K^2_{P3}\,XN^2\,(1 + XC - XOXC - XO^2)}{8}$$

X (CN) Polynomial

$$\sum_{i=1}^{4} C_i \, [X(CN)]^{4-i} \qquad (27)$$

$$C_4 = -\,[X(C)]^2\;K^2_{P5}\,X(N)\,P\,[X(C) + XC + 2XO]\;K_{P6}$$

$$C_3 = (K_{P5})\,X(C)\,[\,X(C)\,K_{P5}\,H + D + 2WSG\,]$$

$$H = PK_{P6}\,[X(C) + XC + 2XO]$$

$$D = P\,(K_{P6}^{2})\,[X(C) + XC + 2XO]\ \ [X(C) + XC + 2XO + X(N)]$$
$$+\ [1 + XC + XO + X(C) + \frac{1}{2}X(N)]\ \ [X(C) + XC + 2XO)\,K_{P6}\,]$$

$$WSG = -(K_{P6} - K_{P5})\,X(N)\,P\,K_{P6}\,[X(C) + XC + 2XO]$$

$$C_2 = X(C)\,K_{P5}\,(F + 2WSH) + F(WS2) + (K_{P6} - K_{P5})\,(D + WSG)$$

$$F = -\,K_{P6}\,[X(C) + XC + 2XO] - K_{P6}^{2}\,P\,[X(C) + XC + 2XO]$$

$$WSH = (K_{P6} - K_{P5})\,P\,K_{P6}\,[X(C) + XC + 2XO]$$

$$WS2 = K_{P6}\,[X(C) + XC + 2XO]$$

$$C_1 = (K_{P6} - K_{P5})\,(F + WSH)$$

4. Zone 3

a. Major Species

Seven major species are considered in zone 3:

$X(N)$, $X(C)$, $X(O)$, and $X(e-)$.

b. Major Species Reactions

$$N \rightarrow N^{+} + e^{-}$$

$$C \rightarrow C^{+} + e^{-}$$

$$O \rightarrow O^{+} + e^{-}$$

c. Major Specie Conservation Equations

$$X(N) = 2XN - X(N^{+}) \tag{28}$$

$$X(C) = XC - X(C^{+}) \tag{29}$$

$$X(O) = 2XO + 2XC - X(O^{+}) \tag{30}$$

$$X(e^-) = X(N^+) + X(C^+) + X(O^+) \tag{31}$$

d. Equilibrium Constants for Major Species Reactions

$$K_{P7} = \frac{X(O^+)\,X(e^-)\,P}{X(O)\,Z} \tag{32}$$

$$K_{P8} = \frac{X(N^+)\,X(e^-)\,P}{X(N)\,Z} \tag{33}$$

$$K_{P9} = \frac{X(C^+)\,X(e^-)\,P}{X(C)\,Z} \tag{34}$$

Total moles

$$Z = 1 + XN + XO + 2XC + X(e^-) \tag{35}$$

e. Minor Species

A number of minor concentrations heavily influence the radiative heating and the following additional specie concentrations are required·

$X(CN)$, $X(NO)$, $X(N_2^+)$

f. Minor Species Reactions

$C + N \rightarrow CN$

$N + O \rightarrow NO$

$N^+ + N \rightarrow N_2^+$

g. Minor Species Concentration

$$X(CN) = X(C)\,X(N)\,K_{P5}\,\frac{P}{Z} \tag{36}$$

$$X(NO) = X(N)\,X(O)\,K_{P6}\,\frac{P}{Z} \tag{37}$$

$$X(N_2^+) = \frac{X(N^+)\,X(N)}{K_{p13}}\,\frac{P}{Z} \qquad (38)$$

h. General Solution

$X(C^+)$ polynomial

$$\sum_{i=1}^{5} C_i\,[X(C^+)]^{5-i} = 0 \qquad (39)$$

$$C_1 = (K_{P8} - K_{P9})(K_{P7} - K_{P9})(K_{P9} + P)$$

$$\begin{aligned}C_2 = {} & (K_{P9} + P)\ \{2XN\,K_{P8}(K_{P7} - K_{P9}) + 2(XC + XO)\,K_{P7}(K_{P8} - K_{P9}) \\ & + XCK_{P9}(K_{P8} + K_{P7} - 2K_{P9})\} + \{(K_{P8} - K_{P9})(K_{P7} - K_{P9}) \cdot \\ & [(1 + 2XC + XO + XN)\,K_{P9} - XCK_{P9}]\}\end{aligned}$$

$$\begin{aligned}C_3 = {} & XCK_{P9}\ \{(K_{P9} + P)\,[2XN\,K_{P8} + 2K_{P7}(XC + XO) + K_{P9}\,XC] \\ & + (K_{P8} + K_{P7} - 2K_{P9})\ [(1 + 2XC + XO + XN)\,K_{P9} - XCK_{P9}] \\ & - [2XN\,K_{P8}(K_{P7} - K_{P9}) + 2(XC + XO)(K_{P7})(K_{P8} - K_{P9})] \\ & - (1 + 2XC + XO + XN)(K_{P8} - K_{P9})(K_{P7} - K_{P9})\}\end{aligned}$$

$$\begin{aligned}C_4 = {} & XC^2\,K_{P9}^2\ \{(1 + 2XC + XO + XN)\,K_{P9} - XC\,K_{P9} \\ & - 2(XC + XO)\,K_{P7} - 2XN\,K_{P8} \\ & - (1 + 2XC + XO + XN)(K_{P8} + K_{P7} - 2K_{P9})\}\end{aligned}$$

$$C_5 = -K_{P9}^3\,XC^3(1 + 2XC + XO + XN)$$

5. Zone 4

Seven major species are considered in Zone 4:

$X(N^+)$, $X(C^+)$, $X(O^+)$, $X(N^{++})$, $X(C^{++})$, $X(O^{++})$, and $X(e^-)$.

a. Major Species Reaction

$N^+ \rightarrow N^{++} + e^-$

$C^+ \rightarrow C^{++} + e^-$

$O^+ \rightarrow O^{++} + e^-$

b. Major Species Conservation Equations

$$X(N^+) = 2XN - X(N^{++}) \quad (40)$$

$$X(C^+) = XC - X(C^{++}) \quad (41)$$

$$X(O^+) = 2XO + 2XC - X(O^{++}) \quad (42)$$

$$X(e^-) = 1 + XN + XO + 2XC + X(C^{++}) + X(O^{++}) + X(N^{++}) \quad (43)$$

c. Equilibrium Constants for Major Species

$$K_{P10} = \frac{X(C^{++})\,X(e^-)\,P}{X(C^+)\,Z} \quad (44)$$

$$K_{P11} = \frac{X(N^{++})\,X(e^-)\,P}{X(N^+)\,Z} \quad (45)$$

$$K_{P12} = \frac{X(O^{++})\,X(e^-)\,P}{X(O^+)\,Z} \quad (46)$$

Total moles:

$$Z = 1 + XN + 2XC + XO + X(e^-) \quad (47)$$

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d. General Solution

$X(O^{++})$ polynomial

$$\sum_{i=1}^{5} C_i \, [X(O^{++})]^{5-i} = 0 \tag{48}$$

$$C_1 = (K_{P12} + P)(K_{P10} - K_{P12})(K_{P11} - K_{P12})$$

$$C_2 = (K_{P12} + P) \{ K_{P12} \, 2 \, (XC + X\phi) \; [K_{P10} + K_{P11} - 2K_{P12}]$$

$$+ \; XC \, K_{P10} (K_{P11} - K_{P12}) + 2XN \, K_{P11} (K_{P10} - K_{P12}) \}$$

$$+ \; (K_{P10} - K_{P12})(K_{P11} - K_{P12}) \{ 1 + 5XC + 3 \, (XO + XN) \, K_{P12}$$

$$+ \; [2 \, (XN + XO) + 3XC] \, P - K_{P12} \, 2 \, (XC + XO) \}$$

$$C_3 = K_{P12} \, 2 \, (XC + XO) \; \{\{(K_{P12} + P) \; [K_{P12} \, 2 \, (XC + XO) + XC K_{P10} + 2XN \, K_{P11}]$$

$$+ \; (K_{P10} \, K_{P11} - 2K_{P12}) \; \{ [1 + 5XC + 3 \, (XO + XN)] \, K_{P12}$$

$$+ \; [2 \, (XN + XO) + 3XC] \; P - 2K_{P12} (XC + XO) \}$$

$$- \, [1 + 5XC + 3 \, (XO + XN)] \; (K_{P10} - K_{P12})(K_{P11} - K_{P12})$$

$$- \; [XC \, K_{P10} (K_{P11} - K_{P12}) + 2XN \, K_{P11} (K_{P10} - K_{P12})]\}\}$$

$$C_4 = [2K_{P12} (XC + XO)]^2 \; \{ [1 + 5XC + 3 \, (XO + XN)] \; K_{P12}$$

$$+ \; [2(XN + XO) + 3XC] \, P - K_{P12} \, 2 \, (XC + XO)$$

$$- \; XC K_{P10} - 2XN \, K_{P11} - [1 + 5XC + 3(XO + XN)] \; .$$

$$[K_{P10} + K_{P11} - 2K_{P12}]\}$$

$$C_5 = - [1 + 5XC + 3 \, (XO + XN)] \; [K_{P12} \, 2 \, (XC + XO)]^3$$

6. Equations Defining the Radiation Heating

a. Basic Equations

$$QR = \bar{\epsilon} \sigma T^4 \tag{49}$$

where,

σ = Stefan-Boltzmann constant

$$\bar{\epsilon} = 1 - 2\,E_3(\Sigma\,\tau_i) \qquad (50)$$

$$\tau_i = 15.24\,\frac{\epsilon_i}{L}\ (\mathrm{DELTA}) \qquad (51)$$

$$E_3(\tau) = \int_0^1 s e^{-\tau/s}\,ds\,. \qquad (52)$$

The tabular values of $\bar{\epsilon}(\tau)$ given in Table I are used in the computer program.

b. Emissivities

The emissivities are taken to have the form:

$$\frac{\epsilon_i}{L} = C_i\,\frac{N_i}{5.4\times10^{19}}\,\frac{e^{-T_i/T}}{(T\times10^{-4})^{n_i}} \qquad (53)$$

where,

$$N_i = 2.7\,\frac{\dfrac{(\mathrm{RHO})\ (\mathrm{M})}{2116}}{(89516)(273.16)}\,10^{19}\,X_i\ . \qquad (54)$$

The values of C_i, T_i, and n_i for the corresponding species X_i are given in Reference 1, Table I-20.

$$P = \frac{\rho_a V^2}{2116} \qquad (55)$$

$$\frac{HM}{RT_o} = \frac{V^2 M}{2RT_o} + \left(\frac{MC_p}{R}\right)\frac{T_a}{T_o} \qquad (56)$$

$$\frac{MC_p}{R} = 3.5\ XN + 3.5\ XO + 4.0\ XC + 2.5\ XA \qquad (57)$$

IV. IBM ROUTINES

A. PROGRAM FLOW

A diagram depicting the flow of information within the program is shown in Figure 6.

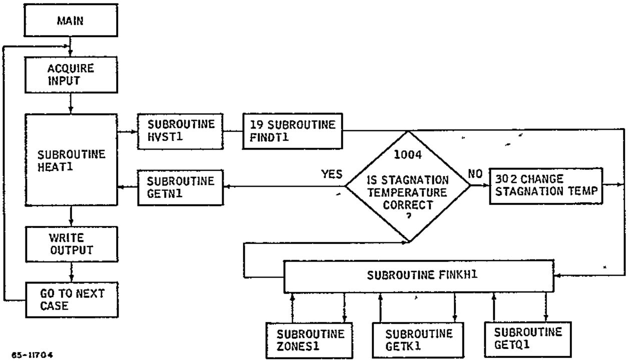

Figure 6 FLOW DIAGRAM FOR PROGRAM 1883

B. MAIN PROGRAM

The purpose of the main program is to define tables used with output from the calculation, to acquire program input and provide output. The main program defines tables of Hollerith words (ZNAM1 and ZNAM2) which appear in the output of Program 1883. ZNAM1 contains the array of specie names in the same order as their concentrations are stored in the array X, and the table ZNAM2 contains the names of the radiation heating sources as they are arrayed in the table QI. The arrays ZNAM1 and ZNAM2 should be referred to for any changes on the computation of an individual specie or radiation component.

There are eleven tables of temperature and enthalpy which, with a pressure table, are used to define the zone[1] in which a solution is computed. The selection of the proper set of tables from the 11 possibilities is determined by the value of the quantity NX. Each of the 11 tables is based on a specific composition of O_2, N_2, A, and CO_2 in the undissociated mixture, and the main program selects NX by choosing the table whose sum of mole fractions of O_2

and CO_2 is closest to the input sum XO and XC. The array TBSUM contains the sum $O_2 + CO_2$ for each of the 11 tables.

All input variables are read in through the namelist array INPUT.

Subroutine HEAT1, called after Statement 2001, begins all of the significant calculations done by the program. When control is passed back to the main program, the only remaining task is to provide the program output, all of which is contained in the calling sequence of HEAT1, save for the effective emissivities written out by Subroutine GETN1.

C. SUBROUTINES

1. HEAT 1

a. Purpose

HEAT1 defines the heats of formation of each specie in the equilibrium mixture, provides data for the computation of the detachment distance if this quantity is not specified as input and defines the zone on which the equilibrium solution will be found. Moreover, it controls the temperature iteration which computes an equilibrium mixture of some known pressure and enthalpy at the stagnation point, and obtains total radiation heating and individual radiation components.

b. Method

The major function of subroutine HEAT1 is to control the iteration in T_s, this stagnation temperature being such that the equilibrium mixture has pressure (P) and an enthalpy (HRT) whose relative error to the known stagnation enthalpy (HRTZ) is less than some number (PCNT).

HEAT1 first defines PCNT, then the heats of formation of each specie (the array E) and the quantities necessary for the detachment distance DELTA. DELTA is computed by a two-dimensional table lookup, unless it is specified in the program input as some number > 0. The lookup has, as independent variables, the inverse density ratio which appears in the output (RHØS/RHØ), and the geometry parameter b/a (see Reference 1). The corresponding tables are called RKTBL and BATBL. The two-dimensional dependent variable table of detachment distance is called DELTBL.

HEAT1 then calls subroutine HVST1 which provides a set of tables -- T1TBL, T2TBL, T3TBL, H1TBL, H2TBL, and H3TBL. This set is selected from 11 possible sets, and depends on the value of NX and thus on the O_2 and CO_2 concentrations of the ambient mixture. These temperature and enthalpy tables are used with a pressure table (PTBL) to define the upper boundaries of the zone, in which a solution will be found, T1TBL being Zone 1, T2TBL being Zone 2, and so forth

After calling HVST1, subroutine HEAT1 defines the pressure (P) and enthalpy (HRTZ) at the stagnation point. If the pressure is lower (higher) than the lowest (highest) value in the array PTBL, it is set equal to the lowest (highest) value (Statements 11 to 14).

Subroutine FINDT1 provides a first guess for temperature, the number of the zone for the solution (NUM), and upper and lower bounds in temperature and enthalpy from the proper zone tables (T1TBL), and so forth Statements 1007 to 1009 test to be certain that no argon will be calculated in Zones 3 or 4, where argon species are not computed. If argon is present in Zones 3 or 4, no solution is provided (GO TO 999). Between Statements 1010 and 106 successive values of the temperature are computed by redefining the bounds in temperature and enthalpy (TUP, TLØW, HUP, and HLØW) and interpolating linearly to the value T which, with P, would give (for a linear variation) an enthalpy HRT=HRTZ. For each iteration subroutine FINDH1 is called; this routine solves the equation of state of the equilibrium mixture at the pressure P and approximate temperature T. In addition to specie concentration, the enthalpy HRT is computed and compared to HRTZ. If it is close enough, the iterative procedure is terminated (Statement 106); if not, TUP and HUP or TLØW and HLØW are recalculated, and a new temperature is interpolated. If no adequate solution is found within 30 iterations, this fact is noted in the output and the last value of temperature is used to provide the solution. Experience indicates that a failure to converge occurs close to the boundary of a zone, and generally where the total radiation heating is small.

Statement 106 deletes the computation of the radiation for velocities lower than 8000 ft/sec. Statements 116 and 107 define the "trace" specie N in Zone 4. If a positive detachment distance has not been provided as program input, Statements 503 to not including, 504 compute the density ratio ρ_a/ρ_s , and a/b and compute the detachment distance from a two-dimensional table lookup performed by AR2 TLU (see description of AR2TLU).

If the species O^+, N^+, C^+, and E^- are present in Zone 2, in which zone they are treated as trace species, their concentrations are entered in the regular array X of specie concentrations from the trace specie table DUM (Statements 504 to 502).

The normalized stagnation density is computed, and this with the list of concentrations, temperature, and detachment distance is used to compute effective emissivities, radiation components, and total radiation in Subroutine GETN1.

2. HVST-1

a. Purpose

Subroutine HVST1 provides subroutine HEAT1 with a set of six tables--T1TBL, T2TBL, T3TBL, H1TBL, H2TBL, and H3TBL--which are used to determine zone boundaries and to obtain a first guess for the stagnation temperature.

b. Method

The quantity NX, computed by the main program as the index of that set of tables which most closely approximates the concentrations of O_2 and CO_2, is used in a computed "go to" statement at the beginning of HVST1 to select the appropriate set of T1TBL, T2TBL, T3TBL, H1TBL, H2TBL, and H3TBL.

These tables are the same as in Reference 1 (pp. 59 to 69), except that for the first nine sets of tables each value in the enthalpy tables is modified from Reference 1 by the subtraction of a constant times the concentration of argon. The indices 1 through 7 correspond to values of PTBL in HEAT1 with indices 1 through 7.

3. FINDT1

a. Purpose

Subroutine FINDT1 provides a first guess for the stagnation temperature iteration, upper and lower bounds for the stagnation temperature and enthalpy, and the number of the zone in which the solution will be found.

b. Method

The quantities H1 and T1 are first found by table lookups using the pressure P and the independent variable table PTBL. If the H1 is within a specified percent of HRTZ, then the zone number is 1 and the first guess T is T1. If the H1 is < HRTZ, but not sufficiently close, the zone number is 1, enthalpy bounds are H1 and 0, temperature bounds are T1 and 0, and the transfer to Statement 100 provides a first guess T by linear interpolation. If H1>HRTZ, but not sufficiently close, then the next higher zone is considered and an H2 and T2 obtained by table lookup from P and the array PTBL. Then H2 is compared to HRTZ as was H1, and the process is carried on until the zone containing HRTZ, the first guess temperature, is obtained from the interpolation at Statement 100.

4. FINDH1

a. Purpose

Subroutine FINDH1 provides the HRT for each of the temperature iterations controlled by subroutine HEAT1. In doing so, the equation of state for the equilibrium mixture must be computed at the pressure and approximate temperature T. Hence, the concentrations of each specie and total values of mixture are also computed.

b. Method

Subroutine FINDH1 first obtains the logs of pertinent partition functions (QP) and their partial derivatives (QPAR) from subroutine GETQ1. Which partition functions are computed depends upon the species in which zone the solution lies. The symbol QP is really the log of the partition function times pressure, and hence the - ln P term in the equations of Reference 1, page 54 is not included in the computations of subroutine GETQ1. With these partition functions, the relevant equilibrium constants for the zone are computed by subroutine GETK1, and are stored in the array PK.

The arrays of specie concentrations are then cleared to zero (X and DUM) and subroutine ZONES1 called. If a solution is found in ZONES1, the X array will contain some nonzero elements. The do-loop ending at Statement 104 uses the heats of formation, molar concentration, and partial derivative of the partition function of each of the first 16 species to compute the dissociation enthalpy and total enthalpy (SUMD and SUMH, respectively). If species A and A+ exist (XC18, XC19), their contributions to the enthalpy are included (the partial derivatives of their partitions having first been computed), since these have not been previously computed in GETQ1 (Statements 107 to 110). N_2+ does not contribute in this model to the enthalpy; hence, its heat of formation is not stored in the array E, and for this reason the 17th heat of formation is for the 18th specie (A), and the 18th heat of formation is for the 19th specie (A+). Having computed the HRT and HDHS, the subroutine returns control to subroutine HEAT1.

5. GETQ1

a. Purpose

Subroutine GETQ1 provides the log of the partition functions times pressure and their partial derivatives with respect to temperature for those species which are included in the relevent zone.

b. Method

The evaluation of the logs of the partition functions times pressure (QP) and their partial derivatives (QPAR) are merely algebraic evaluations of the equations of Reference 1, page 54. Since the equations of reference are ln Q, but our evaluation is for ln QP, the - ln P term of the reference is not included in the GETQ1 calculations.

If the solution lies in Zone 1, the functions evaluated are for N_2, CO_2, CO, O_2, and O (QP and QPAR 1 to 5, respectively). For Zone 2, the functions are evaluated only for N_2, CO, O, N, CN, NO, and C (QP and QPAR 1, 3, 5, 6, 7, 8, and 9, respectively). For Zone 3, the functions are evaluated for O, N, C, O^+, N^+, C^+, and e^- (QP and QPAR 5, 6, 9, 10, 11, 12, and 13 respectively). For Zone 4, the functions are evaluated for N, O^+, N^+, C^+, e^-, N^{++}, O^{++}, and C^{++} (QP and QPAR 6, 10, 11, 12, 13, 14, 15, and 16, respectively).

6. GETK1

a. Purpose

Subroutine GETK1 evaluates appropriate equilibrium constants given In PQ for the relevant species.

b. Method

The equations for the equilibrium constants are given in Reference 1, page 48. In Zone 1, the constants computed are for the reactions $CO_2 \rightarrow CO + 1/2\ O2$ and $O2 \rightarrow 2O$ (PK 1 and 2, respectively). For Zone 2, the reactions are $N_2 \rightarrow 2N$, $CO \rightarrow C+O$, $C+N \rightarrow CN$, and $N+O \rightarrow NO$ (PK 3, 4, 5, and 6, respectively). In Zone 3, the reactions are $O \rightarrow O^+ + e^-$, and $C \rightarrow C^+ + e$ (PK 7, 8, and 9 respectively). In Zone 4, the reactions are $N \rightarrow N^+ + e^-$, $C^+ \rightarrow C^{++} + e^-$, $N^+ \rightarrow N^{++} + e^-$, and $O^+ \rightarrow O^{++} + e^-$ (PK 8, 10, 11, and 12, respectively).

7. ZØNES1

a. Purpose

Subroutine ZØNES1 computes the concentrations of each specie of the equilibrium mixture at the given pressure and temperature of the iteration controlled by subroutine HEAT1.

b. Method

Given temperature, pressure, mole fractions of O_2, N_2, CO_2, and A in the undissociated atmosphere, along with the zone number and pertinent equilibrium constants, subroutine ZØNES1 will compute the moles of each specie in the equilibrium mixture at the stagnation point, and the total moles of gas.

The method of solution depends on finding the roots of a polynominal whose argument is equal (or proportional) to one of the important species in the equilibrium mixture. The root which is used may be determined by physical constraints (e. g. it must be real and positive). If no such root is found, "NO VALID SØLU" is printed and the case deleted. Which specie is solved for depends upon the zone in which the solution is found. The coefficients of the polynominal are functions of the mole fractions of N_2, O_2, CO_2, and A in the atmosphere, and the equilibrium constants of the reactions assumed to be important in the zone. The important reactions thus considered for equilibrium constants are those (and only those) computed by the subroutine GETK1. Where trace species are considered (Zones2 and 3), their concentrations are purely ancillary to the principal reactions considered, and the partition functions and equilibrium constants pertinent to these trace species are computed in subroutine ZØNES1, not in subroutines GETQ1 and GETK1.

In Zone 1, no trace species are present and the species considered from principal reactions are N_2, CO_2, CO, O_2, and O the reactions being $CO_2 \rightarrow CO + 1/2\, O_2$, and $O_2 \rightarrow 2O$. In Zone 2, the species considered from principal reactions are N_2, CO, O, N, CN, NO, and C, the reactions being $N_2 \rightarrow 2N$, $CO \rightarrow C+O$, $C+N \rightarrow CN$, and $N+O \rightarrow NO$. Trace species considered are O^+, N^+, C^+, e^-, and A^+, which come from reactions $O \rightarrow O^+ + e^-$, $N \rightarrow N^+ + e^-$, $C \rightarrow C^+ + e^-$, $N_2^+ \rightarrow N^+ + N$, and $A \rightarrow A^+ + e^-$. The equilibrium constants and necessary partition functions for these last five reactions are computed at the beginning of the subroutine before Statement 100 (DLPQ5, DLPQ6, DLPQ9, DLPQ10, and DLPQ11 are the logs of the partition functions times pressure for O, N, C, N^+, and N_2^+; DGK13 is the equilibrium constant for the reaction $N_2^+ \rightarrow N^+ + N$), and in the Zone 2 calculations between Statements 55 and 8512 (DLPQ12, DLPQ13, DLPQ14, DLPQ15, DLPQ16 are the logs of the partition function times pressure O^+, e^-, C^+, A, and A^+; DGK7, DGK8, DGK9, DGK14 are equilibrium constants for the reactions $O \rightarrow O^+ + e^-$, $N \rightarrow N^+ + e^-$, $C \rightarrow C^+ + e^-$, and $A \rightarrow A^+ + e^-$). In Zone 3, the species considered from principal reactions are O, N, C,

O^+, N^+, C^+, and e^-, the reactions being $O \rightarrow O^+ + e^-$, $N \rightarrow N^+ + e^-$, and $C \rightarrow C^+ + e^-$. Trace species are CN, NO, and N^+ which come from the reactions $C + N \rightarrow CN$, $N + O \rightarrow NO$, $N_2^+ \rightarrow N^+ + N$. The equilibrium constants and logs of the necessary partition functions times pressure are computed at the beginning of the subroutine before Statement 100 (DGK13 is the equilibrium constant for the reaction $N_2^+ \rightarrow N^+ + N$, DLPQ5, DLPQ6, DLPQ9, DLPQ10, and DLPQ11 are the logs of the partition function times pressure for O, N, C, N^+, and N_2^+). In the Zone 3 calculation between Statements 28 and 8112, (DLPQ7 and DLPQ8 are the logs of the partition function times pressure for the species CN and NO. DGK5 and DGK6 are equilibrium constants for the reactions $C + N \rightarrow CN$ and $N + O \rightarrow NO$.

In Zone 4 no trace species are present and the species considered from principal reactions are O^+, N^+, C^+, e^-, N^{++}, O^{++}, and C^{++} from the reactions $N \rightarrow N^+ + e^-$, $C^+ \rightarrow C^{++} + e^-$, $N^+ \rightarrow N^{++} + e^-$, and $O^+ \rightarrow O^{++} + e^-$.

8. GETN1

a. Purpose

Subroutine GETN1 computes the effective emissivities of each component of the total radiation heating and from them computes the total radiation heating and the radiation component of each contributor.

b. Method

Subroutine GETN1 first defines the tables TAUTBL and EPSTBL, a tabulation of $1 - 2E_3(\tau)$ (EPSTBL) as a function of the independent variable τ (TAUTBL). Next the table of emissivities EL is cleared to zero, and then the concentration of each specie in the equilibrium mixture is converted to particles per cm^3 (ZNI). The DO LOOP ending on Statement 199 then computes the emissivities of each component to the total radiation which may come from a positive concentration of any of the first 12 species contained in the array X. These emissivities (EL_i, $i = 1$ to 21 correspond to the radiation contributors in the same order as the Hollerith names in the table ZNAM2 of the main program. No radiation contribution is made from the species X(13-16) (e^-, N^{++}, O^{++}, C^{++}), but contributions are made by X (17-19), and the emissivities for these species are computed from Statement 213 to 218. The emissivity formula and constants used to obtain the average emissivity of the gas (EP BAR) may be found in Reference 1, page 102. The total radiation and contribution of each component is then computed based on the $\bar{\epsilon}$ and ϵ_1 (DO LOOP ending on 301). Output is provided, which includes the $\bar{\epsilon}$, ϵ_1, and Δ.

CALLING SEQUENCE

	Variable Name	V, Velocity	RHØ, density	XN, N_2 mole fraction	XO, O_2 mole fraction	XC, CO_2 mole fraction
HEAT1	Input Or Output of subroutine	Input	Input	Input	Input	Input
	Source	Program Input	Program Input	Program Input	Program Input	Program Input
XA, A mole fraction	NX, enthalpy table no.	P, pressure	THN, Θ_N nose angle	RN, R_N, nose radius	RS, R_S, shoulder radius	RC, R_C, cone radius
Input	Input	Output	Input	Input	Input	Input
Program Input	Main Program	HEAT1	Program Input	Program Input	Program Input	Program Input
T, temperature	Z, moles of mixture	RHØST, ρ_s / ρ_a density ratio	QSUM, Q_R radiation heating	QI, radiation by specie	X, specie concentration	HDHS, dissociation energy ÷ enthalpy
Output	Output	Output	Output	Output	Output	Output
HEAT1	ZØNES1	HEAT1	GETN1	GETN1	ZØNES1	FINDH1
HRT, HM/RTo, total enthalpy	DEL, detachment distance	DUM, concentration of O^+, N^+, C^+, e^-	TINF, ambient temperature			
Output	Input	Output	Input			
FINDH1	Program Input	ZØNES1	Program Input			

	Variable	NX, atmos. table number	T1TBL Zone 1 temp table	T2TBL Zone 2 temp. table	T3TBL Zone 3 temp. table	H1TBL Zone 1 enthalpy table
HVST1	Input Or Output of subroutine	Input	Output	Output	Output	Output
	Source	Main	HVST1	HVST1	HVST1	HVST1
H2TBL Zone 2 enthalpy table	H3TBL Zone 3 enthalpy table	XA, mole fraction of A				
Output	Output	Input				
HVST1	HVST1	Program Input				

FINDT1

Variable	Input or Output for subroutine	Source
P, pressure	Input	HEAT1
HRTZ, stagnation enthalpy	Input	HEAT1
PTBL, pressure table (used with T&H tables)	Input	HEAT1
T1TBL-Zone 1 temp table (used with PTBL & H1TBL)	Input	HVST1
T2TBL-Zone 2 temp table (used with PTBL & H2TBL)	Input	HVST1
T3TBL-Zone 3 temp. table (used with PTBL & H3TBL)	Input	HVST1
H1TBL, Zone 1 enthalpy table (used with PTBL & T1TBL)	Input	HVST1
H2TBL-Zone 2 enthalpy table (used with PTBL & T2TBL)	Input	HVST1
H3TBL Zone 3 enthalpy table (used with PTBL & T3TBL)	Input	HVST1
TUP-Highest temp. for 1st enthalpy iteration	Output	FINDT1
TL0W-Lowest temp. for 1st enthalpy iteration	Output	FINDT1
HUP-Highest enthalpy for 1st enthalpy iteration	Output	FINDT1
HL0W-Lowest enthalpy for 1st enthalpy iteration	Output	FINDT1
T-first guess for in enthalpy iteration	Output	FINDT1
NUM-Zone number for enthalpy iteration	Output	FINDT1
PCNT-percent error acceptable in enthalpy	Input	HEAT1

FINDH1

Variable	Input or Output for Subroutine	Source
NUM, Zone Number	Input	HVST1
P, pressure	Input	HEAT1
T, temperature for current enthalpy iteration	Input	HEAT1
E, Heats of formation at 0° K	Input	HEAT1
PK, equilibrium constants	Output	GETK1
XO, mole fraction of O_2 in atmosphere	Input	Program Input
XC, mole fraction of CO_2 in atmosphere	Input	Program Input
XN, mole fraction of N_2 in atmosphere	Input	Program Input
XA, mole fraction of A in atmosphere	Input	Program Input
Z, total moles of equilibrium mixture	Output	Z0NES1
X, specie moles in equilibrium mixture	Output	Z0NES1
HRT, enthalpy at T and P (HRTZ for last iteration)	Output	FINDH1
HDHS, dissociation energy ÷ enthalpy	Output	FINDH1
DUM-moles of O^+, N^+, C^+ and e^- in Zone 2	Output	Z0NES1

GETQ1

Variable	NZZ, Zone number	TZ-temp. at current enthalpy iteration	ZLPQ, log of partition functions	QPAR-derivatives of QP at constant P
Input or Output for Subroutine	Input	Input	Output	Output
Source	Main	HEAT1	GETQ1	GETQ1

GETK1

Variable	NZ, Zone number	TZ-temp at current enthalpy iteration	ZLPQ, log of partition functions	PK; Equilibrium constants
Input or Output for Subroutine	Input	Input	Input	Output
Source	Main	HEAT1	GETQ1	GETK1

ZØNES1

Variable	NUM, Zone number	ZT-temp at current enthalpy iteration	XØZ mole fraction of O_2 in atmosphere	XCZ mole fraction of CO_2 in atmosphere	XNZ mole fraction of N_2 in atmosphere	XAZ mole fraction of A in atmosphere	PZ, pressure	PK, equilibrium constants	ZZ total moles of equilibrium-mixture	XX specie moles in equilibrium mixture	DUM, moles of O^+, N^+, C^+, & e^- in Zone 2
Input or Output for Subroutine	Input	Input	Input	Input	Input	Input	Input	Input	Output	Output	Output
Source	Main	HEAT1	Program Input	Program Input	Program Input	Program Input	HEAT1	GETK1	ZØNES1	ZØNES1	ZØNES1

GETN 1

Variable	TZ temp. at current enthalpy iteration	X, specie moles in equilibrium mixture	RHØS, normalized stagnation density	DEL, shock detachment distance	QI, specie radiation	QSUM total radiation
Input or Output for Subroutine	Input	Input	Input	Input	Output	Output
Source	HEAT1	ZØNES1	HEAT1	Program Input or from correlation in HEAT1	GETN1	GETN1

D. SIGNIFICANT EQUATIONS

Main Program None

1. HEAT1

$M = ZM = 28\ XN + 32\ X0 + 44\ XC + 40\ XA$ Molecular weight of cold gas

$C_p/R = CP0R = (3.5\ (XN + XO) + 4\ XC + 2.5\ XA)/ZM$ Specific heat of cold gas/R

$$H/RT_o = HRTZ = \frac{V^2}{\left(64.4 \cdot 778 \cdot \dfrac{1.987 \cdot 453.5 \cdot 273.16}{252\ \ ZM}\right)} + ZM \cdot \left(\frac{CP0R}{273.16}\right) \cdot TINF$$ stagnation point enthalpy

$P = P = (RH0\ V^2)/2116.$ stagnation point pressure

The above are computed prior to the execution of the IF test before Statement 11.

If Δ is not specified as program input, the following quantities are computed (Statements 503 to 604)

$$b/a = BA = \left[\frac{RN}{RC}\ (1 - \cos(THN)) + \frac{RS}{RC}\ \cos(THN)\right] \bigg/ \left[\frac{RN}{RC}\ \sin(THN) + \frac{RS}{RC}(1 - \sin(THN))\right]$$

Geometry parameter

$$\rho_s/\rho_a = V^2 \bigg/ \left[Z\ \frac{89516}{ZM}\ \ T\right]$$ Density ratio

$\Delta = DELA\ [RN \sin(THN) + RS\ (1 - \sin(THN))]$ Detachment distance

The radiation depends upon the normalized stagnation density

$$\rho = RH0S = \frac{P}{Z}\ \frac{273.16}{T}$$

HVST1 - Trivial modifications of Reference 1, pp. 59-69.

2. FINDT1

Linear interpolations to find a first guess for the stagnation temperature, the zone number, and the ranges of enthalpy and temperature for the stagnation temperature iteration.

3. FINDH1

$$\frac{H_i M}{RT_o} = HI_{(i)} = E_{(i)} + \frac{T^2}{273.16} QPAR_{(i)}$$ – Enthalpy of ith specie (reference 1, p. 58)

$$\frac{HM}{RT_o} \doteq SUMH = \sum_{i} X(i) \cdot HI(i)$$ – Enthalpy at P and approximate stag. temperature T

$$H_D = SUMD = \sum_{i} X(i)\ E(i)$$ – Dissociation enthalpy

4. GETQ1

This subroutine evaluates $\ln PQ(X_i)$, pressure times the log of the partition and the partial derivative of the partition function with respect to temperature for some set of species dependent on the zone numbers.

The correspondence between $QPAR(i) = \left(\frac{\partial \ln Q_i}{\partial T}\right)_P$ and $ZLPQ(i) = \ln(PQ_i)$

is explained on the description of GETQ, the ZLPQ(i) are contained in the set of functions documented in Reference 1, p..54, and the derivatives are obtainable by inspection.

5. GETK1

The subroutine evaluates equilibrium constants for the principal reactions assumed to exist in the appropriate zone. The equations are in Reference 1. p, 48.

6. ZØNES1

The partition functions, their derivatives, and equilibrium constants computed in ZØNES are explained in the subroutine description and documented in Reference 1 (p. 48 and 54).

The Zone 1 equations are solved between Statements 100 and 200. The specie concentrations are computed by finding on the appropriate root of a polynomial.

$$f(\Sigma_1) = \sum_{i=1}^{4} (C\emptyset ED(i)\Sigma_1^{(4-i)}$$

Real and imaginary roots are computed by the library subroutine POLROT (see subroutine description). The "appropriate" root must be real, positive, and such that no negative specie concentrations result. If no such root is found, the message "NØ VALID SØLN" is written in the output and the case deleted. The equations for the specie concentrations are as follows:

$$\Sigma_2 = \Sigma_1 \ XO + \frac{\Sigma_1}{2} \Big/ \left[2 \frac{PK_1}{\sqrt{PK_2}} (XC - \Sigma_1) + \Sigma_1 \right]$$

$$X(N_2) = X(1) = XN$$

$$X(CO_2) = X(2) = XC - \Sigma_1$$

$$X(CO) = X(3) = \Sigma_1$$

$$X(O_2) = X(4) = XO + \frac{\Sigma_1}{2} - \Sigma_2$$

$$X(O) = X(5) = 2\Sigma_2$$

$$Z = 1 + \frac{\Sigma_1}{2} + \Sigma_2$$

In Zone 2, the computations are done between Statements 200 and 300. First PØLRØT is used to find the roots of the polynomial

$$f(\Sigma_6) = \sum_{i=1}^{5} COED(i) \, \Sigma_6^{(5-i)}$$

Then the roots are computed for the polynomial

$$f(\Sigma_7) = \sum_{6=1}^{4} COED(i) \, \Sigma_7^{(4-i)}$$

As in Zone 1, the root used must be real, positive, and such that no negative concentrations are permitted. The principal species are as follows:

$$\Sigma_4 = (4 \ \Sigma_6^2 \ P/(PK_3(XN - \Sigma_6)) - 1 - XC - XO - \Sigma_6$$

$$\Sigma_8 = \frac{\Sigma_7 (\Sigma_4 + XC + 2XO) PK_6}{(\Sigma_4 - \Sigma_7) PK_5 + \Sigma_7 PK_6}$$

$$X(N_2) = X(1) = XN - \Sigma_6$$

$$X(CO) = X(3) = XC - \Sigma_4$$

$$X(O) = X(5) = \Sigma_4 + 2 \ XO + XC - \Sigma_8$$

$$X(N) = X(6) = 2\Sigma_6 - \Sigma_8 - \Sigma_7$$

$$X(CN) = X(7) = \Sigma_7$$

$$V(NO) = V(8) = \Sigma_8$$

$$X(C) = X(9) = \Sigma_{4,} - \Sigma_7$$

$$Z = 1 + XC + XO + \Sigma_4 + \Sigma_6 - \Sigma_7 - \Sigma_8$$

For trace species,

$$X(e^-) = X(13) = DUM(2) = \left\{ \frac{Z}{P} (X(O) \quad PK_7 + X(N) \cdot PK_8 + X(C) - PK_{14}) + \frac{X(N)^2 \, KP_8}{KP_{13}} \right\}$$

$$X(N^+) = X(11) = DUM(1) = KP_8 \left\{ \frac{Z}{P} \frac{X(N)}{X(e^-)} \right\}$$

$$X(O^+) = X(10) = DUM(3) = K\,P_7 \left\{ \frac{Z}{P} \quad \frac{X(O)}{X(e^-)} \right\}$$

$$X(C^+) = X(12) = DUM(4) = K\,P_9 \left\{ \frac{Z}{P} \quad \frac{X(C)}{X(e^-)} \right\}$$

$$X(N_2{}^+) = X(17) = \frac{K\,P_8 \, X(N)^2}{K\,P_{13} \, X(e^-)}$$

$$X(A) = X(18) = XA$$

$$X(A^+) = X(19) = K\,P_{14} \left\{ \frac{Z}{P} \quad \frac{XA}{X(e^-)} \right\}$$

In Zone 3, the calculations are done between Statements 300 and 400. POLROT is used to fine the roots of a polynomial

$$F(\Sigma_{11}) = \sum_{i=1}^{5} COED(i) \quad \Sigma_{11}{}^{(5-i)}$$

The root used must be real, positive, and such that there are no negative concentrations. The specie equations are as follows:

$$\Sigma_{10} = \frac{2\ \Sigma_{11}\,(XC + XO)\,PK_7}{[XC \cdot PK_9 + \Sigma_{11}\ (PK_7 - PK_9)]}$$

$$\Sigma_9 = \frac{2 \cdot \Sigma_{11} \cdot XN \cdot PK_8}{[XC \cdot PK_9 + \Sigma_{11}\ (PK_8 - PK_9)]}$$

$$X(O) = X(5) = 2\ (XC + X\phi) - \Sigma_{10}$$

$$X(N) = X(6) = 2\ XN - \Sigma_9$$

$$X(C) = X(9) = XC - \Sigma_{11}$$

$$X(O) = X(10) = \Sigma_{10}$$

$$X(N^+) = X(11) = \Sigma_9$$

$$X(C^+) = X(12) = \Sigma_{11}$$

$$X(e^-) = X(13) = \Sigma_9 + \Sigma_{10} + \Sigma_{11}$$

$$Z = 1 + 2\ XC + XO + XN + \Sigma_9 + \Sigma_{11}$$

For trace species,

$$X(CN) = X(7) = \frac{P \cdot PK_5}{Z}\ (2\,XN - \Sigma_9)\ (XC - \Sigma_{11})$$

$$X(NO) = X(8) = \frac{P \cdot PK_6}{Z}\ (2\,XN - \Sigma_9)\,(2\,XO + 2\,XC - \Sigma_{10})$$

$$X(N_2^{\ +}) = X(17) = \frac{\Sigma_9\,(2\,XN - \Sigma_9)\,P}{Z \cdot PK_{13}}$$

In Zone 4, the calculations are done between Statements 400 and 900. POLROT is used to find the roots of a polynomial

$$f(\Sigma_{12}) = \sum_{i=1}^{5} COED(i)\ \Sigma_{12}^{\ (E - i)}$$

The root used must be real, positive, and such that there are no negative concentrations. The equations for the concentrations are:

$$\Sigma_{13} = \frac{\Sigma_{12} \cdot XC \cdot PK_{10}}{[2 \cdot PK_{12}(XC + XO) + \Sigma_{12}(PK_{10} - PK_{12})]}$$

$$\Sigma_{14} = \frac{2 \cdot \Sigma_{12} \cdot XN \cdot PK_{11}}{[2 \cdot XO_{12}(XC + XO) + \Sigma_{12}(PK_{11} - PK_{12})]}$$

$$X(O^{+}) = X(10) = 2(XC + XO) - \Sigma_{12}$$

$$X(N^{+}) = X(11) = 2\ XN - \Sigma_{14}$$

$$X(C^{+}) = X(12) = XC - \Sigma_{13}$$

$$X(e^{-}) = X(13) = 2(XN + XO) + 3 \cdot XC + \Sigma_{12} + \Sigma_{13} + \Sigma_{14}$$

$$X(N^{++}) = X(14) = \Sigma_{14}$$

$$X(O^{++}) = X(15) = \Sigma_{12}$$

$$X(C^{++}) = X(16) = \Sigma_{13}$$

One trace specie is considered,

$$X(N) = X(6) = \frac{X(N^{+}) \cdot X(e^{-}) \cdot P}{Z \cdot PK_{8}}$$

This specie is unique in that it is computed in subroutine HEAT.

7. GETN1

$$ZNI_i = X_i \cdot RHOS \cdot 2.69 \times 10^{19} \qquad i = 1,\ 19$$

Specie concentration to particles per cm^3

$$\frac{\epsilon_i}{L} = EL_i = C_i \left(\frac{ZNI_i}{5.4 \times 10^{19}}\right) \frac{1}{(T \times 10^{-4})^{n_i}}\, e^{-T_i/T} \qquad i = 1,\ 21$$

Emissivities without self-absorption correction. C_i, n_i, and T_i from Reference 1, p 102

$$\tau_i = TAUTP = 1/2\ \Delta \frac{\epsilon_i}{L}$$

Argument of $E_3(\tau_i)$ for effective emissivities

τ = TSUM = $\sum_{i=1}^{21} \tau_i$	Argument of $E_3(\tau)$ for total effective emissivity.
ϵ_i = EPS(i) i = 1, 21	Value of $(1 - 2E_3(\tau_i))$, effective emissivities
ϵ = EPBAR	Value of $(1 - 2E_3(\tau))$, total effective emissivisty
q_i = QI(i) = $\frac{0.174 \times 10^{-8} \quad (1.8 \times T)^4}{3600}$ EPS(i), i = 1, 21	Component radiation heating
Q = QSUM = EPBAR $\frac{0.174 \times 10^{-8} \; (1.8 \times T)^4}{3600}$	Total radiation heating

V. REFERENCES

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PROGRAM 1884

HEAT SHIELD PROGRAM (1884)

CONTENTS

ILLUSTRATIONS

I. INTRODUCTION

A. GENERAL DESCRIPTION

The purpose of this program is to determine the heat shield thickness and weight requirements to protect the heat shield substructure from exceeding a specified temperature limit at any time during the entry trajectory. The general inputs include:

1. Convective heat rates as a function of time in tabular form and an indication if, and when, turbulent flow occurs

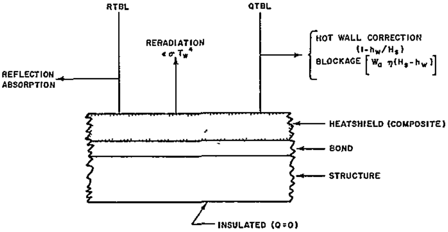
2. Radiation heat rates as a function of time in tabular form

3. Supporting heat transfer data as the stagnation enthalpy variation with time, atmospheric composition, and heat pulse scaling factors

4. Heat shield material properties, including the density, conductivity, specific heat, emissivity, ablation temperature, heat of vaporization, and convective blocking factor

5. Design constraints as the maximum allowable substructure temperature, the total entry time during which the substructure must be protected, the substructure thermal capacitance, and bond thickness and thermal properties.

The calculation model simulates a one-dimensional, heat-conduction problem into a slab of finite thickness, subject to various thermal boundary conditions as depicted in Figure 1.



65-11912

Figure 1 HEAT SHIELD CALCULATION MODEL

The primary output is the heat shield unit area weight (lb/ft^2) required to satisfy the design constraints. If ablation occurs, the relative proportions of ablative and insulative weights are indicated also.

B. CALCULATION MODEL

The calculation model is described in detail in References 1 and 2; hence only a brief summary is given here. The approach utilized considers that aerodynamic heating data are available based on a cold wall consideration (i. e.the heating calculations are developed without a knowledge of the wall temperature history with time, and the assumption is made that $\frac{H_w}{H_s} << 1$). Hence, the convective heating inputs must be corrected for the hot wall reduction, $(1 - \frac{H_w}{H_s})$, as the wall temperature history is computed.

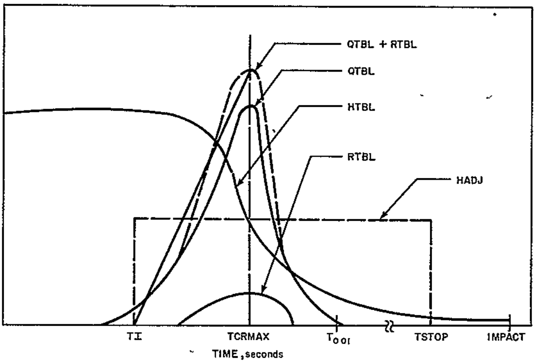
To arrive at a rapid method suitable for parametric studies, an approximate calculation model which permits a direct solution for the unit area heat shield weight is utilized. The approximate model replaces the actual heating history with an equivalent one having the same total integrated heating, but also having a constant surface temperature. The solution for the time wise variation of the temperature distribution in a finite slab with constant surface temperature, and hence the solution to the equivalent simulation model, is well known and the solution is given in Reference 3

As shown in Figure 1, the calculation model allows for the inclusion of a bond and substructure and a composite heat shield material and considers the effects of laminar or turbulent heating, radiative heating, reradiation, the hot wall reduction, and convective heating blockage due to ablation.

In order to apply the approximate method, a number of detailed assumptions regarding the nature of the heat pulse were made. Key features of the calculation model are summarized below.

1. Initial Time (TI)

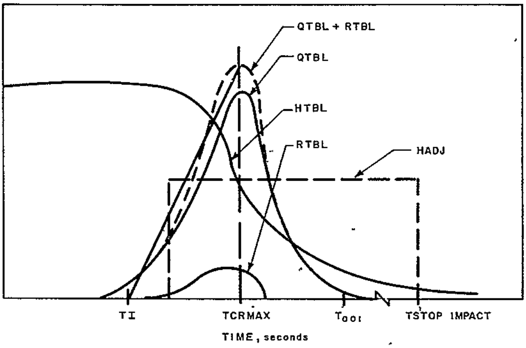
The heating data input to the program is usually based on the flight time history during the entry flight. For the simulated calculation model, an effective initial time is defined such that the portion of the heat pulse up to the combined peak heating rate (i. e. add the convective and radiative pulse and determine the time for their peak) is triangular, and the integrated cold wall heating is identical with the actual data. The location of the initial time (TI) is shown in Figures 2 and 3 for nonablating and ablating cases, respectively.



QTBL	COLD WALL CONVECTIVE HEATING
HTBL	DIMENSIONLESS STAGNATION ENTHALPY
RTBL	RADIATIVE HEATING
HADJ	AVERAGE STAGNATION ENTHALPY
TI	INITIAL TIME OF CONSTANT TEMPERATURE PROBLEM
T_{001}	TIME WHEN QTBL = 0 01 QTBL $_{MAX}$
TSTOP	TIME TO END OF THERMAL PROBLEM

65-11913

Figure 2 NONABLATING HEAT SHIELD CALCULATION MODEL



QTBL	COLD WALL CONVECTIVE HEATING
HTBL	DIMENSIONLESS STAGNATION ENTHALPY
RTBL	RADIATIVE HEATING
TI	INITIAL TIME OF CONSTANT TEMPERATURE PROBLEM
TADJ	START TIME OF INSULATION PROBLEM AFTER END OF ABLATION
HADJ	AVERAGE STAGNATION ENTHALPY
T_{001}	TIME WHEN QTBL = 0 01 QTBL$_{MAX}$
TSTOP	TIME AT END OF THERMAL PROBLEM

65-11914

Figure 3 ABLATING HEAT SHIELD CALCULATION MODEL

2. Final Time (Actual TST0P)

The final time of the simulation model is dependent on a number of program test criteria. The input value of TST0P reflects the trajectory flight time and also the post-flight time during which the substructure must be thermally protected by the heat shield. The input TST0P is therefore a test criterion for the actual TST0P. The linearization of the calculation model by utilizing an average stagnation enthalpy for the nonablating cases, and when obtaining the insulative requirements of the heat shield during the post-ablation period, depends on the actual TST0P. Experience has shown[1] that the actual TST0P should be limited to less than twice the length of the heat pulse (the length of the heat pulse being defined as the time from TSTART to the point where the convective heating is 1 percent of the maximum value). The above two criteria are compared and the smaller value used for the actual TST0P.

In addition to the criteria above, program tests are performed in the case of nonablating slabs that reduce TST0P if the slab equilibrates at a time smaller than the TST0P, in which case the actual TST0P is taken as the time to equilibrate (i.e. for this case, the slab temperature reaches a peak, which is equal to TREAR at the actual TST0P).

3. Ablation Model

The steady-state ablation model is used to estimate the mass loss and heat stored in the heat shield during ablation. A discussion of this approach is given in Reference 1. The calculation model provides for blockage of the convective heating only, during ablation as a result of either radiative or convective heating.

4. Wall Enthalpy

The wall enthalpy is required to correct the cold wall convective heating. Tables are built into the program, which automatically evaluate the wall enthalpy as a function of temperature based on the atmosphere composition which is input.

5. Material Properties

The material properties input are taken as average values commensurate with the range of heating and enthalpy levels expected in the problem. A special consideration has been given to the calculations where radiation heating predominates by permitting an effective radiative heat of vaporization to be input as well as an effective convective heat of vaporization.

The heat shields considered can be homogeneous or composed of two separate materials, as a plastic resin with glass fibers, in which case the material properties for each and the relative proportions of each are specified.

An allowance is made for incomplete vaporization of the melted surface by specifying the vaporizing fraction.

Under ablating conditions, the material properties can be dependent on whether the flow is laminar or turbulent and provision is included for handling both sets of inputs and specifying the transition time; in this case, the convective heat pulse input must contain the laminar and turbulent heating rates.

6. Heat Shield Bond

The calculation model can handle the effects of a bond by specifying the average bond thickness and the bond thermal properties The heat shield weight is reduced by the thermally equivalent (insulative) weight of the bond. The total weight of bond and heat shield is an output.

7. Structural Thermal Capacitance

The calculation model provides for the effects of substructure thermal capacitance on reducing the heat shield weight requirements. Program tests are performed to determine whether a heat shield is needed by comparing the structural thermal capacitance with the total heating and with the peak heat rate to ascertain whether an excessive temperature rise occurs. The possible combinations of tests could yield the result that (a) no heat shield or bond is required, (b) no heat shield is required as the bond and structure are adequate; or (c) a heat shield and bond are required.

C LIMITATIONS

The limitations of the program arise because of the assumptions made in the calculation model, namely:

1. The ablation model does not simulate the detailed phenomena of charring.

2. The choice and performance of heat shield materials could be limited by mechanical forces encountered in flight or while on the ground. These forces are not considered in the program.

3. Minimum thickness limits on the heat shield are not considered.

The simplicity of the calculation model results in the need for spot-checking results with the results of more sophisticated programs, and either modifying the inputs to adjust the agreement or to adjust the outputs with a scale factor. The program is aimed at determining trends parametrically.

II USAGE

A INPUT DEFINITIONS

Name	Preset Values	Symbol	Parameter	Units
AHR	1	H_r/H_s	Recovery factor.	--
CASE	0		A number of the form XX XX used for identification	--
CPB	0	Cp_B	Specific heat of bond.	Btu/lb-°F
CPHS	0	Cp_{HS}	Specific heat of heat shield.	Btu/lb-°F
CPSTR	0	Cp_{STR}	Specific heat of structure.	Btu/lb-°F
DATE	4 01		A number of the form XX.XX used for identification.	--
DTI	0 1	Δt	Time step for graphical integration of q_c and Hg/RT_o and computation of $\dot{W}_A$.	seconds
EMIS	0	ϵ	Emissivity	--
EPSIL	0.005		Maximum relative error allowed in iterations for structural capacitance correction.	--
FACTØR	0.1		Initial relative change in heat shield weight for structural capacitance correction iteration	--
HTBL		H_s/RT_o	Free stream gas enthalpy table, maximum number of entries = 150.	--
HV1R	0	H_{V1R}	Heat of vaporization of solid when convective heating is blocked.	Btu/lb

Name	Preset Values	Symbol	Parameter	Units
HV2R	0.	H_{V2R}	Heat of vaporization of resin when convective heating is blocked.	Btu/lb
KB	0.	K_B	Thermal conductivity of bond.	Btu/hr-ft-°F
KHS	-	K_{HS}	Thermal conductivity of heat shield.	Btu/hr-ft-°F
KSTR	0.	K_{STR}	Thermal conductivity of structure.	Btu/hr-ft-°F
LAM	0.		Array of material properties for laminar flow, arranged as follows:	--
		f_1	Vaporization fraction of solid	--
		H_{V1}	Heat of vaporization of solid	Btu/lb
		η_1	Transpiration fraction of solid	--
		X	Solid fraction	--
		f_2	Vaporization fraction of resin	--
		H_{V2}	Heat of vaporization of resin	Btu/lb
		η_2	Transpiration fraction of resin.	--
MEMO	0.		A number of the form XX XX used for identification.	--
MXIT	50.		Maximum number of iterations in structural capacitance correction.	--
QCMULT	1.		Convective heat pulse multiplier.	--
QRMULT	1.		Radiative heat pulse multiplier.	--
QTBL		q_c	Convective heat pulse table, maximum number of entries = 150.	Btu/ft^2-sec

Name	Preset Values	Symbol	Parameter	Units
RHOB	0.	ρ_B	Density of bond.	lb/ft^3
RHOHS	0.	ρ_{HS}	Density of heat shield.	lb/ft^3
RHOSTR	0.	ρ_{STR}	Density of structure .	lb/ft^3
RTBL		q_r	Radiative heat pulse table, maximum number of entries = 150.	Btu/ft^2-sec
TABL	0.	T_A	Ablation temperature	°F
TBL1	See program		Table of ($\Delta T_R/\Delta T_S, \alpha t/L^2$), arranged with first a value of $\Delta T_R/\Delta T_S$ then $\alpha t/L^2$, then the next pair, etc. Maximum number of entries = 25 pairs.	--
TBL2	See program		Table of ($\alpha t/L^2$, $\Delta T_M/\Delta T_S$), arranged with first a value of $\alpha t/L^2$, then $\Delta T_M/\Delta T_S$, then the next pair, etc. Maximum number of entries = 25 pairs.	--
TEMPI	0.	T_i	Initial Temperature.	°F
TIME	0.	t	Table of independent variable time for use with HTBL, RTBL, and QTBL dependent variable arrays. Maximum number of entries = 150.	seconds
TMSTR	0	$T_{M_{ST}}$	Melting temperature of structure	°F
TREAR	0.	T_R	Maximum allowable design rear temperature.	°F
TSTART	0.	t_o	Start of reentry heating.	seconds
TSTOP	0.	t_f	End of reentry heating	seconds
TTRANS	1000.	$t_{f_{con}}$	Time transition occurs in heating	second

Name	Preset Values	Symbol	Parameter	Units
TURB	0.		Array of material properties for turbulent flow, arranged as LAM (see above)	--
WTB	0.	w_B	Weight of bond.	lb/ft^2
WTSTR	0.	w_{STR}	Weight of structure.	lb/ft^2
XA	0.	x_A	Mole fraction of argon in undissociated mixture.	--
XC	0.	x_C	Mole fraction of CO_2 in undissociated mixture.	--
XN	0.	x_N	Mole fraction of N_2 in undissociated mixture.	--
XØ	0.	x_o	Mole fraction of O_2 in undissociated mixture.	--

B INPUT PROCEDURES

Input procedures include the following:

1. Input heat shield, structure, and bond properties.

2. Input QTBL, HTBL, and RTBL as a function of TIME (NOTE: for each TIME input, there must be a QTBL, HTBL, and RTBL input; maximum 150 values for each table).

   In stacking cases it is necessary to add at least one 0. value at the end of the TIME table after the first case if the number of entries in the table is decreased. This 0. is used internally as an indication of the end of the table.

3. If transition does not occur during the convective heat pulse, input only the LAM array of material properties.

4. If transition occurs during convective heat pulse, input both LAM and TURB arrays and TTRANS, the time at which pulse switches from laminar to turbulent flow.

5. Input atmospheric constituents, initial temperature, and stop time of problem.

6. Input design rear temperature of problem.

7. For succeeding cases, input only the changes desired. However, note (2) above if TIME, HTBL, QTBL, and RTBL are to be changed.

8. A set of computer input forms are provided for the user. All the data shown on the form is keypunched when the variable is supplied.

C OUTPUT DEFINITIONS

External Name	Internal Name	Parameter	Units
ACTUAL TSTOP	TSTOP	t_f used for problem.	seconds
CASE	CASE	Identification number	--
CORRECTED WINS	WEIGHT	Insulation weight corrected for structural capacitance and bond capacitance.	lbs/ft^2
CRMAX	RQCMAX	Maximum combined heating rate.	Btu/ft^2-sec
DATE	DATE	Identification number.	
DTM	DTM	Average temperature rise.	^{o}F
HADJ	HGTOT	Average stagnation enthalpy	--
MEMO	MEMO	Identification number.	--
MINCRABL	QR	Minimum combined heat rate necessary for ablation.	Btu/ft^2-sec
QCTOT	QTOT	Integrated convective heating including multiplier.	Btu/ft^2
QRTOT	QRRA	Integrated radiative heating including multiplier.	Btu/ft^2
QTOTREQ	QTREQT	Combined integrated heating necessary to require heat shield.	Btu/ft^2

External Name	Internal Name	Parameter	Units
TADJ	TADJ	Start time of insulation problem after end of ablation.	seconds
TCRMAX	RTQMAX	Time of maximum combined heating rate.	seconds
TI	TI	Initial time of constant temperature problem.	seconds
TR	TR	Time of maximum rear temperature.	seconds
TSMAX	TS2	Maximum surface temperature of insulation material.	°F
TTEST1	TTEST1	Structural surface temperature attained without heat shield, must be ≤ TMLTSTR to stop problem.	°F
TTEST2	TTEST2	Structural rear temperature attained without heat shield, must be ≤ TREAR to stop problem.	°F
TURB	FC0N (1, 1-7)	Array of material properties for turbulent flow.	--
T1A	T1A	Start time of ablation.	seconds
T2A	T2A	Time ablation ends.	seconds
WA	WA	Ablated weight.	lb/ft^2
WINS	WT, W9	Insulation weight before capacitance corrections.	lb/ft^2
WT0T	WT0TAL	Total heat shield weight including bond.	lb/ft^2

When ablation occurs, there are printed out 8 columns arranged time, ablation rate, time, ablation rate, etc., from left to right. Time is in seconds, ablation rate is in $lb/sec\text{-}ft^2$. Internally, these are called A27A(J), WD0T(J).

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D. SAMPLE PROBLEM

1. Statement of Problem

Determine the heat shield weight for the configuration and trajectory used in the sample problems of Programs 1880, 1885. The heat shield material properties are to be specified as well as the necessary data on the bond and substructure.

2. Input Form

The input form containing all the necessary input is shown on the following pages. A number of cases are shown, representing the heating at several stations on the vehicle. The keypunched input shown should be checked with the input form.

The results indicate the integrated radiation and convective heating, and the heat load for which a heat shield is required. The maximum combined heating rate, and the time at which it occurs is shown. The minimum combined rate necessary for ablation is shown, and can be seen to be larger than the maximum rate occurring. The initial time and adjusted enthalpy are given.

The solution indicates that no ablation occurs and that the heat shield has not fully equilibrated at the time TST0P; this is further shown by the time required to achieve the maximum rear face temperature. The surface temperature and maximum mean temperature of the heat shield are given. The insulation weight (nonablating) required with and without the effects of thermal capacitance of the structure and bond are shown. Finally, the total weight, including the bond weight is given.

Case 4 indicates that the required convergence was not achieved and the results must be interpreted with caution. Case 5 indicates that the heating level has been reduced to the point where no heat shield is required.

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DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO 1884			PROGRAMMER			
	TITLE						
MEMO NO	SECTION NO	WORK ORDER NO	(E240 USE ONLY)	REQUESTED BY	EXT	EST. TIME	PAGE 1 OF 6 PAGES

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CPHS = ____________,
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TABL = ____________,
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DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO 1884	MEMO NO.	SECTION NO.	CONTINUATION SHEET PAGE 2 OF 6 PAGES

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DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO. 1884	MEMO NO	SECTION NO	CONTINUATION SHEET PAGE 3 OF 6 PAGES

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DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO 1884	MEMO NO.	SECTION NO.	CONTINUATION SHEET PAGE 4 OF 6 PAGES

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DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO 1884	MEMO NO.	SECTION NO	CONTINUATION SHEET PAGE 5 OF 6 PAGES

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DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO 1884	MEMO NO	SECTION NO	CONTINUATION SHEET PAGE 6 OF 6 PAGES

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DIGITAL COMPUTER INPUT REQUEST FORM

PROBLEM NO 1884				PROGRAMMER:			
TITLE							
MEMO NO	SECTION NO	WORK ORDER NO	(E240 USE ONLY)	REQUESTED BY	EXT.	EST TIME	PAGE 1 OF 6 PAGES
	K420	W305-050-0005		P. Levine	2996		

$INPUT

DATE = ____,
AHR = ____,
CPB = .25,
CPHS = .44,
CPSTR = .3,
DTI = ____,
EMIS = .76,
EPSIL = ____,
FACTØR = ____,
HV1R = 10000.,
HV2R = ____,
KB = .1,

MEMØ = ____,
KHS = .058,
KSTR = 125.,
MXIT = ____,
QCMULT = 1.,
QRMULT = ____,
RHØB = 30.,
RHØHS = 39.4,
RHØSTR = 172.0,
TABL = 3700.,
TEMPI = 100.,
TMSTR = 1000.,

CASE = 1.0,
TREAR = 400.,
TSTART = ____,
TSTØP = 411.6,
TTRANS = ____,
WTB = .16,
WTSTR = 0.5075,
XA = ____,
XC = .20,
XN = .80,
XØ = ____,

LAM = 1., -2390., 1.53, 1., ____,
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DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO 1884	MEMO NO	SECTION NO	CONTINUATION SHEET PAGE 2 OF 6 PAGES

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HTBL	=	127.5 ,	130.9 ,	131.1 ,	131.4 ,	131.7 ,
		132.0 ,	132.2 ,	132.5 ,	132.7 ,	132.9 ,
		133.0 ,	133.1 ,	133.0 ,	132.8 ,	132.3 ,
		131.4 ,	129.9 ,	128.0 ,	126.4 ,	122.8 ,
		116.7 ,	108.2 ,	98.6 ,	89.4 ,	80.7 ,
		72.5 ,	64.7 ,	57.4 ,	50.5 ,	44.1 ,
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		15 3 ,	12.9 ,	10.8 ,	8.9 ,	7.2 ,
		5.8 ,	4.7 ,	3.9 ,	3.7 ,	4.0 ,
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DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO.	MEMO NO.	SECTION NO	CONTINUATION SHEET
	1884			PAGE 3 OF 6 PAGES

HTBL (Continued) =

QTBL =

0.1,	1.0,	1.2,	1.5,	1.9,
2.3,	2.8,	3.4,	4.1,	5.1,
6.2,	7.6,	9.4,	11.4,	14.1,
16.8,	20.3,	23.8,	27.2,	28.3,
29.4,	30.4,	28.7,	26.4,	23.8,
21.1,	18.5,	15.9,	13.5,	11.2,
9.2,	7.4,	5.8,	4.4,	3.2,
2 3,	1.7,	1.2,	0.8,	0.6,
0.3,	0.2,	0.1,	0.0,	0.0,

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DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO.	MEMO NO	SECTION NO	CONTINUATION SHEET
	1884			PAGE 4 OF 6 PAGES

QTBL = ______, ______, ______, ______, ______,
(Continued)

RTBL = 45* 0.0, ______, ______, ______, ______,

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DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO	MEMO NO	SECTION NO	CONTINUATION SHEET
	1884			PAGE 5 OF 6 PAGES

RTBL (Continued) =

TIME = 0.0, 83.59, 91.01, 98.59, 106.29,
114.11, 122.04, 130.15, 138.41, 146.83,
155.43, 164.26, 173.32, 182.60, 192.13,
201.94, 212.11, 221.42, 229.50, 236.71,
243.49, 250.18, 256.24, 261.31 265.89,
270.19, 274.35, 278.41, 282.47, 286.62,
290.91, 295.42, 300.24, 305.47, 311.25,
317.80, 323.33, 329.62, 336.92, 345.61,
356 33, 370.26, 389.41, 426.40, 473.0,

RAD 2-0964
5-63

DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO. 1884	MEMO NO	SECTION NO	CONTINUATION SHEET PAGE 6 OF 6 PAGES

TIME = ________, ________, ________, ________, ________,
(Continued)
________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
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________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________, ________,

$

$ INPUT

CASE = 2.0

WTSTR = 0.5266
QCMULT = 0.76

$

$ INPUT

CASE = 3 0

QCMULT = 0.354

$

$ INPUT

CASE = 4 0

QCMULT = 0 081

$

$ INPUT

CASE = 5.0

QCMULT = 0.00332

$

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DATE=     5.16     MEMO= 184.00      CASE=    1.00

                IBLDR                                               12/01/64

                      * MEMORY MAP *

  SYSTEM                                    00000 THRU  02717
  FILE BLOCK ORIGIN                         02720
  FILES        1.     UNIT05
               2.     UNIT06
  FILE LIST ORIGIN                          02750
  PRE-EXECUTION INITIALIZATION              02754
  CALL ON OBJECT PROGRAM                    02777
  OBJECT PROGRAM                            03004 THRU  41134

       DECK  ORIGIN        CONTROL SECTIONS  (/NAME/=NON 0 LENGTH, (LOC)=DELETED, *=NOT REFERENCED)

    1. 1884    03004       ......  05247 *
    2. SP1884  05261       PR1884  17241
    3. SFINW1  17606       FINW1   17736
    4. SCURVE  20007       CURVE   20075
    5. SCORFT  20151       CORFIT  22261
    6. STLUQ   22340       TLUQ    22443
    7. SARTLU  22505       ARTLU   22717
    8. .LXCON  23070       .LXSTR  23070 *    .LXSTP  23074      .LXOUT  23142      .LXRTN  23154      IBFXIT  23154 *
                           .LXCAL  23157 *    .LXFRR  23157      .DBCLS  23341 *    .LXARG  23510      .L9     23533 *
                           .CLSE   23541      .LFBL   23542 *    .LUNB   23543      .DFOUT  23544
    9. .IODEF  23550       .DEFIN  23550      .ATTAC  23554 *    .CLOSE  23556      .OPEN   23560      .READ   23562
                           .WRITE  23564      .BSR    23574 *    .RFADR  23604      .RELES  23606 *    .LAREA  23617
                           .LFBLK  23635      .LTSX   23640 *    .AREAI  23652      .LUNBL  23660      .ENTRY  23664
                           .GOA    23717      .GO     23723      .DERR   23737      .NDPXI  23740      .COMXI  23742
                           .EX34   23764
   10. .LXSL   23771       .LXSEL  23771      LXCSEL  23772      .LXTST  23775 *    .LXOVL  24035 *    .LXRCT  24046 *
                           .LXIND  24115 *    .LXDIS  24120 *    .LXFLG  24121 *    .LTCH   24122
   11. .FPTRP  24130       .FFPT.  24130 *    .FPOUT  24267      .FPARG  24306     /.COUNT/ 24310 *    OVFLOW  24361 *'
   12. .ERAS.  24370       E.1     24370      E.2     24371      E.3     24372      E.4     24373
   13. .XCC.   24374       CC.1    24374      CC.2    24375      CC.3    24376      CC.4    24377
   14. XIT     24400       EXIT    24400      .EXIT.  24400 *
   15. FXEM    24401       .FXEM.  24401      .FXOUT  24736      .FXARG  24744     /.OPTW./ 25020
   16. FOUT    25031       .FOUT.  25031
   17. FCNV ,  25373       .FCON.  25373      .FCNV.  25416      .ENDFS  25431      .CNVSW  25433      .FOX1   25437
                           .FOX2   25440      .DBC    25442      .DBC8   25563      .DBC9   25566      .DBC10  25573
                           .DBC20  25621      .DDSW   25631      .DDFIX  25640      .FIXSW  25646      .DDBC   25723
                           .DDRS1  26175      .DDRS2  26177      .D1     26202      .D2     26204      .FERR2  26271 *
                           .ANPT   26325      .ONPT   26342      .LNTP   26415      .AOUT   26465      .DFLT   26503
                           .FLT    26637      .DEXPN  26727      .FXD    26730      .HOUT   27060      .INTG   27130
                           .LOUT   27246      .OOUT   27265      .XCF    27316      .TEST   30023      .KOUNT  30026
                           .LIST   30031      .DONE   30042      .OUTBF  30106      .BUF    30134      .OSTB   30135
                           .WIDTH  30136      .GAIN   30137      .GAIN1  30140      .FBDBF  30150      .DDDFL  30173
                           .DDFLG  30174      .MQD    30175      .PEX    30176      .FEXP   30177      .DIG    30200
   18. FIOS    30220       .FIOS.  30220      .FSEL.  30360      .FILR.  30364      .FRTB.  30373 *    .FRTD.  30400
                           .FILL.  30403      .FCLS   30405 *    .FOPN   30411 *    REOF    30415 *    .TOUT.  30540
                           .REED   30566 *    .BIN    30567 *    .FCT    30570      .FCKSZ  30572 *
   19. FIOH    30654       .FIOH.  30654      .FFIL.  31443      .FRTN.  31470 *
   20. FWRD    31655       .FWRD.  31655
   21. FWRU    31701       .FWRU.  31701
   22. FWRO    31725       .FWRO.  31725      .FREST  32230 *
   23. FRDU    32332       .FRDU.  32332
   24. UN05    32373       .UN05.  32373
   25. UN06    32374       .UN06.  32374      .BUFSZ  32375

                IBLDR                                               12/01/64

   26. FIOU    32400       .FIOU.  32400      .CTUIO  33053      .NMLST  33076      .NAME.  34201      .INTAP  34202
   27. FLOG    34625       ALOG10  34625 *    ALOG    34627
   28. FXPF    34766       EXP     34766
   29. FSQR    35106       SQRT    35106
   30. FXP3    35213       .XP3.   35213
   31. .IOCS   35340       .L(0)   35340      .MONSW  35360      .TEOR   35427      .DEFI.  35507      .JOINX  35553 *
                           .CLOS.  35572      .ATTC.  35605      .SH1    36017 *    .SH9    36061 *    .OPEN.  36102
                           .OP4    36130 *    .OP7    36161 *    .OP9.2  36175 *    .RLSE.  36247      .REP2.  36247
                           .READ.  36250      .RER1.  36273      .WRIT.  36275      .MVT1A  36463 *    .EOFEX  36544 *
                           .FFEIT  36614      .GTIOX  36635      .RW7    36753 *    .RE7    37372 *    .ENDTR  40033
                           .SEL59  40035 *    .BSR.   40446      .EOTOF  40573      .ETOF3  40601 *    .SWITC  40630
                           .TCHEX  41131      .BASIO  41134 *
   32. .IOCS4  41135

  I/O BUFFERS                               41135 THRU  77700

  UNUSED CORE                               77701 THRU  77777
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 TABL   =          0.37000000E 04,
 TREAR  =          0.40000000E 03,
 TEMPI  =          0.10000000E 03,
 EMIS   =          0.76000000E 00,
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KHS    =        0.58000000E-01,

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RHOHS  =        0.39400000E 02,

CPHS   =        0.44000000E 00,

XN     =        0.80000000E 00,

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KSTR   =        0.12500000E 03,

WTB    =        0.16000000E 00,

CPB    =        0.25000000E 00,

TSTOP  =        0.41160000E 03,

KB     =        0.10000000E 00,

RHOSTR =        0.17200000E 03,

THSTR  =        0.10000000E 04,

RHOB   =        0.30000000E 02,

HV1R   =        0.10000000E 05,

HV2R   =        0.00000000E-38,

$ END
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     TI=  0.12110E 03      MINCRABL=  0.17746E 03

       NON-ABLATING CASE
 HABJ      72.161
 SLAB NOT EQUILIBRATED AT END OF PROBLEM
 TTRMAX=  0.11034E 05      TSMAX=  0.15792E 04      DTH=  0.72336E 03      ACTUAL TSTOP=  0.41160E 03
 WINS=  0.14996E 01      CORRECTED WINS=  0.11399E 01      WTOT=  0.12999E 01

 DATE=   5.16     MEMO=  184.00     CASE=   2.00


 $INPUT
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 CASE     =         0.20000000E 01,
 AHR      =         0.10000000E 01,
 TABL     =         0.37000000E 04,
 TREAR    =         0.40000000E 03,
 TEMPI    =         0.16000000E 03,
 EMIS     =         0.76000000E 00,
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 WTSTR    =         0.52660000E 00,
 MXIT     =         0.50000000E 02,
 EPSIL    =         0.50000000E-02,
 FACTOR   =         0.10000000E 00,
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 LAM     =       0.10000000E-01,    0.23900000E 04,    0.15300000E 01,    0.10000000E-01,    0.00000000E-38,
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 TURB    =       0.00000000E-38,    0.00000000E-38,    0.00000000E-38,    0.00000000E-38,    0.00000000E-38,
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 QCMULT =        0.76000000E 00,

 QRMULT =        0.10000000E 01,

 KHS     =       0.58000000E-01,

 TTRANS =        0.10000000E 04,

 RHOHS   =       0.39400000E 02,

 CPHS    =       0.44000000E 00,

 XN      =       0.80000000E 00,

 XO      =       0.00000000E-38,

 XA      =       0.00000000E-38,

 XC      =       0.20000000E 00,

 KSTR    =       0.12500000E 03,

 HTB     =       0.16000000E 00,

 CPB     =       0.25000000E 00,

 TSTOP   =       0.41160000E 03,

 KB      =       0.10000000E 00,

 RHOSTR =        0.17200000E 03,

 TMSTR   =       0.10000000E 04,

 RHOB    =       0.20000000E 02,

 HV1R    =       0.10000000E 05,

 HV2R    =       0.00000000E-38,

 $ END
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QRTOT=  0.00000E-38     QCTOT=  0.22651E 04     QTOTREQ=  0.47394E 02     CRMAX=  0.23104E-02     TCRMAX=  0.25018E 03
     TI=  0.12110E 03     MINERABL=  0.17746E 03

     NON-ABLATING CASE
HADJ      72.161
SLAB NOT EQUILIBRATED AT END OF PROBLEM
TTRMAX=  0.81248E 04     TSMAX=  0.14348E 04     DTM=  0.67248E 03     ACTUAL TSTOP=  0.41160E 03
WINS=  0.14537E 01     CORRECTED WINS=  0.10858E 01     WTOT=  0.12458E 01

DATE=   5.16     MEMO= 184.00     CASE=   3.00

$INPUT
DATE    =         0.51600000E 01,
MEMO    =         0.18400000E 03,
CASE    =         0.30000000E 01,
AHR     =         0.10000000E-01,
TABL    =         0.37000000E 04,
TREAR   =         0.40000000E 03,
TEMPI   =         0.10000000E 03,
EMIS    =         0.76000000E 00,
TSTART  =         0.00000000E-38,
DTI     =         0.10000000E 00,
TBL1    =         0.00000000E-38,    0.00000000E-38,    0.50000000E-02,    0.50000000E-01,    0.80000000E 02,
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                  0.39000000E-01,    0.90000000E-01,    0.51000000E-01,    0.10000000E 00,    0.92000000E-01,
                  0.12500000E 00,    0.18200000E 00,    0.17500000E 00,    0.27400000E 00,    0.22500000E 00,
                  0.35700000E 00,    0.27500000E 00,    0.46500000E 00,    0.35000000E 00,    0.52700000E 00,
                  0.40000000E 00,    0.58400000E 00,    0.45000000E 00,    0.63000000E 00,    0.50000000E 00,
                  0.67400000E 00,    0.55000000E 00,    0.71300000E 00,    0.60000000E 00,    0.72000000E 00,
                  0.65000000E 00,    0.77400000E 00,    0.70000000E 00,    0.80100000E 00,    0.75000000E 00,
                  0.82400000E 00,    0.80000000E 00,    0.84500000E 00,    0.85000000E 00,    0.86300000E 00,
                  0.90000000E 00,    0.10000000E 01,    0.10000000E 01,    0.50000000E 03,    0.10000000E 01,
TBL2    =         0.00000000E-38,    0.00000000E-38,    0.25000000E-02,    0.50000000F-01,    0.10000000E-01,
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                  0.69000000E-01,    0.30000000E 00,    0.10000000E 00,    0.35000000E 00,    0.13500000E 00,
                  0.42000000E 00,    0.17500000E 00,    0.47500000E 00,    0.20000000E 00,    0.50600000E 00,
                  0.25000000E 00,    0.56200000E 00,    0.30000000E 00,    0.61400000E 00,    0.35000000E 00,
                  0.65000000E 00,    0.40000000E 00,    0.69900000E 00,    0.45000000E 00,    0.73300000E 00,
                  0.50000000E 00,    0.76400000E 00,    0.55000000E 00,    0.79100000E 00,    0.60000000E 00,
                  0.81600000E 00,    0.65000000E 00,    0.83800000E 00,    0.70000000E 00,    0.85700000E 00,
                  0.75000000E 00,    0.87400000E 00,    0.80000000E 00,    0.88800000E 00,    0.90000000E 00,
                  0.91200000E 00,    0.10000000E 01,    0.10000000E 01,    0.00000000E-38,    0.00000000E-38,
CPSTR   =         0.30000000E 00,
WTSTR   =         0.52660000E 00,
MXIT    =         0.50000000E 02,
EPSIL   =         0.50000000E-02,
FACTOR  =         0.10000000E 00,
TIME    =         0.00000000E-38,    0.83590000E 02,    0.91010000E 02,    0.98590000E 02,    0.10629000F 03,
                  0.11411000E 03,    0.12204000E 03,    0.13015000E 03,    0.13841000E 03,    0.14683000E 03,
                  0.15543000E 03,    0.16426000E 03,    0.17332000E 03,    0.18260000F 03,    0.19213000E 03,
                  0.20194000E 03,    0.21211000E 03,    0.22142000E 03,    0.22950000E 03,    0.23671000E 03,
                  0.24349000E 03,    0.25018000E 03,    0.25624000E 03,    0.26131000E 03,    0.26599000E 03,
                  0.27019000E 03,    0.27435000E 03,    0.27841000E 03,    0.28247000E 03,    0.28662000E 03,
```

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                   0.29091000E 03,     0.29542000E 03,     0.30024000E 03,     0.30547000E 03,     0.31125000E 03,
                   0.31780000E 03,     0.32333000E 03,     0.32962000E 03,     0.33692000E 03,     0.34561000E 03,
                   0.35633000E 03,     0.37026000E 03,     0.38941000E 03,     0.42640000E 03,     0.47300000E 03,
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                   0.21100000E 02,     0.18500000E 02,     0.15900000E 02,     0.13500000E 02,     0.11200000E 02,
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                   0.23000000E 01,     0.17000000E 01,     0.12000000E 01,     0.80000000E 00,     0.60000000E 00,
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                   0.13300000E 03,     0.13310000E 03,     0.13300000E 03,     0.13280000E 03,     0.13230000E 03,
                   0.13140000E 03,     0.12990000E 03,     0.12800000E 03,     0.12640000E 03,     0.12280000E 03,
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              0.38200000E 02,   0.32700000E 02,   0.27600000E 02,   0.23100000E 02,   0.19000000E 02,
              0.15300000E 02,   0.12900000E 02,   0.10800000E 02,   0.89000000E 01,   0.72000000E 01,
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 LAM    =     0.10000000E 01,   0.23900000E 04,   0.15300000E-01,   0.10000000E 01,   0.00000000E-38,
              0.00000000E-38,   0.00000000E-38,


 TURB   =     0.00000000E-38,   0.00000000E-38,   0.00000000E-38,   0.00000000E-38,   0.00000000F-38,
              0.00000000E-38,   0.00000000E-38,

 QCMULT =     0.35400000E 00,

 QRMULT =     0.10000000E 01,

 KHS    =     0.58000000E-01,

 TTRANS =     0.10000000E 04,

 RHOHS  =     0.39400000E 02,

 CPHS   =     0.44000000E 00,

 XN     =     0.80000000E 00,

 XO     =     0.00000000E-38,

 XA     =     0.00000000E-38,

 XC     =     0.20000000E 00,

 KSTR   =     0.12500000E 03,

 WTB    =     0.16000000E 00,

 CPB    =     0.25000000E 00,

 TSTOP  =     0.41160000E 03,

 KB     =     0.10000000E 00,

 RHOSTR =     0.17200000E 03,

 TMSTR  =     0.10000000E 04,

 RHOB   =     0.30000000E 02,

 HV1R   =     0.10000000E 05,

 HV2R   =     0.00000000E-38,

 $ END
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QRTOT= 0.00000E-38      QCTOT= 0.10551E-04      QTOTREQ= 0.47394E 02      GRMAX= 0.10762E-02      TERMAX= 0.25018E 03
   TI= 0.12110E 03      MINCRABL= 0.17746E 03

      NON-ABLATING CASE
HADJ     72.161
SLAB NOT EQUILIBRATED AT END OF PROBLEM
TTRMAX= 0.33761E 04      TSMAX= 0.10658E 04      DTM= 0.53959E 03      ACTUAL TSTOP= 0.41160E 03
WINS= 0.13022E-01      CORRECTED WINS= 0.92142E 00      WTOT= 0.10814E 01

DATE= 5.16     MEMO= 184.00     CASE= 4.00


$INPUT
DATE    =          0.51600000E 01,
MEMO    =          0.18400000E 03,
CASE    =          0.40000000E 01,
AHR     =          0.10000000E 01,
TABL    =          0.37000000E 04,
TREAR   =          0.40000000E 03,
TEMPI   =          0.10000000E 03,
EMIS    =          0.76000000E 00,
TSTART  =          0.00000000E-38,
DTI     =          0.10000000E 00,
TBL1    =          0.00000000E-38,     0.00000000E-38,     0.50000000E-02,     0.50000000E-01,     0.80000000E-02,
                   0.60000000E-01,     0.15000000E-01,     0.70000000E-01,     0.26000000E-01,     0.80000000E-01,
                   0.39000000E-01,     0.90000000E-01,     0.51000000E-01,     0.10000000E 00,     0.92000000E-01,
                   0.12500000E 00,     0.18200000E 00,     0.17500000E 00,     0.27400000E 00,     0.22500000E 00,
                   0.35700000E 00,     0.27500000E 00,     0.46500000E 00,     0.35000000E 00,     0.52700000E 00,
                   0.40000000E 00,     0.58400000E 00,     0.45000000E 00,     0.63000000E 00,     0.50000000E 00,
                   0.67400000E 00,     0.55000000E 00,     0.71300000E 00,     0.60000000E 00,     0.72000000E 00,
                   0.65000000E 00,     0.77400000E 00,     0.70000000E 00,     0.80100000E 00,     0.75000000E 00,
                   0.82400000E 00,     0.80000000E 00,     0.84500000E 00,     0.85000000E 00,     0.86300000E 00,
                   0.90000000E 00,     0.10000000E 01,     0.10000000E 01,     0.50000000E 03,     0.10000000E 01,
TBL2    =          0.00000000E-38,     0.00000000E-38,     0.25000000E-02,     0.50000000E-01,     0.10000000E-01,
                   0.11400000E 00,     0.25000000E-01,     0.18000000E 00,     0.50000000E-01,     0.25400000E 00,
                   0.69000000E-01,     0.30000000E 00,     0.10000000E 00,     0.35000000E 00,     0.13500000E 00,
                   0.42000000E 00,     0.17500000E 00,     0.47500000E 00,     0.20000000E 00,     0.50600000E 00,
                   0.25000000E 00,     0.56200000E 00,     0.30000000E 00,     0.61400000E 00,     0.35000000E 00,
                   0.65000000E 00,     0.40000000E 00,     0.69900000E 00,     0.45000000E 00,     0.73300000E 00,
                   0.50000000E 00,     0.76400000E 00,     0.55000000E 00,     0.79100000E 00,     0.60000000E 00,
                   0.81600000E 00,     0.65000000E 00,     0.83800000E 00,     0.70000000E 00,     0.85700000E 00,
                   0.75000000E 00,     0.87400000E 00,     0.80000000E 00,     0.88800000E 00,     0.90000000E 00,
                   0.91200000E 00,     0.10000000E 01,     0.10000000E 01,     0.00000000E-38,     0.00000000E-38,
CPSTR   =          0.30000000E 00,
WTSTR   =          0.52660000E 00,
MXIT    =          0.50000000E-02,
EPSIL   =          0.50000000E-02,
FACTOR  =          0.10000000E 00,
TIME    =          0.00000000E-38,     0.83590000E 02,     0.91010000E 02,     0.99590000E 02,     0.10629000E 03,
                   0.11411000E 03,     0.12204000E 03,     0.13015000E 03,     0.13841000E 03,     0.14683000E 03,
                   0.15543000E 03,     0.16426000E 03,     0.17332000E 03,     0.18260000E 03,     0.19213000E 03,
                   0.20194000E 03,     0.21211000E 03,     0.22142000E 03,     0.22950000E 03,     0.23671000E 03,
                   0.24349000E 03,     0.25018000E 03,     0.25624000E 03,     0.26131000E 03,     0.26589000E 03,
                   0.27019000E 03,     0.27435000E 03,     0.27841000E 03,     0.28247000E 03,     0.28662000E 03,
```

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                         0.29091000E 03,      0.29542000E 03,      0.30024000E 03,      0.30547000E 03,      0.31125000E 03,
                         0.31780000E 03,      0.32333000E 03,      0.32962000E 03,      0.33692000E 03,      0.34561000E 03,
                         0.35633000E 03,      0.37026000E 03,      0.38941000E 03,      0.42640000E 03,      0.47300000E 03,
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                         0.00000000E-38,      0.00000000E-38,      0.00000000E-38,      0.00000000E-38,      0.00000000E-38,
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                         0.00000000E-38,      0.00000000E-38,      0.00000000E-38,      0.00000000E-38,      0.00000000E-38,
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  QTBL     =           ' 0.10000000E 00,      0.10000000E 01,      0.12000000E 01,      0.15000000E 01,      0.19000000E 01,
                         0.23000000E 01,      0.28000000E 01,      0.34000000E 01,      0.41000000E 01,      0.51000000E 01,
                         0.62000000E 01,      0.76000000E 01,      0.94000000E 01,      0.11400000E 02,      0.14100000E 02,
                         0.16800000E 02,      0.20300000E 02,      0.23300000E 02,      0.27200000E 02,      0.28300000E 02,
                         0.29400000E 02,      0.30400000E 02,      0.28700000E 02,      0.26400000E 02,      0.23800000E 02,
                         0.21100000E 02,      0.18500000E 02,      0.15900000E 02,      0.13500000E 02,      0.11200000E 02,
                         0.92000000E 01,      0.74000000E 01,      0.58000000E 01,      0.44000000E 01,      0.32000000E 01,
                         0.23000000E 01,      0.17000000E 01,      0.12000000E 01,      0.80000000E 00,      0.60000000E 00,
                         0.30000000E 00,      0.20000000E 00,      0.10000000E 00,      0.00000000E-38,      0.00000000E-38,
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  HTBL     =             0.12750000E 03,      0.13090000E 03,      0.13110000E 03,      0.13140000E 03,      0.13170000E 03,
                         0.13200000E 03,      0.13220000E 03,      0.13250000E 03,      0.13270000E 03,      0.13290000E 03,
                         0.13300000E 03,      0.13310000E 03,      0.13300000E 03,      0.13280000E 03,      0.13230000E 03,
                         0.13140000E 03,      0.12990000E 03,      0.12800000E 03,      0.12640000E 03,      0.12280000E 03,
```

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                 0.11670000E 03,   0.10820000E 03,   0.98600000E 02,   0.89400000E 02,   0.80700000E 02,
                 0.72500000E 02,   0.64700000E 02,   0.57400000E 02,   0.50500000E 02,   0.44100000E 02,
                 0.38200000E 02,   0.32700000E 02,   0.27600000E 02,   0.23100000E 02,   0.19000000E 02,
                 0.15300000E 02,   0.12900000E 02,   0.10800000E 02,   0.89000000E 01,   0.72000000E 01,
                 0.58000000E-01,   0.47000000E 01,   0.39000000E 01,   0.37000000E-01,   0.40000000E-01,
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 RTBL   =        0.00000000E-38,   0.00000000E-38,   0.00000000E-38,   0.00000000E-38,   0.00000000E-38,
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 LAM    =        0.10000000E-01,  -0.23900000E 04,   0.15300000E 01,   0.10000000E 01,   0.00000000E-38,
                 0.00000000E-38,   0.00000000E-38,

 TURB   =        0.00000000E-38,   0.00000000E-38,   0.00000000E-38,   0.00000000E-38,   0.00000000E-38,
                 0.00000000E-38,   0.00000000E-38,
 OCMULT =        0.81000000E-01,
 ORMULT =        0.10000000E 01,
 KHS    =        0.58000000E-01,
 TTRANS =        0.10000000E 04,
 RHOHS  =        0.39400000E 02,
 CPHS   =        0.44000000E 00,
 XN     =        0.80000000E 00,
 XO     =        0.00000000E-38,
 XA     =        0.00000000E-38,
 XC     =        0.20000000E 00,
 KSTR   =        0.12500000E 03,
 WTB    =        0.16000000E 00,
 CPB    =        0.25000000E 00,
 TSTOP  =        0.41160000E 03,
 KB     =        0.10000000E 00,
 RHOSTR =        0.17200000E 03,
 TMSTR  =        0.10000000E 04,
 RHOB   =        0.30000000E 02,
 HV1R   =        0.10000000E 05,
 HV2R   =        0.00000000E-38,
 $ END
```

```
 QRTOT=  0.00000E-38     QCTOT=  0.24141E 03     QTOTREQ=  0.47394E 02     ERMAX=  0.24624E 01     TERMAX=  0.25018E 03
    TI=  0.12118E 03     MINERABL=  0.17746E 03

      NON-ABLATING CASE

 HADJ      72.161

 SLAB NOT EQUILIBRATED AT END OF PROBLEM
   THIS   DID NOT CONVERGE IN 20 ITERATIONS , THE LAST VALUES ARE AS FOLLOWS
 TTRMAX=  0.52747E 03     TSMAX=  0.46960E 03     DTM=  0.35627E 03     ACTUAL TSTOP=  0.41160E 03
 WINS=  0.88799E 00     CORRECTED WINS=  0.33522E 00     WTOT=  0.49522E 00

 DATE=   5.16     MEMO=  184.00     CASE=   5.00


 $INPUT
 DATE     =          0.51600000E 01,
 MEMO     =          0.18400000E 03,
 CASE     =          0.50000000E 01,
 AHR      =          0.10000000E 01,
 TABL     =          0.37000000E 04,
 TREAR    =          0.40000000E 03,
 TEMPI    =          0.10000000E 03,
 EMIS     =          0.76000000E 00,
 TSTART   =          0.00000000E-38,
 DTI      =          0.10000000E 00,
 TBL1     =          0.00000000E-38,     0.00000000E-38,     0.50000000E-02,     0.50000000E-01,     0.80000000E-02,
                     0.60000000E-01,     0.15000000E-01,     0.70000000E-01,     0.26000000E-01,     0.80000000E-01,
                     0.39000000E-01,     0.90000000E-01,     0.51000000E-01,     0.10000000E 00,     0.92000000E-01,
                     0.12500000E 00,     0.18200000E 00,     0.17500000E 00,     0.27400000E 00,     0.22500000E 00,
                     0.35700000E 00,     0.27500000E 00,     0.46500000E 00,     0.35000000E 00,     0.52700000E 00,
                     0.40000000E 00,     0.58400000E 00,     0.45000000E 00,     0.63000000E 00,     0.50000000E 00,
                     0.67400000E 00,     0.55000000E 00,     0.71300000E 00,     0.60000000E 00,     0.72000000E 00,
                     0.65000000E 00,     0.77400000E 00,     0.70000000E 00,     0.80100000E 00,     0.75000000E 00,
                     0.82400000E 00,     0.80000000E 00,     0.84500000E 00,     0.85000000E 00,     0.86300000E 00,
                     0.90000000E 00,     0.10000000E 01,     0.10000000E 01,     0.50000000E 03,     0.10000000E 01,
 TBL2     =          0.00000000E-38,     0.00000000E-38,     0.25000000E-02,     0.50000000E-01,     0.10000000E-01,
                     0.11400000E 00,     0.25000000E-01,     0.18000000E 00,     0.50000000E-01,     0.25400000E 00,
                     0.69000000E-01,     0.30000000E 00,     0.10000000E 00,     0.35000000E 00,     0.13500000E 00,
                     0.42000000E 00,     0.17500000E 00,     0.47500000E 00,     0.20000000E 00,     0.50600000E 00,
                     0.25000000E 00,     0.56200000E 00,     0.30000000E 00,     0.61400000E 00,     0.35000000E 00,
                     0.65000000E 00,     0.40000000E 00,     0.69900000E 00,     0.45000000E 00,     0.73300000E 00,
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III. COMPUTATIONS

A. BLOCK DIAGRAM

The block diagram for Program 1884 is given in Figure 4.

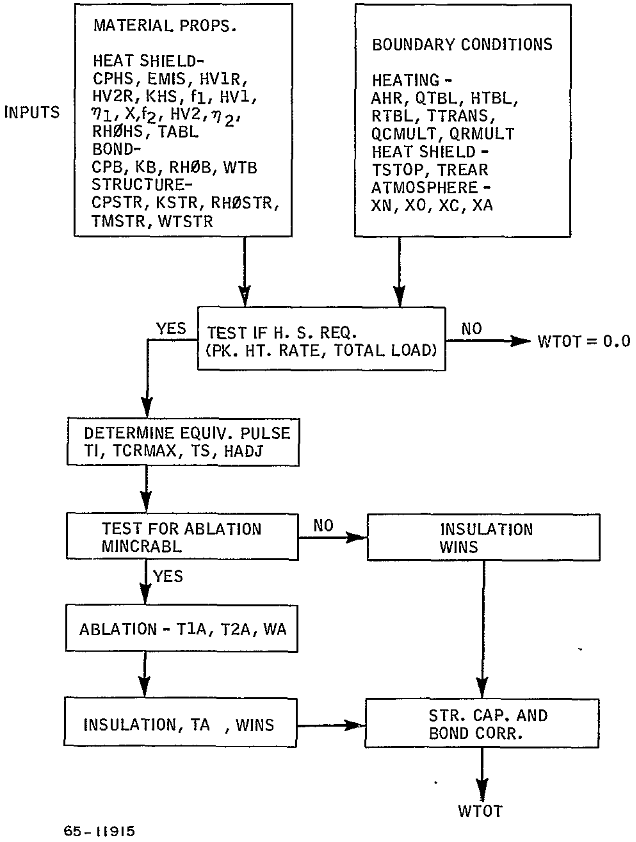


Figure 4 BLOCK DIAGRAM FOR PROGRAM 1884

B. SYMBOLS

Symbol	Definition	Units
C_B, C_{HS}, C_{ST}	Specific heat of bond, heat shield, and structure.	Btu/lb-°F
K_B, K_{HS}, K_{ST}	Conductivity of bond, heat shield, and structure.	Btu/ft-hr-°F
$\rho_B, \rho_{HS}, \rho_{ST}$	Density of bond, heat shield, and structure.	lb/ft^3
ϵ	Emissivity.	
σ	Stefan-Bolzmann constant.	Btu/ft^2-sec-°R
t_i	Initial time.	seconds
t_m	Time at peak combined heating.	seconds
t_f	Final time of problem.	seconds
t_{ia}, t_{ta}	Times when ablation starts and stops.	seconds
t_R	Time when rear temperature equals specified value.	seconds
t_{adj}	Start time for post-ablation insulation problem.	seconds
T_i	Initial temperature.	°R
T1, T2	Temperature defined by Equations (6) and (7).	°R
T_A	Ablation temperature.	°R
ΔT_m	Mean temperature rise.	°R
q_m	Maximum combined heat rate.	Btu/ft^2-sec
q_c, q_R	Convective and radiative heat rates.	Btu/ft^2-sec
H_s, h_w	Stagnation and wall enthalpy.	Btu/lb
Q_c, Q_R	Integrated convective and radiative heating.	Btu/ft^2
Q_{PA}	Total heat load for post-ablation insulation analysis.	Btu/ft^2

Symbols	Definition	Units
$\dot{W}_a$, $\dot{W}_{aR}$	Ablation rates for convection and radiation and for radiation only.	lb/ft^2-sec
W_A	Total ablated weight.	lb/ft^2

C. EQUATIONS

1. Initial Time

$$t_i = t_m - 2 \int_{o}^{t_m} q_c \, dt + 2 \int_{o}^{t_m} q_R \, dt \qquad (1)$$

2. Integrated Heating

$$Q_c = \int_{t_i}^{t_f} q_c \, dt \qquad (2)$$

$$Q_R = \int_{t_i}^{t_f} q_R \, dt \qquad (3)$$

3. Average Total Enthalpy

a. Nonablating Case

$$H_{SA} = \frac{1}{(t_f - t_i)} \int_{t_i}^{t_f} H_s \, dt \qquad (4)$$

b. Ablating Case

$$H_{SA} = \frac{1}{(t_f - t_{adj})} \int_{t_{adj}}^{t_f} H_s \, dt \qquad (5)$$

4. Heat Shield Requirement Tests

$$T1 = T_i + \frac{33\, q_m \sqrt{2(t_m - t_i)}}{\sqrt{K_{ST}\, \rho_{ST}\, C_{ST}}} \qquad (6)$$

$$T2 = T_i + \frac{(Q_C + Q_R)}{W_{ST}\, C_{ST}} \qquad (7)$$

5. Thermal Capacitance of Bond

$$\Delta W_{HS} = W_B \sqrt{\frac{K_{HS}\, \rho_{HS}\, C_B}{K_B\, \rho_B\, C_{HS}}} \qquad (8)$$

6. Insulation Weight -- Nonablating Case

a. Test Time for Equilibration (t_R)

$$t_R = t_i + \left\{ \frac{\sqrt{\rho_{HS} K_{HS} C_{HS} \Delta T_R^2 + 4\epsilon\sigma T_R^4 \left[Q_c \left(1 - \frac{h_w}{H_{SA}} \right) + Q_R \right]}}{2\,\epsilon\sigma T_R^4} - \frac{\Delta T_R \sqrt{\rho_{HS} K_{HS} C_{HS}}}{2\epsilon\sigma T_R^4} \right\} \qquad (9)$$

b. Weight for $t_R \leq t_f$

$$W_{HS} = \sqrt{\frac{\rho_{HS}\, K_{HS}}{C_{HS}}} \sqrt{t_R - t_i} \qquad (10)$$

c. Weight for $t_R > t_f$

$$Q_C \left[1 - \frac{h_w}{H_{SA}} \right] + Q_R - \epsilon\sigma T_w^4 \, (t_f - t_i) = W_{HS}\, C_{HS}\, \Delta T_M \qquad (11)$$

Where $\Delta T_M/\Delta T_W$ and $\Delta T_R/\Delta T_W$ are assumed to be a function of $\left(\frac{\rho_{HS}\, K_{HS}\, (t_f - t_i)}{C_{HS}\, W_{HS}^2} \right)$ in accordance with the constant surface temperature model and the solution given in Reference 3. The solution is found via iteration on (T_W) using the relationships for $\Delta T_m/\Delta T_W$ and $\Delta T_R/\Delta T_W$ developed in Reference 3.

7. Ablation Weight

a. Test for Occurrence of Ablation

$$q_c \left(1 - \frac{h_w}{H_S}\right) + q_R > 1.82 \sqrt{\frac{\rho_{HS} K_{HS} C_{HS}}{2(t_m - t_i)}} + \epsilon \sigma T_A^4 \qquad (12)$$

b. Ablation Rate ($\dot{w}_a$)

1) Convective and Radiation Heating

$$\dot{W}_a = \frac{q_c \left[1 - \frac{h_w}{H_s}\right] + q_R - \sigma \epsilon T_A^4}{C_{HS} \Delta T_A + X f_1 [H_{V1} + \eta_1 (H_S - h_w)] + (1 - X) f_2 [H_{V2} + \eta_2 (H_S - h_w)]} \qquad (13)$$

c. Test for Blockage of all Convective Heating

$$\dot{W}_{aR} \{\eta_1 (H_s - h_w) X f_1 + \eta_2 (H_s - h_w)\} > \qquad (14)$$

$$q_c \left[1 - \frac{h_w}{H_s}\right]$$

$$\dot{W}_{aR} = \frac{q_R - \epsilon \sigma T_A^4}{C_{HS} \Delta T_A + X f_1 H_{V1R} + (1 - X) f_2 H_{V2R}} \qquad (15)$$

If Equation (14) is satisfied, then ablation rate calculation switches from Equations (13) to (15).

d. Start and Stop of Ablation

Ablation starts and stops when:

$$q_c \left(1 - \frac{h_w}{H_s}\right) + q_R = \epsilon \sigma T_A^4 \qquad (16)$$

e. Insulation Weight for Ablation Period

$$W_{INA} = \frac{4(t_{fa} - t_{ia})}{\dot{W}_a} \left(\frac{\rho_{HS} K_{HS}}{C_{HS}}\right) \qquad (17)$$

f. Adjusted Time

$$t_{adj} = t_{fa} - \frac{4}{5}\left(\frac{\rho_{NS} K_{HS}}{C_{HS}}\right)\left(\frac{t_{fa} - t_{ia}}{W_A}\right)^2 \qquad (18)$$

g. Post-Ablation Heat Stored

$$Q_{PA} = \int_{t_{adj}}^{t_f} \left[q_c \left(1 - \frac{h_w}{H_S}\right) + q_R\right] dt - Q_A \qquad (19)$$

where Q_A is the heat absorbed and blocked by the ablation process, which is found by consideration of Equations (13) and (14).

h. Post-Ablation Insulation Weight

$$Q_{PA} - \epsilon \sigma T_w^4 \, (t_f - t_{adj}) = W_{INP} C_{HS} \, \Delta T_m \qquad (20)$$

Solve Equation (20) for W_{INP} as described previously for Equation (11).

8. Structural Capacitance

A table lookup uses the solution for the rear temperature response in a finite slab backed by a capacitive structure whose surface is at a constant temperature and whose backface is insulated.[3] The temperature ratio $(\Delta T_R / \Delta T_w)$ is assumed unchanged by the structure.

9. Wall Enthalpy

The wall enthalpy is given by:

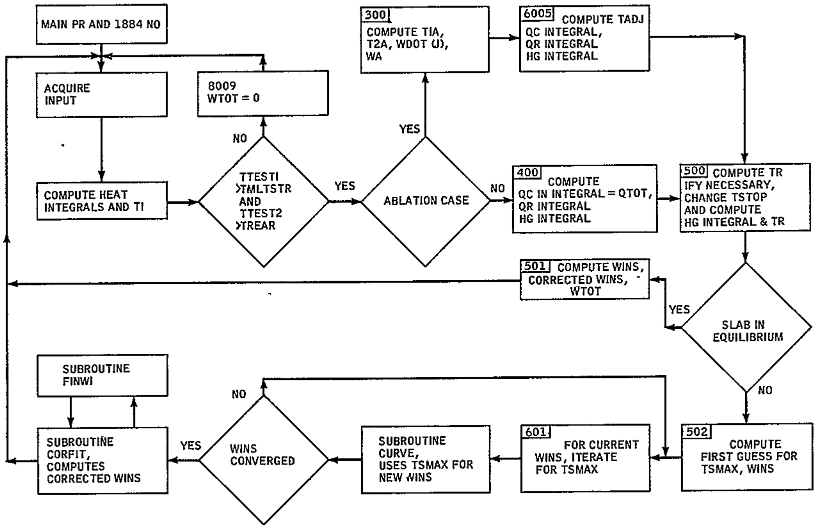
$$\frac{h_w M}{RT_0} = A T_w + B T_w^2 \qquad (21)$$

The coefficients A and B are computed automatically by specifying the atmospheric composition and utilizing tabular thermochemical data stored in the program. All modules are assumed to have zero enthalpy at 0°K.

IV. IBM ROUTINES

A. PROGRAM FLOW

The program flow is shown in Figure 5.



65–11916

Figure 5 FLOW DIAGRAM FOR PROGRAM 1884

B. MAIN PROGRAM

1. Purpose

The purpose of the main program is to acquire the necessary input data, and to transmit this data to subroutine PR1884 within which the computations are completed.

2. Method

The input variables are defined by their inclusion in the namelist array INPUT, and their types and dimensions specified. The data statements and the arithmetic statements setting the elements of TBL1 and TBL2 preset values are of the solution for a finite slab with one end insulated and the other at constant temperature (Reference 1, p. 244, Equation (9)). These tables are arranged so that for TBL1 add indices are monotonic increasing values of the parameter $\Delta T_R / \Delta T_W$ and even indices are monotonic increasing values of $\alpha t/L^2$ and even indices are values of $\Delta T_m / \Delta T_w$.

The program input is read through namelist at Statement 100. The identification numbers DATE, MEMO, and CASE are written on the output tape followed by the namelist data. The call to Subroutine PR1884 initiates all of the calculations and output of results for the case. After this call control is transferred immediately back to Statement 1000 for consideration of the next case.

C. SUBROUTINES

CALLING SEQUENCES

PR1884	Variable Input or Output Source	AHR Input Program Input	TABL Input Program Input	TREAR Input Program Input	TEMPI Input Program Input
EMIS Input Program Input	TSTART Input Program Input	DTI Input Program Input	TBL1 Input Program Input	TBL2 Input Program Input	CP2DG(CPSTR) Input Program Input
W2DG(WTSTR) Input Program Input	XITDG(MXIT) Input Program Input	EPSDG(EPSIL) Input Program Input	FCTDG(FACTØR) Input Program Input	DDG1(TIME) Input Program Input	DDG2(QTBL) Input Program Input
DDG3(HTBL) Input Program Input	DDG4(RTBL) Input Program Input	XLAM(LAM) Input Program Input	XTURB(TURB) Input Program Input	QMULT(QCMULT) Input Program Input	ERT(QRMULT) Input Program Input
ZK1 (KHS) Input Program Input	TFCØN(TTRANS) Input Program Input	RHØ(RHØHS) Input Program Input	CP(CPHS) Input Program Input	XN Input Program Input	XØ Input Program Input
XA Input Program Input	XC Input Program Input	ZKSTR(KSTR) Input Program Input	WTB Input Program Input	CPB Input Program Input	TSTPØ(TSTØP) Input Program Input
ZKB(KB) Input Program Input	RØST(RHØSTR) Input Program Input	TMST(TMSTR) Input Program Input	RØB(RHØB) Input Program Input	HV1R Input Program Input	HV2R Input Program Input

TLUQ	Variable	ARG, value of indep. variable	TBL, table of alternate indep. and dep. vars.	ANS, result of table look-up
	Input or Output	Input	Input	Output
	Source	Calling program	Main	TLUQ

CURVE	Variable Input or Output Source	ZK, K_{HS} Input Program Input	RHO, ρ_{HS} Input Program Input	CP, C_{PHS} Input Program Input	TR, t_R Input MAIN
TSS, T_s Input MAIN	TEMPI, T_i Input Program Input	WW, W_{INS} Input CURVE	TSTØP, t_f Input Program Input or MAIN	TI, t_i Input MAIN	ANS Input TLUQ
ANS2 Output CURVE	TBL1 Input Program Input	TBL2 Input Program Input	DTM, Δ_{Tm} Output CURVE	TREAR Input Program Input	

CØRFIT	VARIABLE Subroutine Input or Output Source	MITDG, max iterations for corrected WINS Input Program Input	EPSDG, convergence tolerance for corrected WINS Input Program Input	FCTDG, relative change iteration for corrected WINS Input Program Input	CP1DG, C_{PHS}, Specific heat of heat shield Input Program Input
CP2DG, C_{PSTR} Specific heat of structure Input Program Input	W2DG, W_{STR}, weight of structure Input Program Input	RHØ1DG, ρ, heat shield density Input Program Input	ZK1DG, K_{HS}, heat shield thermal cond Input Program Input	TIMIDG, t_i, effective initial time Input Main	WW, W_{INS}, uncorrected heat shield weight Input Main
TSTPDG, t_f, actual TSTØP Input Main	TSRDG, T_R, max allowable rear temp Input Program Input	TSBID, T_i, initial temperature Input Program Input	TSSDG, T_s, average surface temperature Input Main	QTDURZ, duration of heat pulse Input Main	TSTTDG, t_i, initial time of problem Input Program Input
DTMZ, ΔT_m, mean temperature Input Main	WEIGHZ, corrected heat-shield weight Output CØRFIT				

FINW1	VARIABLE Subroutine Input or Output Source	R, $1/\phi$, thermal-capacitance ratio Input CØRFIT	TAU, τ, dimensionless time Input CØRFIT	DV, V_2, dimensionless temperature Output FINW1	RT, indep. var table of R Input CØRFIT
TAUT, indep var. table of τ Input CØRFIT	DVT, dep var. table of dimensionless temp Input CØRFIT				

SUBROUTINE DESCRIPTIONS

1. PR 1884

a. Purpose

The purpose of Subroutine PR 1884 is to compute the heat shield weight necessary to limit the backface temperature to some (input) design limit given a knowledge of the heating environment, and provide the necessary output from the calculation.

b. Method

Immediately following the subroutine and dimension statements is the definition of the wall enthalpy function HWALL(T), where T is some temperature in degrees F and the coefficients A27N and B27N are computed as functions of the input atmosphere.

The first executable statements initialize WTØTAL, WA, and NM, the DØ 50 loop counts the number of values entered in the TIME table (DDG1), by checking for the first zero entry beyond the first table element.

By Statement 8003, the sum of the atmosphere constituent mole fractions has been checked to see if it is = 1 ± 0.001, and by the Statement DØ 8000, the wall enthalpy coefficients A27N and B27N have been computed. The DØ 10 loop arranges the tables QTB, HTBL, and RTBL so that odd indices contain values of the TIME table, and even indices contain the corresponding values of the input convective heating, enthalpy, and radiation heating, respectively.

The tests and calculations preceding Statement 8005 redefine the value of TSTØP if necessary. The duration of the heat pulse (QTDUR) is defined as the time after maximum convective heating that the convective heating is ≤ 1 percent of the maximum heating, minus the input TSTART. If the input TSTØP minus the input TSTART is > 2·QTDUR, TSTØP is changed to = 2(QTDUR-TSTART).

Between Statements 8005 and 7331, constants are stored for use by subroutine C0RFIT, QTBL is defined (loop ending on 102) to be the convective heating time QCMULT, RADR, RADA, DELTA, and DELTR are defined, the heat shield thermal conductivity is changed for agreements in units, and the maximum combined radiative and convective heating is computed along with the time it occurred (RQCMAX and RTQMAX, respectively).

The D0 loop ending on 7332 computes three integrals by the trapezoidal method, the integrals from the first entry on the TIME table to TST0P of the combined radiative and convective heating (QRT0T) and of the radiative heating (QRRA), and the integral from the first entry in TIME to RTQMAX (see above) of the combined radiative and convective heating (RQINT).

The D0 loop 203 computes the maximum convective heating (QCMAX) and the time when it occurred (TQMAX). D0 loop 207 computes by the trapezoidal method two integrals, the integral from the first entry of the TIME table to TST0P of the convective heating (QT0T), and the integral from the first entry on the TIME table to TQMAX of the convective heating (QINT).

Statement 208 defines an effective initial time TI, and by Statement 6048 the enthalpy at TABL and TREAR (HWABL and HWABR), along with the output quantity MINCRABL (internally, QR) and the quantity QPIMER are computed. By Statement 8008 the quantities TTEST 1 and TTEST 2 are computed. If TTEST 1 < TMST (input as TMSTR) and TTEST 2 < TREAR, no protective shield is required and the next case is considered (RETURN). Between Statements 8011 and 7248, the quantity QTREQT is computed and selected heating integrals, and time are provided as output. After Statement 7248 T1A is defined to be TSTART, and a test is made so that if QR < RQMAX, (Reference 1, p 250, Equation(23)) the ablation case is solved (Statements 300 to, but not including, 400). Otherwise the nonablating case is computed (Statements 400 to, but not including, 500).

Statements 301 to 308 compute the times T1A and T2A which define the time interval during which ablation is occurring. This logical loop provides for successive evaluations of the quantity DIF as the independent variable. TIME is incremented by the input DTI, and T1A is defined as that time before RTQMAX that DIF passes through zero, and T2A is the time after RTQMAX that DIF passes through zero. Test 302 indicates a change of sign in the residual and hence the existence of a near root, Test 1778 assures that the value of DIF is within ±0.01 of zero. It should be noticed that if DIF > 0.01 at TSTART + DTI, then T1A is arbitrarily set equal to TSTART, and/or if DIF >

0.01 at TSTOP, T2A is arbitrarily set equal to TSTOP. For problems of this nature, the potential errors inherent are obvious.

The block of statements between 928 and 926 are executed twice, first with the control variable KKK = 1, then with KKK = 2. For KKK = 1, the DO loop entry at 311 computes the ablation rate (WDOT(J)) as a function of time (A32A(J)) between T1A and T2A. The test before Statement 826 determines if laminar or turbulent material properties will be used to compute WDOT(J). The first row of the array FCON when the input TTRANS (internally TFCON) is $\leq$ TIME, the second row when TTRANS > TIME. The IF test before 3085 will modify the computation of WDOT(J) when the convective heating is "blocked". The DO loop ending on 312 integrates WDOT(J) by the trapezoidal rule to compute the total ablation rate (WA).

The statements between 313 and 6003 initialize T_{11} and KKK for the second pass through Statements 928 and 926. This pass provides for the calculations of WDOT(J) between the times RTQMAX and T2A, which are used to compute the "adjusted" time TADJ. Again suitable properties are selected depending on whether the heating is laminar or turbulent, or the convective heating is blocked: The DO loop ending on Statement 6004 computes the cumulative sum WA7C, which is used after Statement 6005 to compute TADJ (Reference 1, p. 253, Equation (34)). For the purposes of the structural capacitance correction, TI is taken to be TADJ for ablating cases (after Statement 326, TIMIDG).

Between 6005 and 500, three integrals are computed for use in the insulation weight calculation. These are the enthalpy and convective heating integrals HGADJ and QINS between TADJ and TSTOP (loop ending on 326), and the radiation heating integral QRTOT1 between T2A and TSTOP. The first two integrals are computed by the trapezoidal rule, and the third by a firts-order Euler method. After 326 the average enthalpy is computed and stored in HGTOT. Output is provided as HGTOT, TI, T1A, T2A, and WA before 3026. This ends the calculations made for ablation, and the GOTO 500 before Statement 700 transfers to the final insulation weight calculations.

The nonablation calculation is done between Statements 400 and 500. Three entegrals are computed, the first of which, QC, is simply equal to QTOT (see above), the integral of the convective heating from the first entry of the TIME table to TSTOP. In the DO loop ending on 3325 the radiation heating integral QRTOT1 between TSTART (equal to T1A for nonablating cases) and TSTOP is computed by a first-order Euler method. The DO loop ending on 404 computes the enthalpy integral HGTOT between the effective initial time TI and TSTOP.

After Statement 404, this enthalpy is averaged over the time range and stored in GHTØT. The nonablating calculation ends at Statement 500, where the insulation weight calculation starts for both ablating and nonablating cases.

The Statements from 500 to 132 check the validity of the average enthalpy calculation. The first restriction is that the average enthalpy times AHR $\geq$ the enthalpy at temperature TREAR. If it is not, TSTØP is arbitrarily shortened by 5 seconds, NØGØ set = 1, and the GØTØ 499 provides for reaveraging the enthalpy. More specifically, the variable NØGØ is 1 if TSTØP is decreased, 2 if TSTØP is increased, and 0 if no corrections were necessary.

If the average enthalpy is sufficiently large, then the quantity TR, the time at which the backface reaches the design limit temperatures is computed. If TSTØP has not been adjusted to recompute the average enthalpy (NØGØ = 0), and TR $\geq$ TSTØP-TI, then the slab has not equilibrated and the transfer to Statement 502 begins the insulation weight computation. If TR<TSTØP-TI, NØGØ is set to 1 and TSTØP is decreased by 5 seconds and the average enthalpy is recomputed (GØTØ499) and the tests start again.

If the average enthalpy is sufficiently large but TSTØP has been decreased immediately before (NØGØ = 1), then TR is again compared to TSTØP-TI; if <, NØGØ is set to 1, TSTØP is decreased, and a new average enthalpy computed; if =, then the slab is in equilibrium and the transfer to 501 starts the insulation weight calculation; if >, NØGØ is set to 2, TSTØP is increased by 1 second, and a new average enthalpy is computed. Resetting the counter NM assures that TSTØP cannot be thus increased more than 40 times.

If the average enthalpy is sufficiently large but TSTØP has been increased immediately before (NØGØ = 2), then TR is compared to TSTØP-TI. If the slab is in equilibrium, the transfer to 501 starts the insulation weight calculation. If >, NØGØ is set to 2, TSTART is increased by 1 second and if NM< 40, a new average enthalpy is computed.

The calculation of the insulation weight is done in two ways, depending on whether the slab has equilibrated by the end of the problem. If so, then this fact is indicated and the statements from 501 to (not including) 502 compute the insulation weight (WT), corrected insulation weight (WEIGHT) and total weight (WTØTAL) from algebraic evaluations involving only input and TR. Output is provided (after Statement 8015) and the next case is considered (RETURN before Statement 502).

When the slab has not equilibrated at the end of the problem, the insulation weight is computed between Statement 502 and the end of the program. There are two iterations necessary to compute the insulation weight. The outer iteration is for the weight (W9). Statements 600 to, but not including, 6605, and inner iteration is for the average surface temperature TSS from Statements 601 to, but not including 603. The statements from 502 to 600 define the first iteration coefficients for the function of TSS whose root is computed by an accelerated Newton-Raphson procedure in the temperature iteration loop. The first guess for weight is 0, and the first guess for the temperature is a maximum value (TSR) from Reference 1, p. 245, Equation (13). The temperature iteration starts at 601. If the temperature converges to within 1 degree R in less than 41 iterations (counted by INØT), and is > 460, subroutine CURVE is called at Statement 6606. CURVE uses the converged temperature to compute an insulation weight WW from the tables of the solution to the constant surface temperature problem, TBL1 and TBL2. If this weight WW converges with a relative error less than 0.0001 to the weight computed in the previous iteration (W9), then the iteration stops. If not, then a successive approximation is done if the number of iterations (counted by III) is < 20. If more than 20, the iterative procedure is terminated and the last values of TSS and W9 are used.

Statement 703 follows the iteration for insulation weight. The call CØRFIT statement provides Subroutine CØRFIT with the necessary information to compute the insulation weight (WEIGHT), corrected for structural capacitance. After the return from CØRFIT, the insulation weight (WEIGHT) is further corrected for the effective thermal resistance of the bond, and the total weight is computed. Before 8007, output is provided including the insulation weight (W9), the corrected insulation weight (WEIGHT, ≥ 0), and the total weight (WTØTAL). The RETURN provides for the consideration of the next case.

2. TLUQ

a. Purpose

TLUQ performs a linear interpolation on the tables in 1884 TBL1, TBL2, QTBL, HTBL, and RTBL.

b. Method

The value of the independent variable is ARG, and both dependent and independent variable tables are contained in TBL, the odd indexes referring to independent variable values and the even indexes to the corresponding values of the dependent variable. The result of the linear interpolation is placed in ANS. TLUQ is used instead of ARTLU, only because of the arrangement of the Tables TBL1, TBL2, QTBL, HTBL, and RTBL.

3. CURVE

a. Purpose

CURVE uses input data and tables plus a value of the average surface temperature to compute the insulation weight.

b. Method

Given input constants and the tables TBL1 and TBL2, CURVE first defines DTRTS, and performs a table look-up in TBL1 to obtain a value of at/L^2 , which is stored in ANS. This value is then used to compute the insulation weight WW and is used as the value of the independent variable in the table look-up in TBL2 to define a value of $\Delta T_m/\Delta T_S$. This quantity is stored in ANS 2, and is used to compute the average temperature rise DTM.

4. CØRFIT

a. Purpose

For the case in which the slab has not equilibrated by the end of the problem. CØRFIT is used to compute the insulation weight corrected for structural capacitance (see Reference 1, p.p. 254, 255, and the first two lines of p. 256).

b. Method

CØRFIT first defines DVT as a two-dimensional dependent variable table, the function of Reference 1, p. 255. The independent variable tables are TAUT (τ of Reference 1), and RT ($1/\phi$ of References 1). By statement 30 these tables have been defined, along with the necessary input to CØRFIT for the calculation. By Statement 2, a value of t_f (TLIL) is defined for computing τ . TLIL is first defined as the actual TSTØP used by the main program minus the effective initial time for the calculation (the output TI for nonablating cases, TADJ for ablating cases). If the actual TSTØP minus the input TSTART is greater than twice the duration of the heat pulse (see MAIN program description). TLIL is redefined (Statement 1) to be twice the duration of the heat pulse minus the effective initial time.

The solution for W1 must be an iterative procedure since τ and $1/\bar{\phi}$ depend on W1. The procedure used here is a method of false position, with WI for the first guess corresponding to the largest value of τ in the tables (10), as defined by Statement 3. Immediately before Statement 3, the reference temperature difference ratio is defined as DTREF.

Having selected a W1, τ and $1/\phi$ are computed (TAU and R), their values checked to see if they are inside the range of TAUT and RT, and the subroutine FINW1 provides the temperature difference ratio (DV) corresponding to TAU and R. This value of DV is compared to DT REF (before Statement 9), and if the relative error is less than the input EPSIL, the iteration procedure is terminated. If greater than EPSIL, W1 is decreased by the input quantity FCT (FACT0R externally) and a new DV computed by going to Statement 4, etc. This continues until a change of sign in the residual indicates a near root (Statement 12), at which time W1 is reset, but FCT is reduced by multiplying by 0.3 (Statement 13). This process continues until convergence is reached, or until the number of iterations exceeds the input MIT (MXIT externally).

Errors are checked for by the program by four successive IF tests ending at Statement 7. If W1 is negative, a message is printed in the output and the corrected weight (WEIGHT) is not computed. If W1 is too large (TAU lower than first entry of TAUT, the upper limit for W1 is tried. If the sign of the residual has not changed, the quantity WEIGHT is not computed, and a message is written. If W1 is too small (TAU larger than the last entry of TAUT), the lower bound for W1 is tried to see if the sign of the residual has changed. If there is a root, the iteration continues. If not, the corrected insulation weight is computed at Statement 14 (Reference 1, p. 257, Equation (41)). An additional error noted occurs when no convergence has occurred before MIT iterations (counted by IT), in which case this fact is noted and no WEIGHT is computed. The weight corrected for structural capacitance must be ≥ 0.

5. FINW1

a. Purpose

Given in tabular form the function of Reference 1, p. 255, FINW1 computes the temperature difference ratio (DV) given values of TAU and R as independent variables.

b. Method

FINW1 performs a two-dimensional table look-up using the independent variable table DVT whose rows correspond to the independent variable array TAUT and whose columns correspond to the independent variable arrat RT. Using the value of TAU, two table look-ups are done, the first for the entry in RT$\leq$ R, the second for the first entry in RT> R. The results are interpolated linearly in R to compute DV. If R=RT(1), only one table look-up is performed.

D. SIGNIFICANT EQUATIONS

1. MAIN Program

$$h\ (T) = \mathrm{HWALLF}(T) = \mathrm{A27N}\ (T+460.) + \mathrm{B27N}\ (T+460)^2$$

$$\mathrm{RADR} = \mathrm{EMIS.}\left(\frac{\mathrm{TREAR} + 460}{1203.9}\right)^4$$

$$\mathrm{RADA} = \mathrm{EMIS.}\left(\frac{\mathrm{TABL} + 460.}{1203.9}\right)^4$$

$$K = \mathrm{ZK1}/3600.$$

QR & QC from RTBL & QTBL

$$q_{max} = \mathrm{RQCMAX} = \underset{time}{\mathrm{Max}}\ (\mathrm{ERT} \cdot \mathrm{QR}_t + \mathrm{QC}_t \cdot \mathrm{QCMULT})$$ (Statement 7330)

$$t_{q_{max}} = \mathrm{RTQMAX} = \text{time RQCMAX occurs}$$ (Statement 7330)

$$\mathrm{QRTOT} = \int_{\mathrm{TIME(1)}}^{\mathrm{TSTOP}} (\mathrm{QR}_t + \mathrm{QC}_t \cdot \mathrm{QCMULT})dt$$

, QR from RTBL input (Statement 7335)
QC from QTBL input

$$\mathrm{QRTØT} = \mathrm{QRRA} = \int_{\mathrm{TIME(1)}}^{\mathrm{TSTOP}} (\mathrm{QR}_t \cdot \mathrm{ERT})\ dt$$

QR from RTBL input (Statement 7335)

$$\mathrm{RQINT} = \int_{\mathrm{TIME\ (1)}}^{\mathrm{RTQMAX}} (\mathrm{QR}_t \cdot \mathrm{ERT} + \mathrm{QC}_t \cdot \mathrm{QCMULT})dt$$

QR from RTBL
QC from QTBL
(Statement 7335)

$$\mathrm{QCMAX} = \mathrm{MAX}\ (\mathrm{QC}_t \cdot \mathrm{QCMULT})$$

TQMAX = time QCMAX occurs.

$$\text{QT}\emptyset\text{T} = \int_{\text{TIME}(1)}^{\text{TST}\emptyset\text{P}} (\text{QC}_t \cdot \text{QCMULT})dt$$ QC from QTBL (Statement 207)

$$\text{QINT} = \int_{\text{TIME}(1)}^{\text{TQMAX}} (\text{QC}\cdot \text{QCMULT})dt,$$ QC from QTBL input (Statement 205)

$$t_i = \text{TI} = \text{RTQMAX} - \frac{2\cdot \text{RQINT}}{\text{RQCMAX}}$$ (Statement 208)

HWABL = HWALLF (TABL) - enthalpy

HWABR = HWALLF (TREAR) - enthalpy

$$\text{QR} = \frac{1.82 \left\{\frac{\text{ZK}\cdot \text{RH}\emptyset\cdot \text{CP}}{2(\text{TQMAX}-\text{TI})}\right\}^{1/2} (\text{TABL}-\text{TEMPI}) + \text{RADA}}{\left(\text{AHR} - \frac{\text{HWABL}}{\text{HGMAX}}\right)}$$

HGMAX = enthalpy from HTBL at time TQMAX (Statement 6048)

$$\text{TTEST1} = \text{TEMPI} + 33\cdot \text{RQCMAX} \left\{\frac{2\ (\text{RTQMAX} - \text{TI})}{\text{ZKSTR}\cdot \text{R}\emptyset\text{ST}\cdot \text{CP2DG}}\right\}^{1/2}$$

$$\text{TTEST2} = \text{TEMPI} + \frac{(\text{QT}\emptyset\text{T} + \text{QRRA})}{(\text{W2DG}\cdot \text{CP2DG})}$$ (Statement 8003)

$$\text{QTREQT} = \text{W2DG}\cdot\text{CP2DG}\ (\text{TREAR} - \text{TEMPI})$$

If QR (above) <RQCMAX, ablation; $\geq$, nonablation

Ablation equations

TIA = Time before RTQMAX that

$$\left| \mathrm{QCMULT}\cdot \mathrm{QC}_t \left\{\mathrm{AHR} - \frac{\mathrm{HWABL}}{\mathrm{HG}_t}\right\} + \mathrm{ERT}\cdot \mathrm{RC}_t - \mathrm{RADA}\right| \leq 0.01 \quad \text{(Statement 307)}$$

where QC_t, HG_t, RC_t are from the tables QTBL, HTBL, RTBL
If such a time is not found, T1A = TSTART

t_{fa} = T2A = time after RTQMAX that the relation for T1A holds,
If such a time is not found, T2A = TSTOP

$$\dot{W}_a = \mathrm{WD\emptyset T}_t = \frac{\left(\mathrm{QCMULT}\cdot \mathrm{QC}_t\left(\mathrm{AHR} - \frac{\mathrm{HWABL}}{\mathrm{HG}_t}\right) + \mathrm{ERT}\cdot \mathrm{RC}_t - \mathrm{RADA}\right)}{\mathrm{CP}\ (\mathrm{TABL} - \mathrm{TEMPI}) + \mathrm{FCRD}}$$

when $\mathrm{WD\emptyset T}_t\cdot \mathrm{WSA} \leq \mathrm{QC}_t\cdot \mathrm{QCMULT}\ \left(\mathrm{AHR} - \frac{\mathrm{HWABL}}{\mathrm{HG}_t}\right)$

$$\dot{W}_a = \mathrm{WD\emptyset T}_t = \frac{(\mathrm{ERT}\cdot \mathrm{RC}_t - \mathrm{RADA}}{\mathrm{CP}\cdot (\mathrm{TABL} - \mathrm{TEMPI})} + \mathrm{DEN\emptyset M} \quad \text{when the above is not true.}$$

QC_t, HG_t, and RC_t are from tables QTBL, HTBL , and RTBL at time t.

When TFCON $\leq$ TIME, FCRD in above equation is

$$\mathrm{TURB}(4)\cdot \mathrm{TURB}(1)\ \left[\mathrm{TURB}(2) + \mathrm{TURB}(3)\cdot (\mathrm{HG}_t - \mathrm{HWABL})\cdot 33.86\right] + \left[1 - \mathrm{TURB}\ (4)\right]\ \mathrm{TURB}(5)\ \left[\mathrm{TURB}(6) + \mathrm{TURB}(7)(\mathrm{HG}_t - \mathrm{HWABL})\cdot 33.86\right]$$

when TFCON >TIME, FCØN is the same but TURB (1-7) is replaced by LAM (1-7). TURB and LAM are input tables, which are stored as the first and second rows of the matrix FCØN (i, j)

When TFCØN $\leq$ TIME,

$$\mathrm{DEN\emptyset M} = \mathrm{TURB}\ (4)\cdot\ \mathrm{TURB}(1)\cdot \mathrm{HV1R} + \left[1 - \mathrm{TURB}(4)\right]\ \mathrm{TURB}\ (5)\ \cdot\ \mathrm{HV2R}$$

When TFCON > TIME, TURB(i), alone are replaced by LAM(i)

When TFCON $\leq$ TIME

$$\mathrm{WSA} = \left\{\mathrm{TURB}(4)\cdot \mathrm{TURB}(1)\cdot \mathrm{TURB}(3) + \left[1 - \mathrm{TURB}(4)\right]\ \cdot \mathrm{TURB}(5)\cdot \mathrm{TURB}(7)\right\}$$

$$\times\ (\mathrm{HG}_t - \mathrm{HWABL})\cdot 33.86$$

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when TFCØN>TIME, TURB (i) above are replaced by LAM(i)

$$W_a = \text{WA} = \int_{\text{T1A}}^{\text{T2A}} \text{WDØT (t) dt} \qquad \text{(Statement 312)}$$

t_{adj} = TADJ requires the computation of the above WDØT(j) over the time interval from RTQMAX to T2A, DØ loop ending at 6003. Each increment to the WA integral over this time is computed (WA7), and if its squared inverse is individually larger than the quantity

C_P (T2A-TI) /(.8·RHØ·ZK·DT^2), DT being the true time increment

the sum WA7C is incremented by the inverse of the above expression. If the integral increment's squared inverse is $\leq$ the above expression, WA7C, is not incremented, (loop ending 6004)

$$t_{adj} = \text{TADJ} = \text{T2A} - \frac{0.8 \cdot \text{ZK} \cdot \text{RHØ} \cdot \text{DT}^2 \cdot \text{WA7C}}{\text{CP} \cdot \text{ZN}}$$, where ZN = the number

of points (separated by DT time increments) between T2A and RTQMAX.

$$\text{QC} = \int_{\text{TIME (1)}}^{\text{TSTØP}} \text{QDI1}_t \, dt \qquad \text{(Statement 326)}$$

where QDI1 = QCMULT·QC_t-QQQ, QC_t from input table QTBL.

$$\text{QQQ} = \begin{cases} 0, & t \leq \text{T1A},\ t \leq \text{T2A} \\ \text{QCMULT} \cdot QC_t \left[\text{AHR} - \frac{\text{HWABL}}{\text{HG}} \right] - \text{RADA}, & \text{T1A} < t < \text{T2A} \end{cases}$$

HG_t and QC_t from input HTBL and QTBL at time t. (Statement 325)

$$\text{HGTØT} = \frac{\int_{\text{TADJ}}^{\text{TSTOP}} HG_t \, dt}{(\text{TSTØP} - \text{TADJ})}$$, HG_t from HTBL at time t

$$\text{QRTØT1} = \int_{\text{T2A}}^{\text{TSTØP}} RC_t \, dt, \quad RC_t \text{ from input RTBL (Statement 6373)}$$

This ends the ablation calculation. The nonablation equations are as follow:

$$\text{QRTØT1} = \int_{\text{TSTART}}^{\text{TSTØP}} RC_t \, dt, \quad RC_t \text{ from input RTBL (Statement 3329)}$$

$$\text{QC} = \text{QTØT (see above)}$$

$$\text{HGTØT} = \frac{\int_{\text{TI}}^{\text{TSTØP}-\text{TI}} HG_t \, dt}{(\text{TSTØP} - \text{TI})}, \quad HG_t \text{ from HTBL at time t (Statement 404)}$$

This ends the nonablation section. For the calculation of TR between Statements 500 and 594, see main program write-up.

$$t_R = \text{TR} = \Big\{ \left[\text{ZK} \cdot \text{RHØ} \cdot \text{CP}\right]^{1/2} (\text{TREAR} - \text{TEMPI}) - \Big[\text{Zk} \cdot \text{RHØ} \cdot \text{CP} \cdot (\text{TREAR} - \text{TEMPI})^2 + 4.\,\text{RADR} \left(\text{QC}\left(\text{AHR} - \frac{\text{HREAR}}{\text{HGTØT}}\right) \cdot \text{ERT} \cdot \text{QRTØT1}\right) \Big]^{1/2} \Big\} \Big/ (2 \cdot \text{RADR}) \quad \text{(Statement 599)}$$

If the slab is equilibrated at the end of the problem,

$$\text{WINS} = \text{WT} = \left[\frac{\text{RHØ} \cdot \text{Zk} \cdot \text{TR}}{\text{CP}}\right]^{1/2} \qquad \text{(Statement 501)}$$

$$\begin{array}{c}\text{Corrected} \\ \text{WINS}\end{array} = \text{WEIGHT} = \text{WT} \cdot \left\{ 1 - \frac{(\text{W2DG} \cdot \text{CP2DG} + \text{WTB} \cdot \text{CPB}}{\text{WT} \cdot \text{CP}} \right\}, \geq$$

WTØT = WTØTAL = WEIGHT + WA + WTB

If the slab is not equilibrated at the end of the problem, the weight is found as follows TSMAX = T S R , computed from an accelerated Newton-Raphson iteration for the polynomial $f(t) = A \cdot TSR + B \cdot TSR^2 + C \cdot TSR + D$, where the coefficients are a function of the current (iterated) insulation weight. (Statements 601 to 603)

WINS = WW-computed by subroutine CURVE based on value of TSS during current iteration for insulation weight (Statements 600 to 6604).

Corrected WINS = WEIGHT (computed from CØRFIT subroutine)-

$$WT_B \left[\frac{ZK1 \cdot RHØ/CP}{ZKB \cdot RØB/CPB} \right]^{1/2}$$

WTØT = WTØTAL = WEIGHT + WA + WTB.

2. Subroutine CURVE

$$\frac{\Delta T_R}{\Delta T_S} = \frac{(TREAR-TEMPI)}{(TSS-460-TEMPI)}$$, TSS from main program iteration

A table look up (TLUQ) produces a value of $\alpha t/L^2$ from TBL1, and

the weight is

$$WW = \left[\frac{Zk \cdot RHØ \cdot (TSTØP-TI)}{Cp \quad (\alpha t/L^2)_T} \right]^{1/2} , \text{—} \left(\frac{\alpha t}{L^2} \right)_T$$ from table look-up.

$$DTM = DTM = \left(\frac{\Delta T_m}{\Delta T_S} \right)_{\alpha t/L^2} (TSS - 460 - TEMPI) ,$$

$\left(\frac{\Delta T_m}{\Delta T_S} \right)_{\alpha t/L^2}$ from TLUQ look-up at current $\alpha t/L^2$

3. Subroutine TLUQ -

No significant equations (linear interpolation table look-up).

4. Subroutine CØRFIT

DTREF = (TSR - TSI) / (TSS-TSI)

TSR = input TREAR, TSI = input TEMPI,

TSS = output TSMAX

TLIL = TSTØP - TI, TSTØP - TSTART $\leq$ 2·QTDUR

= 2·QTDUR - TI, TSTØP-TSTART > 2·QTDUR

QTDUR is computed in the main program as the time after peak convective heating that $QC_t \leq .01 \cdot QC_{max}$, minus $\overline{\text{TSTART}}$.

CONTAU = (RHØ·ZK1·TLIL)/(CP ·3600).

CØNR = (W2 ·CP2)/CP1

TAU = CØNTAU / $(W1)^2$

R = CØNR /W1

A method of false position is used with W1 changing TAU and R computed, and a table look-up done in FINW1 to obtain a temperature difference ratio, W1 changing until this ratio is sufficiently close to DTREF. At that time the corrected insulation weight is set equal to W1.

If TAU > 10., WEIGHT is computed as

$$\text{Weight} = \text{WW} \left(1 - \frac{\text{W2}\cdot\text{CP2}\cdot(\text{TSR-TSI})}{\text{WW}\cdot\text{CP1}\cdot\text{DTM}}\right)$$

, W2, CP2 being the structure weight and specific heat; TSR, TSI as above, DTM the average temperature rise, WW and CP1 the heat shield uncorrected weight and specific heat.

5. Subroutine FINW1

No equations, two dimensional table look-up.

V. REFERENCES

1. RAD, Mars-Venus Capsule Parameter Study, V. I, Introduction and Analysis, JPL Contract No. 950626, Avco/RAD, TR-64-1 (1964).
2. Brown, J.E., and F.A. Shukis, An Approximate Method for Design of Thermal Protection System, Contract AF 33(616)-7483, Avco/RAD TM-62-3 (25 January 1962).
3. Carslaw, H.S., and J.S. Jaeger, Conduction of Heat In Solids, 2nd edition, p. 282, Oxford Press, London (1959).

PROGRAM 1885

C99<

PROGRAM
1885

PRESSURE AND HEATING DISTRIBUTIONS (1885)

CONTENTS

ILLUSTRATIONS

TABLES

I. INTRODUCTION

A. GENERAL DESCRIPTION

The object of this program is to compute the pressure distribution, laminar heating distribution, turbulent heating distribution, and radiative heating distribution at arbitrary angle of attack for axisymmetric bodies. The resultant distributions can be applied as multiplicative factors on the trajectory data of Program 1880, yielding the local pressure and heating histories at a point on the body. A general functional diagram of the program is given in Figure 1.

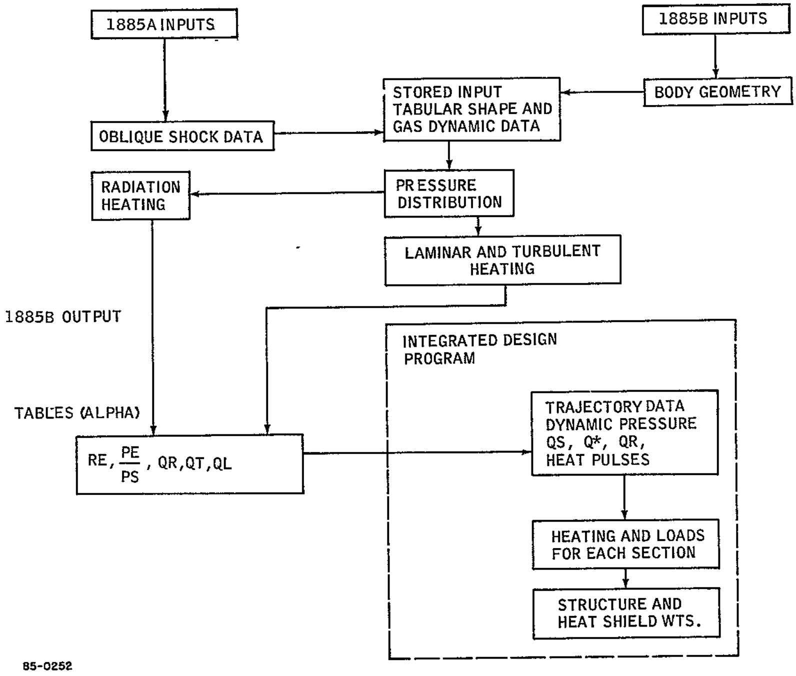


Figure 1 FUNCTIONAL DIAGRAM OF PROGRAM 1885

The general inputs include:

1. The pertinent shape parameters describing the vehicle geometry. The shape parameters are depicted in Figures 2 and 3 and a partial listing of parametric combinations is given in Table I.

2. The flight conditions, namely, the velocity, ambient temperature, density, and atmospheric composition

3. The angles of attack at which pressure and heating distributions desired

4. The option to consider the windward and leeward meridians as symmetric or two-dimensional bodies

5. A control on the boundary layer edge conditions by specifying the shock angle to which the total conditions correspond (temperature, pressure, etc.) adiabatic exponent γ_s is computed.

6. A control on the shock shape calculation by specifying the degree of the polynomial used to approximate the mass flow distribution across the shock layer

7. A control on the radiation heating calculation by specifying the degree of the polynomial used to approximate the radiation heating distribution across the shock layer.

The general outputs include·

1. The coordinates, surface distance, slope, and curvature of points on the windward and leeward meridians for each angle of attack (in body axes aligned with the relative wind vector, and having their origin at the stagnation point)

2. The location of the stagnation and sonic points

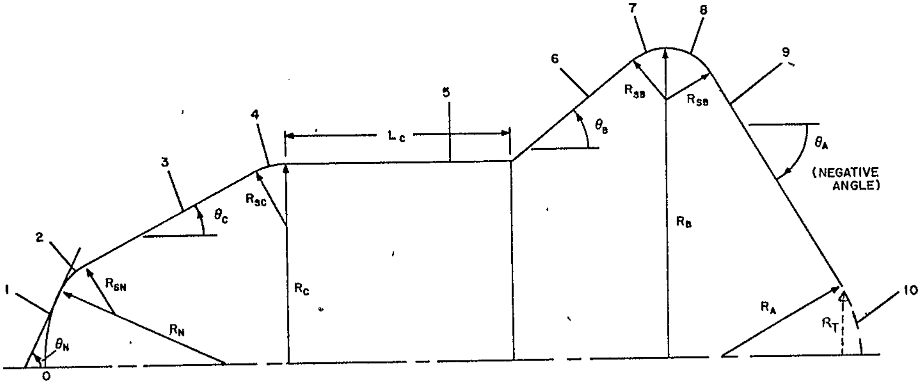
3. The pressure distribution as a fraction of the normal shock stagnation pressure

4. The stagnation point convective heating

5. The sonic point turbulent heating

6. The laminar and turbulent heating distributions

7. The local Reynolds number



SECTION	
1	NOSE SPHERE
2	R_{SN} TORUS
3	CONE (SEE FIGURE 3 FOR ADDITIONAL OPTIONS)
4	R_{SC} TORUS
5	CYLINDER
6	FLARE
7	FORE R_{SB} TORUS
8	AFT R_{SB} TORUS
9	AFT CONE
10	AFT SPHERE (R_A) OR BASE (R_T)

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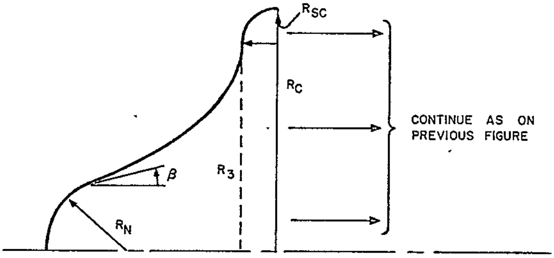
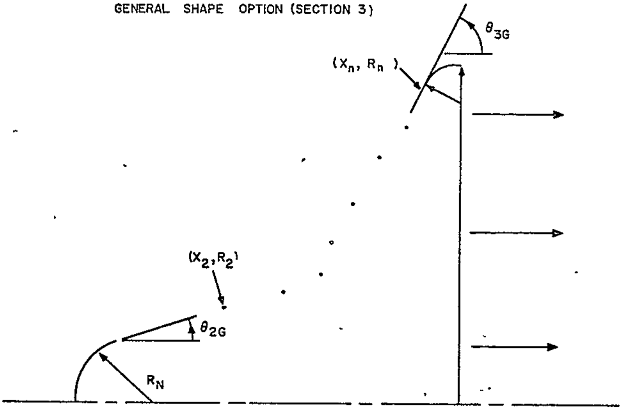
Figure 2 VEHICLE SHAPE PARAMETERS

TENSION SHELL OPTION (SECTION 3)



β - TENSION SHELL INPUT PARAMETER
R_3 - BASE RADIUS OF TENSION SHELL (NOT INPUT)

GENERAL SHAPE OPTION (SECTION 3)



$\theta_{2G}, \theta_{3G}, X, R$ - GENERAL SHAPE INPUT PARAMETERS
$n \leq 25$

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Figure 3 TENSION SHELL AND GENERAL SHAPE PARAMETERS

TABLE I

PARTIAL TABLE OF POSSIBLE SHAPES

Shape	RN	THN	RSN	THC	RC	THB	RSB	RB	THA	RA	RT	BETA	TH2G TH3G	RSC	LC
1. Sphere	x	x	x		x		x		x	x					
2. Blunt Cones,	x	x		x	x		x			x				x	
a. Mod. nose	x	x	x	x	x		x			x				x	
b. Mod. aft. body	x	x	x	x	x		x		x	x					
c. Mod. aft. body	x	x	x	x	x		x		x		x				
3. Cone Cyl., Flare	x	x		x	x	x	x	x	x	x					x
a. Mod. nose	x	x	x	x	x	x	x	x	x	x					x
b. Mod. aft. body	x	x	x	x	x	x	x	x	x		x				x
c. Mod. aft. body	x	x	x	x	x	x	x	x		x					x
4. Capsule Type	x	x	x		x		x		x	x					
a. Mod. aft. body	x	x	x	x	x		x		x		x				
b. Add. Cyl.	x	x	x		x		x		x	(x)	(x)				x
5. Tension Shell	x	x					x		x			x		x	
a. Mod. nose	x	x	x								x	x		x	
6. General Shape	x	x									x		x	x	
a. Mod. nose	x	x	x										x		
7. Sphere, Cyl., Flare	x				x	x	x	x	x	x					x
a. Mod. nose	x	x	x		x	x	x	x	x						
b. Mod. aft. body	x				x	x	x	x	x	x					
8. Sphere, Cone, Cone	x	x		x	x	x	x	x	x	x					

8. The local shock standoff distance and corresponding wave angle

9. The radiation heating distribution.

B. CALCULATION MODEL

1. Vehicle Shapes

Axisymmetric vehicle shapes are considered by prescribing a number of separate conic sections which, when mated together, form the desired shape. The sections allowed are spherical, conical, toroidal, continuous flare(or tension shell), as shown in Figures 2 and 3 A general form for the continuous flare is permitted as an option. A maximum of nine separate sections can be specified at one time. A minimum of two (a sphere) sections can be specified. Further discussion on the omission of various sections is given in the section on usage. Table I lists some of the shapes which can be studied.

2. Angle-of-Attack Geometry and Axes

The angle of attack is measured from the body axis of symmetry, and is the angle between this body axis and the relative wind vector. A new set of body axes are created at each angle of attack, lying along the wind vector and orthogonal to it; these axes are designated wind axes. Essentially, wind axes are utilized at all times, but only at $\alpha = 0, 180,$ does this result in an axisymmetric geometry about the relative wind vector (except for a sphere). The origin of these wind axes is taken at the stagnation point, which is assumed to be located at the most forward point on the body, measured in wind axes as shown in Figure 4. At angle of attack, therefore, there are two sets of body coordinates; one for the windward and one for the leeward meridian. The flow-field calculations are in general taken as dependent on the local body coordinates, slope, surface distance, and curvature, all measured in wind axes.

A special problem area arises when the angle of attack is such that the stagnation point occurs on a straight section (e. g. cone or cylinder), in which case the stagnation point is taken at the midpoint of the straight section. Another problem area is that of a sharp convex corner. In general, sufficient tori sections exist to preclude the occurrence of a sharp convex corner; however, when the flat base section (BASE) is specified, then a sharp convex corner can exist between the aft cone (AFTCØN) and the base (BASE).

The calculation model for the translation and rotation of the axes is shown in Figure 5. The stagnation point is located by maximizing $\bar{x}_\alpha$ where

$$\bar{x}_\alpha = y_{os} \sin\alpha - x_{os} \cos\alpha \ .$$

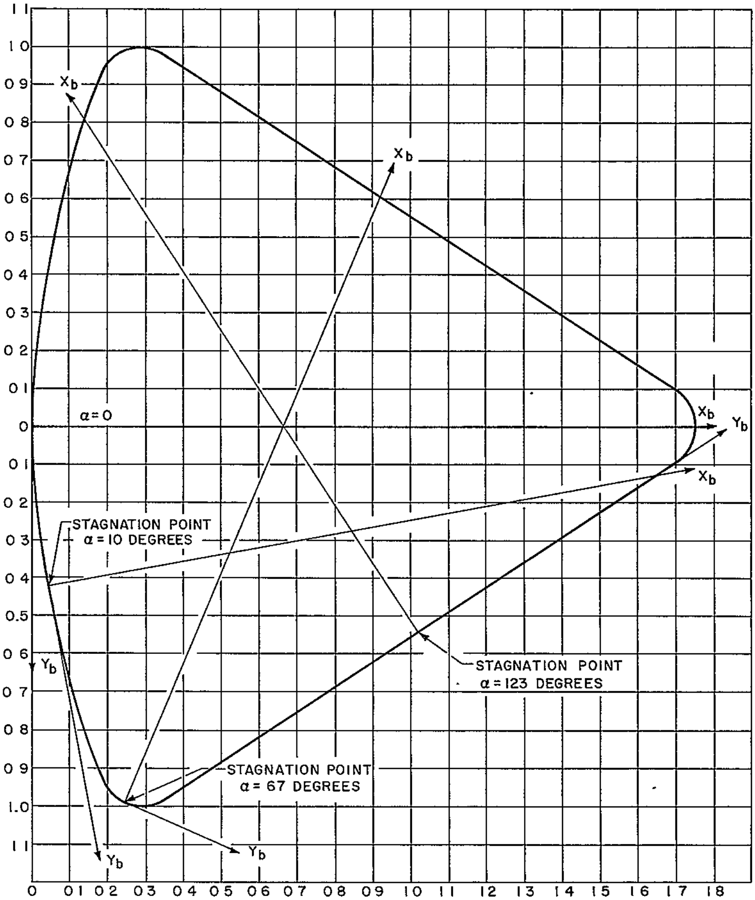

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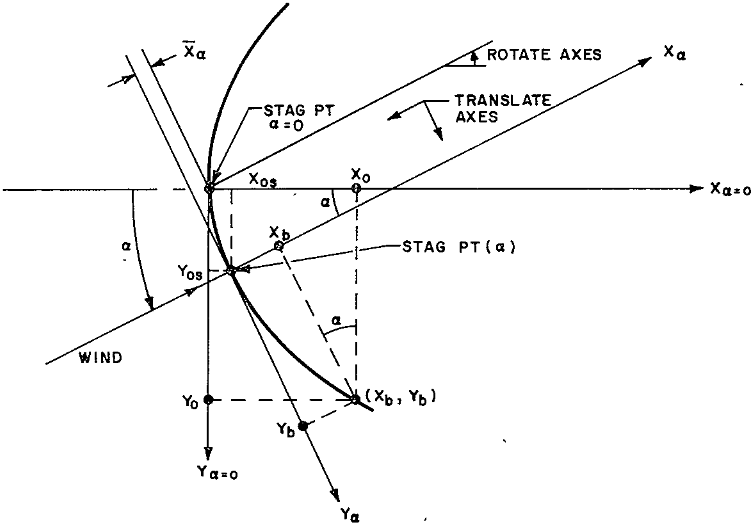
Figure 4 TYPICAL WIND AXES LOCATIONS FOR SEVERAL ANGLES OF ATTACK



COORDINATE TRANSFORMATION EQUATIONS:

$$Y_b(\alpha) = (Y_o - Y_{os})\,\mathrm{COS}\,\alpha + (X_o - X_{os})\,\mathrm{SIN}\,\alpha$$

$$X_b(\alpha) = (X_o - X_{os})\,\mathrm{COS}\,\alpha - (Y_o - Y_{os})\,\mathrm{SIN}\,\alpha$$

85-0256

Figure 5 TRANSLATION AND ROTATION OF AXES

Interpolation formulas are provided for each section to determine the location of the stagnation point precisely. Each section is uniformly divided into a number of N divisions of surface distance, where N is an input number for each section. The coordinates of the N divisions are transformed for each angle of attack as shown in Figure 5. In addition, the local slope is transformed to be the slope with respect to the wind axis and the surface distance of each point is adjusted for the newly found stagnation point.

3. Sonic Point Location

The sonic point location is necessary to aid in determining the pressure distribution in the subsonic region and the stagnation point velocity gradient and shock standoff distance. The calculation model assumes that the sonic point location occurs at the smallest value of (x_b) where

$$\sin^2 \theta_b = \left(\frac{2}{\gamma_s + 1}\right)^{\frac{\gamma_s}{(\gamma_s - 1)}} .$$

The sonic-point relationship given above assumes that the local slope where the flow first becomes sonic is given by Newtonian theory. The adiabatic exponent (γ_s) may either be an input value or is calculated within the program, as discussed in the following section. The precise (x_b, y_b) coordinates corresponding to the sonic point angle are interpolated.

4. Adiabatic Exponent (γ_s)

An adiabatic exponent (γ_s) is utilized based on the density ratio across a normal shock at the specified flight conditions using the strong shock approximation:

$$\gamma_s = \frac{\rho_w/\rho_a + 1}{\rho_w/\rho_a - 1} .$$

The derivation of the above result from the normal shock equations is premised on the thermodynamic relationship that

$$h = \frac{\gamma_s}{(\gamma_s - 1)} \frac{P}{\rho} .$$

Since for isentropic flow,

$$dh = - \frac{1}{\rho} d_P$$

it can be seen that if (γ_s) is assumed constant along a streamline, then

$$\frac{h}{H} = \left(\frac{P}{P_s}\right)^{\frac{\gamma_s - 1}{\gamma_s}} .$$

The adiabatic exponent noted above is only an approximation for determining the speed of sound, and hence the Mach number as,

$$a^2 = \left(\frac{\partial P}{\partial \rho}\right)_{S/R} \cong \frac{\gamma_s P}{\rho}$$

and further

$$\frac{P}{P_s} = \left(\frac{\rho}{\rho_s}\right)^{\gamma_s}$$

Comparisons of the adiabatic exponents for the enthalpy-pressure and for density-pressure are given in Reference 1. A single adiabatic exponent is used freely to compute all conditions along a streamline, including the Prandtl-Meyer variable in supersonic flow.

5. Oblique Shock Calculations

The oblique shock calculation employs Program 1883 as a subroutine. The conditions behind an oblique shock are needed to perform the shock shape and radiative heating calculations. An iteration is performed using the enthalpy and pressure equation, where

$$\frac{h_w M}{R T_o} = \frac{HM}{RT_o} \left\{ 1 - \frac{V^2}{2H} \left[\left(\frac{\rho_a}{\rho_w}\right)^2 \sin^2 \theta_w + \cos^2 \theta_w \right] \right\}$$

$$\frac{P_w}{P_o} = \frac{\rho_a V^2}{P_o} \sin^2 \theta_w \left(1 - \frac{\rho_a}{\rho_w}\right) + \frac{P_a}{P_o} .$$

The calculation model is depicted in Figure 6. The flight conditions are specified; hence the molecular weight of the atmosphere (M) and the velocity (V), the ambient pressure (P_a) and density (ρ_a), and the total enthalpy (H) are all known. An initial estimate on $(\rho_a/\rho_w)^{a}$ is made and the enthalpy and pressure computed by the equations, Program 1883 computes the density ratio (ρ_a/ρ_w) for these conditions and the enthalpy and pressure are recomputed, tested for accuracy, and further iterated if necessary.

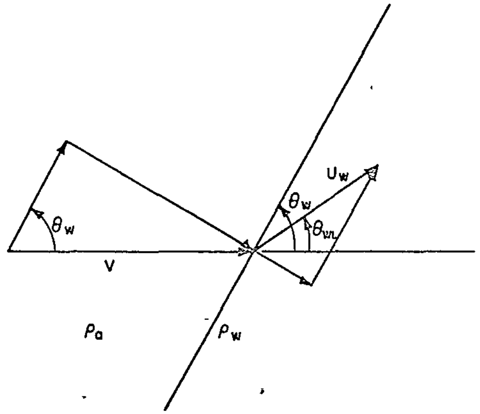


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Figure 6 OBLIQUE SHOCK MODEL

6. Stagnation Point Velocity Gradient

The calculation of the velocity gradient on the windward and leeward meridians is performed as follows:

a. If no straight section $\left(\frac{d\theta}{dS}<0\right)$ exists between $0 \leq S_b < S_b^*$, evaluate (du/ds) via Table II (from Reference 2), letting x_T, y_T correspond to the sonic point values.

b. If a straight section occurs between $0 < S_b < S_b^*$, and if

$$\frac{d\theta}{dS} = 0, \text{ at } S_b = 0$$

$$x_b^* \leq \Delta_{so}$$

then,

$$\frac{dU}{dS} = \frac{V}{R_{wo}} \sqrt{\frac{8}{3} \frac{\rho_a}{\rho_s}}$$

(Reference 4, Page 161)

Otherwise (dU/dS) is evaluated from Table II with x_T, y_T corresponding to the coordinates of meridian at the start of the straight section.

7. Subsonic Pressure Distribution $(S \leq S_b^*)$

Two pressure calculation methods are possible within the program, Newtonian or a polynomial distribution. The choice of either depends on the following tests:

a. $$\left\{ \begin{array}{l} \frac{d\theta}{dS} < 0 \quad \text{at all points } 0 \leq S_b < S_b^* \\ \text{and,} \\ x_b^*/y_b^* \geq \frac{1 - \sin\theta_b^*}{\cos\theta_b^*} \end{array} \right.$$

b. $\frac{d\theta}{dS} = 0$ at one point or more $0 < S_b < S_b^*$, and

$$\frac{d\theta}{dS_b} < 0 \text{ at } S_b = 0$$

If either of the tests is satisfied, the Newtonian method is used; if not, the polynomial distribution is used. The polynomial distribution is of the form:

$$\frac{P_e}{P_s} = 1 + C_1 S_b^2 + C_2 S_b^4$$

TABLE II*

VELOCITY GRADIENT CORRELATION

$$\frac{y_T}{V}\frac{du}{dS}\left(\frac{\rho_a}{\rho_s},\frac{x^*}{y^*}\right)$$

ρ_a/ρ_s	x_T/y_T					
	0	0.10	0.20	0.30	0.35	.40
0	0	0	0	0	0	0
0.005	0.004	0.007	0.014	0.035	0.050	0.110
0.01	0.008	0.015	0.025	0.060	0.090	0.150
0.02	0.016	0.022	0.050	0.100	0.140	0.195
0.04	0.032	0.052	0.087	0.150	0.195	0.255
0.08	0.070	0.098	0.145	0.225	0.278	0.324
0.16	0.143	0.183	0.238	0.325	0.380	0.455

*Obtained using the method of Reference 2

at some point where $\theta_b^* = \sin^{-1}\left(\frac{2}{\gamma_s + 1}\right)^{\frac{\gamma_s}{2(\gamma_s - 1)}}$.

TABLE III

SHOCK PARAMETERS FOR BLUNT CYLINDER

Δ_{so}/y_b^*	R_{wo}/y_b^*	ρ_s/ρ_a
1.20	2.40	1
0.72	3.40	3
0.60	3.75	4
0.53	4.05	5
0.47	4.30	6
0.40	4.90	8
0.36	5.25	10
0.33	5.55	12
0.28	6.20	16
0.13	9.30	50

where the coefficients C_1 and C_2 are found by the conditions

a. $S_b = S_b^*$, $\frac{P_e}{P_s} = \frac{P_e^*}{P_s}$

b. $S_b = 0$, $\frac{d^2 P_e}{dS^2} = - \rho_s \left(\frac{dU}{dS}\right)^2$

8. Pressure Distributions for $S_b > S_b^*$

The pressure distribution downstream of the sonic point ($S_b > S_b^*$) is found by selecting one of several possible methods. The possible methods included in the program are:

a. Newtonian theory

b. Constant pressure

c. Entropy Layer Theory

d. Prandtl-Meyer

The choice of the method to be used at each succeeding division (or section), along the meridian is dependent on tests of curvature, slope, and pressure at the last point calculated. The test criteria are summarized in Table IV. The MP data are given in Table V.

The entropy layer theory is described in References 5 and 6 and provision is included for considering the meridian as that of an axisymmetric or two-dimensional body by input of the sentinel XJ = 1. or XJ = 0., respectively.

A limit is placed on the pressure distribution computation in that when the pressure first reaches the ambient value, then the pressure is kept constant at this value over the remainder of the body.

The Prandtl-Meyer calculation is performed via table lookup using the data in Table VI, obtained from Reference 7.

A comparison of the pressure distributions obtained via Program 1885 with experimental data for a hemisphere cylinder is shown in Figure 7.

9. Total Pressure Option

For bodies of small bluntness, an option is provided to compute the boundary layer edge conditions corresponding to flow through a specified oblique shock as discussed in Reference 9. The static pressure distribution is assumed to be unchanged. A shock wave angle other than 90 degrees is specified as input, for which the new total conditions are computed

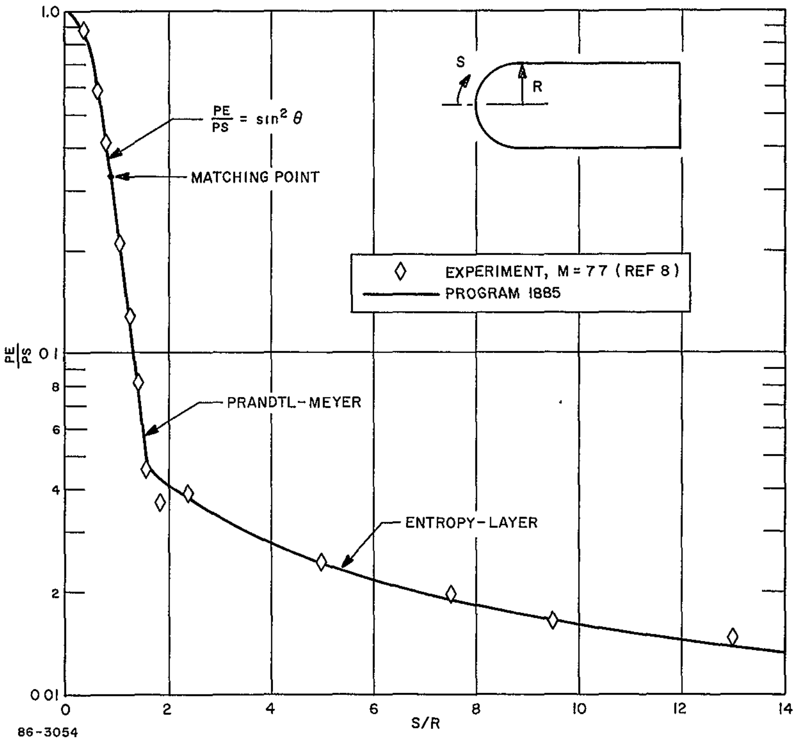


Figure 7 PRESSURE DISTRIBUTION ON A HEMISPHERE CYLINDER

TABLE IV

TEST CRITERIA FOR PRESSURE METHOD SELECTION

$\left(\frac{d\theta}{dS}\right)_{j},\ x_{oj} \leq x_{oi}$ $\left(\frac{d\theta}{dS}\right)_{i},\ x_{oj} > x_{oi}$	$\frac{P_e}{P_s}$	θ_b	Method
+	$\leq$MP	All	NEWT
+	>MP	All	NEWT
0	>MP	≥ 0	PC
0	$\leq$MP	≥ 0	EL
0	ALL	≤ 0	PC
-	>MP	All	NEWT
-	$\leq$MP	All	PM

TABLE V

NEWTONIAN-PRANDTL MEYER MATCH POINTS

γ_s	MP
1.15	0.4086
1.18	0.3985
1.20	0.3918
1.22	0.3854
1.24	0.3790
1.26	0.3728
1.28	0.3667
1.30	0.3607
1.40	0.3318
1.67	0.2678

TABLE VI

PRANDTL - MEYER - TABULAR DATA FOR P/P_T

ν	$\gamma = 1.15$	1.2	1.3	1.4
0	0.5744	0.5645	0.5457	0.5283
4	0.4567	0.4451	0.4230	0.4029
8	0.3867	0.3743	0.3511	0.3298
12	0.3292	0.3165	0.2927	0.2712
16	0.2801	0.2673	0.2436	0.2222
20	0.2375	0.2249	0.2016	0.1808
24	0.2006	0.1882	0.1656	0.1459
28	0.1685	0.1564	0.1352	0.1165
32	0.1406	0.1294	0.1093	0.09202
36	0.1174	0.1061	0.08747	0.07176
40	0.09606	0.08635	0.06934	0.05519
44	0.07860	0.07069	0.05433	0.04181
48	0.06381	0.05577	0.04206	0.03116
52	0.05144	0.04421	0.03214	0.02280
56	0.04114	0.03471	0.02424	0.01635
60	0.03296	0.02698	0.01800	0.01148
64	0.02565	0.02078	0.01317	0.00786
68	0.01998	0.01580	0.00946	0.00524
72	0.01543	0.01189	0.00668	0.00339
76	0.01181	0.00883	0.00462	0.00212
80	0.00894	0.00649	0.00313	0.00127
84	0.00670	0.00470	0.00207	0.00073
88	0.00497	0.00335	0.00133	0.00040
92	0.00364	0.00237	0.00083	0.00020
96	0.00264	0.00163	0.00050	0.00010
100	0.00189	0.00111	0.00029	0.00004
104	0.00134	0.00074	0.00016	0.00002
108	0.00093	0.00049	0.00009	0.0
112	0.00064	0.00031	0.00004	0.0
116	0.00044	0.00020	0.00002	0.0
120	0.00029	0.00012	0.00001	0.0

TABLE VII

SHOCK STAND OFF DISTANCE (Δ_s/y_T) FOR CONVEX BODIES

$x_T/y_T \rightarrow$

$\frac{\rho_a}{\rho_s} \downarrow$	0	0.1	0.2	0.3	0.4
0.02	0.21	0.135	0.070	0.032	0.020
0.04	0.275	0.190	0.115	0.065	0.040
0.05	0.30	0.210	0.135	0.080	0.050
0.06	0.32	0.235	0.155	0.095	0.060
0.08	0.357	0.272	0.192	0.125	0.080
0.10	0.387	0.305	0.225	0.150	0.100
0.12	0.415	0.335	0.255	0.177	0.118
0.16	0.462	0.390	0.310	0.232	0.157

(p_T, ρ_T, T_T) and for which a new adiabatic exponent (γ) is found, these quantities are then used to calculate the necessary flow variables needed to compute the convective heating.

10. Stagnation Point Convective Heating

The stagnation point heating is computed using the correlations of Reference 10 for air The stagnation point velocity gradient on which the heating is based depends on what section of the body the stagnation point occurs If the stagnation point occurs on a spherical cap, then the velocity gradient, for the purposes of computing heat transfer, is taken as the average of the windward and leeward value. If the stagnation point occurs on a torus, cone, or cylinder, the velocity gradient, for the purposes of computing the heating, is taken as the average of the value found above and the value corresponding to a cylinder of radius y_{os} $/\sin\alpha$.

The stagnation point heating expression from Reference 10 is:

$$q_{LS} = \frac{0.76}{\sigma^{0.6}} \left(\frac{\rho_b \mu_b}{\rho_s \mu_s}\right)^{0.1} \sqrt{\rho_s \mu_s}\ \frac{H}{778}\ \sqrt{\left(\frac{dU}{dS}\right)}\ \left[1 + (L^a - 1)\frac{h_D}{H}\right]$$

The Lewis and Prandtl numbers are input as well as the exponent (a). The dissociation enthalpy (h_D) is computed in the oblique shock subroutine.

The stagnation point heating to a three dimensional stagnation point has been derived by Reshotko[11]. The result indicates that the heating can be found in a similar way as in the case of the axisymmetric stagnation point, except that the velocity gradient is given by

$$\frac{dU}{dS} = \left(\frac{dV}{dy} + \frac{dW}{dz}\right)\frac{1}{2}$$

where (dV/dy) and (dW/dz) are the gradients along the two principal radii of curvature. In axisymmetric flow the two velocity gradients are equal, whereas, in two dimensional flow, one is zero, hence, the heating to a cylinder is $\sqrt{1/2}$ of that to a sphere of the same radius.

The velocity gradient dU/dS must be singly valued for both the leeward and windward meridian When the stagnation point is on a spherical cap, the velocity gradient is approximated as·

$$\frac{dU}{dS} = \frac{1}{2}\left(\frac{dU}{dS}\right)_{\text{leeward}} + \frac{1}{2}\left(\frac{dU}{dS}\right)_{\text{windward}}$$

When the stagnation point is on a torus or straight section, the velocity gradient is approximated as

$$\frac{dU}{dS} = \frac{1}{2}\left[\frac{1}{2}\left(\frac{dU}{dS}\right)_{\text{leeward}} + \frac{1}{2}\left(\frac{dU}{dS}\right)_{\text{windward}}\right] + \frac{V}{2}\ \frac{\sin\alpha}{y_{os}}\sqrt{\frac{3\ \rho_a}{\rho_s}}$$

where the last term on the right is the velocity gradient for a cylinder (Reference 4) of radius $(y_{os} / \sin\alpha)$.

11. Laminar Heating Distribution

The laminar heating equations are based on Reference 9 for air The distribution is obtained by normalizing the results with the zero angle of attack stagnation point value. An option is provided to calculate the heating along the windward and leeward meridians assuming either a two-dimensional or axisymmetric body. The calculation includes the affect of local pressure gradient using the approach of local similarity, however, unfavorable pressure gradients (e g., along a tension shell) are not accounted for, in which case the pressure gradient term is placed equal to zero.

The laminar distribution, generalized for either two-dimensional or axial symmetric flows, is given by

$$\frac{q_L}{q_{LS}} = \frac{y_b^j\ \rho_b \mu_b U_e (1 + 0.096\sqrt{\beta})}{(1.068)\sqrt{2\xi}\sqrt{2\rho_{bs}\mu_b\left(\frac{dU}{dS}\right)_{W,L}}}\sqrt{\frac{2}{j+1}}$$

where,

$$\xi = \int_0^S \rho_b \mu_b U_e y_b^{2j}\ dS \quad , \quad \beta = 2\ \frac{d\ln U_e}{d\ln\xi}$$

$\left(\frac{du}{dS}\right)_{W,L}$ is velocity gradient for either windward or leeward meridian.

The tabulated output references the heating to the zero angle-of-attack stagnation point values and so,

$$\frac{q_L}{(q_{LS})_{\alpha = 0}} = \frac{q_L}{q_{LS}} \times \frac{q_{LS}}{(q_{LS})_{\alpha = 0}}$$

12. Turbulent Heating

The turbulent heating calculation utilizes the flat plate reference enthalpy method of Reference 12. The inputs include the Prandtl number and a correction term for axial symmetry if J=1. (XJ = 1.). The output is normalized with respect to the zero angle-of-attack sonic point value.

13 Radiation Heating

The radiation heating model is based on the following equation:

$$q_R = \frac{\xi_w}{2} \left[\frac{m}{m+1} I_b + \frac{1}{m+1} I_w \right]$$

where (m) defines the radiation profile across the shock layer as

$$I = I_b + (I_w - I_b) \left(\frac{\xi}{\xi_w} \right)^m$$

and where I_b and I_w are the radiation intensities at the body and at the shock along a line normal to the body at the coordinates x_b, y_b. The exponent (m) is an input quantity The intensities are computed by the subroutine containing Program 1883. The quantities (ξ_w, θ_w) are computed from the shock shape as described in the following section. The laminar, turbulent and radiative heating distributions on a hemisphere cylinder are shown in Figure 8, as computed by Program 1885.

14. Shock Standoff Distance

The shock shape calculation uses the approach of Reference 3 to compute the shock standoff distance and the shock curvature at the stagnation point. The value of the shock standoff distance at the stagnation point depends on whether,

a. $j = 0, 1$

b. $\frac{d\theta}{dS} < 0 \;,\; 0 \leq S_b < S_b^*$

c. $x_b^* > \Delta_{so}$.

For $j = 1$, and if $\frac{d\theta}{dS} < 0$ for $0 \leq S_b < S_b^*$, then Table VII is utilized with $x_T = x_b^*$, $y_T = y_b^*$ If a straight section$\left(\frac{d\theta}{dS} = 0\right)$ occurs at any point, $0 \leq S_b < S_b^*$, and if $x_b^* \geq \Delta_{so}$, then utilize Table VII, and $x_T = x_{bb}$, $y_T = y_{bb}$ where x_{bb} and y_{bb} are the coordinates at the start of the straight section However, if $x_b^* < \Delta_{so}$, then utilize Table VII with $x_T = x_b^*$, $y_T = y_b^*$ and $\Delta_s = \Delta_{so} - x_b^*$. For $j = 0$, and if $\frac{d\theta}{dS} < 0$ between $0 \leq S_b < S_b^*$ then,

$$\Delta_s = \rho_a / \rho_s \, F \qquad \text{(Reference 4)}$$

where,

$$F = \frac{1}{\sqrt{1 - 3\frac{\rho_a}{\rho_s}}} \left[\cosh^{-1} \frac{1}{\sqrt{\frac{3\rho_a}{\rho_s}}} \right] \left(-\frac{dS}{d\theta} \right)_{S_b = 0}$$

If $\frac{d\theta}{dS} = 0$ at any point $0 \leq S_b < S_b^*$, and if $x_b^* \gtrsim \Delta_{so}$ where,

$$\Delta_{so} = \frac{3}{2} \, y_b^* \left(\frac{\rho_a}{\rho_s} \right)^{0.25} \qquad \text{(Reference 4)}$$

evaluate Δ_s as noted above. However, if $x_b^* < \Delta_{so}$, evaluate Δ_s as noted above but with

$$\left(-\frac{dS}{d\theta} \right)_{S_b = 0} = \frac{y_{os}}{\sin \alpha}$$

15 Shock Curvature at Stagnation Point

Following an approach similar to that of Reference 3, the shock is assumed to be of constant curvature between the stagnation and sonic points. By geometry the radius of curvature is a function of the shock standoff distance at the stagnation and at the sonic points By continuity of mass flow, the standoff distance is further related to the radius of curvature and hence the shock wave is determined. The continuity is invoked by estimating the unit mass flow distribution along a normal (ξ) to the body as

$$\rho U \cos(\theta_{WL} - \theta_b) = (\rho U)_e + [\rho U_w \cos(\theta_{WL} - \theta_b) - (\rho U)_e] \left(\frac{\xi}{\xi_w} \right)^n$$

as depicted in Figure 9.

The exponent n is an input quantity. The conditions at the shock wave (sub w) are found via the oblique shock computations.

16. Shock Shape

The shock shape is assumed to have the form

$$Y_w^2 = 2 R_w (X_w + \Delta s) + B (X_w + \Delta s)^2$$

The value of R_w (the shock wave curvative at the stagnation point) is found as described in Section 15. above. The coefficient (B) is found by satisfying continuity at the first point where $\theta_b \leq 0$. The continuity check involves the input of the exponent (n) described above and the choice of the flow index j = 0, 1

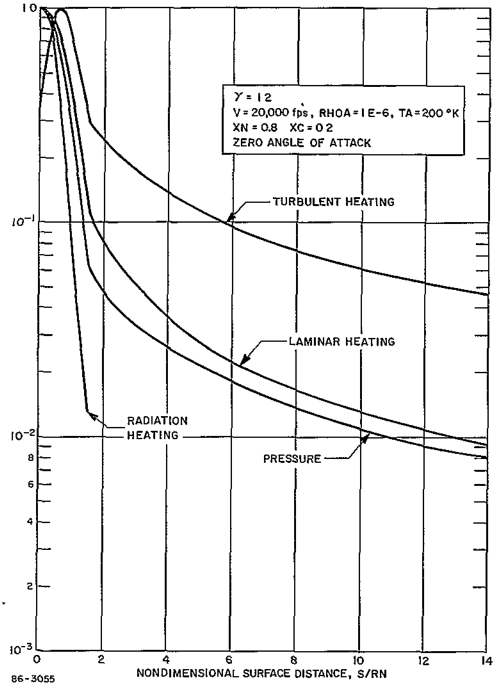
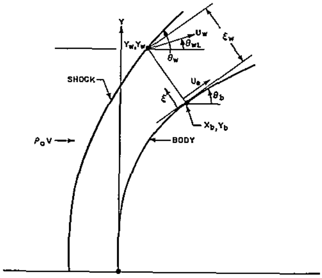


Figure 8 HEATING DISTRIBUTIONS ON A HEMISPHERE CYLINDER



UNIT MASS FLOW DISTRIBUTION:

$$\rho U - (\rho U)_e + \left[\rho_w U_w \cos(\theta_{wL} - \theta_b) - (\rho U)_e\right]\left(\frac{\xi}{\xi_w}\right)^n$$

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Figure 9 MASS FLOW CONTINUITY MODEL

As options, the quantities Δ_s, R_w, B can be input for the windward and leeward meridians and varied for each angle of attack

C. LIMITATIONS

Program 1885 was developed primarily for determining the pressure and heating distribution for preliminary design purposes To handle the wide range of configurations and the whole range of angle of attack, within a reasonably sized and quick program, the approach selected was to utilize simple but powerful analytical techniques. The techniques in general are based on the nature of the physics of the problem and should, in general, yield useful initial predictions The limitations which can be clearly identified include:

1. Separated flow effects are not considered

Experimental results of Larson[13] for laminar and turbulent flows have shown that the average heat transfer for the separated laminar boundary layer was found to be 56 percent of that for the equivalent attached laminar boundary layer, independent of Mach number and Reynolds number in agreement with Chapman's[14] theoretical results. Average turbulent heating for the separated case was found to be about 60 percent of that for the equivalent attached boundary layer, but a trend was observed where the reduction in heat transfer increases with increasing Reynolds number.

2 Three-dimensional flow effects are not considered, except in a minor way for the stagnation point heating as the calculation models presume, in general, that the flow field is either axisymmetric or two-dimensional.

3 The convective heating distributions are based on relationships developed for air

4. The viscosity table is for nitrogen.

5. The shock shape and radiation predictions depend on a priori knowledge of (m) and (n) which are important in determining the distributions of mass flow and radiation intensity across the shock layer. These inputs can be adjusted so as to calibrate the program with more detailed numerical calculations or with experiment.

6. The effects of shock interactions on the tension, general, and flare-shaped bodies are not considered

7. Perfectly sharp nosed shapes cannot be considered.

8. Angle-of-attack conditions leading to attached shocks cannot be considered.

II. USAGE

A. 1885A INPUT DEFINITIONS

Due to the size of the program, it was necessary to divide the program into two parts, 1885A and 1885B. Program 1885A computes all the oblique shock data necessary for the heating and pressure distribution calculation. Program 1885B may be run separately provided tabular oblique shock data is input, to replace what would otherwise be computed by the 1885A Program.

The inputs for the 1885A Program are given initially.

Name	Preset Values	Symbol	Parameter	Units
CASE	0.		Identification number of the form XX.XX.	--
DATE	4.01		Identification number of the form XX.XX.	--
DELAL	2.		Calculation interval of oblique shock data.	degrees
MEMØ	0.		Identification number of the form XX.XX.	
RHØA	0.	ρ_a	Atmospheric density.	slugs/ft^3
TA	0.		Atmospheric temperature.	Kelvin
V	0.	V	Flight velocity.	ft/sec
XA	0.	x_A	Mole fraction argon.	--
XC	0.	x_C	Mole fraction carbon dioxide.	--
XN	0.	x_N	Mole fraction nitrogen.	--
XØ	0.	x_o	Mole fraction oxygen.	--
XPLAST	0.		Print out sentinel for all thermochemical data at each shock angle.	--

Name	Preset Values	Symbol	Parameter	Units
ILAST	0.		If > 0., tape 8 is rewound at the end of the case. ILAST should normally be set >0 only for the last case of a run.	--
INSTØP	1.		Radiation intensity below which the equilibrium problem is not solved.	Btu/ft^3
PRTAB	1.		If >0., will print tables of shock data.	--
PRTAPE	1.		If >0., the array TABLE and selected 1885A input are written on Tape 8 for linkage with an 1885B run.	--
XPEVER	0.		If >0., will print all thermochemical data for every iteration for each shock angle.	--

B. 1885B INPUT DEFINITIONS

Name	Preset Values	Symbol	Parameter	Units
ALPHA	0.	α	Array of angles of attack. Max number is 10, of which the first must be 0.	degrees
BETA	0.	β	Tension shell angle.	degrees
BSHØCT		B_S	10 by 2 matrix of values of the shock parameter β if the shock shape is input. The first column (1-10) corresponds to each α on the windward side, the second column (11-20) to each α on the leeward side. See DELS and RW.	--
CASE	0.		CASE number for identification, of form XXXX. 0.	--

Name	Preset Values	Symbol	Parameter	Units
CØMQRD	0.		Shock shape sentinel; if 0., no shock shape and radiation is to be computed, > 0 otherwise.	--
DATE	4.01		DATE number for identification of form X.XX	--
DELT		Δs	An array of at most 10 values of the shock detachment distance Δs, one for each α. It is to be specified if the shock shape is input. See BSHØCT and RW.	feet
DN2	0.0001		Lower limit for accuracy in integrating $d(Pe/Ps)/dx$ by the entropy-layer formulation.	--
DTDSTB		$(d\theta/dS)_b$	Array of at most 25 values of $(d\theta/dS)_b$ for the general shape option.	rad/ft
ENTH	0.	h_A	Ambient enthalpy when shock gas dynamics data are input, rather than from 1885A. See TABLE, RHØA, XA, XC, XN, XØ, TA, V, PRES, XM, MACH, HDHS90, and TAPE.	ft^2/sec^2
GAMSØ	0.	γ_s	Value of adiabatic exponent at the stagnation point if it is different from the 1885A data, or if 1885A is not used. If = 0, 1885A or TABLE (1, 5) value is used.	--
HDHS90	0.	HD/HS	Ratio of dissociation enthalpy to stagnation enthalpy, specify when 1885A is not used.	--

Name	Preset Values	Symbol	Parameter	Units
ILAST	0.		If > 0., the tape prepared by 1885A will be rewound. It must be > 0 for the last case if 1885A data are used, and if > 0 for an intermediate 1885B case the gas dynamics data of the first 1885A case will be used, and the sequence of 1885A-1885B cases regenerated.	--
XØTBL	0.		If $\neq$ 1., the $\alpha = 0$ body geometry data will be printed in the output.	--
LC	0.	L_C	Cylinder length.	feet
LE	0.	L	Lewis number.	--
LX	0.		Lewis number exponent.	--
MACH	0.	M	Mach number, specify if 1885A is not used.	--
MEMØ	0.		MEMØ number for identification of form X.X.	--
MM	0.	m	A 10 by 2 matrix of exponents on the radiation polynomial, specified like BSHØCT above.	--
N	0.		An array of at most 10 numbers, each of which is the number of increments to be used on the i^{th} body section. For Section 3, i.e. N(3), XX.1, XX.2 and XX.3 are the number of increments for cone, tension shell, or general shape, respectively. For Section 10, i.e. N(10), XX.1, and XX.2 are the number of increments for spherical cap or flat base, respectively.	--

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Name	Preset Values	Symbol	Parameter	Units
NALPHA	0.		Number of α's in the ALPHA array.	--
NN	0.	n	A 10 by 2 matrix of exponents on the mass flow polynomial. Specified like BSHØCT above.	--
PN	0.	σ	Prandtl number.	--
PRES	0.	P_A	Ambient pressure, specified when 1885A is not used.	lb/ft^2
RA	0.	R_A	Aft cap radius.	feet
RB	0.	R_B	Flare and aft cone base radius.	feet
RC	0.	R_C	Cylinder and cone base radius.	feet
RHØA	0.	ρ_a	Atmospheric density. Specify when 1885A is not used.	$slugs/ft^3$
RN	0.	R_N	Nose radius.	feet
RSB	0.	R_{SB}	Toroidal radius at aft cone.	feet
RSC	0.	R_{SC}	Toroidal radius at base of cone.	feet
RSN	0.	R_{SN}	Toroidal radius aft of nose.	feet
RT	0.	R_T	Base truncation radius.	feet
RTBL	0.	Y_i	Array of ordinates for general shapes, maximum 25 points.	feet
RWØ		R_W	A matrix of at most 10 by 2 numbers which are bow wave radii, specified like BSHØCT above. If any RW(i, j) for an α and windward or leeward meridian is specified ≤ 0, it is assumed that DELT, BSHØCT, and RW are to be computed by the program for use on the shock shape and radiation computations.	feet

Name	Preset Values	Symbol	Parameter	Units
TA	0.	T_a	Ambient temperature, specify if 1885A is not used.	Kelvin
TABLE			A matrix of at most 46 by 13 numbers, each of whose columns is a corresponding column from 1885A. For example, TABLE (1-46) = THW_i, TABLE (47-92) = RW/RA_1, ... TABLE (553-598) = IB_1. See 1885A output. Specify in the same order as 1885A, and only when 1885A is not used.	--
TAPE	1.		If > 0, 1885A input is read in from A2. If ≤ 0, shock gas dynamics data is assumed to be program input.	--
TB	0.		Body temperature.	Kelvin
THA	0.	θ_A	Aft cone angle.	degrees
THB	0.	θ_B	Flare angle.	degrees
THC	0.	θ_C	Fore cone angle.	degrees
THETAT	0.	θ_{TT}	Shock angle for stagnation conditions. Used only if $TT \leq 0$.	degrees
THN	0.	θ_N	Nose cap angle	degrees
TH2G	0.	θ_2	Angle at first point of general shape.	degrees
TH3G	0.	θ_3	Angle at last point of general shape.	degrees

Name	Preset Values	Symbol	Parameter	Units
TTØ	0.		Total pressure sentinal. If $\leq$ 0 uses normal shock, if >0, P_T, T_T, ρ_T and γ_s come from shock gas dynamic data at THW = THETAT (above).	--
UP2	0.001		Upper limit for accuracy in integrating $\frac{d(P_e/P_s)}{d_x}$ by the entropy-layer formulation.	--
V	0.	V	Flight velocity, specify if 1885A is not used.	ft/sec
XA	0.	X_A	Mole fraction of argon in atmosphere. Specify if 1885A not used.	--
XC	0.	X_C	Mole fraction of $CØ/_2$ in atmosphere. Specify if 1885A not used.	--
XJ	0.	j	A 10 by 2 matrix of flow field indixes, 1 = axisymmetric, 0 = two dimensional. Specify like BSHØCT above.	--
XM	0.	$\overline{M}$	Mean molecular weight of atmosphere, specify if 1885A is not used.	--
XN	0.	X_N	Mole fraction of N_2 in atmosphere. Specify if 1885A not used.	--
XØ	0.	X_O	Mole fraction of $Ø_2$ in atmosphere. Specify if 1885A not used.	--
XTBL	0.	X_i	An array of at most 25 points which are the X_i for the general shape.	feet

C. INPUT PROCEDURES

1. Vehicles Section Specification (refer to Figures 2 and 3).

The vehicle sections are identified as follows:

Section 1 -- Nose sphere - Specify N (1) followed by number of points desired, i.e., if 8 points are desired, specify N (1) = 8. Specify as input RN, THN, Section 1 cannot be omitted.

Section 2 -- Toroidal section following nose cap. If present, specify N (2) followed by number of points desired. Specify also RSN.

Section 3 -- Three options existing for Section 3, the cone, tension shell, or general shell. If, for example, 25 points are desired for any one of these, then for the cone the input would be N (3) = 25.1, and for the tension shell N (3) = 25.2, and for the general shell N (3) = 25.3. Specify THC for cone, BETA for the tension shell, and TH2G, TH3G for the general shape.

Section 4 -- Toroidal section aft of Section 3, specified as N (4) and also specify RSC, RC. For example, if 12 points are desired, specify N (4) = 12.

Section 5 -- Cylinder section, specified as N (5) and also specify LC, RC. For example, if five points are desired, specify N (5) = 5.

Section 6 -- Flare cone specified as N (6) and with RB, RSB, THB, and with number of points desired as above.

Section 7 -- Toroidal radius aft of flare cone as N (7) and with RSB and with number of points desired as above.

Section 8 -- Toroidal radius at base of aft cone as N (8) and with RSB number of points desired as above.

Section 9 -- Aft cone as N (9) and with THA, and either RA or RT and number of points desired.

Section 10 -- Base section is specified either as a spherical cap or as a flat base. A spherical cap is specified, for example, as N (10) = 8.1, where 8 is the number of points desired and RA is input. A flat base is specified similarly as N(10) = 8.2 and RT is given.

2. Stagnation Conditions Option.

An option is provided for considering stagnation conditions, other than those for a normal shock, at the edge of the boundary layer, to compute the convective heat transfer. The option is used by specifying TT0 as the desired shock angle.

3. Adiabatic Exponent Option.

An option is provided to input a value of (γ) rather than utilizing the value computed in the oblique and normal shock subroutine.

4. Straight Sections

On straight sections, an odd number (N) of points is recommended because roundoff may confuse the point count.

5. Shock Shape Parameters

Values of the coefficients (R_w) and (B) have been correlated from numerical flow solutions in Reference 15 for spherical bodies. The value of R_w was found to be given by

$$R_w = R_N\ (2.09) \left(\frac{\rho_a}{\rho_s} \right)^{0.1958} .$$

The value of B was found to be a function of (x_w) and the normal shock density ratio, however, an approximate form was found to provide good agreement when (B) was taken as a constant and equal to (-0.646).

Studies of the shock shapes about elipsoids and blunt cones are reported in References 16 and 17, but these are directed principally at the region downstream of the nose.

Additional shock shape studies are presented in References 18 and 19. The shock shape form utilized in Reference 18 is of a slightly different form, but the numerical results presented can be used to deduce the parameter (R_w) and (B) for elipsoidal and parabolic bodies as well as spheres.

The values of (R_w), (B_s), and (Δ_s) can be input for both the windward and leeward meridians, as a function of angle of attack. The first ten values specified correspond to the windward meridian and values (11-20) correspond to the leeward meridian.

6. Value of (NN)

The value of (NN) to be used is found via comparison of shock calculations with results of "exact" calculations and/or experiment.

Values of (NN) can be found from the results given in Reference 18 for a point slightly downstream of the sonic point for a sphere. A typical correlation of the theoretical distribution of mass flow rate across the shock layer is shown in Figure 10.

Values of NN can be input for both the windward and leeward meridians, as a function of the angle of attack. The first ten values specified correspond to the windward meridian and values (11-20) correspond to the leeward meridian.

7. Value of (MM)

The value of (MM) to be used is found via comparison of radiation predictions with more "exact" calculations and/or experimental data where available.

Values of MM can be input for both the windward and leeward meridians as a function of the angle of attack. The first ten values specified correspond to the windward meridian and values (11-20) correspond to the leeward meridian.

8. Flow Field Option

By specifying XJ as 0. or 1, the calculations consider the body as either two dimensional or axisymmetric. The values of XJ can be specified for both the windward and leeward meridians as a function of angle of attack. The first ten values specified correspond to the windward meridian and values (11-20) correspond to the leeward meridian.

9. Two-Part Program

The program consists of two parts, 1885A and 1885B as the latter portion fills the core of the IBM 7094. An option is provided to read in the data of 1885A as tables or via tape. A typical output of 1885A is shown in the following IBM listing. The tabular inputs must include the 13 listed tables as given by a typical 1885A calculation. In addition, several aerodynamic and thermodynamic variables must be input if 1885A is not used, including HDHS90, PRES, MACH, ENTH, XA, XN, XC, X0, RH0A, V, MACH, TA.

10. Angle-of-Attack Choices

Avoid angles-of-attack choices which place stagnation point close to discontinuities in body curvature because the simplified flow model is inadequate to cope with strong 3-dimensional effects.

11. Number of Output Points (N)

Specify (N) large enough for each section such that first (5) points on each side of stagnation point occur on the same section, the choice of (N) is therefore related to the angle-of-attack choices. Discontinuities in curvature near the stagnation point may affect the accuracy of the laminar heating distribution.

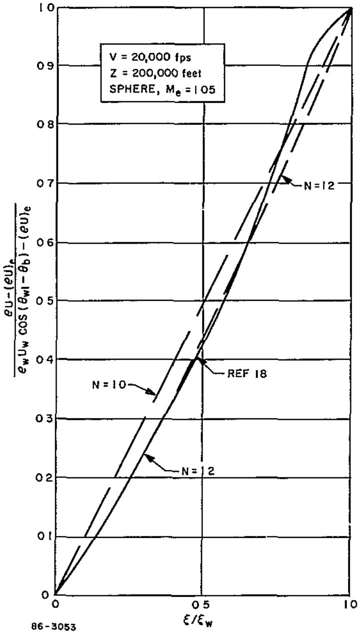

Figure 10 MASS FLOW DISTRIBUTION ACROSS THE SHOCK LAYER

12. Input Forms

An input form is provided for the user. All the information shown is keypunched for those variables specified. All numerical values have decimal points.

D. OUTPUT DEFINITIONS

1885A OUTPUT

External Name	Parameter	Units
GAMMA W	Adiabatic exponent behind shock.	--
HW/H	Ratio of local to total enthalpy behind shock.	--
IB	Radiation intensity at body.	Btu/ft^3
IW	Radiation intensity behind shock.	Btu/ft^3
PW/P0	Pressure behind shock.	atmosphere
PWS/P0	Stagnation pressure behind shock.	atmosphere
RW/RA	Ratio of density behind shock to ambient density.	--
RWS/RA	Ratio of stagnation density behind shock to ambient value.	--
RWUW/RAV	Ratio of specific mass flow rate behind shock to freestream value.	--
TH WL	Flow angle behind shock.	degrees
THW	Shock wave angle.	degrees
TW	Temperature behind shock.	°K
TWS	Stagnation temperature behind shock.	°K

437<

1885B OUTPUT

External Name	Parameter	Units
ALPHA	Angle of attack.	degrees
DP/DSL, DP/DSW	Leeward and windward pressure gradients.	lb/ft^3
DT/DSTBL	Body curvature.	rad/ft
DTDS ST	Body curvature at the stagnation point.	rad/ft
I ST	Coordinate location number for stagnation point.	--
IWSN, ILSN	Coordinate location for sonic point in windward and leeward meridians.	--
M0TBL	Body section number.	--
PE/PSL, PE/PS W	Leeward and windward pressure distribution.	--
QLL, QLW	Leeward and windward laminar heating distribution; ratio of local to zero angle-of-attack stagnation point value.	--
QLS AL0	Laminar heating rate at stagnation point at zero angle of attack; used to normalize all laminar heating rates.	Btu/ft^2-sec
QRL, QRW	Leeward and windward radiation heating distribution; ratio of local to zero angle-of-attack stagnation point value.	--
QRS AL0	Radiation heating rate at stagnation point at zero angle of attack; used to normalize all laminar heating rates.	Btu/ft^{-2}-sec

External Name	Parameter	Units
QTL, QTW	Leeward and windward turbulent heating distribution; ratio of local to zero angle-of-attack sonic point value.	--
QTS AL0	Turbulent heating rate at sonic point at zero angle of attack, used to normalize all turbulent heating rates.	Btu/ft^2-sec
REL, REW	Leeward and windward Reynolds number distribution; ratio of local to free stream value.	--
REYA	Free stream Reynolds number based on vehicle diameter (2RC); used to normalize all Reynolds numbers.	--
SECT	Section Number	--
THETBL, THETBW	Body slope of windward and leeward meridians.	degrees
THETOTBL	Body angle in zero angle-of-attack axes.	degrees
THET ST	Body angle at stagnation point in zero angle-of-attack coordinates.	degrees
THETW SN THETL SN	Windward and leeward sonic point angle in wind axes.	degrees
XBL, YBL, SBL XBW, YBW, SBW	Body windward and leeward coordinates and surface distance in wind axes.	feet
XBWSN, TBWSN, SBWSN, XBLSN, YBLSN, SBLSN	Coordinates and surface distance to windward and leeward sonic points measured in wind axes.	feet
X0L, Y0L X0W, Y0W	Body windward and leeward coordinates at angle of attack measured in zero angle-of-attack axes.	feet

External Name	Parameter	Units
X0TBL, Y0TBL, S0TBL	Body coordinates and surface distance at zero angle of attack as measured in zero angle-of-attach axes.	feet
X0WSN, Y0WSN, X0LSN, Y0LSN	Location of windward and leeward sonic point at angle of attack in zero angle-of-attack axes.	feet
XSIL, XSIW	Leeward and windward shock detachment distance.	feet
XST, YST, SST	Body coordinates and surface distance to stagnation point at angle of attack as measured in zero angle-of-attack axes.	feet

E. SAMPLE PROBLEM

1. Statement of Problem

Determine the pressure and heating distributions on a blunt cone configuration for the trajectories obtained in the Sample Problem for Program 1880. The angle of attack range is specified as 0 to 180 degrees.

2. Input Forms

The input forms for Programs 1885A and B containing all the necessary input data are shown on following pages. All the variable names should be keypunched where data is specified; decimals are used throughout. Additional input forms are also provided on following pages for the program user.

3. Output

The output of Program 1885A is also included in following pages. The oblique shock data are given as a function of the wave angle. In this case, only limited radiation intensity data is given as it is so low; an automatic test on IW and IB is done in the program such that their calculation is dropped if the last value calculated is less than 1.0.

The output of Program 1885B is shown on following pages. The first tabular array contains the basic geometric data of the vehicle.

Following the first array of data are rows of data summarizing pertinent results contained in the subsequent data array, such as the locations of the stagnation and sonic points. The distribution of pressure, laminar heating, turbulent heating, Reynolds number, and radiation heating are given along with a list of axial coordinates in the zero angle of attack axes which identifies each point. The transformed body coordinates, meridian distance, and local body angles are also given for each point. The shock detachment distance (XSI) is given, permitting the shock shape to be drawn. Tests are provided on (QR) and (XSI) to terminate these quantities when QR becomes less than one percent of the stagnation point value and when (XSI) exceeds (RC), or if the shock angle becomes negative or less than the Mach angle. In the present case, as only one point was found for IB and IW, the radiation is interpolated between these values and zero until the shock angle decreases more than two degrees and the body pressure drops slightly, beyond which the IB and IW are both zero and hence QR is zero.

The values of (B) and (Δ_s) and (RW) which were used for the shockwave calculation are indicated.

Two cases are present for which the program was unable to determine shock shapes. These cases are the windward meridian at α = 20 degrees the leeward meridian at α = 40 degrees. For these two points, inputs are required for (RW) and (B).

F. DIAGNOSTICS

1885A

A number of messages are given in the printout reflecting the following program diagnostics.

1. NØ VALID SØLUTIØN

The equilibrium gas dynamics (1883) solution was not able to obtain a solution with positive concentrations for all the species satisfying the element and charge conservation relationships. In this case the data is linearly interpolated between the last and the next point, for which a solution is found.

2. NØT CØNVERGED IN 30 ITERATIØNS

The equilibrium gas dynamics (1883) solution was unable to converge within 30 iterations to within 1 percent on the enthalpy, uses last value found.

1885B

1. CANNØT FIND THETA FOR RW ØR B, SKIP CASE

A shock shape cannot be found satisfying continuity for the assumed flow model; Requires input DELT, RWØ, BSHØCT.

2. SIN(THETAW) NEG. FØR XB = ( ).

The shock shape curves toward body beyond given XB, stops the calculation at the last prior XB output.

3. THETAW BELØW LIMIT AT XB = ( ).

The shock shape calculation is stopped, as at the next output point, the wave angle is less than the mach angle.

4. YW LESS THAN YB:

The shock wave calculation is stopped as, at the next output point, the wave ordinate is less than the body ordinate.

RAD 2 0963
5 63

DIGITAL COMPUTER INPUT REQUEST FORM		PROBLEM NO 1885A			PROGRAMMER		
		TITLE					
MEMO NO	SECTION NO	WORK ORDER NO	(E240 USE ONLY)	REQUESTED BY	EXT	EST TIME	PAGE 1 OF 1 PAGES

PROGRAM WILL SELECT TAPE A5

$INPUT

DATE = ________,

DELAL = ________,

ILAST = ________,

INSTØP = ________,

PRTAB = ________,

PRTAPE = ________,

MEMØ = ________,

RHØA = ________,

TA = ________,

V = ________,

XA = ________,

XC = ________,

CASE = ________,

XN = ________,

XØ = ________,

XPEVER = ________,

XPLAST = ________,

$

RAD 2 0963
5 63

DIGITAL COMPUTER INPUT REQUEST FORM		PROBLEM NO 1885B			PROGRAMMER		
		TITLE					
MEMO NO	SECTION NO	WORK ORDER NO	(E240 USE ONLY)	REQUESTED BY	EXT	EST TIME	PAGE 1 OF 3 PAGES

PROGRAM WILL SELECT A5. IF LINKED TO AN 1885A RUN, THIS MUST BE TAPE OF 1885A RESULTS.

$INPUT

DATE = ____________,
BETA = ____________,
CØMQRD = ____________,
DN2 = ____________,
ENTH = ____________,
GAMSØ = ____________,
HDHS90 = ____________,
ILAST = ____________,
LC = ____________,
LE = ____________,
LX = ____________,
MACH = ____________,
NALPHA = ____________,
PN = ____________,
PRES = ____________,

MEMØ = ____________,
RA = ____________,
RB = ____________,
RC = ____________,
RHØA = ____________,
RN = ____________,
RSB = ____________,
RSC = ____________,
RSN = ____________,
RT = ____________,
TA = ____________,
TAPE = ____________,
TB = ____________,
THA = ____________,
THB = ____________,

CASE = ____________,
THC = ____________,
THETAT = ____________,
THN = ____________,
TH2G = ____________,
TH3G = ____________,
TTØ = ____________,
UP2 = ____________,
V = ____________,
XA = ____________,
XC = ____________,
XM = ____________,
XN = ____________,
XØ = ____________,
XØTBL = ____________,

ALPHA = ____________, ____________, ____________, ____________, ____________,
____________, ____________, ____________, ____________, ____________,

DELT = ____________, ____________, ____________, ____________, ____________,
____________, ____________, ____________, ____________, ____________,

RAD 2-0984
5 63

DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO 1885B	MEMO NO	SECTION NO	CONTINUATION SHEET PAGE 2 OF 3 PAGES

N = ________, ________, ________, ________, ________,
________, ________, ________, ________, ________,

BSHØCT = ________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________, ________,

MM = ________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________, ________,

NN = ________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________, ________,

RWØ = ________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________, ________,

XJ = ________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________, ________,

RAD 2-0964
5 63

DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO	MEMO NO	SECTION NO	CONTINUATION SHEET PAGE 3 OF 3 PAGES

DTDSTB = __________, __________, __________, __________, __________,
__________, __________, __________, __________, __________,
__________, __________, __________, __________, __________,
__________, __________, __________, __________, __________,
__________, __________, __________, __________, __________,

RTBL = __________, __________, __________, __________, __________,
__________, __________, __________, __________, __________,
__________, __________, __________, __________, __________,
__________, __________, __________, __________, __________,
__________, __________, __________, __________, __________,

TABLE __________, __________, __________, __________, __________,
__________, __________, __________, __________, __________,
__________, __________, __________, __________, __________,
__________, __________, __________, __________, __________,
__________, __________, __________, __________, __________,

XTBL = __________, __________, __________, __________, __________,
__________, __________, __________, __________, __________,
__________, __________, __________, __________, __________,
__________, __________, __________, __________, __________,
__________, __________, __________, __________, __________,

$

RAD 2-0963
5 63

DIGITAL COMPUTER INPUT REQUEST FORM		PROBLEM NO 1885A			PROGRAMMER		
		TITLE					
MEMO NO PL169	SECTION NO K420	WORK ORDER NO W305-050-0005	(E240 USE ONLY)	REQUESTED BY P. Levine	EXT 2996	EST TIME	PAGE 1 OF 1 PAGES

$INPUT

DATE = ________,
DELAL = ________,
ILAST = 1.,
INSTØP = ________,
PRTAB = ________,
PRTAPE = ________,

MEMØ = ________,
RHØA = 4.4E-07,
TA = 200.0,
V = 12874,
XA = ________,
XC = 0.20,

CASE = 1.0,
XN = 0.80,
XØ = ________,
XPEVER = ________,
XPLAST = ________,

$

RAD 2-0963
5 63

DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO 1885B			PROGRAMMER			
	TITLE						
MEMO NO PL169	SECTION NO K420	WORK ORDER NO W305-050-0005	(E240 USE ONLY)	REQUESTED BY P. Levine	EXT 2996	EST TIME	PAGE 1 OF 3 PAGES

$INPUT

DATE = ______,
BETA = ______,
CØMQRD = 1.,
DN2 = ______,
ENTH = ______,
GAMSØ = ______,
HDHS90 = ______,
ILAST = 1.0,
LC = ______,
LE = 1.4,
LX = 0.52,
MACH = ______,
NALPHA = 9,
PN = 0.7,
PRES = ______,

MEMØ = ______,
RA = ______,
RB = ______,
RC = 7.5,
RHØA = ______,
RN = 1.25,
RSB = .15,
RSC = .15,
RSN = ______,
RT = 3.75,
TA = ______,
TAPE = ______,
TB = 1000.0,
THA = -80.0,
THB = ______,

CASE = 1.0,
THC = ______,
THETAT = ______,
THN = 60.0,
TH2G = ______,
TH3G = ______,
TTØ = 0.,
UP2 = ______,
V = ______,
XA = ______,
XC = ______,
XM ______ = ______,
XN = ______,
XØ = ______,
XØTBL = ______,

ALPHA = 0., 10., 20., 30., 40.,
60., 90., 120., 150., ______,

DELT = ______, ______, ______, ______, ______,
______, ______, ______, ______, ______,

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RAD 2-0964
5-63

DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO 1885B	MEMO NO. PL169	SECTION NO K420	CONTINUATION SHEET PAGE 2 OF PAGES 3

N = 20., 0., 20.1, 20., 0.,
0., 0., 20., 20., 20.2,

BSHØCT = , , , , ,
, , , , ,
, , , , ,
, , , , ,

MM = 20*1., , , , ,
, , , , ,
, , , , ,
, , , , ,

NN = 20 * 1., , , , ,
, , , , ,
, , , , ,
, , , , ,

RWØ = , , , , ,
, , , , ,
, , , , ,
, , , , ,

XJ = 5 * 1., 5 * 0., 5 * 1., 5 * 0., ,
, , , , ,
, , , , ,
, , , , ,

RAD 2 0984
5-63

DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO 1885B	MEMO NO PL 169	SECTION NO K420	CONTINUATION SHEET PAGE 3 OF 3 PAGES

DTDSTB = ________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________, ________,

RTBL = ________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________, ________,

TABLE = ________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________, ________,

XTBL = ________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________, ________,
________, ________, ________, ________, ________,

$

```
        *      DATE 07/05/66  JOB NO. 68 REMOVE BEFORE RESUBMITTING
        *SILLERS  63                                                 027230        070555
        *     GOING TO IBSYS
        *     IBSYS
```

```
                $JOB
                $ATTACH         A5
                $AS             SYSUT5
                $EXECUTE        IBJOB
   IBJOB VERSION 5 HAS CONTROL.
   $IBJOB          GO,MAP,NOSOURCE
```

```
                     * MEMORY MAP *

   SYSTEM                                  00000 THRU  02717
   FILE BLOCK ORIGIN                       02720
   FILES          1.      UNIT08
                  2.      UNIT05
                  3.      UNIT06
   FILE LIST ORIGIN                        02764
   PRE-EXECUTION INITIALIZATION            02772
   CALL ON OBJECT PROGRAM                  03023
   OBJECT PROGRAM                          03030 THRU  51431

         DECK   ORIGIN        CONTROL SECTIONS  (/NAME/=NON O LENGTH, (LOC)=DELETED, *=NOT REFERENCED)

     1. 1885A   03030        ......  04456 *
     2. UN08    04474        .UN08.  04474
     3. SOBLIK  04475        OBLIK   07210
     4. SFINDT  07405        FINDT   07636
     5. SHVST   07752        HVST    13741
     6. SZONES  14757        ZONES   20513
     7. SGETQ   20656        GETQ    22732
     8. SGETK   23054        GETK    23435
     9. SFINDH  23546        FINDH   24105
    10. SHEAT2  24222        HEAT2   25031
    11. SPHIL   25214        PHIL    25430
    12. SGETN   25474        GETN    27400
    13. SARTLU  27443        ARTLU   27655
    14. .LXCON  30026        .LXSTR  30026 *   .LXSTP  30032     .LXOUT  30100     .LXRTN  30112     IBEXIT  30112 *
                             .LXCAL  30115 *   .LXERR  30115     .DBCLS  30277 *   .LXARG  30446     .LO     30471 *
                             .CLSE   30477     .LFBL   30500 *   .LUNB   30501     .DFOUT  30502
    15. .IODEF  30506        .DEFIN  30505     .ATTAC  30512 *   .CLOSE  30514     .OPEN   30516     .READ   30520
                             .WRITE  30522     .BSR    30532 *   .READR  30542     .RELES  30544 *   .LAREA  30555
                             .LFBLK  30573     .LTSX   30576 *   .AREA1  30610     .LONBL  30616     .ENTRY  30622
                             .GOA    30655     .GO     30661     .DERR   30675     .NOPXI  30676     .COMXI  30700
                             .EX34   30722
    16. .LXSL   30727        .LXSEL  30727     LXCSEL  30730     .LXTST  30733 *   .LXOVL  30773 *   .LXRCT  31004 *
                             .LXIND  31053 *   .LXDIS  31056 *   .LXFLG  31057 *   .LTCH   31050
    17. .FPTRP  31066        .FFPT.  31066 *   .FPOUT  31225     .FPARS  31244    /.COUNT/ 31246 *   OVFLOW  31317 *
    18. .ERAS.  31326        E.1     31326     E.2     31327     E.3     31330     E.4     31331
    19. .XCC.   31332        CC.1    31332     CC.2    31333     CC.3    31334     CC.4    31335
    20. XIT     31336        EXIT    31336     .EXIT.  31336 *
    21. FXEM    31337        .FXEM.  31337     .FXOUT  31674     .FXARG  31702    /.OPTW./ 31756
    22. FOUT    31767        .FOUT.  31767
    23. FCNV    32330        .FCON.  32330     .FCNV.  32353     .ENDFS  32365     .CNVSW  32370     .FDX1   32374
                             .FDX2   32375     .DBC    32377     .DBC10  32535     .DBC20  32563     .DDSW   32573
                             .DDFIX  32602     .FIXSW  32610     .DDBC   32655     .DDRS1  33130     .DDRS2  33132
                             .D1     33135     .D2     33137     .FERR2  33224 *   .ANPT   33250     .ONPT   33275
                             .LNTP   33360     .AOUT   33427     .DFLT   33445     .FLT    33601     .DEXPN  33671
                             .FXD    33672     .HOUT   34072     .INTG   34072     .LOUT   34210     .DOUT   34227
                             .XCF    34250     .TEST   34767     .KOUNT  34772     .LIST   34775     .DONE   35006
                             .OUTBF  35052     .BUF    35102     .QSTO   35103     .WIDTH  35104     .GAIN   35105
                             .GAIN1  35106     .FBDBF  35116     .DDDFL  35142     .DDFLG  35143     .MOD    35144
                             .PEX    35145     .FEXP   35146     .DIG    35147
    24. FIOB    35165        .FIOB.  35165     .FCNT   35270 *   .FBLT.  35355     .FRDT.  35406     .FRLR.  35432
                             .FRLR. (35432)    .FWLR.  35476     .FWLR. (35476)    .FBIBF  35536     .FRITE  35630
    25. FIOS    35636        .FIOS.  35635     .FSEL.  35776     .FILR.  36002     .FRTB.  36011     .FRTD.  36016
```

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```
              IBLDR                                                          12/01/64                              PAGE  2

                                  .FILL.  36021        .FCLS   36023 *    .FOPN   35027 *    REOF    36033 *    .TOUT.  36176
                                  .REFD   36204 *      .BIN    36205 *    .FCT    36206      .FCKSZ  36210
    26. FIOH     36272            .FIOH.  36272        .FFIL.  37057      .FRTN.  37104 *
    27. FWRD     37302            .FWRD.  37302
    28. FWRB     37326            .FWRB.  37326
    29. FWRU     37352            .FWRU.  37352
    30. FWRO     37376            .FWRO.  37376        .FREST  37701 *
    31. FRDU     40003            .FRDU.  40003
    32. UN05     40044            .UN05.  40044
    33. UN06     40045            .UN06.  40045        .BUFSZ  40046
    34. FIOU     40051            .FIOU.  40051        .CTUID  40524      .NMLST  40547      .NAME.  41652      .INTAP  41653
    35. JASIN    42276            ASINR   42356 *      ASIN    42365 *    ASIND   42374
    36. JTNQR    42403            ATANQR  42461        ATANQ   42470 *    ATANQD  42477
    37. JPLRT    42506            POLROT  43673
    38. JCDIV    43746            COMDIV  44007
    39. JPRT1    44045            POLRT1  44230
    40. FLOG     44327            ALOG10  44327 *      ALOG    44330
    41. FXPF     44533            EXP     44533
    42. FSCN     44653            COS     44653        SIN     44655
    43. FSQR     45064            SQRT    45064
    44. FATN     45171            ATAN2   45171        ATAN    45173 *
    45. FXP3     45377            .XP3.   45377
    46. FRWT     45524            .FRWT.  45524
    47. .IOCS    45631            .L(0)   45631        .MONSW  45651      .TEOR   45720      .DEFI.  46000      .JOINX  46044 *
                                  .CLOS.  46063        .ATTC.  46076      .SH1    46310 *    .SH9    46352 *    .OPEN.  46373
                                  .OP4    46421 *      .OP7    46452 *    .OP9.2  46455 *    .RLSE.  46540      .RER2.  46540
                                  .READ.  46541        .RER1.  46564      .WRIT.  46556      .MNT1A  46754 *    .EOFEX  47035 *
                                  .FEEIT  47105        .GTIDX  47126      .RW7    47244 *    .RE7    47567 *    .ENDTR  50330
                                  .SEL59  50332 *      .BSR.   50743      .EOTOF  51070      .ETOF3  51076 *    .SWITC  51125
                                  .TCHEX  51426        .BASIO  51431 *
    48. .IOCSM   51432

  I/O BUFFERS                             51432 THRU  77613

  UNUSED CORE                             77614 THRU  77777
```

```
 $INPUT
 RHOA    =          +0.44000000F-06,
 V       =          +0.12874000E+05,
 XA      =          +0.00000000E-38,
 XC      =          +0.20000000E+00,
 XN      =          +0.80000000E+00,
 XO      =          +0.00000000E-38,
 XPLAST  =          +0.00000000E-38,
 XPEVER  =          +0.00000000E-38,
 DECAL   =          +0.20000000E+01,
 TA      =          +0.20000000E+03,
 PRTAB   =          +0.10000000E+01,
 PRTAPE  =          +0.10000000E+01,
 ILAST   =                        1,
 INSTOP  =          +0.10000000E+01,
 DATE    =          +0.75000000E+01,
 MEMO    =          +0.00000000E-38,
 CASE    =          +0.10000000E+01,
 $ END
```

```
  TH W     RW/RA    RWUW/RAV   TH WL  GAMMA W      TW        PW/PO      HW/H      RWS/RA     PWS/PO      TWS        IW         IB

 +90.00 +1.21E+01 +1.00E+00  +0.00 +1.18E+00 +3.66E+03 +3.17E-02 +9.93E-01 +1.25E+01 +3.32E-02 +3.69E+03 +1.74E-03 +1.74E-03
 +88.00 +1.13E+01 +1.07E+00 +19.48 +1.18E+00 +4.57E+03 +3.15E-02 +9.91E-01 +1.13E+01 +3.33E-02 +4.61E+03 +0.00E-39 +0.00E-39
 +86.00 +1.10E+01 +1.26E+00 +33.62 +1.19E+00 +4.65E+03 +3.13E-02 +9.87E-01 +1.13E+01 +3.39E-02 +4.71E+03 +0.00E-39 +0.00E-39
 +84.00 +1.08E+01 +1.50E+00 +42.58 +1.19E+00 +4.71E+03 +3.10E-02 +9.81E-01 +1.19E+01 +3.49E-02 +4.81E+03 +0.00E-39 +0.00E-39
 +82.00 +1.06E+01 +1.77E+00 +48.01 +1.20E+00 +4.77E+03 +3.07E-02 +9.73E-01 +1.21E+01 +3.63E-02 +4.90E+03 +0.00E-39 +0.00E-39
 +80.00 +1.03E+01 +2.05E+00 +51.24 +1.20E+00 +4.81E+03 +3.03E-02 +9.62E-01 +1.25E+01 +3.82E-02 +5.00E+03 +0.00E-39 +0.00E-39
 +78.00 +1.01E+01 +2.32E+00 +53.08 +1.21E+00 +4.84E+03 +2.98E-02 +9.49E-01 +1.30E+01 +4.05E-02 +5.10E+03 +0.00E-39 +0.00E-39
 +76.00 +9.92E+00 +2.59E+00 +53.99 +1.21E+00 +4.85E+03 +2.93E-02 +9.34E-01 +1.37E+01 +4.33E-02 +5.20E+03 +0.00E-39 +0.00E-39
 +74.00 +9.73E+00 +2.85E+00 +54.28 +1.22E+00 +4.85E+03 +2.87E-02 +9.15E-01 +1.45E+01 +4.68E-02 +5.29E+03 +0.00E-39 +0.00E-39
 +72.00 +9.54E+00 +3.10E+00 +54.12 +1.22E+00 +4.83E+03 +2.80E-02 +8.97E-01 +1.55E+01 +5.09E-02 +5.39E+03 +0.00E-39 +0.00E-39
 +70.00 +9.36E+00 +3.34E+00 +53.64 +1.23E+00 +4.80E+03 +2.73E-02 +8.75E-01 +1.63E+01 +5.58E-02 +5.48E+03 +0.00E-39 +0.00E-39
 +68.00 +9.18E+00 +3.56E+00 +52.91 +1.23E+00 +4.76E+03 +2.65E-02 +8.53E-01 +1.82E+01 +6.17E-02 +5.57E+03 +0.00E-39 +0.00E-39
 +66.00 +9.01E+00 +3.78E+00 +52.01 +1.24E+00 +4.70E+03 +2.57E-02 +8.29E-01 +1.99E+01 +6.86E-02 +5.67E+03 +0.00E-39 +0.00E-39
 +64.00 +8.85E+00 +3.98E+00 +50.95 +1.24E+00 +4.62E+03 +2.48E-02 +8.02E-01 +2.20E+01 +7.69E-02 +5.76E+03 +0.00E-39 +0.00E-39
 +62.00 +8.69E+00 +4.17E+00 +49.79 +1.25E+00 +4.53E+03 +2.39E-02 +7.75E-01 +2.45E+01 +8.69E-02 +5.85E+03 +0.00E-39 +0.00E-39
 +60.00 +8.53E+00 +4.35E+00 +48.53 +1.25E+00 +4.43E+03 +2.29E-02 +7.46E-01 +2.74E+01 +9.88E-02 +5.94E+03 +0.00E-39 +0.00E-39
 +58.00 +8.38E+00 +4.52E+00 +47.19 +1.26E+00 +4.32E+03 +2.19E-02 +7.16E-01 +3.09E+01 +1.13E-01 +6.03E+03 +0.00E-39 +0.00E-39
 +56.00 +8.24E+00 +4.68E+00 +45.80 +1.26E+00 +4.19E+03 +2.09E-02 +6.85E-01 +3.52E+01 +1.31E-01 +6.12E+03 +0.00E-39 +0.00E-39
 +54.00 +8.09E+00 +4.82E+00 +44.35 +1.27E+00 +4.05E+03 +1.99E-02 +6.53E-01 +4.03E+01 +1.52E-01 +6.21E+03 +0.00E-39 +0.00E-39
 +52.00 +7.95E+00 +4.96E+00 +42.85 +1.27E+00 +3.91E+03 +1.88E-02 +6.21E-01 +4.55E+01 +1.77E-01 +6.30E+03 +0.00E-39 +0.00E-39
 +50.00 +7.81E+00 +5.08E+00 +41.33 +1.27E+00 +3.75E+03 +1.78E-02 +5.87E-01 +5.41E+01 +2.09E-01 +6.38E+03 +0.00E-39 +0.00E-39
 +48.00 +7.68E+00 +5.19E+00 +39.77 +1.28E+00 +3.58E+03 +1.67E-02 +5.54E-01 +6.34E+01 +2.49E-01 +6.47E+03 +0.00E-39 +0.00E-39
 +46.00 +7.54E+00 +5.29E+00 +38.18 +1.28E+00 +3.41E+03 +1.56E-02 +5.20E-01 +7.50E+01 +2.98E-01 +6.56E+03 +0.00E-39 +0.00E-39
 +44.00 +7.41E+00 +5.37E+00 +36.57 +1.29E+00 +3.23E+03 +1.45E-02 +4.87E-01 +8.95E+01 +3.60E-01 +6.64E+03 +0.00E-39 +0.00E-39
 +42.00 +7.27E+00 +5.45E+00 +34.94 +1.29E+00 +3.05E+03 +1.34E-02 +4.53E-01 +1.08E+02 +4.39E-01 +6.73E+03 +0.00E-39 +0.00E-39
 +40.00 +7.14E+00 +5.51E+00 +33.30 +1.30E+00 +2.86E+03 +1.24E-02 +4.20E-01 +1.31E+02 +5.40E-01 +6.81E+03 +0.00E-39 +0.00E-39
 +38.00 +7.01E+00 +5.56E+00 +31.64 +1.30E+00 +2.66E+03 +1.13E-02 +3.87E-01 +1.51E+02 +6.71E-01 +6.89E+03 +0.00E-39 +0.00E-39
 +36.00 +6.87E+00 +5.59E+00 +29.96 +1.31E+00 +2.47E+03 +1.03E-02 +3.54E-01 +1.99E+02 +8.42E-01 +6.98E+03 +0.00E-39 +0.00E-39
 +34.00 +6.73E+00 +5.61E+00 +28.28 +1.31E+00 +2.28E+03 +9.29E-03 +3.23E-01 +2.50E+02 +1.07E+00 +7.06E+03 +0.00E-39 +0.00E-39
 +32.00 +6.59E+00 +5.61E+00 +26.58 +1.32E+00 +2.08E+03 +8.33E-03 +2.92E-01 +3.17E+02 +1.37E+00 +7.14E+03 +0.00E-39 +0.00E-39
 +30.00 +6.44E+00 +5.60E+00 +24.87 +1.32E+00 +1.89E+03 +7.40E-03 +2.62E-01 +4.08E+02 +1.79E+00 +7.22E+03 +0.00E-39 +0.00E-39
 +28.00 +6.28E+00 +5.56E+00 +23.16 +1.33E+00 +1.71E+03 +6.51E-03 +2.34E-01 +5.31E+02 +2.35E+00 +7.30E+03 +0.00E-39 +0.00E-39
 +26.00 +6.11E+00 +5.51E+00 +21.43 +1.33E+00 +1.53E+03 +5.66E-03 +2.07E-01 +7.03E+02 +3.15E+00 +7.38E+03 +0.00E-39 +0.00E-39
 +24.00 +5.92E+00 +5.42E+00 +19.70 +1.34E+00 +1.35E+03 +4.86E-03 +1.81E-01 +9.44E+02 +4.28E+00 +7.46E+03 +0.00E-39 +0.00E-39
 +22.00 +5.71E+00 +5.31E+00 +17.95 +1.34E+00 +1.18E+03 +4.11E-03 +1.57E-01 +1.29E+03 +5.90E+00 +7.54E+03 +0.00E-39 +0.00E-39
 +20.00 +5.48E+00 +5.16E+00 +16.20 +1.35E+00 +1.03E+03 +3.41E-03 +1.35E-01 +1.79E+03 +8.29E+00 +7.62E+03 +0.00E-39 +0.00E-39
 +18.00 +5.21E+00 +4.96E+00 +14.43 +1.35E+00 +8.78E+02 +2.78E-03 +1.14E-01 +2.52E+03 +1.18E+01 +7.70E+03 +0.00E-39 +0.00E-39
 +16.00 +4.89E+00 +4.71E+00 +12.64 +1.36E+00 +7.41E+02 +2.20E-03 +9.53E-02 +3.60E+03 +1.70E+01 +7.77E+03 +0.00E-39 +0.00E-39
 +14.00 +4.50E+00 +4.37E+00 +10.83 +1.36E+00 +6.17E+02 +1.69E-03 +7.86E-02 +5.20E+03 +2.48E+01 +7.85E+03 +0.00E-39 +0.00E-39
 +12.00 +4.03E+00 +3.95E+00  +8.98 +1.37E+00 +5.06E+02 +1.24E-03 +6.39E-02 +7.43E+03 +3.60E+01 +7.92E+03 +0.00E-39 +0.00E-39
 +10.00 +3.44E+00 +3.40E+00  +7.07 +1.37E+00 +4.10E+02 +8.57E-04 +5.13E-02 +1.05E+04 +5.11E+01 +8.00E+03 +0.00E-39 +0.00E-39
  +8.00 +2.73E+00 +2.71E+00  +5.05 +1.38E+00 +3.28E+02 +5.42E-04 +4.07E-02 +1.39E+04 +6.81E+01 +8.08E+03 +0.00E-39 +0.00E-39
  +6.00 +1.89E+00 +1.89E+00  +2.82 +1.38E+00 +2.61E+02 +2.97E-04 +3.20E-02 +1.53E+04 +8.01E+01 +8.15E+03 +0.00E-39 +0.00E-39
  +4.00 +1.01E+00 +1.01E+00  +0.05 +1.38E+00 +2.01E+02 +1.21E-04 +2.44E-02 +1.58E+04 +7.73E+01 +8.22E+03 +0.00E-39 +0.00E-39
  +3.97 +1.00E+00 +1.00E+00  +0.00 +1.38E+00 +2.00E+02 +1.19E-04 +2.43E-02 +1.57E+04 +7.72E+01 +8.22E+03 +0.00E-39 +0.00E-39
```

```
158 LINES OUTPUT.
   $IBSYS
   $PAUSE
   OPER. ACTION PAUSE

   ..CONTINUING

   $PAUSE
   OPER. ACTION PAUSE

   ..CONTINUING

   $IBSYS
000000000000000000009800001I-0101GQ00000080001F0000000IBSYST-000010000027343000000000 )
     1 LINES OUTPUT THIS JOB.
```

```
$IBLDR SGETB                                                  12/01/64    SGET0000
$IBLDR SGETOR                                                 12/01/64    SGET0000
$IBLDR SFINDR                                                 12/01/64    SFIN0000
$DATA
```

456

-54-

```
                     * MEMORY MAP *

 SYSTEM                                  00000 THRU  02717
 FILE BLOCK ORIGIN                       02720
 FILES           1.     UNIT08
                 2.     UNIT05
                 3.     UNIT06
 FILE LIST ORIGIN                        02764
 PRE-EXECUTION INITIALIZATION            02772
 CALL ON OBJECT PROGRAM                  03023
 OBJECT PROGRAM                          03030 THRU  70731

        DECK  ORIGIN        CONTROL SECTIONS  (/NAME/=NON 0 LENGTH, (LOC)=DELETED, *=NOT REFERENCED)

   1. 1885    03030       ///     /(75154)     ......  16437 *
   2. SARTLU  16455        ARTLU   16667
   3. SADAMS  17040        ADAMS4  22220
   4. SPREP   22360       ///     /(75154)     PREP    24536
   5. UN08    25146        .UN08.  25146
   6. STABLE  25147        TABLES  27074
   7. SDERQ5  30451       ///     /(75154)     DERQ5   30614
   8. SWIND   30637       ///     /(75154)     WIND    31650
   9. SQCONV  32072        QCONV   32750
  10. SSUB11  33143       ///     /(75154)     SUB110  40267
  11. SHDPRN  40305        HDPRN1  40367
  12. SGETDS  40423        GETDS   41245
  13. SQRCLE  41423        QRCLER  41446
  14. SQRNMA  41474        QRNMAD  41523
  15. SSTAGP  41551       ///     /(75154)     STAGPT  42453
  16. SGETPR  42574        GETPRE  42656
  17. SGETNU  42723        GETNU   43005
  18. SGETTO  43052        GETTOT  43167
  19. SLEE    43306       ///     /(75154)     LEE     44303
  20. SACOSH  44524        ACOSH   44671
  21. SGETB   44717        GETB    45072
  22. SGETQR  45167        GETQRS  46451
  23. SFINDR  46670        FINDRW  50413
  24. .LXCON  50606        .LXSTR  50606 *     .LXSTP  50612       .LXOUT  50650       .LXRTN  50672       IBEXIT  50672 *
                           .LXCAL  50675 *     .LXERR  50675       .DBCLS  51057 *     .LXARG  51225       .LO     51251 *
                           .CLSE   51257       .LFBL   51260 *     .LUNB   51251       .DFOUT  51262
  25. .IODEF  51266        .DEFIN  51266       .ATTAC  51272 *     .CLOSE  51274       .OPEN   51276       .READ   51300
                           .WRITE  51302       .BSR    51312 *     .READR  51322       .RELES  51324 *     .LAREA  51335
                           .LFBLK  51353       .LTSX   51356 *     .AREA1  51370       .LUNBL  51376       .ENTRY  51402
                           .GOA    51435       .GO     51441       .DERR   51455       .NOPXI  51456       .COMXI  51450
                           .EX34   51502
  26. .LXSL   51507        .LXSEL  51507       LXCSEL  51510       .LXTST  51513 *     .LXOVL  51553 *     .LXRCT  51564 *
                           .LXIND  51633 *     .LXDIS  51636 *     .LXFLS  51637 *     .LTCH   51640
  27. .FPTRP  51646        .FFPT.  51645 *     .FPOUT  52005       .FPARG  52024      /.COUNT/ 52026 *     OVFLOW  52077 *
  28. .ERAS.  52106        E.1     52106       E.2     52107       E.3     52110       E.4     52111
  29. .XCC.   52112        CC.1    52112       CC.2    52113       CC.3    52114       CC.4    52115
  30. XIT     52116        EXIT    52116       .EXIT.  52116 *
  31. FXEM    52117        .FXEM.  52117       .FXOUT  52454       .FXARG  52452      /.OPTW./ 52536
  32. FOUT    52547        .FOUT.  52547
  33. FCNV    53110        .FCON.  53110       .FCNV.  53133       .ENDFS  53145       .CNVSW  53150       .FDX1   53154
                           .FDX2   53155       .DBC    53157       .DBC10  53315       .DBC20  53343       .DDSW   53353
                           .DDFIX  53362       .FIXSW  53370       .DDBC   53445       .DDRS1  53710       .DDRS2  53712
```

```
                          .D1      53715     .D2      53717     .FERR2   54004 *   .ANPT    54040     .DNPT    54055
                          .LNTP    54140     .AOUT    54207     .DFLT    54225     .FLT     54361     .DFXPN   54451
                          .FXD     54452     .HOUT    54602     .INTG    54652     .LOUT    54770     .DOUT    55007
                          .XCF     55040     .TEST    55547     .KOUNT   55552     .LIST    55555     .DONF    55556
                          .OUTBF   55632     .BUF     55662     .QSTO    55653     .WIDTH   55664     .GAIN    55665
                          .GAIN1   55665     .FBOBF   55676     .DDDFL   55722     .DDFLG   55723     .MOD     55724
                          .PEX     55725     .FEXP    55726     .DIG     55727
  34. FIOB     55745      .FIOB.   55745     .FCNT    56050     .FBLT.   56145     .FBDT.   56166     .FRLR.   56212
                          .FRLR. (56212)     .FWLR.   56256     .FWLR. (56255)     .FBIBF   56316     .FRITE   56410 *
  35. FIOS     56416      .FIOS.   56415     .FSEL.   56556     .FILR.   56552     .FRTB.   56571 *   .FRTD.   56576
                          .FILL.   56601     .FCLS    56603 *   .FOPN    56607 *   REDF     56513 *   .TOUT.   56756
                          .REFD    56764 *   .BIN     56765 *   .FCT     56755     .FCKSZ   56770
  36. FIOH     57052      .FIOH.   57052     .FFIL.   57637     .FRTN.   57654 *
  37. FWRD     60062      .FWRD.   60062
  38. FRDB     60106      .FRDB.   60105
  39. FWRU     60132      .FWRU.   60132
  40. FWRO     60156      .FWRO.   60156     .FREST   60461 *
  41. FRDU     60563      .FRDU.   60563
  42. UNO5     60624      .UNO5.   60624
  43. UNO6     60625      .UNO6.   60625     .BUFSZ   60626
  44. FIOU     60631      .FIOU.   60631     .CTUIO   61304     .NMLST   61327     .NAME.   62432     .INTAP   62433
  45. JASIN    63056      ASINR    63135 *   ASIN     63145     ASIND    63154
  46. JTNQR    63163      ATANQR   63241     ATANQ    63250 *   ATANQD   63257
  47. FLOG     63266      ALOG10   63265 *   ALOG     63267
  48. FXPF     63472      EXP      63472
  49. FSCN     63612      COS      63612     SIN      63614
  50. FSQR     64023      SQRT     64023
  51. FATN     64130      ATAN2    64130     ATAN     64132 *
  52. FXP2     64336      .XP2.    64336
  53. FXP3     64454      .XP3.    64454
  54. FRWT     64601      .FRWT.   64601
  55. FTNC     64706      COTAN    64705     TAN      64707     CRIT     65052 *
  56. .IOCS    65131      .L(0)    65131     .MONSW   65151     .TEOR    65220     .DEFI.   65300     .JOINX   65344 *
                          .CLOS.   65363     .ATTC.   65376     .SH1     65610 *   .SH9     65652 *   .OPEN.   65673
                          .OP4     65721 *   .OP7     65752 *   .OP9.2   65756 *   .RLSE.   66040     .RER2.   66040
                          .READ.   66041     .RER1.   66064     .WRIT.   66055     .MNTIA   66254 *   .EOFEX   66335 *
                          .FEEIT   66405     .GTIOX   66426     .RW7     65544 *   .RE7     67167 *   .ENDTR   67630
                          .SEL59   67632 *   .BSR.    70243     .FOTOF   70370     .ETOF3   70376 *   .SWITC   70425
                          .TCHEX   70726     .BASIO   70731 *
  57. .IOCSM   70732
  58. //       75154

 I/O BUFFERS                        70732 THRU  75044

 UNUSED CORE                        75045 THRU  75153
```

```
$INPUT
DATE    =        +0.75000000E+01,     -0.00000000E-19,
MEMO    =        +0.00000000E-38,     -0.00000000E-19,
CASE    =        +0.10000000E+01,
N       =        +0.10000000E+02,     +0.00000000E-38,     +0.10100000E+02,     +0.10000000E+02,     +0.00000000E-38,
                 +0.00000000E-38,     +0.00000000E-38,     +0.10000000E+02,     +0.10000000E+02,     +0.10200000E+02,
RN      =        +0.12500000E+01,
RSN     =        +0.00000000E-38,
THC     =        +0.00000000E-38,
RC      =        +0.75000000E+01,
RSC     =        +0.15000000E+00,
LC      =        +0.00000000E-38,
THB     =        +0.00000000E-38,
RSB     =        +0.15000000E+00,
RB      =        +0.00000000E-38,
THA     =        -0.80000000E+02,
RA      =        +0.00000000E-38,
RT      =        +0.37500000E+01,
BETA    =        +0.00000000E-38,
TH2G    =        +0.00000000E-38,
TH3G    =        +0.00000000E-38,
XA      =        +0.00000000E-38,
XO      =        +0.00000000E-38,
XC      =        +0.00000000E-38,
XN      =        +0.00000000E-38,     -0.00000000E-19,     -0.00000000E-19,     -0.00000000E-19,     -0.00000000E-19,
                 -0.00000000E-19,     -0.00000000E-19,     -0.00000000E-19,     -0.00000000E-19,     -0.00000000E-19,
RHOA    =        +0.00000000E-38,
TA      =        +0.00000000E-38,
V       =        +0.00000000E-38,
TB      =        +0.10000000E+04,
THN     =        +0.60000000E+02,
GAMSO   =        +0.00000000E-38,
```

```
 XDTBL  =     +0.00000000E-38,

 XTBL   =     +0.00000000E-38,    +0.00000000E-38,    +0.00000000E-38,    +0.00000000E-38,    +0.00000000E-38,
              +0.00000000E-38,    +0.00000000E-38,    +0.00000000E-38,    +0.00000000E-38,    +0.00000000E-38,
              +0.00000000E-38,    +0.00000000E-38,    +0.00000000E-38,    +0.00000000E-38,    +0.00000000E-38,
              +0.00000000E-38,    +0.00000000E-38,    +0.00000000E-38,    +0.00000000E-38,    +0.00000000E-38,
              +0.00000000E-38,    +0.00000000E-38,    +0.00000000E-38,    +0.00000000E-38,    +0.00000000E-38,

 RTBL   =     +0.00000000E-38,    +0.00000000E-38,    +0.00000000E-38,    +0.00000000E-38,    +0.00000000E-38,
              +0.00000000E-38,    +0.00000000E-38,    +0.00000000E-38,    +0.00000000E-38,    +0.00000000E-38,
              +0.00000000E-38,    +0.00000000E-38,    +0.00000000E-38,    +0.00000000E-38,    +0.00000000E-38,
              +0.00000000E-38,    +0.00000000E-38,    +0.00000000E-38,    +0.00000000E-38,    +0.00000000E-38,
              +0.00000000E-38,    +0.00000000E-38,    +0.00000000E-38,    +0.00000000E-38,    +0.00000000E-38,

 DTDSTB =     +0.00000000E-38,    +0.00000000E-38,    +0.00000000E-38,    +0.00000000E-38,    +0.00000000E-38,
              +0.00000000E-38,    +0.00000000E-38,    +0.00000000E-38,    +0.00000000E-38,    +0.00000000E-38,
              +0.00000000E-38,    +0.00000000E-38,    +0.00000000E-38,    +0.00000000E-38,    +0.00000000E-38,
              +0.00000000E-38,    +0.00000000E-38,    +0.00000000E-38,    +0.00000000E-38,    +0.00000000E-38,
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 PN     =     +0.70000000E+00,

 LE     =     +0.14000000E+01,

 LX     =     +0.52000000E+00,

 THETAT =     +0.00000000E-38,

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DN2    =  +0.10000000E-03,
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 $ END


   CASE  +1.00      MEMO  +0.00      DATE  +7.50                                                   PAGE  1


      XOTBL            YOTBL            SOTBL           DT/DSTBL         THETOTBL       MOTBL
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   +1.7130934E-03   +6.5419983E-02   +6.5449846E-02   -8.0000000E-01   +8.7000000E+01     1
   +6.8476424E-03   +1.3066062E-01   +1.3089969E-01   -8.0000000E-01   +8.4000000E+01     1
   +1.5389584E-02   +1.9554309E-01   +1.9634954E-01   -8.0000000E-01   +8.1000000E+01     1
   +2.7315505E-02   +2.5988962E-01   +2.6179938E-01   -8.0000000E-01   +7.8000000E+01     1
   +4.2592725E-02   +3.2352381E-01   +3.2724923E-01   -8.0000000E-01   +7.5000000E+01     1
   +6.1179362F-02   +3.8627125E-01   +3.9269907E-01   -8.0000000E-01   +7.2000000E+01     1
   +8.3024483E-02   +4.4795994E-01   +4.5814892E-01   -8.0000000E-01   +6.9000000E+01     1
   +1.0806819E-01   +5.0842081E-01   +5.2359877E-01   -8.0000000E-01   +6.6000000E+01     1
   +1.3624186E-01   +5.6748813E-01   +5.8904861E-01   -8.0000000E-01   +6.3000000E+01     1
   +1.6746826E-01   +6.2500001E-01   +6.5449845E-01   +0.0000000E-39   +5.0000000E+01     3
   +5.6006644E-01   +1.3050000E+00   +1.4396948E+00   +0.0000000E-39   +6.0000000E+01     3
   +9.5266461E-01   +1.9850000F+00   +2.2248911F+00   +0.0000000E-39   +5.0000000E+01     3
   +1.3452628E+00   +2.6649999E+00   +3.0100874E+00   +0.0000000E-39   +5.0000000E+01     3
   +1.7378610F+00   +3.3449999E+00   +3.7952838E+00   +0.0000000E-39   +5.0000000E+01     3
   +2.1304592E+00   +4.0249999E+00   +4.5804802E+00   +0.0000000E-39   +5.0000000E+01     3
   +2.5230573E+00   +4.7049999E+00   +5.3656764E+00   +0.0000000E-39   +5.0000000E+01     3
   +2.9156555E+00   +5.3849999E+00   +6.1508728E+00   +0.0000000E-39   +5.0000000E+01     3
   +3.3082537E+00   +6.0649999E+00   +6.9360692E+00   +0.0000000E-39   +6.0000000E+01     3
   +3.7008519E+00   +6.7449998E+00   +7.7212655E+00   +0.0000000E-39   +5.0000000E+01     3
   +4.0934501E+00   +7.4249998E+00   +8.5064619E+00   -6.6666666E+00   +5.0000000E+01     4
   +4.1020017F+00   +7.4381675F+00   +8.5221597E+00   -6.6666666E+00   +5.4000043E+01     4
   +4.1118820E+00   +7.4503693E+00   +8.5378777E+00   -6.6666666E+00   +4.8000040E+01     4
   +4.1229847E+00   +7.4614714E+00   +8.5535856E+00   -6.6666666E+00   +4.2000038E+01     4
   +4.1351860E+00   +7.4713523E+00   +8.5692935E+00   -6.6666666E+00   +3.6000035E+01     4
   +4.1483538E+00   +7.4799036E+00   +8.5850016E+00   -6.6666666E+00   +3.0000033E+01     4
   +4.1623433F+00   +7.4870316E+00   +8.6007096E+00   -6.6666666E+00   +2.4000031E+01     4
   +4.1770012E+00   +7.4926583E+00   +8.6164175F+00   -6.6666666F+00   +1.8000028E+01     4
   +4.1921670F+00   +7.4967219F+00   +8.6321255F+00   -6.6666666E+00   +1.2000025E+01     4
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 +4.2076745E+00  +7.4991781E+00  +8.6478335E+00  -6.6666666E+00  +6.0000237E+00     4
 +4.2233537E+00  +7.4999998E+00  +8.6635413E+00  -6.6666666E+00  +0.0000000E-39     8
 +4.2447296E+00  +7.4985400E+00  +8.6844852E+00  -6.6666666E+00  -7.9999729E+00     8
 +4.2646992E+00  +7.4941890E+00  +8.7054292E+00  -6.6666666E+00  -1.5999991E+01     8
 +4.2843640E+00  +7.4870316E+00  +8.7253731E+00  -6.6666666E+00  -2.3999954E+01     8
 +4.3028415E+00  +7.4772070E+00  +8.7473171E+00  -6.6666666E+00  -3.1999982E+01     8
 +4.3197717E+00  +7.4649065E+00  +8.7632510E+00  -6.6666666E+00  -3.9999955E+01     8
 +4.3348253E+00  +7.4503694E+00  +8.7892050E+00  -6.6666666E+00  -4.7999974E+01     8
 +4.3477093E+00  +7.4338787E+00  +8.8101490E+00  -6.6666666E+00  -5.5999991E+01     8
 +4.3581727E+00  +7.4157556E+00  +8.8310928E+00  -6.6666666E+00  -6.3999965E+01     8
 +4.3660121E+00  +7.3963524E+00  +8.8520368E+00  -6.6666666E+00  -7.1999983E+01     8
 +4.3710748E+00  +7.3760471E+00  +8.8729807E+00  +0.0000000E-39  -8.0000000E+01     9
 +4.4350117E+00  +7.0134425E+00  +9.2411791E+00  +0.0000000E-39  -8.0000000E+01     9
 +4.4989488E+00  +6.6508377E+00  +9.6093776E+00  +0.0000000E-39  -8.0000000E+01     9
 +4.5628858E+00  +6.2882330E+00  +9.9775761E+00  +0.0000000E-39  -9.0000000E+01     9
 +4.6268228E+00  +5.9256284E+00  +1.0345775E+01  +0.0000000E-39  -8.0000000E+01     9
 +4.6907597E+00  +5.5630236E+00  +1.0713973E+01  +0.0000000E-39  -8.0000000E+01     9
 +4.7546967E+00  +5.2004189E+00  +1.1082172E+01  +0.0000000E-39  -8.0000000E+01     9
 +4.8186337E+00  +4.8378143E+00  +1.1450370E+01  +0.0000000E-39  -8.0000000E+01     9
 +4.8825707E+00  +4.4752095E+00  +1.1818568E+01  +0.0000000E-39  -8.0000000E+01     9
 +4.9465078E+00  +4.1126047E+00  +1.2186767E+01  +0.0000000E-39  -8.0000000E+01     9
 +5.0104447E+00  +3.7500001E+00  +1.2554965E+01  +0.0000000E-39  -9.0000000E+01    10
 +5.0104447E+00  +3.3749999E+00  +1.2929965E+01  +0.0000000E-39  -9.0000000E+01    10
 +5.0104447E+00  +2.9999999E+00  +1.3304965E+01  +0.0000000E-39  -9.0000000E+01    10
 +5.0104447E+00  +2.6249999E+00  +1.3679965E+01  +0.0000000E-39  -9.0000000E+01    10
 +5.0104447E+00  +2.2499999E+00  +1.4054965E+01  +0.0000000E-39  -9.0000000E+01    10
 +5.0104447E+00  +1.8749999E+00  +1.4429965E+01  +0.0000000E-39  -9.0000000E+01    10
 +5.0104447E+00  +1.4999999E+00  +1.4804965E+01  +0.0000000E-39  -9.0000000E+01    10
 +5.0104447E+00  +1.1249999E+00  +1.5179965E+01  +0.0000000E-39  -9.0000000E+01    10
 +5.0104447E+00  +7.4999988E-01  +1.5554965E+01  +0.0000000E-39  -9.0000000E+01    10
 +5.0104447E+00  +3.7499988E-01  +1.5929965E+01  +0.0000000E-39  -9.0000000E+01    10
 +5.0104447E+00  +0.0000000E-39  +1.6304965E+01  +0.0000000E-39  -9.0000000E+01    10

 I ST     X ST           Y ST          S ST         DTDS ST       THET ST    SECT  ALPHA

    1  +0.00000E-39  +0.00000E-39  +0.00000E-39  -8.00000E-01  +9.00000E+01    1    +0.00

 IW SN    XOW SN         YOW SN        XBW SN        YBW SN        SBW SN       THETW SN    SECT  ALPHA

   23  +4.10200E+00  +7.43817E+00  +4.11026E+00  +7.44853E+00  +8.53542E+00  +4.89372E+01     4    +0.00
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 AT ALPHA =  +0.0000F-39 WINDWARD, RW =  +1.4258E+00 DFLS =  +9.0391E-02 RSHOCK =  +4.7070E+00

 DES ALO =  +2.5867E+01 DTS ALO =  +4.4360E+00 REYA =  +3.1086E+05 QRS ALD =  +2.9783E-04

 SEC     XO W        XB W        YB W        SB W     THETBW  PE/PS W     DP/DS W      QL W        QT W        RE W        QR W        XSI W

  1 +0.000E-39 +0.000E-39 +0.000E-39 +0.000E-39 +90.00 +1.000E+00 +4.809E-03 +1.000E+00 +0.000E-39 +0.000E-39 +1.000E+00 +9.089E-02
  1 +1.713E-03 +1.713E-03 +6.542E-02 +6.545E-02 +87.00 +9.973E-01 -5.857E+00 +9.967E-01 +4.899E-01 +1.473E-04 +8.211E-01 +9.101E-02
  1 +6.848E-03 +6.848E-03 +1.307E-01 +1.309E-01 +84.00 +9.891E-01 -1.157E+01 +9.872E-01 +7.380E-01 +5.857E-04 +6.832E-01 +9.142E-02
  1 +1.539E-02 +1.539E-02 +1.955F-01 +1.963E-01 +81.00 +9.755E-01 -1.735E+01 +9.532E-01 +9.294E-01 +1.301E-03 +4.532E-01 +9.233E-02
  1 +2.732E-02 +2.732E-02 +2.599E-01 +2.618E-01 +78.00 +9.568E-01 -2.233E+01 +9.479E-01 +1.089E+00 +2.282E-03 +1.278E-01 +9.402E-02
  1 +4.259E-02 +4.259E-02 +3.235E-01 +3.272E-01 +75.00 +9.330E-01 -2.836E+01 +9.376E-01 +1.223E+00 +3.506F-03 +0.000E-39 +9.681E-02
  1 +6.118E-02 +6.118E-02 +3.863E-01 +3.927E-01 +72.00 +9.045E-01 -3.299E+01 +9.217E-01 +1.335E+00 +4.942E-03 +0.000E-39 +1.011E-01
  1 +8.302E-02 +8.302E-02 +4.480E-01 +4.581E-01 +69.00 +8.715F-01 -3.756E+01 +9.011E-01 +1.425F+00 +6.559E-03 +0.000E-39 +1.071E-01
  1 +1.081E-01 +1.081E-01 +5.084E-01 +5.235E-01 +66.00 +8.346E-01 -4.171E+01 +8.762E-01 +1.497E+00 +8.317E-03 +0.000E-39 +1.153E-01
  1 +1.362E-01 +1.362E-01 +5.675E-01 +5.890E-01 +63.00 +7.939E-01 -4.541E+01 +8.477E-01 +1.550E+00 +1.017E-02 +0.000E-39 +1.259E-01
  3 +1.675E-01 +1.675E-01 +6.250E-01 +6.545E-01 +60.00 +7.500E-01 +0.000E-39 +7.516E-01 +1.586F+00 +1.209E-02 +0.000E-39 +1.392E-01
  3 +5.601E-01 +5.601E-01 +1.305E+00 +1.440E+00 +60.00 +7.500E-01 +0.000E-39 +4.345E-01 +1.354E+00 +2.658E-02 +0.000E-39 +2.611E-01
  3 +9.527E-01 +9.527E-01 +1.985E+00 +2.225E+00 +60.00 +7.500E-01 +0.000E-39 +3.709E-01 +1.241E+00 +4.108E-02 +0.000F-39 +3.525E-01
  3 +1.345E+00 +1.345E+00 +2.665E+00 +3.010E+00 +60.00 +7.500E-01 +0.000E-39 +3.218E-01 +1.169F+00 +5.557E-02 +0.000F-39 +4.347E-01
  3 +1.738E+00 +1.738E+00 +3.345E+00 +3.795E+00 +60.00 +7.500E-01 +0.000E-39 +2.882E-01 +1.116E+00 +7.007F-02 +0.000F-39 +5.130E-01
  3 +2.130E+00 +2.130E+00 +4.025E+00 +4.580E+00 +60.00 +7.500E-01 +0.000E-39 +2.633E-01 +1.074E+00 +8.456E-02 +0.000E-39 +5.893E-01
  3 +2.523E+00 +2.523E+00 +4.705E+00 +5.366E+00 +60.00 +7.500E-01 +0.000E-39 +2.438E-01 +1.041F+00 +9.906E-02 +0.000E-39 +6.644E-01
  3 +2.916E+00 +2.916E+00 +5.385E+00 +6.151E+00 +60.00 +7.500E-01 +0.000E-39 +2.281E-01 +1.013E+00 +1.136E-01 +0.000E-39 +7.389E-01
  3 +3.308E+00 +3.308E+00 +6.065E+00 +6.936E+00 +60.00 +7.500E-01 +0.000E-39 +2.151E-01 +9.889E-01 +1.281E-01 +0.000E-39 +8.128E-01
  3 +3.701E+00 +3.701E+00 +6.745E+00 +7.721E+00 +60.00 +7.500E-01 +0.000E-39 +2.041E-01 +9.679F-01 +1.425E-01 +0.000F-39 +8.864E-01
  4 +4.093E+00 +4.093E+00 +7.425E+00 +8.506E+00 +60.00 +7.500E-01 -4.051E+02 +3.547E-01 +9.493E-01 +1.570E-01 +0.000E-39 +9.597E-01
  4 +4.102E+00 +4.102E+00 +7.438E+00 +8.522E+00 +54.00 +6.545E-01 -4.449E+02 +3.475E-01 +9.960E-01 +1.721E-01 +0.000E-39 +9.769E-01
  4 +4.102E+00 +4.110E+00 +7.449E+00 +8.535E+00 +48.94 +5.685E-01 -4.633E+02 +3.382E-01 +1.000E+00 +1.786E-01 +0.000E-39 +1.002E+00
  4 +4.112E+00 +4.112E+00 +7.450E+00 +8.538E+00 +48.00 +5.539E-01 -4.652E+02 +3.425E-01 +9.976E-01 +1.791E-01 +0.000E-39 +1.007E+00
  4 +4.123E+00 +4.123E+00 +7.461E+00 +8.554E+00 +42.00 +4.497E-01 -4.652E+02 +3.083E-01 +9.556E-01 +1.778E-01 +0.000E-39 +1.053E+00
  4 +4.135E+00 +4.135E+00 +7.471E+00 +8.569E+00 +36.00 +3.478E-01 -4.449E+02 +2.713E-01 +8.729E-01 +1.681E-01 +0.000E-39 +1.117E+00
  4 +4.148E+00 +4.148E+00 +7.480E+00 +8.585E+00 +30.00 +2.706E-01 -3.037E+02 +2.237E-01 +7.800E-01 +1.545E-01 +0.000E-39 +1.204E+00
  4 +4.162E+00 +4.162E+00 +7.487E+00 +8.601E+00 +24.00 +2.097E-01 -2.452E+02 +1.882E-01 +6.853E-01 +1.391E-01 +0.000E-39 +1.321E+00
  4 +4.177E+00 +4.177E+00 +7.493E+00 +8.616E+00 +18.00 +1.599E-01 -1.967E+02 +1.555E-01 +5.910E-01 +1.225E-01 +0.000E-39 +1.480E+00
  4 +4.192E+00 +4.192E+00 +7.497E+00 +8.632E+00 +12.00 +1.210E-01 -1.570E+02 +1.273E-01 +5.009E-01 +1.062E-01 +0.000E-39 +1.700E+00
  4 +4.208E+00 +4.208E+00 +7.499E+00 +8.648E+00  +6.00 +8.933E-02 -1.227E+02 +1.018E-01 +4.160E-01 +9.006E-02 +0.000E-39 +2.015E+00
  8 +4.223E+00 +4.223E+00 +7.500F+00 +8.664E+00  +0.00 +6.548E-02 -9.516E+01 +8.106E-02 +3.415F-01 +7.538E-02 +0.000E-39 +2.495E+00
  8 +4.244E+00 +4.244E+00 +7.499E+00 +8.684E+00  -8.00 +4.157E-02 -5.530E+01 +5.655E-02 +2.535E-01 +5.740E-02 +0.000E-39 +3.697E+00
  8 +4.265E+00 +4.265E+00 +7.494E+00 +8.705E+00 -16.00 +2.573E-02 -4.352E+01 +3.951E-02 +1.833E-01 +4.253E-02 +0.000E-39 +7.151E+00
  8 +4.284E+00 +4.284E+00 +7.487E+00 +8.726E+00 -24.00 +1.533E-02 -2.806E+01 +2.534E-02 +1.281E-01 +3.043E-02 +0.000E-39 +8.551E+01
  8 +4.303E+00 +4.303E+00 +7.477E+00 +8.747E+00 -32.00 +8.790E-03 -1.739E+01 +1.783E-02 +8.652F-02 +2.104E-02 +0.000E-39 +0.000E-39
  8 +4.320E+00 +4.320E+00 +7.465E+00 +8.768E+00 -40.00 +4.847E-03 -1.036E+01 +1.160E-02 +5.645F-02 +1.403E-02 +0.000E-39 +0.000E-39
  8 +4.335E+00 +4.335E+00 +7.450E+00 +8.789E+00 -48.00 +3.598E-03 +0.000E-39 +3.350E-03 +4.547E-02 +1.144E-02 +0.000E-39 +0.000E-39
  8 +4.348E+00 +4.348E+00 +7.434E+00 +8.810E+00 -56.00 +3.598E-03 +0.000E-39 +3.352E-03 +4.545F-02 +1.147E-02 +0.000E-39 +0.000E-39
  8 +4.358E+00 +4.358E+00 +7.416E+00 +8.831E+00 -64.00 +3.598E-03 +0.000E-39 +3.344E-03 +4.543E-02 +1.151F-02 +0.000E-39 +0.000E-39
  8 +4.366E+00 +4.366E+00 +7.396E+00 +8.852E+00 -72.00 +3.598E-03 +0.000E-39 +3.335E-03 +4.541E-02 +1.152F-02 +0.000E-39 +0.000E-39
  9 +4.371E+00 +4.371E+00 +7.376E+00 +8.873E+00 -80.00 +3.598E-03 +0.000E-39 +3.325E-03 +4.539E-02 +1.155E-02 +0.000E-39 +0.000E-39
  9 +4.435E+00 +4.435E+00 +7.013E+00 +9.241E+00 -80.00 +3.598E-03 +0.000E-39 +3.159E-03 +4.502E-02 +1.203E-02 +0.000E-39 +0.000E-39
  9 +4.499E+00 +4.499E+00 +6.651E+00 +9.609E+00 -80.00 +3.598E-03 +0.000E-39 +2.993E-03 +4.467E-02 +1.251F-02 +0.000F-39 +0.000E-39
  9 +4.563F+00 +4.563E+00 +6.288E+00 +9.978E+00 -80.00 +3.598E-03 +0.000E-39 +2.827E-03 +4.434E-02 +1.299E-02 +0.000E-39 +0.000E-39
  9 +4.627E+00 +4.627F+00 +5.926E+00 +1.035E+01 -80.00 +3.598E-03 +0.000E-39 +2.662E-03 +4.402F-02 +1.347E-02 +0.000E-39 +0.000E-39
  9 +4.691E+00 +4.691E+00 +5.563E+00 +1.071E+01 -80.00 +3.598F-03 +0.000E-39 +2.498E-03 +4.371F-02 +1.395E-02 +0.000E-39 +0.000E-39
  9 +4.755E+00 +4.755E+00 +5.200E+00 +1.108E+01 -80.00 +3.598E-03 +0.000E-39 +2.334E-03 +4.341E-02 +1.443F-02 +0.000E-39 +0.000E-39
  9 +4.819F+00 +4.819F+00 +4.838F+00 +1.145E+01 -80.00 +3.598E-03 +0.000E-39 +2.170E-03 +4.313E-02 +1.490F-02 +0.000F-39 +0.000E-39
  9 +4.883E+00 +4.883E+00 +4.475E+00 +1.182E+01 -80.00 +3.598E-03 +0.000E-39 +2.006E-03 +4.286E-02 +1.538F-02 +0.000E-39 +0.000E-39
  9 +4.947E+00 +4.947E+00 +4.113F+00 +1.219E+01 -80.00 +3.598E-03 +0.000E-39 +1.843E-03 +4.260F-02 +1.586E-02 +0.000E-39 +0.000E-39
 10 +5.010E+00 +5.010E+00 +3.750F+00 +1.255E+01 -90.00 +3.598E-03 +0.000E-39 +1.530E-03 +4.234E-02 +1.634E-02 +0.000E-39 +0.000E-39
 10 +5.010F+00 +5.010E+00 +3.375E+00 +1.293E+01 -90.00 +3.598E-03 +0.000E-39 +1.512E-03 +4.210F-02 +1.683F-02 +0.000E-39 +0.000F-39
 10 +5.010E+00 +5.010F+00 +3.000E+00 +1.330E+01 -90.00 +3.598E-03 +0.000E-39 +1.344E-03 +4.186F-02 +1.732E-02 +0.000F-39 +0.000F-39
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 10 +5.010E+00 +5.010E+00 +2.625E+00 +1.358E+01 -90.00 +3.598E-03 +0.000E-39 +1.175E-03 +4.162E-02 +1.781E-02 +0.000E-39 +0.000E-39
 10 +5.010E+00 +5.010E+00 +2.250E+00 +1.405E+01 -90.00 +3.598E-03 +0.000E-39 +1.007E-03 +4.140E-02 +1.830E-02 +0.000E-39 +0.000E-39
 10 +5.010E+00 +5.010E+00 +1.875E+00 +1.443E+01 -90.00 +3.598E-03 +0.000E-39 +8.394E-04 +4.118E-02 +1.878E-02 +0.000E-39 +0.000E-39
 10 +5.010E+00 +5.010E+00 +1.500E+00 +1.480E+01 -90.00 +3.598E-03 +0.000E-39 +6.715E-04 +4.097E-02 +1.927E-02 +0.000E-39 +0.000E-39
 10 +5.010E+00 +5.010E+00 +1.125E+00 +1.518E+01 -90.00 +3.598E-03 +0.000E-39 +5.036E-04 +4.077E-02 +1.976E-02 +0.000E-39 +0.000E-39
 10 +5.010E+00 +5.010E+00 +7.500E-01 +1.555E+01 -90.00 +3.598E-03 +0.000E-39 +3.357E-04 +4.057E-02 +2.025E-02 +0.000E-39 +0.000E-39
 10 +5.010E+00 +5.010E+00 +3.750E-01 +1.593E+01 -90.00 +3.598E-03 +0.000E-39 +1.679E-04 +4.038E-02 +2.074E-02 +0.000E-39 +0.000E-39
 10 +5.010E+00 +5.010E+00 +0.000E-39 +1.630E+01 -90.00 +3.598E-03 +0.000E-39 +0.000E-39 +4.019E-02 +2.122E-02 +0.000E-39 +0.000E-39

  I ST       X ST            Y ST            S ST           DTDS ST         THET ST       SECT  ALPHA

    5  +1.89903E-02  +2.17060E-01  +2.18166E-01  -8.00000E-01  +8.00000E+01     1    +10.00

  IW SN     XOW SN          YOW SN          XBW SN          YBW SN          SBW SN          THETW SN    SECT  ALPHA

   22  +4.12298E+00  +7.46147E+00  +2.78877E+00  +7.85319E+00  +8.34344E+00  +4.89372E+01     4    +10.00

  IL SN     XOL SN          YOL SN          XBL SN          YBL SN          SBL SN          THETL SN    SECT  ALPHA

   27  +4.09345E+00  +7.42500E+00  +5.34140E+00  +6.82055E+00  +8.72741E+00  +4.89372E+01     4    +10.00
```

```
AT ALPHA =  +1.0000E+01 WINDWARD, RW =  +2.4949E+01 DFLS =  +5.3548E-03 BSHOCK =  -7.3225E+00
SIN(THETAW) NEG. FOR XB =  +2.9581E+00 RW =  +2.4949E+01 DFLS =  +5.3548E-03 BSHOCK =  -7.3225E+00

SEC     XO W        XB W        YB W        SB W      THETBW  PE/PS W     DP/DS W      QL W        QT W        RE W        DR W        XST W

  1 +1.899E-02 +0.000E-39 +0.000E-39 +0.000E-39 +90.00 +1.000E+00 +4.809E-06 +1.033E+00 +0.000E-39 +0.000E-39 +5.903E-02 +5.365E-03
  1 +2.732E-02 +7.615E-04 +4.362E-02 +4.363E-02 +88.00 +9.988E-01 -3.915E+00 +1.032E+00 +3.786E-01 +5.427E-05 +6.517E-02 +6.091E-03
  1 +4.259E-02 +4.757E-03 +1.089E-01 +1.091E-01 +85.00 +9.924E-01 -9.747E+00 +1.024E+00 +6.529E-01 +3.998E-04 +9.303E-02 +9.917E-03
  1 +6.118E-02 +1.216E-02 +1.740E-01 +1.745E-01 +82.00 +9.806E-01 -1.547E+01 +9.912E-01 +8.692E-01 +1.032E-03 +1.202E-01 +1.707E-02
  1 +8.302E-02 +2.297E-02 +2.385E-01 +2.400E-01 +79.00 +9.636E-01 -2.103E+01 +9.397E-01 +1.039E+00 +1.927E-03 +1.023E-01 +2.765E-02
  1 +1.081E-01 +3.713E-02 +3.024E-01 +3.054E-01 +76.00 +9.415E-01 -2.635E+01 +9.320E-01 +1.181E+00 +3.073E-03 +3.914E-02 +4.178E-02
  1 +1.362E-01 +5.462E-02 +3.655E-01 +3.709E-01 +73.00 +9.145E-01 -3.139E+01 +9.577E-01 +1.300E+00 +4.442E-03 +4.882E-02 +5.965E-02
  3 +1.675E-01 +7.538E-02 +4.275E-01 +4.353E-01 +70.00 +8.830E-01 +0.000E-39 +8.567E-01 +1.397E+00 +5.003E-03 +5.677E-02 +8.151E-02
  3 +5.601E-01 +3.439E-01 +1.165E+00 +1.222E+00 +70.00 +8.830E-01 +0.000E-39 +4.459E-01 +1.137E+00 +1.690E-02 +0.000E-39 +3.366E-01
  3 +9.527E-01 +6.125E-01 +1.903E+00 +2.007E+00 +70.00 +8.830E-01 +0.000E-39 +3.595E-01 +1.030E+00 +2.761E-02 +0.000E-39 +5.626E-01
  3 +1.345E+00 +8.810E-01 +2.641E+00 +2.792E+00 +70.00 +8.830E-01 +0.000E-39 +3.087E-01 +9.640E-01 +3.841E-02 +0.000E-39 +7.592E-01
  3 +1.738E+00 +1.150E+00 +3.379E+00 +3.577E+00 +70.00 +8.830E-01 +0.000E-39 +2.744E-01 +9.174E-01 +4.921E-02 +0.000E-39 +9.251E-01
  3 +2.130E+00 +1.418E+00 +4.117E+00 +4.362E+00 +70.00 +8.830E-01 +0.000E-39 +2.494E-01 +8.917E-01 +6.001E-02 +0.000E-39 +1.058E+00
  3 +2.523E+00 +1.687E+00 +4.855E+00 +5.148E+00 +70.00 +8.830E-01 +0.000E-39 +2.301E-01 +8.530E-01 +7.081E-02 +0.000E-39 +1.155E+00
  3 +2.916E+00 +1.955E+00 +5.592E+00 +5.933E+00 +70.00 +8.830E-01 +0.000E-39 +2.145E-01 +8.291E-01 +8.162E-02 +0.000E-39 +1.211E+00
  3 +3.308E+00 +2.224E+00 +6.330E+00 +6.718E+00 +70.00 +8.830E-01 +0.000E-39 +2.019E-01 +8.088E-01 +9.242E-02 +0.000E-39 +1.218E+00
  3 +3.701E+00 +2.492E+00 +7.068E+00 +7.503E+00 +70.00 +8.830E-01 +0.000E-39 +1.912E-01 +7.911E-01 +1.032E-01 +0.000E-39 +1.160E+00
  4 +4.093E+00 +2.761E+00 +7.806E+00 +8.288E+00 +70.00 +8.830E-01 -3.007E+02 +3.512E-01 +7.755E-01 +1.140E-01 +0.000E-39 +1.012E+00
  4 +4.102E+00 +2.767E+00 +7.820E+00 +8.304E+00 +64.00 +8.078E-01 -3.636E+02 +3.332E-01 +8.972E-01 +1.398E-01 +0.000E-39 +9.845E-01
  4 +4.112E+00 +2.775E+00 +7.834E+00 +8.320E+00 +58.00 +7.192E-01 -4.204E+02 +3.950E-01 +9.744E-01 +1.592E-01 +0.000E-39 +9.672E-01
  4 +4.123E+00 +2.784E+00 +7.847E+00 +8.335E+00 +52.00 +6.210E-01 -4.539E+02 +3.909E-01 +1.006E+00 +1.714E-01 +0.000E-39 +9.588E-01
  4 +4.123E+00 +2.789E+00 +7.853E+00 +8.343E+00 +48.94 +5.685E-01 -4.633E+02 +3.872E-01 +1.005E+00 +1.745E-01 +0.000E-39 +9.578E-01
  4 +4.135E+00 +2.794E+00 +7.859E+00 +8.351E+00 +46.00 +5.192E-01 -4.675E+02 +3.767E-01 +9.928E-01 +1.756E-01 +0.000E-39 +9.589E-01
  4 +4.148E+00 +2.805E+00 +7.870E+00 +8.367E+00 +40.00 +4.153E-01 -4.606E+02 +3.375E-01 +9.366E-01 +1.715E-01 +0.000E-39 +9.673E-01
  4 +4.162E+00 +2.818E+00 +7.879E+00 +8.383E+00 +34.00 +3.152E-01 -4.337E+02 +2.917E-01 +8.409E-01 +1.594E-01 +0.000E-39 +9.835E-01
  4 +4.177E+00 +2.831E+00 +7.887E+00 +8.398E+00 +28.00 +2.457E-01 -2.797E+02 +2.389E-01 +7.472E-01 +1.454E-01 +0.000E-39 +1.008E+00
  4 +4.192E+00 +2.846E+00 +7.894E+00 +8.414E+00 +22.00 +1.890E-01 -2.253E+02 +1.991E-01 +6.509E-01 +1.297E-01 +0.000E-39 +1.040E+00
  4 +4.208E+00 +2.861E+00 +7.899E+00 +8.430E+00 +16.00 +1.440E-01 -1.808E+02 +1.640E-01 +5.579E-01 +1.137E-01 +0.000E-39 +1.079E+00
  8 +4.223E+00 +2.876E+00 +7.902E+00 +8.445E+00 +10.00 +1.081E-01 -1.433E+02 +1.329E-01 +4.700E-01 +9.778E-02 +0.000E-39 +1.126E+00
  8 +4.244E+00 +2.897E+00 +7.905E+00 +8.456E+00  +2.00 +7.201E-02 -1.029E+02 +9.577E-02 +3.646E-01 +7.789E-02 +0.000E-39 +1.196E+00
  8 +4.265E+00 +2.918E+00 +7.904E+00 +8.487E+00  -6.00 +4.587E-02 -7.038E+01 +5.850E-02 +2.718E-01 +5.950E-02 +0.000E-39 +1.274E+00
  8 +4.284E+00 +2.938E+00 +7.900E+00 +8.508E+00 -14.00 +2.852E-02 -4.759E+01 +4.736E-02 +1.975E-01 +4.439E-02 +0.000E-39 +1.352E+00
  8 +4.303E+00 +2.958E+00 +7.894E+00 +8.529E+00 -22.00 +1.697E-02 -3.061E+01 +3.224E-02 +1.381E-01 +3.180E-02 +0.000E-39 +1.427E+00
  8 +4.320E+00 +2.977E+00 +7.885E+00 +8.550E+00 -30.00 +9.712E-03 -1.895E+01 +2.122E-02 +9.329E-02 +2.199E-02 +0.000E-39 +0.000E-39
  8 +4.335E+00 +2.994E+00 +7.873E+00 +8.571E+00 -38.00 +5.325E-03 -1.125E+01 +1.352E-02 +6.069E-02 +1.464E-02 +0.000E-39 +0.000E-39
  8 +4.348E+00 +3.010E+00 +7.859E+00 +8.592E+00 -46.00 +3.598E-03 +0.000E-39 +4.000E-03 +4.568E-02 +1.118E-02 +0.000E-39 +0.000E-39
  8 +4.358E+00 +3.023E+00 +7.843E+00 +8.613E+00 -54.00 +3.598E-03 +0.000E-39 +3.992E-03 +4.556E-02 +1.121E-02 +0.000E-39 +0.000E-39
  8 +4.366E+00 +3.034E+00 +7.825E+00 +8.634E+00 -62.00 +3.598E-03 +0.000E-39 +3.983E-03 +4.554E-02 +1.124E-02 +0.000E-39 +0.000E-39
  9 +4.371E+00 +3.043E+00 +7.806E+00 +8.655E+00 -70.00 +3.598E-03 +0.000E-39 +3.973E-03 +4.562E-02 +1.127E-02 +0.000E-39 +0.000E-39
  9 +4.435E+00 +3.169E+00 +7.460E+00 +9.023E+00 -70.00 +3.598E-03 +0.000E-39 +3.791E-03 +4.524E-02 +1.175E-02 +0.000E-39 +0.000E-39
  9 +4.499E+00 +3.295E+00 +7.114E+00 +9.391E+00 -70.00 +3.598E-03 +0.000E-39 +3.611E-03 +4.488E-02 +1.222E-02 +0.000E-39 +0.000E-39
  9 +4.563E+00 +3.421E+00 +6.768E+00 +9.759E+00 -70.00 +3.598E-03 +0.000E-39 +3.432E-03 +4.453E-02 +1.270E-02 +0.000E-39 +0.000E-39
  9 +4.627E+00 +3.547E+00 +6.422E+00 +1.013E+01 -70.00 +3.598E-03 +0.000E-39 +3.253E-03 +4.420E-02 +1.318E-02 +0.000E-39 +0.000E-39
  9 +4.691E+00 +3.672E+00 +6.076E+00 +1.050E+01 -70.00 +3.598E-03 +0.000E-39 +3.075E-03 +4.389E-02 +1.366E-02 +0.000E-39 +0.000E-39
  9 +4.755E+00 +3.798E+00 +5.730E+00 +1.085E+01 -70.00 +3.598E-03 +0.000E-39 +2.898E-03 +4.359E-02 +1.414E-02 +0.000E-39 +0.000E-39
  9 +4.819E+00 +3.924E+00 +5.384E+00 +1.123E+01 -70.00 +3.598E-03 +0.000E-39 +2.721E-03 +4.330E-02 +1.462E-02 +0.000E-39 +0.000E-39
  9 +4.883E+00 +4.050E+00 +5.038E+00 +1.160E+01 -70.00 +3.598E-03 +0.000E-39 +2.544E-03 +4.302E-02 +1.510E-02 +0.000E-39 +0.000E-39
  9 +4.947E+00 +4.176E+00 +4.692E+00 +1.197E+01 -70.00 +3.598E-03 +0.000E-39 +2.368E-03 +4.275E-02 +1.559E-02 +0.000E-39 +0.000E-39
 10 +5.010E+00 +4.307E+00 +4.346E+00 +1.234E+01 -80.00 +3.598E-03 +0.000E-39 +2.193E-03 +4.249E-02 +1.606E-02 +0.000E-39 +0.000E-39
 10 +5.010E+00 +4.367E+00 +3.977E+00 +1.271E+01 -90.00 +3.598E-03 +0.000E-39 +2.006E-03 +4.224E-02 +1.655E-02 +0.000E-39 +0.000E-39
 10 +5.010E+00 +4.432E+00 +3.607E+00 +1.309E+01 -80.00 +3.598E-03 +0.000E-39 +1.819E-03 +4.199E-02 +1.703E-02 +0.000E-39 +0.000E-39
 10 +5.010E+00 +4.497E+00 +3.238E+00 +1.346E+01 -80.00 +3.598E-03 +0.000E-39 +1.632E-03 +4.176E-02 +1.752E-02 +0.000E-39 +0.000E-39
 10 +5.010E+00 +4.563E+00 +2.869E+00 +1.384E+01 -80.00 +3.598E-03 +0.000E-39 +1.446E-03 +4.153E-02 +1.801E-02 +0.000E-39 +0.000E-39
 10 +5.010E+00 +4.628E+00 +2.500E+00 +1.421E+01 -80.00 +3.598E-03 +0.000E-39 +1.259E-03 +4.131E-02 +1.850E-02 +0.000E-39 +0.000E-39
 10 +5.010E+00 +4.693E+00 +2.130E+00 +1.459E+01 -80.00 +3.598E-03 +0.000E-39 +1.073E-03 +4.109E-02 +1.899E-02 +0.000E-39 +0.000E-39
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10 +5.010E+00 +4.758E+00 +1.761E+00 +1.496E+01 -80.00 +3.598E-03 +0.000E-39 +8.370E-04 +4.088E-02 +1.948E-02 +0.000E-39 +0.000E-39
10 +5.010E+00 +4.823E+00 +1.392E+00 +1.534E+01 -80.00 +3.598E-03 +0.000E-39 +7.010E-04 +4.068E-02 +1.996E-02 +0.000E-39 +0.000E-39
10 +5.010E+00 +4.888E+00 +1.022E+00 +1.571E+01 -80.00 +3.598E-03 +0.000E-39 +5.149E-04 +4.049E-02 +2.045E-02 +0.000E-39 +0.000E-39
10 +5.010E+00 +4.953E+00 +6.530E-01 +1.609E+01 -80.00 +3.598E-03 +0.000E-39 +3.289E-04 +4.030E-02 +2.094E-02 +0.000E-39 +0.000E-39
10 +5.010E+00 +5.018E+00 +2.837E-01 +1.646E+01 -80.00 +3.598E-03 +0.000E-39 +1.429E-04 +4.011E-02 +2.143E-02 +0.000E-39 +0.000E-39
10 +5.010E+00 +5.084E+00 +8.561E-02 +1.684E+01 -80.00 +3.598E-03 +0.000E-39 +4.312E-05 +3.993E-02 +2.192E-02 +0.000E-39 +0.000E-39
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AT ALPHA =  +1.0000E+01, LEEWARD, RW =  +2.2599E+00 DELS =  +5.3648E-03 BSHOCK =  +1.5198E+00

SEC     XO L        XB L        YB L        SB L     THETBL  PE/PS L     DP/DS L      QL L        QT L        QF L        QR L       XSI L

  1 +1.899E-02 +0.000E-39 +0.000E-39 +0.000E-39 +90.00 +1.000E+00 +4.809E-05 +1.033E+00 +0.000E-39 +0.000E-39 +5.903E-02 +5.365E-03
  1 +1.539E-02 +1.904E-04 +2.182E-02 +2.182E-02 +89.00 +9.997E-01 -1.959E+00 +1.033E+00 +2.849E-01 +1.894E-05 +5.743E-02 +5.450E-03
  1 +6.848E-03 +3.045E-03 +8.720E-02 +8.727E-02 +86.00 +9.951E-01 -7.812E+00 +1.027E+00 +6.524E-01 +3.020E-04 +5.798E-02 +6.727E-03
  1 +1.713E-03 +9.317E-03 +1.523E-01 +1.527E-01 +83.00 +9.851E-01 -1.353E+01 +3.841E-01 +8.049E-01 +7.923E-04 +5.426E-02 +9.549E-03
  1 +0.000E-39 +1.899E-02 +2.171E-01 +2.182E-01 +80.00 +9.698E-01 -1.920E+01 +9.046E-01 +9.859E-01 +1.600E-03 +5.346E-02 +1.395E-02
  1 +1.713E-03 +3.204E-02 +2.812E-01 +2.835E-01 +77.00 +9.494E-01 -2.461E+01 +9.050E-01 +1.137E+00 +2.665E-03 +0.000E-39 +1.997E-02
  1 +6.848E-03 +4.842E-02 +3.445E-01 +3.491E-01 +74.00 +9.240E-01 -2.974E+01 +3.953E-01 +1.263E+00 +3.962E-03 +0.000E-39 +2.767E-02
  1 +1.539E-02 +6.810E-02 +4.070E-01 +4.145E-01 +71.00 +8.940E-01 -3.455E+01 +8.732E-01 +1.367E+00 +5.463E-03 +0.000E-39 +3.713E-02
  1 +1.899E-02 +7.538E-02 +4.275E-01 +4.353E-01 +70.00 +8.830E-01 -3.608E+01 +8.738E-01 +1.397E+00 +6.003E-03 +0.000E-39 +4.069E-02
  1 +2.732E-02 +9.102E-02 +4.683E-01 +4.800E-01 +68.00 +8.597E-01 -3.899E+01 +8.594E-01 +1.451E+00 +7.132E-03 +0.000E-39 +4.846E-02
  1 +4.259E-02 +1.171E-01 +5.283E-01 +5.454E-01 +65.00 +8.214E-01 -4.300E+01 +8.339E-01 +1.517E+00 +8.928E-03 +0.000E-39 +6.176E-02
  1 +6.118E-02 +1.463E-01 +5.868E-01 +6.109E-01 +62.00 +7.796E-01 -4.653E+01 +8.053E-01 +1.554E+00 +1.081E-02 +0.000E-39 +7.717E-02
  1 +8.302E-02 +1.785E-01 +6.438E-01 +6.763E-01 +59.00 +7.347E-01 -4.956E+01 +7.735E-01 +1.593E+00 +1.272E-02 +0.000E-39 +9.484E-02
  1 +1.081E-01 +2.137E-01 +6.990E-01 +7.418E-01 +56.00 +6.873E-01 -5.204E+01 +7.339E-01 +1.606E+00 +1.462E-02 +0.000E-39 +1.150E-01
  1 +1.362E-01 +2.517E-01 +7.523E-01 +8.072E-01 +53.00 +6.378E-01 -5.396E+01 +7.014E-01 +1.601E+00 +1.645E-02 +0.000E-39 +1.378E-01
  3 +1.675E-01 +2.924E-01 +8.035E-01 +8.727E-01 +50.00 +5.868E-01 +0.000E-39 +5.155E-01 +1.581E+00 +1.817E-02 +0.000E-39 +1.634E-01
  3 +5.601E-01 +7.972E-01 +1.405E+00 +1.658E+00 +50.00 +5.868E-01 +0.000E-39 +4.159E-01 +1.390E+00 +3.452E-02 +0.000E-39 +3.783E-01
  3 +9.527E-01 +1.302E+00 +2.006E+00 +2.443E+00 +50.00 +5.868E-01 +0.000E-39 +3.459E-01 +1.287E+00 +5.087E-02 +0.000E-39 +5.065E-01
  3 +1.345E+00 +1.807E+00 +2.608E+00 +3.228E+00 +50.00 +5.868E-01 +0.000E-39 +3.035E-01 +1.217E+00 +6.722E-02 +0.000E-39 +5.931E-01
  3 +1.738E+00 +2.311E+00 +3.209E+00 +4.013E+00 +50.00 +5.868E-01 +0.000E-39 +2.740E-01 +1.165E+00 +8.359E-02 +0.000E-39 +6.570E-01
  3 +2.130E+00 +2.816E+00 +3.811E+00 +4.799E+00 +50.00 +5.868E-01 +0.000E-39 +2.517E-01 +1.124E+00 +9.993E-02 +0.000E-39 +7.073E-01
  3 +2.523E+00 +3.321E+00 +4.412E+00 +5.584E+00 +50.00 +5.868E-01 +0.000E-39 +2.341E-01 +1.090E+00 +1.163E-01 +0.000E-39 +7.487E-01
  3 +2.916E+00 +3.825E+00 +5.014E+00 +6.369E+00 +50.00 +5.868E-01 +0.000E-39 +2.193E-01 +1.062E+00 +1.326E-01 +0.000E-39 +7.840E-01
  3 +3.308E+00 +4.330E+00 +5.615E+00 +7.154E+00 +50.00 +5.868E-01 +0.000E-39 +2.073E-01 +1.038E+00 +1.490E-01 +0.000E-39 +8.150E-01
  3 +3.701E+00 +4.835E+00 +6.217E+00 +7.939E+00 +50.00 +5.868E-01 +0.000E-39 +1.975E-01 +1.016E+00 +1.653E-01 +0.000E-39 +8.429E-01
  4 +4.093E+00 +5.340E+00 +6.818E+00 +8.725E+00 +50.00 +5.868E-01 -4.606E+02 +3.274E-01 +9.974E-01 +1.817E-01 +0.000E-39 +8.683E-01
  4 +4.093E+00 +5.341E+00 +6.821E+00 +8.727E+00 +48.94 +5.685E-01 -4.633E+02 +3.230E-01 +9.956E-01 +1.826E-01 +0.000E-39 +8.691E-01
  4 +4.102E+00 +5.350E+00 +6.830E+00 +8.740E+00 +44.00 +4.844E-01 -4.675E+02 +2.998E-01 +9.770E-01 +1.832E-01 +0.000E-39 +8.773E-01
  4 +4.112E+00 +5.362E+00 +6.840E+00 +8.756E+00 +38.00 +3.813E-01 -4.539E+02 +2.565E-01 +9.097E-01 +1.762E-01 +0.000E-39 +8.979E-01
  4 +4.123E+00 +5.375E+00 +6.849E+00 +8.772E+00 +32.00 +2.981E-01 -3.310E+02 +2.235E-01 +8.127E-01 +1.637E-01 +0.000E-39 +9.315E-01
  4 +4.135E+00 +5.389E+00 +6.857E+00 +8.787E+00 +26.00 +2.309E-01 -2.655E+02 +1.881E-01 +7.175E-01 +1.482E-01 +0.000E-39 +9.800E-01
  4 +4.148E+00 +5.403E+00 +6.863E+00 +8.803E+00 +20.00 +1.776E-01 -2.142E+02 +1.559E-01 +6.233E-01 +1.318E-01 +0.000E-39 +1.047E+00
  4 +4.162E+00 +5.418E+00 +6.868E+00 +8.819E+00 +14.00 +1.343E-01 -1.708E+02 +1.285E-01 +5.307E-01 +1.147E-01 +0.000E-39 +1.137E+00
  4 +4.177E+00 +5.434E+00 +6.871E+00 +8.835E+00  +8.00 +1.004E-01 -1.350E+02 +1.042E-01 +4.454E-01 +9.924E-02 +0.000E-39 +1.258E+00
  4 +4.192E+00 +5.449E+00 +6.872E+00 +8.850E+00  +2.00 +7.401E-02 -1.052E+02 +8.327E-02 +3.678E-01 +8.274E-02 +0.000E-39 +1.473E+00
  4 +4.208E+00 +5.465E+00 +6.872E+00 +8.866E+00  -4.00 +5.310E-02 -8.004E+01 +6.503E-02 +2.957E-01 +6.976E-02 +0.000E-39 +1.655E+00
  8 +4.223E+00 +5.481E+00 +6.870E+00 +8.882E+00 -10.00 +3.743E-02 -5.931E+01 +5.019E-02 +2.353E-01 +5.500E-02 +0.000E-39 +1.993E+00
  8 +4.244E+00 +5.501E+00 +6.865E+00 +8.903E+00 -18.00 +2.269E-02 -3.921E+01 +3.375E-02 +1.674E-01 +4.011E-02 +0.000E-39 +2.770E+00
  8 +4.265E+00 +5.520E+00 +6.857E+00 +8.924E+00 -26.00 +1.324E-02 -2.474E+01 +2.265E-02 +1.151E-01 +2.924E-02 +0.000E-39 +4.558E+00
  8 +4.284E+00 +5.538E+00 +6.846E+00 +8.945E+00 -34.00 +7.405E-03 -1.498E+01 +1.482E-02 +7.623E-02 +1.915E-02 +0.000E-39 +1.230E+01
  8 +4.303E+00 +5.555E+00 +6.833E+00 +8.965E+00 -42.00 +3.958E-03 -8.676E+00 +9.458E-03 +4.854E-02 +1.247E-02 +0.000E-39 +0.000E-39
  8 +4.320E+00 +5.569E+00 +6.818E+00 +8.985E+00 -50.00 +3.598E-03 +0.000E-39 +3.095E-03 +4.527E-02 +1.170E-02 +0.000E-39 +0.000E-39
  8 +4.335E+00 +5.582E+00 +6.802E+00 +9.007E+00 -58.00 +3.598E-03 +0.000E-39 +3.087E-03 +4.525E-02 +1.172E-02 +0.000E-39 +0.000E-39
  8 +4.348E+00 +5.592E+00 +6.783E+00 +9.028E+00 -66.00 +3.598E-03 +0.000E-39 +3.079E-03 +4.523E-02 +1.175E-02 +0.000E-39 +0.000E-39
  8 +4.358E+00 +5.599E+00 +6.763E+00 +9.049E+00 -74.00 +3.599E-03 +0.000E-39 +3.070E-03 +4.521E-02 +1.178E-02 +0.000E-39 +0.000E-39
  8 +4.366E+00 +5.603E+00 +6.743E+00 +9.070E+00 -82.00 +3.598E-03 +0.000E-39 +3.060E-03 +4.519E-02 +1.181E-02 +0.000E-39 +0.000E-39
  9 +4.371E+00 +5.604E+00 +6.722E+00 +9.091E+00 -90.00 +3.598E-03 +0.000E-39 +3.051E-03 +4.517E-02 +1.183E-02 +0.000E-39 +0.000E-39
  9 +4.435E+00 +5.604E+00 +6.354E+00 +9.459E+00 -90.00 +3.598E-03 +0.000E-39 +2.881E-03 +4.481E-02 +1.231E-02 +0.000E-39 +0.000E-39
  9 +4.499E+00 +5.604E+00 +5.986E+00 +9.828E+00 -90.00 +3.598E-03 +0.000E-39 +2.712E-03 +4.447E-02 +1.279E-02 +0.000E-39 +0.000E-39
  9 +4.563E+00 +5.604E+00 +5.617E+00 +1.020E+01 -90.00 +3.598E-03 +0.000E-39 +2.543E-03 +4.414E-02 +1.327E-02 +0.000E-39 +0.000E-39
  9 +4.627E+00 +5.604E+00 +5.249E+00 +1.056E+01 -90.00 +3.598E-03 +0.000E-39 +2.375E-03 +4.383E-02 +1.375E-02 +0.000E-39 +0.000E-39
  9 +4.691E+00 +5.604E+00 +4.881E+00 +1.093E+01 -90.00 +3.598E-03 +0.000E-39 +2.207E-03 +4.353E-02 +1.423E-02 +0.000E-39 +0.000E-39
  9 +4.755E+00 +5.604E+00 +4.513E+00 +1.130E+01 -90.00 +3.598E-03 +0.000E-39 +2.040E-03 +4.325E-02 +1.471E-02 +0.000E-39 +0.000E-39
  9 +4.819E+00 +5.604E+00 +4.145E+00 +1.167E+01 -90.00 +3.598E-03 +0.000E-39 +1.873E-03 +4.297E-02 +1.519E-02 +0.000E-39 +0.000E-39
  9 +4.883E+00 +5.604E+00 +3.776E+00 +1.204E+01 -90.00 +3.598E-03 +0.000E-39 +1.706E-03 +4.270E-02 +1.567E-02 +0.000E-39 +0.000E-39
  9 +4.947E+00 +5.604E+00 +3.408E+00 +1.240E+01 -90.00 +3.598E-03 +0.000E-39 +1.539E-03 +4.245E-02 +1.615E-02 +0.000E-39 +0.000E-39
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 10 +5.010E+00 +5.604E+00 +3.040E+00 +1.277E+01 ****** +3.598E-03 +0.000E-39 +1.372E-03 +4.220E-02 +1.663E-02 +0.000E-39 +0.000E-39
  I ST       X ST           Y ST           S ST         DTDS ST        THET ST      SECT  ALPHA
      8  +7.53842E-02  +4.27525E-01  +4.36332E-01  -8.00000E-01  +7.00000E+01      1    +20.00
  IW SN     XOW SN         YOW SN         XBW SN         YBW SN       SBW SN        THETW SN     SECT  ALPHA
     21  +4.14835E+00  +7.47990E+00  +1.41709E+00  +8.02222E+00  +8.15145E+00  +4.89372E+01      4    +20.00
  IL SN     XOL SN         YOL SN         XBL SN         YBL SN       SBL SN        THETL SN     SECT  ALPHA
     17  +8.30245E-02  +4.47960E-01  +3.07513E-01  +8.21108E-01  +8.95352E-01  +4.89372E+01      1    +20.00
  CANNOT FIND THETA FOR RW OR B, SKIP CASE
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 AT ALPHA =  +2.0000E+01 WINDWARD, RW =  +0.0000E-39 DELS =  +7.4505E-02 BSHOCK =  +0.0000E-39

 SEC     XO W        XB W        YB W        SB W      THETBW  PE/PS W     DP/DS W      QL W        QT W        RF W        QR W        XSI W

   1 +7.538E-02 +0.000E-39 +0.000E-39 +0.000E-39 +90.00 +1.000E+00 +4.809E-05 +1.123E+00 +0.000E-39 +0.000E-39 +0.000E-39 +0.000E-39
   1 +8.302E-02 +1.904E-04 +2.182E-02 +2.182E-02 +89.00 +9.997E-01 -1.959E+00 +1.127E+00 +3.251E-01 +2.233E-05 +0.000E-39 +0.000E-39
   1 +1.081E-01 +3.045E-03 +8.720E-02 +8.727E-02 +86.00 +9.951E-01 -7.812E+00 +1.121E+00 +7.442E-01 +3.561E-04 +0.000E-39 +0.000E-39
   1 +1.362E-01 +9.317E-03 +1.523E-01 +1.527E-01 +83.00 +9.851E-01 -1.359E+01 +3.593E-01 +8.049E-01 +7.923E-04 +0.000E-39 +0.000E-39
   3 +1.675E-01 +1.899E-02 +2.171E-01 +2.182E-01 +80.00 +9.698E-01 +0.000E-39 +8.444E-01 +9.859E-01 +1.600E-03 +0.000E-39 +0.000E-39
   3 +5.601E-01 +1.553E-01 +9.903E-01 +1.003E+00 +80.00 +9.698E-01 +0.000E-39 +3.229E-01 +7.266E-01 +7.357E-03 +0.000E-39 +0.000E-39
   3 +9.527E-01 +2.917E-01 +1.764E+00 +1.789E+00 +80.00 +9.698E-01 +0.000E-39 +2.534E-01 +6.473E-01 +1.311E-02 +0.000E-39 +0.000E-39
   3 +1.345E+00 +4.280E-01 +2.537E+00 +2.574E+00 +80.00 +9.698E-01 +0.000E-39 +2.197E-01 +6.018E-01 +1.887E-02 +0.000E-39 +0.000E-39
   3 +1.738E+00 +5.644E-01 +3.310E+00 +3.359E+00 +80.00 +9.698E-01 +0.000E-39 +1.939E-01 +5.706E-01 +2.463E-02 +0.000E-39 +0.000E-39
   3 +2.130E+00 +7.007E-01 +4.083E+00 +4.144E+00 +80.00 +9.698E-01 +0.000E-39 +1.753E-01 +5.472E-01 +3.039E-02 +0.000E-39 +0.000E-39
   3 +2.523E+00 +8.371E-01 +4.857E+00 +4.929E+00 +80.00 +9.698E-01 +0.000E-39 +1.511E-01 +5.285E-01 +3.614E-02 +0.000E-39 +0.000E-39
   3 +2.916E+00 +9.734E-01 +5.630E+00 +5.715E+00 +80.00 +9.698E-01 +0.000E-39 +1.490E-01 +5.131E-01 +4.190E-02 +0.000E-39 +0.000E-39
   3 +3.308E+00 +1.110E+00 +6.403E+00 +6.500E+00 +80.00 +9.698E-01 +0.000E-39 +1.407E-01 +5.001E-01 +4.766E-02 +0.000E-39 +0.000E-39
   3 +3.701E+00 +1.246E+00 +7.176E+00 +7.285E+00 +80.00 +9.698E-01 +0.000E-39 +1.330E-01 +4.888E-01 +5.342E-02 +0.000E-39 +0.000E-39
   4 +4.093E+00 +1.382E+00 +7.950E+00 +8.070E+00 +80.00 +9.698E-01 -1.600E+02 +2.992E-01 +4.789E-01 +5.917E-02 +0.000E-39 +0.000E-39
   4 +4.102E+00 +1.386E+00 +7.965E+00 +8.086E+00 +74.00 +9.240E-01 -2.479E+02 +3.536E-01 +5.734E-01 +9.178E-02 +0.000E-39 +0.000E-39
   4 +4.112E+00 +1.391E+00 +7.980E+00 +8.102E+00 +68.00 +8.597E-01 -3.249E+02 +4.053E-01 +8.248E-01 +1.204E-01 +0.000E-39 +0.000E-39
   4 +4.123E+00 +1.398E+00 +7.994E+00 +8.117E+00 +62.00 +7.796E-01 -3.878E+02 +4.357E-01 +9.323E-01 +1.436E-01 +0.000E-39 +0.000E-39
   4 +4.135E+00 +1.406E+00 +8.008E+00 +8.133E+00 +56.00 +6.873E-01 -4.337E+02 +4.454E-01 +9.946E-01 +1.603E-01 +0.000E-39 +0.000E-39
   4 +4.148E+00 +1.415E+00 +8.020E+00 +8.149E+00 +50.00 +5.868E-01 -4.606E+02 +4.375E-01 +1.011E+00 +1.697E-01 +0.000E-39 +0.000E-39
   4 +4.148E+00 +1.417E+00 +8.022E+00 +8.151E+00 +48.94 +5.685E-01 -4.633E+02 +4.413E-01 +1.009E+00 +1.705E-01 +0.000E-39 +0.000E-39
   4 +4.162E+00 +1.426E+00 +8.032E+00 +8.164E+00 +44.00 +4.844E-01 -4.675E+02 +4.122E-01 +9.833E-01 +1.711E-01 +0.000E-39 +0.000E-39
   4 +4.177E+00 +1.438E+00 +8.042E+00 +8.180E+00 +38.00 +3.813E-01 -4.539E+02 +3.556E-01 +9.131E-01 +1.646E-01 +0.000E-39 +0.000E-39
   4 +4.192E+00 +1.451E+00 +8.051E+00 +8.195E+00 +32.00 +2.981E-01 -3.310E+02 +3.094E-01 +8.239E-01 +1.529E-01 +0.000E-39 +0.000E-39
   4 +4.208E+00 +1.464E+00 +8.059E+00 +8.212E+00 +26.00 +2.309E-01 -2.655E+02 +2.600E-01 +7.273E-01 +1.385E-01 +0.000E-39 +0.000E-39
   8 +4.223E+00 +1.479E+00 +8.065E+00 +8.227E+00 +20.00 +1.776E-01 -2.142E+02 +2.160E-01 +6.317E-01 +1.232E-01 +0.000E-39 +0.000E-39
   8 +4.244E+00 +1.499E+00 +8.070E+00 +8.248E+00 +12.00 +1.226E-01 -1.587E+02 +1.527E-01 +5.096E-01 +1.022E-01 +0.000E-39 +0.000E-39
   8 +4.265E+00 +1.520E+00 +8.073E+00 +8.269E+00  +4.00 +8.230E-02 -1.148E+02 +1.201E-01 +3.987E-01 +8.219E-02 +0.000E-39 +0.000E-39
   8 +4.284E+00 +1.541E+00 +8.073E+00 +8.290E+00  -4.00 +5.341E-02 -8.043E+01 +8.591E-02 +3.019E-01 +6.387E-02 +0.000E-39 +0.000E-39
   8 +4.303E+00 +1.561E+00 +8.070E+00 +8.311E+00 -12.00 +3.367E-02 -5.472E+01 +5.994E-02 +2.220E-01 +4.816E-02 +0.000E-39 +0.000E-39
   8 +4.320E+00 +1.581E+00 +8.065E+00 +8.332E+00 -20.00 +2.039E-02 -3.580E+01 +4.046E-02 +1.576E-01 +3.503E-02 +0.000E-39 +0.000E-39
   8 +4.335E+00 +1.601E+00 +8.056E+00 +8.353E+00 -28.00 +1.194E-02 -2.254E+01 +2.671E-02 +1.084E-01 +2.467E-02 +0.000E-39 +0.000E-39
   8 +4.348E+00 +1.618E+00 +8.045E+00 +8.374E+00 -36.00 +6.728E-03 -1.379E+01 +1.721E-02 +7.212E-02 +1.679E-02 +0.000E-39 +0.000E-39
   8 +4.358E+00 +1.634E+00 +8.032E+00 +8.395E+00 -44.00 +3.627E-03 -8.037E+00 +1.081E-02 +4.616E-02 +1.099E-02 +0.000E-39 +0.000E-39
   8 +4.366E+00 +1.648E+00 +8.016E+00 +8.416E+00 -52.00 +3.598E-03 +0.000E-39 +4.915E-03 +4.587E-02 +1.095E-02 +0.000E-39 +0.000E-39
   9 +4.371E+00 +1.660E+00 +7.999E+00 +8.437E+00 -60.00 +3.598E-03 +0.000E-39 +4.904E-03 +4.585E-02 +1.098E-02 +0.000E-39 +0.000E-39
   9 +4.435E+00 +1.844E+00 +7.680E+00 +8.805E+00 -60.00 +3.598E-03 +0.000E-39 +4.697E-03 +4.546E-02 +1.146E-02 +0.000E-39 +0.000E-39
   9 +4.499E+00 +2.028E+00 +7.361E+00 +9.173E+00 -60.00 +3.598E-03 +0.000E-39 +4.493E-03 +4.519E-02 +1.194E-02 +0.000E-39 +0.000E-39
   9 +4.563E+00 +2.212E+00 +7.042E+00 +9.541E+00 -60.00 +3.598E-03 +0.000E-39 +4.289E-03 +4.473E-02 +1.242E-02 +0.000E-39 +0.000E-39
   9 +4.627E+00 +2.396E+00 +6.723E+00 +9.909E+00 -60.00 +3.598E-03 +0.000E-39 +4.033E-03 +4.440E-02 +1.290E-02 +0.000E-39 +0.000E-39
   9 +4.691E+00 +2.581E+00 +6.404E+00 +1.028E+01 -60.00 +3.598E-03 +0.000E-39 +3.888E-03 +4.407E-02 +1.338E-02 +0.000E-39 +0.000E-39
   9 +4.755E+00 +2.765E+00 +6.085E+00 +1.065E+01 -60.00 +3.598E-03 +0.000E-39 +3.537E-03 +4.376E-02 +1.386E-02 +0.000E-39 +0.000E-39
   9 +4.819E+00 +2.949E+00 +5.767E+00 +1.101E+01 -60.00 +3.598E-03 +0.000E-39 +3.491E-03 +4.347E-02 +1.434E-02 +0.000E-39 +0.000E-39
   9 +4.883E+00 +3.133E+00 +5.448E+00 +1.138E+01 -60.00 +3.598E-03 +0.000E-39 +3.294E-03 +4.318E-02 +1.482E-02 +0.000E-39 +0.000E-39
   9 +4.947E+00 +3.317E+00 +5.129E+00 +1.175E+01 -60.00 +3.598E-03 +0.000E-39 +3.098E-03 +4.291E-02 +1.530E-02 +0.000E-39 +0.000E-39
  10 +5.010E+00 +3.501E+00 +4.810E+00 +1.212E+01 -70.00 +3.598E-03 +0.000E-39 +2.902E-03 +4.255E-02 +1.577E-02 +0.000E-39 +0.000E-39
  10 +5.010E+00 +3.629E+00 +4.459E+00 +1.249E+01 -70.00 +3.598E-03 +0.000E-39 +2.537E-03 +4.239E-02 +1.626E-02 +0.000E-39 +0.000E-39
  10 +5.010E+00 +3.758E+00 +4.105E+00 +1.287E+01 -70.00 +3.598E-03 +0.000E-39 +2.473E-03 +4.214E-02 +1.675E-02 +0.000E-39 +0.000E-39
  10 +5.010E+00 +3.886E+00 +3.753E+00 +1.324E+01 -70.00 +3.598E-03 +0.000E-39 +2.257E-03 +4.189E-02 +1.724E-02 +0.000E-39 +0.000E-39
  10 +5.010E+00 +4.014E+00 +3.400E+00 +1.362E+01 -70.00 +3.598E-03 +0.000E-39 +2.045E-03 +4.166E-02 +1.773E-02 +0.000E-39 +0.000E-39
  10 +5.010E+00 +4.142E+00 +3.048E+00 +1.399E+01 -70.00 +3.598E-03 +0.000E-39 +1.834E-03 +4.144E-02 +1.822E-02 +0.000E-39 +0.000E-39
  10 +5.010E+00 +4.271E+00 +2.696E+00 +1.437E+01 -70.00 +3.598E-03 +0.000E-39 +1.621E-03 +4.122E-02 +1.870E-02 +0.000E-39 +0.000E-39
  10 +5.010E+00 +4.399E+00 +2.343E+00 +1.474E+01 -70.00 +3.598E-03 +0.000E-39 +1.407E-03 +4.101E-02 +1.919E-02 +0.000E-39 +0.000E-39
  10 +5.010E+00 +4.527E+00 +1.991E+00 +1.512E+01 -70.00 +3.598E-03 +0.000E-39 +1.197E-03 +4.080E-02 +1.968E-02 +0.000E-39 +0.000E-39
  10 +5.010E+00 +4.655E+00 +1.639E+00 +1.549E+01 -70.00 +3.598E-03 +0.000E-39 +9.349E-04 +4.060E-02 +2.017E-02 +0.000E-39 +0.000E-39
  10 +5.010E+00 +4.784E+00 +1.286E+00 +1.587E+01 -70.00 +3.598E-03 +0.000E-39 +7.730E-04 +4.041E-02 +2.066E-02 +0.000E-39 +0.000E-39
```

```
10 +5.010E+00 +4.912E+00 +9.338E-01 +1.624E+01 -70.00 +3.598E-03 +0.000E-39 +5.512E-04 +4.022E-02 +2.114E-02 +0.000E-39 +0.000E-39
10 +5.010E+00 +5.040E+00 +5.814E-01 +1.662E+01 -70.00 +3.598E-03 +0.000E-39 +3.494E-04 +4.004E-02 +2.163E-02 +0.000E-39 +0.000E-39
10 +5.010E+00 +5.168E+00 +2.290E-01 +1.699E+01 -70.00 +3.598E-03 +0.000E-39 +1.376E-04 +3.986E-02 +2.217E-02 +0.000E-39 +0.000E-39
10 +5.010E+00 +5.297E+00 +1.234E-01 +1.737E+01 -70.00 +3.598E-03 +0.000E-39 +7.415E-05 +3.968E-02 +2.261E-02 +0.000E-39 +0.000E-39
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A124

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AT ALPHA =  +2.0000E+01, LEEWARD, RW =  +1.5237E+00 DELS =  +7.4505E-02 BSHOCK =  +5.6318E-01

SEC     XO L          XB L         YB L         SB L      THETBL  PF/PS L     DP/DS L       QL L         QT L         RF L         QR L         XSI L

  1 +7.538E-02 +0.000E-39 +0.000E-39 +0.000E-39 +90.00 +1.000E+00 +4.809E-05 +1.123E+00 +0.000E-39 +0.000E-39 +8.197E-01 +7.450E-02
  1 +6.118E-02 +7.615E-04 +4.362E-02 +4.353E-02 +88.00 +9.988E-01 -3.915E+00 +1.125E+00 +4.395E-01 +7.745E-05 +7.090E-01 +7.461E-02
  1 +4.259E-02 +4.757E-03 +1.089E-01 +1.091E-01 +85.00 +9.924E-01 -9.747E+00 +1.113E+00 +7.579E-01 +4.818E-04 +6.091E-01 +7.517E-02
  1 +2.732E-02 +1.216E-02 +1.740E-01 +1.745E-01 +82.00 +9.806E-01 -1.547E+01 +9.575E-01 +8.692E-01 +1.032E-03 +4.480E-01 +7.626E-02
  1 +1.539E-02 +2.297E-02 +2.385E-01 +2.400E-01 +79.00 +9.636E-01 -2.103E+01 +9.755E-01 +1.039E+00 +1.927E-03 +2.055E-01 +7.793E-02
  1 +6.848E-03 +3.713E-02 +3.024E-01 +3.054E-01 +76.00 +9.415E-01 -2.635E+01 +9.730E-01 +1.181E+00 +3.073E-03 +0.000E-39 +8.028E-02
  1 +1.713E-03 +5.462E-02 +3.655E-01 +3.709E-01 +73.00 +9.145E-01 -3.139E+01 +9.605E-01 +1.300E+00 +4.442E-03 +0.000E-39 +8.343E-02
  1 +0.000E-39 +7.538E-02 +4.275E-01 +4.353E-01 +70.00 +8.830E-01 -3.608E+01 +9.415E-01 +1.397E+00 +6.003E-03 +0.000E-39 +8.750E-02
  1 +1.713E-03 +9.937E-02 +4.884E-01 +5.018E-01 +67.00 +8.473E-01 -4.038E+01 +9.175E-01 +1.475E+00 +7.718E-03 +0.000E-39 +9.265E-02
  1 +6.848E-03 +1.265E-01 +5.480E-01 +5.672E-01 +64.00 +8.078E-01 -4.423E+01 +8.994E-01 +1.535E+00 +9.547E-03 +0.000E-39 +9.902E-02
  1 +1.539E-02 +1.567E-01 +6.060E-01 +6.327E-01 +61.00 +7.650E-01 -4.750E+01 +8.575E-01 +1.576E+00 +1.144E-02 +0.000E-39 +1.068E-01
  1 +2.732E-02 +1.899E-01 +6.624E-01 +6.981E-01 +58.00 +7.192E-01 -5.045E+01 +8.223E-01 +1.599E+00 +1.335E-02 +0.000E-39 +1.161E-01
  1 +4.259E-02 +2.261E-01 +7.170E-01 +7.635E-01 +55.00 +6.710E-01 -5.274E+01 +7.840E-01 +1.606E+00 +1.524E-02 +0.000E-39 +1.273E-01
  1 +6.118E-02 +2.650E-01 +7.696E-01 +8.290E-01 +52.00 +6.210E-01 -5.446E+01 +7.429E-01 +1.596E+00 +1.705E-02 +0.000E-39 +1.403E-01
  1 +7.538E-02 +2.924E-01 +8.035E-01 +8.727E-01 +50.00 +5.868E-01 -5.528E+01 +7.147E-01 +1.581E+00 +1.817E-02 +0.000E-39 +1.502E-01
  1 +8.302E-02 +3.066E-01 +8.201E-01 +8.945E-01 +49.00 +5.696E-01 -5.558E+01 +7.005E-01 +1.570E+00 +1.871E-02 +0.000E-39 +1.555E-01
  1 +8.302E-02 +3.075E-01 +8.211E-01 +8.959E-01 +48.94 +5.685E-01 -5.560E+01 +7.001E-01 +1.570E+00 +1.874E-02 +0.000E-39 +1.558E-01
  1 +1.081E-01 +3.508E-01 +8.683E-01 +9.599E-01 +46.00 +5.192E-01 -5.610E+01 +5.341E-01 +1.530E+00 +2.018E-02 +0.000E-39 +1.731E-01
  1 +1.362E-01 +3.975E-01 +9.142E-01 +1.025E+00 +43.00 +4.670E-01 -5.599E+01 +5.055E-01 +1.476E+00 +2.142E-02 +0.000E-39 +1.932E-01
  3 +1.675E-01 +4.465E-01 +9.576E-01 +1.091E+00 +40.00 +4.153E-01 +0.000E-39 +5.146E-01 +1.408E+00 +2.237E-02 +0.000E-39 +2.163E-01
  3 +5.601E-01 +1.048E+00 +1.462E+00 +1.876E+00 +40.00 +4.153E-01 +0.000E-39 +3.356E-01 +1.763E+00 +3.848E-02 +0.000E-39 +4.017E-01
  3 +9.527E-01 +1.650E+00 +1.967E+00 +2.661E+00 +40.00 +4.153E-01 +0.000E-39 +3.296E-01 +1.178E+00 +5.458E-02 +0.000E-39 +5.098E-01
  3 +1.345E+00 +2.251E+00 +2.472E+00 +3.445E+00 +40.00 +4.153E-01 +0.000E-39 +2.933E-01 +1.118E+00 +7.068E-02 +0.000E-39 +5.794E-01
  3 +1.738E+00 +2.852E+00 +2.976E+00 +4.232E+00 +40.00 +4.153E-01 +0.000E-39 +2.671E-01 +1.073E+00 +8.579E-02 +0.000E-39 +6.269E-01
  3 +2.130E+00 +3.454E+00 +3.481E+00 +5.017E+00 +40.00 +4.153E-01 +0.000E-39 +2.470E-01 +1.037E+00 +1.029E-01 +0.000E-39 +6.604E-01
  3 +2.523E+00 +4.055E+00 +3.986E+00 +5.802E+00 +40.00 +4.153E-01 +0.000E-39 +2.309E-01 +1.008E+00 +1.190E-01 +0.000E-39 +5.846E-01
  3 +2.916E+00 +4.657E+00 +4.491E+00 +6.587E+00 +40.00 +4.153E-01 +0.000E-39 +2.176E-01 +9.825E-01 +1.351E-01 +0.000E-39 +7.021E-01
  3 +3.308E+00 +5.258E+00 +4.995E+00 +7.372E+00 +40.00 +4.153E-01 +0.000E-39 +2.063E-01 +9.606E-01 +1.512E-01 +0.000E-39 +7.147E-01
  3 +3.701E+00 +5.860E+00 +5.500E+00 +8.158E+00 +40.00 +4.153E-01 +0.000E-39 +1.957E-01 +9.413E-01 +1.673E-01 +0.000E-39 +7.236E-01
  4 +4.093E+00 +6.461E+00 +6.005E+00 +8.943E+00 +40.00 +4.153E-01 +0.000E-39 +1.883E-01 +9.242E-01 +1.834E-01 +0.000E-39 +7.297E-01
  4 +4.102E+00 +6.474E+00 +6.014E+00 +8.959E+00 +34.00 +3.152E-01 -4.337E+02 +2.543E-01 +8.298E-01 +1.704E-01 +0.000E-39 +7.351E-01
  4 +4.112E+00 +6.487E+00 +6.022E+00 +8.974E+00 +28.00 +2.457E-01 -2.797E+02 +2.152E-01 +7.374E-01 +1.554E-01 +0.000E-39 +7.505E-01
  4 +4.123E+00 +6.502E+00 +6.029E+00 +8.990E+00 +22.00 +1.890E-01 -2.253E+02 +1.804E-01 +6.423E-01 +1.386E-01 +0.000E-39 +7.767E-01
  4 +4.135E+00 +6.517E+00 +6.034E+00 +9.006E+00 +16.00 +1.440E-01 -1.808E+02 +1.488E-01 +5.506E-01 +1.214E-01 +0.000E-39 +8.153E-01
  4 +4.148E+00 +6.532E+00 +6.038E+00 +9.021E+00 +10.00 +1.081E-01 -1.433E+02 +1.209E-01 +4.638E-01 +1.045E-01 +0.000E-39 +8.689E-01
  4 +4.162E+00 +6.547E+00 +6.039E+00 +9.037E+00  +4.00 +8.001E-02 -1.122E+02 +9.700E-02 +3.848E-01 +8.838E-02 +0.000E-39 +9.415E-01
  4 +4.177E+00 +6.563E+00 +6.040E+00 +9.053E+00  -2.00 +5.769E-02 -8.573E+01 +7.501E-02 +3.119E-01 +7.305E-02 +0.000E-39 +1.039E+00
  4 +4.192E+00 +6.579E+00 +6.038E+00 +9.068E+00  -8.00 +4.102E-02 -6.456E+01 +5.702E-02 +2.491E-01 +5.944E-02 +0.000E-39 +1.171E+00
  4 +4.208E+00 +6.594E+00 +6.035E+00 +9.084E+00 -14.00 +2.867E-02 -4.730E+01 +4.525E-02 +1.956E-01 +4.755E-02 +0.000E-39 +1.355E+00
  8 +4.223E+00 +6.609E+00 +6.031E+00 +9.100E+00 -20.00 +1.956E-02 -3.456E+01 +3.407E-02 +1.505E-01 +3.723E-02 +0.000E-39 +1.621E+00
  8 +4.244E+00 +6.628E+00 +6.022E+00 +9.121E+00 -28.00 +1.139E-02 -2.175E+01 +2.225E-02 +1.031E-01 +2.611E-02 +0.000E-39 +2.215E+00
  8 +4.265E+00 +6.646E+00 +6.011E+00 +9.142E+00 -36.00 +6.378E-03 -1.316E+01 +1.458E-02 +6.820E-02 +1.767E-02 +0.000E-39 +3.507E+00
  8 +4.284E+00 +6.662E+00 +5.998E+00 +9.163E+00 -44.00 +3.598E-03 +0.000E-39 +3.452E-03 +4.510E-02 +1.193E-02 +0.000E-39 +8.098E+00
  8 +4.303E+00 +6.676E+00 +5.982E+00 +9.184E+00 -52.00 +3.598E-03 +0.000E-39 +3.443E-03 +4.508E-02 +1.195E-02 +0.000E-39 +0.000E-39
  8 +4.320E+00 +6.688E+00 +5.965E+00 +9.205E+00 -60.00 +3.598E-03 +0.000E-39 +3.433E-03 +4.506E-02 +1.198E-02 +0.000E-39 +0.000E-39
  8 +4.335E+00 +6.697E+00 +5.946E+00 +9.226E+00 -68.00 +3.598E-03 +0.000E-39 +3.422E-03 +4.504E-02 +1.201E-02 +0.000E-39 +0.000E-39
  8 +4.348E+00 +6.703E+00 +5.926E+00 +9.246E+00 -76.00 +3.598E-03 +0.000E-39 +3.410E-03 +4.502E-02 +1.204E-02 +0.000E-39 +0.000E-39
  8 +4.358E+00 +6.707E+00 +5.905E+00 +9.267E+00 -84.00 +3.598E-03 +0.000E-39 +3.398E-03 +4.500E-02 +1.206E-02 +0.000E-39 +0.000E-39
  8 +4.366E+00 +6.708E+00 +5.885E+00 +9.288E+00 -92.00 +3.598E-03 +0.000E-39 +3.386E-03 +4.498E-02 +1.209E-02 +0.000E-39 +0.000E-39

I ST       X ST          Y ST          S ST          DTDS ST         THET ST      SECT   ALPHA

  16  +2.13046E+00  +4.02500E+00  +4.58048E+00  +0.00000E-39  +5.00000E+01     3   +30.00

IW SN    XOW SN        YOW SN        XBW SN        YBW SN        SBW SN        THETW SN     SECT  ALPHA
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   13  +4.16234E+00  +7.48703E+00  +3.69015E-02  +4.02451E+00  +4.03348E+00  +4.89372E+01     4   +30.00
 IL SN     XOL SN        YOL SN        XBL SN        YBL SN       SBL SN        THETL SN    SECT  ALPHA
   20  +1.53896E-02  +1.95543E-01  +3.07513E-01  +4.74709E+00  +4.82133E+00  +4.39372E+01     1   +30.00
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AT ALPHA =  +3.0000E+01 WINDWARD, RW =  +1.3235E+01 DELS =  +1.3815E+00 BSHOCK =  -7.7105E+00
THETAW LESS THAN LIMIT

SEC     XO W        XB W        YB W        SB W      THETBW  PE/PS W     DP/DS W      DL W        QT W        RE W        QR W        XSI W

  3 +2.130E+00 +0.000E-39 +0.000E-39 +0.000E-39 +90.00 +1.000E+00 +4.809E-05 +1.717E-01 +0.000E-39 +0.000E-39 +1.520E+01 +1.381E+00
  3 +2.523E+00 -7.451E-09 +7.852E-01 +7.852E-01 +90.00 +9.978E-01 -4.946E-01 +1.713E-01 +2.408E-01 +1.353E-03 +1.239E+01 +1.359E+00
  3 +2.916E+00 -2.235E-08 +1.570E+00 +1.570E+00 +90.00 +9.845E-01 -2.134E+00 +1.590E-01 +3.613E-01 +5.350E-03 +8.497E+00 +1.286E+00
  3 +3.308E+00 -1.490E-08 +2.356E+00 +2.355E+00 +90.00 +9.400E-01 -5.252E+00 +2.594E-01 +7.221E-01 +2.397E-02 +0.000E-39 +1.157E+00
  3 +3.701E+00 -1.490E-08 +3.141E+00 +3.141E+00 +90.00 +8.309E-01 -1.392E+01 +2.597E-01 +1.053E+00 +5.032E-02 +0.000E-39 +9.561E-01
  4 +4.093E+00 +0.000E-39 +3.926E+00 +3.926E+00 +90.00 +6.105E-01 -2.635E+01 +2.518E-01 +1.170E+00 +8.108E-02 +0.000E-39 +6.384E-01
  4 +4.102E+00 +8.217E-04 +3.942E+00 +3.942E+00 +84.00 +6.046E-01 -2.657E+01 +2.537E-01 +1.170E+00 +8.160E-02 +0.000E-39 +6.001E-01
  4 +4.112E+00 +3.278E-03 +3.957E+00 +3.957E+00 +78.00 +5.985E-01 -2.698E+01 +2.527E-01 +1.159E+00 +8.210E-02 +0.000E-39 +5.706E-01
  4 +4.123E+00 +7.341E-03 +3.972E+00 +3.973E+00 +72.00 +5.925E-01 -2.729E+01 +2.516E-01 +1.158E+00 +8.259E-02 +0.000E-39 +5.486E-01
  4 +4.135E+00 +1.297E-02 +3.987E+00 +3.989E+00 +66.00 +5.864E-01 -2.760E+01 +2.505E-01 +1.166E+00 +8.307E-02 +0.000E-39 +5.331E-01
  4 +4.148E+00 +2.010E-02 +4.001E+00 +4.005E+00 +60.00 +5.801E-01 -2.792E+01 +2.493E-01 +1.165E+00 +8.354E-02 +0.000E-39 +5.233E-01
  4 +4.162E+00 +2.865E-02 +4.014E+00 +4.020E+00 +54.00 +5.739E-01 -2.824E+01 +2.480E-01 +1.163E+00 +8.400E-02 +0.000E-39 +5.187E-01
  4 +4.162E+00 +3.690E-02 +4.025E+00 +4.033E+00 +48.94 +5.685E-01 -2.851E+01 +2.459E-01 +1.152E+00 +8.438E-02 +0.000E-39 +5.188E-01
  4 +4.177E+00 +3.853E-02 +4.026E+00 +4.036E+00 +48.00 +5.539E-01 -4.652E+02 +3.166E-01 +1.159E+00 +8.465E-02 +0.000E-39 +5.191E-01
  4 +4.192E+00 +4.963E-02 +4.037E+00 +4.052E+00 +42.00 +4.497E-01 -4.657E+02 +2.373E-01 +1.110E+00 +8.424E-02 +0.000E-39 +5.242E-01
  4 +4.208E+00 +6.183E-02 +4.047E+00 +4.067E+00 +36.00 +3.478E-01 -4.449E+02 +2.523E-01 +1.013E+00 +7.981E-02 +0.000E-39 +5.338E-01
  8 +4.223E+00 +7.500E-02 +4.056E+00 +4.083E+00 +30.00 +2.706E-01 -3.037E+02 +2.099E-01 +9.050E-01 +7.342E-02 +0.000E-39 +5.475E-01
  8 +4.244E+00 +9.381E-02 +4.065E+00 +4.104E+00 +22.00 +1.916E-01 -2.278E+02 +1.635E-01 +7.569E-01 +6.368E-02 +0.000E-39 +5.721E-01
  8 +4.265E+00 +1.137E-01 +4.072E+00 +4.125E+00 +14.00 +1.326E-01 -1.691E+02 +1.249E-01 +6.132E-01 +5.327E-02 +0.000E-39 +6.026E-01
  8 +4.284E+00 +1.343E-01 +4.075E+00 +4.145E+00  +6.00 +8.915E-02 -1.225E+02 +9.244E-02 +4.813E-01 +4.313E-02 +0.000E-39 +6.367E-01
  8 +4.303E+00 +1.552E-01 +4.076E+00 +4.167E+00  -2.00 +5.814E-02 -8.627E+01 +5.539E-02 +3.651E-01 +3.379E-02 +0.000E-39 +6.712E-01
  8 +4.320E+00 +1.760E-01 +4.074E+00 +4.188E+00 -10.00 +3.660E-02 -5.859E+01 +4.518E-02 +2.694E-01 +2.557E-02 +0.000E-39 +7.023E-01
  8 +4.335E+00 +1.964E-01 +4.069E+00 +4.209E+00 -18.00 +2.220E-02 -3.849E+01 +3.115E-02 +1.916E-01 +1.870E-02 +0.000E-39 +0.000E-39
  8 +4.348E+00 +2.158E-01 +4.061E+00 +4.230E+00 -26.00 +1.296E-02 -2.431E+01 +2.045E-02 +1.317E-01 +1.320E-02 +0.000E-39 +0.000E-39
  8 +4.358E+00 +2.339E-01 +4.050E+00 +4.251E+00 -34.00 +7.264E-03 -1.474E+01 +1.306E-02 +8.725E-02 +8.981E-03 +0.000E-39 +0.000E-39
  8 +4.366E+00 +2.504E-01 +4.037E+00 +4.272E+00 -42.00 +3.889E-03 -8.544E+00 +8.123E-03 +5.559E-02 +5.870E-03 +0.000E-39 +0.000E-39
  9 +4.371E+00 +2.649E-01 +4.022E+00 +4.293E+00 -50.00 +3.598E-03 +0.000E-39 +3.579E-03 +5.248E-02 +5.587E-03 +0.000E-39 +0.000E-39
  9 +4.435E+00 +5.016E-01 +3.740E+00 +4.561E+00 -50.00 +3.598E-03 +0.000E-39 +3.320E-03 +5.153E-02 +6.067E-03 +0.000E-39 +0.000E-39
  9 +4.499E+00 +7.383E-01 +3.458E+00 +5.029E+00 -50.00 +3.598E-03 +0.000E-39 +3.053E-03 +5.085E-02 +6.546E-03 +0.000E-39 +0.000E-39
  9 +4.563E+00 +9.749E-01 +3.176E+00 +5.397E+00 -50.00 +3.598E-03 +0.000E-39 +2.808E-03 +5.013E-02 +7.025E-03 +0.000E-39 +0.000E-39
  9 +4.627E+00 +1.212E+00 +2.894E+00 +5.765E+00 -50.00 +3.598E-03 +0.000E-39 +2.555E-03 +4.943E-02 +7.505E-03 +0.000E-39 +0.000E-39
  9 +4.691E+00 +1.448E+00 +2.612E+00 +6.133E+00 -50.00 +3.598E-03 +0.000E-39 +2.303E-03 +4.887E-02 +7.984E-03 +0.000E-39 +0.000E-39
  9 +4.755E+00 +1.685E+00 +2.330E+00 +6.502E+00 -50.00 +3.598E-03 +0.000E-39 +2.052E-03 +4.830E-02 +8.463E-03 +0.000E-39 +0.000E-39
  9 +4.819E+00 +1.922E+00 +2.048E+00 +6.870E+00 -50.00 +3.598E-03 +0.000E-39 +1.802E-03 +4.777E-02 +8.942E-03 +0.000E-39 +0.000E-39
  9 +4.883E+00 +2.158E+00 +1.766E+00 +7.238E+00 -50.00 +3.598E-03 +0.000E-39 +1.553E-03 +4.729E-02 +9.422E-03 +0.000E-39 +0.000E-39
  9 +4.947E+00 +2.395E+00 +1.484E+00 +7.606E+00 -50.00 +3.598E-03 +0.000E-39 +1.305E-03 +4.681E-02 +9.901E-03 +0.000E-39 +0.000E-39
 10 +5.010E+00 +2.632E+00 +1.207E+00 +7.974E+00 -60.00 +3.598E-03 +0.000E-39 +1.055E-03 +4.637E-02 +1.038E-02 +0.000E-39 +0.000E-39
 10 +5.010E+00 +2.819E+00 +8.771E-01 +8.349E+00 -60.00 +3.598E-03 +0.000E-39 +7.707E-04 +4.594E-02 +1.087E-02 +0.000E-39 +0.000E-39
 10 +5.010E+00 +3.007E+00 +5.523E-01 +8.724E+00 -60.00 +3.598E-03 +0.000E-39 +4.853E-04 +4.554E-02 +1.136E-02 +0.000E-39 +0.000E-39
 10 +5.010E+00 +3.194E+00 +2.276E-01 +9.099E+00 -60.00 +3.598E-03 +0.000E-39 +1.999E-04 +4.514E-02 +1.184E-02 +0.000E-39 +0.000E-39
 10 +5.010E+00 +3.382E+00 +9.720E-02 +9.474E+00 -60.00 +3.598E-03 +0.000E-39 +8.341E-05 +4.490E-02 +1.233E-02 +0.000E-39 +0.000E-39
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AT ALPHA =  +3.0000E+01, LEEWARD, RW =  +1.5081F+01 DELS =  +1.3815E+00 DSHOCK =  -1.5338E+00
THETAW LESS THAN LIMIT

SEC     XO L        XB L        YB L        SB L     THETBL  PE/PS L     DP/DS L       QL L        QT L        RE L        QR L        XSI L

  3 +2.130E+00 +0.000F-39 +0.000E-39 +0.000E-39 +90.00 +1.000F+00 +4.809E-06 +1.717E-01 +0.000F-39 +0.000E-39 +1.520E+01 +1.381E+00
  3 +1.738E+00 -0.000E-39 +7.852E-01 +7.852E-01 +90.00 +9.985E-01 -3.096E-01 +1.714E-01 +2.111E-01 +1.149E-03 +1.261E+01 +1.361E+00
  3 +1.345E+00 -0.000E-39 +1.570E+00 +1.570E+00 +90.00 +9.909E-01 -1.202E+00 +1.701E-01 +3.181E-01 +4.566E-03 +1.016E+01 +1.299E+00
  3 +9.527E-01 -0.000E-39 +2.356E+00 +2.356E+00 +90.00 +9.673E-01 -3.251E+00 +2.412E-01 +6.320E-01 +1.797E-02 +4.003E+00 +1.196E+00
  3 +5.601E-01 -0.000E-39 +3.141E+00 +3.141E+00 +90.00 +9.114E-01 -7.070E+00 +2.591E-01 +8.584F-01 +3.823E-02 +0.000E-39 +1.049E+00
  3 +1.675E-01 -0.000E-39 +3.926E+00 +3.926E+00 +90.00 +8.003E-01 -1.321E+01 +2.577E-01 +1.052E+00 +5.703E-02 +0.000E-39 +8.565E-01
  1 +1.362E-01 +1.713E-03 +3.991E+00 +3.991E+00 +87.00 +7.877E-01 -1.385E+01 +2.588E-01 +1.065E+00 +6.968E-02 +0.000E-39 +8.289E-01
  1 +1.081E-01 +6.848E-03 +4.057E+00 +4.057E+00 +84.00 +7.745E-01 -1.450E+01 +2.635E-01 +1.077E+00 +7.235E-02 +0.000E-39 +8.068E-01
  1 +8.302E-02 +1.539E-02 +4.122E+00 +4.122E+00 +81.00 +7.607E-01 -1.518E+01 +2.679E-01 +1.087F+00 +7.502E-02 +0.000E-39 +7.898E-01
  1 +6.118E-02 +2.732E-02 +4.186E+00 +4.188E+00 +78.00 +7.462E-01 -1.538E+01 +2.671E-01 +1.097E+00 +7.769E-02 +0.000E-39 +7.778E-01
  1 +4.259E-02 +4.259E-02 +4.250E+00 +4.253E+00 +75.00 +7.310E-01 -1.660E+01 +2.660E-01 +1.106F+00 +8.035E-02 +0.000E-39 +7.706E-01
  1 +2.732E-02 +6.118E-02 +4.312E+00 +4.319E+00 +72.00 +7.152E-01 -1.734E+01 +2.645E-01 +1.113E+00 +8.299E-02 +0.000E-39 +7.682E-01
  1 +1.539E-02 +8.302E-02 +4.374E+00 +4.384E+00 +69.00 +6.987F-01 -1.810E+01 +2.629E-01 +1.120E+00 +8.559E-02 +0.000E-39 +7.706E-01
  1 +6.848E-03 +1.081E-01 +4.434E+00 +4.450E+00 +66.00 +6.814E-01 -1.889E+01 +2.609E-01 +1.125E+00 +8.814E-02 +0.000E-39 +7.777E-01
  1 +1.713E-03 +1.362E-01 +4.493E+00 +4.515E+00 +63.00 +6.634E-01 -1.970E+01 +2.535E-01 +1.128E+00 +9.062E-02 +0.000E-39 +7.896E-01
  1 +0.000E-39 +1.675E-01 +4.551E+00 +4.580E+00 +60.00 +6.447E-01 -2.053E+01 +2.558E-01 +1.130E+00 +9.303E-02 +0.000E-39 +8.065E-01
  1 +1.713E-03 +2.017E-01 +4.607E+00 +4.645E+00 +57.00 +6.251E-01 -2.139E+01 +2.525E-01 +1.130E+00 +9.534E-02 +0.000E-39 +8.285E-01
  1 +6.848E-03 +2.387E-01 +4.661E+00 +4.711E+00 +54.00 +6.048E-01 -2.227E+01 +2.491E-01 +1.129E+00 +9.752E-02 +0.000E-39 +8.559E-01
  1 +1.539E-02 +2.786E-01 +4.713E+00 +4.777E+00 +51.00 +5.836E-01 -2.317E+01 +2.451E-01 +1.125E+00 +9.956E-02 +0.000E-39 +8.889E-01
  1 +1.539E-02 +3.075E-01 +4.747E+00 +4.822E+00 +48.94 +5.685E-01 -2.331E+01 +2.422E-01 +1.121F+00 +1.009E-01 +0.000E-39 +9.151E-01
  1 +2.732E-02 +3.211E-01 +4.762E+00 +4.842E+00 +48.00 +5.539E-01 -5.532E+01 +2.523E-01 +1.117E+00 +1.016E-01 +0.000E-39 +9.279E-01
  1 +4.259E-02 +3.661E-01 +4.810E+00 +4.908E+00 +45.00 +5.018E-01 -5.613E+01 +2.414E-01 +1.097F+00 +1.031E-01 +0.000E-39 +9.734E-01
  1 +6.118E-02 +4.136E-01 +4.855E+00 +4.973E+00 +42.00 +4.497E-01 -5.532E+01 +2.290E-01 +1.065E+00 +1.034E-01 +0.000E-39 +1.026E+00
  1 +8.302E-02 +4.633E-01 +4.897E+00 +5.039E+00 +39.00 +3.982E-01 -5.490E+01 +2.143E-01 +1.022E+00 +1.024E-01 +0.000E-39 +1.086E+00
  1 +1.081E-01 +5.153E-01 +4.937E+00 +5.104E+00 +35.00 +3.515E-01 -4.658E+01 +1.972E-01 +9.723E-01 +1.005E-01 +0.000E-39 +1.154E+00
  1 +1.362E-01 +5.692E-01 +4.974E+00 +5.170E+00 +33.00 +3.102E-01 -4.121E+01 +1.311E-01 +9.198E-01 +9.780E-02 +0.000E-39 +1.232E+00
  3 +1.675E-01 +6.250E-01 +5.009E+00 +5.235E+00 +30.00 +2.734E-01 -3.678E+01 +1.556E-01 +8.654E-01 +9.460E-02 +0.000E-39 +1.320E+00
  3 +5.601E-01 +1.305E+00 +5.401E+00 +6.020E+00 +30.00 +2.500E-01 -1.657E+00 +1.257E-01 +8.057E-01 +1.050E-01 +0.000E-39 +1.822E+00
  3 +9.527E-01 +1.985E+00 +5.794E+00 +6.805E+00 +30.00 +2.349E-01 -1.094E+00 +1.154E-01 +7.618E-01 +1.157E-01 +0.000E-39 +2.248E+00
  3 +1.345E+00 +2.665E+00 +6.186E+00 +7.591E+00 +30.00 +2.248E-01 -7.245E-01 +1.051E-01 +7.288E-01 +1.256E-01 +0.000E-39 +2.603E+00
  3 +1.738E+00 +3.345F+00 +6.579E+00 +8.376E+00 +30.00 +2.183E-01 -4.655E-01 +9.931E-02 +7.036E-01 +1.379E-01 +0.000E-39 +2.889E+00
  3 +2.130E+00 +4.025F+00 +6.972E+00 +9.161E+00 +30.00 +2.142E-01 -2.757E-01 +9.413E-02 +6.843E-01 +1.495E-01 +0.000E-39 +3.110F+00
  3 +2.523E+00 +4.705E+00 +7.364E+00 +9.946E+00 +30.00 +2.119E-01 -1.329E-01 +9.002E-02 +6.694E-01 +1.616E-01 +0.000E-39 +3.267F+00
  3 +2.916E+00 +5.385E+00 +7.757E+00 +1.073E+01 +30.00 +2.111E-01 -2.438E-02 +8.550E-02 +6.579E-01 +1.741E-01 +0.000E-39 +3.359E+00
  3 +3.308E+00 +6.065E+00 +8.149E+00 +1.152E+01 +30.00 +2.113E-01 +5.772E-02 +3.370E-02 +6.490F-01 +1.869E-01 +0.000E-39 +3.385E+00
  3 +3.701E+00 +6.745E+00 +8.542E+00 +1.230E+01 +30.00 +2.123E-01 +1.184E-01 +3.136E-02 +6.421F-01 +2.000E-01 +0.000E-39 +3.342E+00
  4 +4.093E+00 +7.425E+00 +8.934E+00 +1.309E+01 +30.00 +2.103E-01 -1.293E-01 +8.057E-02 +6.311E-01 +2.119E-01 +0.000E-39 +3.228E+00
  4 +4.102E+00 +7.439E+00 +8.942E+00 +1.310E+01 +24.00 +1.604E-01 -1.972E+02 +1.073E-01 +5.434E-01 +1.866F-01 +0.000E-39 +3.172E+00
  4 +4.112E+00 +7.454F+00 +8.947E+00 +1.312E+01 +18.00 +1.213E-01 -1.573E+02 +8.798E-02 +4.615E-01 +1.617F-01 +0.000E-39 +3.138E+00
  4 +4.123E+00 +7.469E+00 +8.951E+00 +1.313E+01 +12.00 +8.957E-02 -1.230E+02 +7.052E-02 +3.833E-01 +1.370E-01 +0.000E-39 +3.125F+00
  4 +4.135E+00 +7.484E+00 +8.954E+00 +1.315E+01  +6.00 +6.567F-02 -9.539E+01 +5.528E-02 +3.147E-01 +1.146E-01 +0.000E-39 +3.135E+00
  4 +4.148E+00 +7.500E+00 +8.955E+00 +1.317E+01  +0.00 +4.661E-02 -7.133E+01 +4.353E-02 +2.516E-01 +9.337E-02 +0.000E-39 +3.166E+00
  4 +4.162E+00 +7.516E+00 +8.954E+00 +1.318E+01  -6.00 +3.284E-02 -5.359E+01 +3.379E-02 +1.991F-01 +7.520F-02 +0.000E-39 +3.219E+00
  4 +4.177E+00 +7.531E+00 +8.951E+00 +1.320E+01 -12.00 +2.245E-02 -3.838E+01 +2.554E-02 +1.537E-01 +5.908F-02 +0.000F-39 +0.000E-39
  4 +4.192E+00 +7.546E+00 +8.947F+00 +1.321E+01 -18.00 +1.514E-02 -2.776E+01 +1.919E-02 +1.169E-01 +4.569E-02 +0.000F-39 +0.000E-39
  4 +4.208E+00 +7.561E+00 +8.942E+00 +1.323E+01 -24.00 +9.941E-03 -1.934E+01 +1.417E-02 +8.691E-02 +3.457F-02 +0.000E-39 +0.000E-39
  8 +4.223F+00 +7.575E+00 +8.934E+00 +1.324E+01 -30.00 +6.403E-03 -1.321E+01 +1.039E-02 +6.351E-02 +2.567E-02 +0.000E-39 +0.000E-39
  8 +4.244E+00 +7.592F+00 +8.923E+00 +1.326E+01 -38.00 +3.598E-03 +0.000E-39 +2.227E-03 +4.188F-02 +1.727F-02 +0.000E-39 +0.000E-39
  8 +4.265E+00 +7.608E+00 +8.909E+00 +1.329E+01 -46.00 +3.598F-03 +0.000E-39 +2.223E-03 +4.187E-02 +1.729F-02 +0.000F-39 +0.000E-39
  8 +4.284E+00 +7.621F+00 +8.893E+00 +1.331E+01 -54.00 +3.598E-03 +0.000E-39 +2.219E-03 +4.185E-02 +1.732F-02 +0.000E-39 +0.000F-39
  8 +4.303F+00 +7.632E+00 +8.875E+00 +1.333E+01 -62.00 +3.598E-03 +0.000E-39 +2.215E-03 +4.184F-02 +1.735E-02 +0.000F-39 +0.000F-39
  8 +4.320F+00 +7.641F+00 +8.856E+00 +1.335E+01 -70.00 +3.598F-03 +0.000E-39 +2.210E-03 +4.183E-02 +1.738E-02 +0.000F-39 +0.000E-39
  8 +4.335F+00 +7.647F+00 +8.836F+00 +1.337E+01 -78.00 +3.598E-03 +0.000E-39 +2.205E-03 +4.182E-02 +1.740E-02 +0.000F-39 +0.000F-39
  8 +4.348E+00 +7.650E+00 +8.815E+00 +1.339E+01 -86.00 +3.598E-03 +0.000E-39 +2.200E-03 +4.180E-02 +1.743F-02 +0.000F-39 +0.000E-39
  8 +4.358E+00 +7.650F+00 +8.794E+00 +1.341E+01 -94.00 +3.598F-03 +0.000E-39 +2.194E-03 +4.179E-02 +1.746E-02 +0.000E-39 +0.000F-39
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  I ST      X ST           Y ST           S ST          DTDS ST        THET ST      SECT  ALPHA

    23  +4.10845E+00  +7.44642E+00  +8.53264E+00  -6.66667E+00  +5.00000E+01     4   +40.00

  IW SN     XOW SN         YOW SN         XBW SN         YBW SN        SBW SN        THETW SN     SECT  ALPHA

     9  +4.19217E+00  +7.49672E+00  +3.69015E-02  +9.85329E-02  +1.07502E-01  +4.89372E+01     4   +40.00

  IL SN     XOL SN         YOL SN         XBL SN         YBL SN        SBL SN        THETL SN     SECT  ALPHA

    24  +0.00000E-39  +0.00000E-39  +1.55428E+00  +8.36277E+00  +8.55533E+00  ++.39372E+01     1   +40.00


  AT ALPHA =   +4.0000E+01 WINDWARD, RW =  +1.8284E-01 DELS =  +8.9405E-03 DSHOCK =  -8.7277E-01
  SIN(THETAW) NEG. FOR XB =  +2.7315E-02 RW =  +1.8284E-01 DELS =  +8.9406E-03 DSHOCK =  -8.7277E-01

  SEC    XO W        XB W        YB W        SB W     THETBW  PE/PS W    DP/DS W     QL W        QT W        RE W        QR W        XSI W

     4 +4.108E+00 +0.000E-39 +0.000E-39 +0.000E-39 +90.00 +1.000E+00 +4.008E-05 +1.610E+00 +0.000E-39 +0.000E-39 +9.837E-02 +8.941E-03
     4 +4.112E+00 +9.135E-05 +5.235E-03 +5.236E-03 +88.00 +9.988E-01 -3.253E+01 +1.507E+00 +5.716E-01 +9.293E-06 +8.507E-02 +8.953E-03
     4 +4.123E+00 +1.460E-03 +2.088E-02 +2.094E-02 +82.00 +9.806E-01 -1.239E+02 +1.573E+00 +1.522E+00 +1.467E-04 +5.371E-02 +9.144E-03
     4 +4.135E+00 +4.456E-03 +3.629E-02 +3.665E-02 +76.00 +9.415E-01 -2.196E+02 +1.320E+00 +1.805E+00 +3.687E-04 +0.000E-39 +9.565E-03
     4 +4.148E+00 +9.046E-03 +5.130E-02 +5.236E-02 +70.00 +8.830E-01 -3.007E+02 +1.310E+00 +2.135E+00 +7.203E-04 +0.000E-39 +1.022E-02
     4 +4.162E+00 +1.518E-02 +6.576E-02 +6.807E-02 +64.00 +8.078E-01 -3.636E+02 +1.251E+00 +2.345E+00 +1.146E-03 +0.000E-39 +1.113E-02
     4 +4.177E+00 +2.279E-02 +7.949E-02 +8.378E-02 +58.00 +7.192E-01 -4.204E+02 +1.154E+00 +2.444E+00 +1.603E-03 +0.000E-39 +1.229E-02
     4 +4.192E+00 +3.180E-02 +9.235E-02 +9.943E-02 +52.00 +6.210E-01 -4.539E+02 +1.054E+00 +2.439E+00 +2.045E-03 +0.000E-39 +1.373E-02
     4 +4.192E+00 +3.690E-02 +9.853E-02 +1.075E-01 +48.94 +5.685E-01 -4.633E+02 +9.939E-01 +2.399E+00 +2.249E-03 +0.000E-39 +1.457E-02
     4 +4.208E+00 +4.210E-02 +1.042E-01 +1.152E-01 +46.00 +5.192E-01 -4.675E+02 +9.315E-01 +2.339E+00 +2.422E-03 +0.000E-39 +1.545E-02
     8 +4.223E+00 +5.358E-02 +1.149E-01 +1.309E-01 +40.00 +4.153E-01 -4.606E+02 +7.922E-01 +2.151E+00 +2.685E-03 +0.000E-39 +1.748E-02
     8 +4.244E+00 +7.051E-02 +1.272E-01 +1.518E-01 +32.00 +2.834E-01 -4.204E+02 +5.971E-01 +1.797E+00 +2.781E-03 +0.000E-39 +2.068E-02
     8 +4.265E+00 +8.899E-02 +1.370E-01 +1.723E-01 +24.00 +2.014E-01 -2.372E+02 +4.477E-01 +1.465E+00 +2.744E-03 +0.000E-39 +2.450E-02
     8 +4.284E+00 +1.087E-01 +1.442E-01 +1.937E-01 +16.00 +1.400E-01 -1.757E+02 +3.300E-01 +1.167E+00 +2.575E-03 +0.000E-39 +2.897E-02
     8 +4.303E+00 +1.291E-01 +1.485E-01 +2.147E-01  +8.00 +9.488E-02 -1.289E+02 +2.359E-01 +9.044E-01 +2.313E-03 +0.000E-39 +3.411E-02
     8 +4.320E+00 +1.500E-01 +1.500E-01 +2.336E-01  +0.00 +5.244E-02 -9.152E+01 +1.623E-01 +6.811E-01 +1.993E-03 +0.000E-39 +3.993E-02
     8 +4.335E+00 +1.709E-01 +1.485E-01 +2.566E-01  -8.00 +3.950E-02 -6.256E+01 +1.072E-01 +4.955E-01 +1.543E-03 +0.000E-39 +4.642E-02
     8 +4.348E+00 +1.913E-01 +1.442E-01 +2.775E-01 -16.00 +2.421E-02 -4.142E+01 +5.788E-02 +3.592E-01 +1.304E-03 +0.000E-39 +5.353E-02
     8 +4.358E+00 +2.110E-01 +1.370E-01 +2.985E-01 -24.00 +1.427E-02 -2.639E+01 +4.094E-02 +2.393E-01 +9.926E-04 +0.000E-39 +0.000E-39
     8 +4.366E+00 +2.295E-01 +1.272E-01 +3.194E-01 -32.00 +8.075E-03 -1.615E+01 +2.354E-02 +1.579E-01 +7.252E-04 +0.000E-39 +0.000E-39
     9 +4.371E+00 +2.464E-01 +1.149E-01 +3.403E-01 -40.00 +4.378E-03 -9.476E+00 +1.292E-02 +1.004E-01 +5.077E-04 +0.000E-39 +0.000E-39
     9 +4.435E+00 +5.285E-01 +1.218E-01 +7.085E-01 -40.00 +4.378E-03 +0.000E-39 +9.754E-03 +8.674E-02 +1.057E-03 +0.000E-39 +0.000E-39
  CANNOT FIND THETA FOR RW OR B, SKIP CASE
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AT ALPHA =  +4.0000E+01, LEEWARD, RW =  +0.0000E-39 DFLS =  +8.9405E-03 BSHOCK =  +0.0000E-39

SFC    XO L        XB L        YB L        SB L     THETBL  PE/PS L     DP/DS L      QL L        QT L        RE L        QR L        XSI L

  4 +4.108E+00 +0.000E-39 +0.000E-39 +0.000E-39 +90.00 +1.000E+00 +4.008E-05 +1.510E+00 +0.000E-39 +0.000E-39 +0.000E-39 +0.000E-39
  4 +4.102E+00 +3.654E-04 +1.046E-02 +1.047E-02 +86.00 +9.951E-01 -6.510E+01 +1.501E+00 +9.641E-02 +1.955E-06 +0.000E-39 +0.000E-39
  4 +4.093E+00 +2.279E-03 +2.605E-02 +2.618E-02 +80.00 +9.698E-01 -1.600E+02 +1.553E+00 +1.639E-01 +1.199E-05 +0.000E-39 +0.000E-39
  3 +3.701E+00 +1.386E-01 +7.993E-01 +8.114E-01 +80.00 +9.698E-01 +0.000E-39 +7.569E-01 +7.581E-01 +5.949E-03 +0.000E-39 +0.000E-39
  3 +3.308E+00 +2.750E-01 +1.573E+00 +1.597E+00 +80.00 +9.698E-01 +0.000E-39 +5.227E-01 +5.622E-01 +1.171E-02 +0.000E-39 +0.000E-39
  3 +2.916E+00 +4.113E-01 +2.346E+00 +2.382E+00 +80.00 +9.698E-01 +0.000E-39 +5.254E-01 +6.112E-01 +1.746E-02 +0.000E-39 +0.000E-39
  3 +2.523E+00 +5.477E-01 +3.119E+00 +3.167E+00 +80.00 +9.698E-01 +0.000E-39 +4.607E-01 +5.774E-01 +2.322E-02 +0.000E-39 +0.000E-39
  3 +2.130E+00 +6.840E-01 +3.892E+00 +3.952E+00 +80.00 +9.698E-01 +0.000E-39 +4.145E-01 +5.524E-01 +2.898E-02 +0.000E-39 +0.000E-39
  3 +1.738E+00 +8.204E-01 +4.666E+00 +4.737E+00 +80.00 +9.698E-01 +0.000E-39 +3.798E-01 +5.327E-01 +3.474E-02 +0.000E-39 +0.000E-39
  3 +1.345E+00 +9.567E-01 +5.439E+00 +5.523E+00 +80.00 +9.698E-01 +0.000E-39 +3.524E-01 +5.166E-01 +4.049E-02 +0.000E-39 +0.000E-39
  3 +9.527E-01 +1.093E+00 +6.212E+00 +6.308E+00 +80.00 +9.698E-01 +0.000E-39 +3.301E-01 +5.031E-01 +4.525E-02 +0.000E-39 +0.000E-39
  3 +5.601E-01 +1.229E+00 +6.985E+00 +7.093E+00 +80.00 +9.698E-01 +0.000E-39 +3.116E-01 +4.914E-01 +5.201E-02 +0.000E-39 +0.000E-39
  3 +1.675E-01 +1.366E+00 +7.759E+00 +7.878E+00 +80.00 +9.698E-01 +0.000E-39 +2.953E-01 +4.812E-01 +5.777E-02 +0.000E-39 +0.000E-39
  1 +1.362E-01 +1.379E+00 +7.823E+00 +7.944E+00 +77.00 +9.494E-01 -2.451E+01 +5.105E-01 +5.836E-01 +7.453E-02 +0.000E-39 +0.000E-39
  1 +1.081E-01 +1.395E+00 +7.886E+00 +8.009E+00 +74.00 +9.240E-01 -2.974E+01 +5.793E-01 +6.747E-01 +9.091E-02 +0.000E-39 +0.000E-39
  1 +8.302E-02 +1.415E+00 +7.949E+00 +8.074E+00 +71.00 +8.940E-01 -3.456E+01 +5.382E-01 +7.549E-01 +1.064E-01 +0.000E-39 +0.000E-39
  1 +6.118E-02 +1.438E+00 +8.010E+00 +8.140E+00 +68.00 +8.597E-01 -3.899E+01 +5.353E-01 +8.240E-01 +1.209E-01 +0.000E-39 +0.000E-39
  1 +4.259E-02 +1.464E+00 +8.070E+00 +8.205E+00 +65.00 +8.214E-01 -4.300E+01 +7.231E-01 +8.820E-01 +1.343E-01 +0.000E-39 +0.000E-39
  1 +2.732E-02 +1.493E+00 +8.129E+00 +8.271E+00 +62.00 +7.796E-01 -4.653E+01 +7.485E-01 +9.288E-01 +1.463E-01 +0.000E-39 +0.000E-39
  1 +1.539E-02 +1.525E+00 +8.185E+00 +8.336E+00 +59.00 +7.347E-01 -4.956E+01 +7.527E-01 +9.642E-01 +1.568E-01 +0.000E-39 +0.000E-39
  1 +6.848E-03 +1.560E+00 +8.241E+00 +8.402E+00 +56.00 +6.873E-01 -5.204E+01 +7.550E-01 +9.882E-01 +1.656E-01 +0.000E-39 +0.000E-39
  1 +1.713E-03 +1.598E+00 +8.294E+00 +8.467E+00 +53.00 +6.378E-01 -5.396E+01 +7.592E-01 +1.001E+00 +1.726E-01 +0.000E-39 +0.000E-39
  1 +0.000E-39 +1.639E+00 +8.345E+00 +8.533E+00 +50.00 +5.868E-01 -5.528E+01 +7.429E-01 +1.002E+00 +1.777E-01 +0.000E-39 +0.000E-39
  1 +0.000E-39 +1.654E+00 +8.363E+00 +8.556E+00 +48.94 +5.685E-01 -5.560E+01 +7.374E-01 +9.995E-01 +1.790E-01 +0.000E-39 +0.000E-39
  1 +1.713E-03 +1.683E+00 +8.394E+00 +8.598E+00 +47.00 +5.366E-01 -5.599E+01 +7.200E-01 +9.922E-01 +1.807E-01 +0.000E-39 +0.000E-39
  1 +6.848E-03 +1.728E+00 +8.441E+00 +8.664E+00 +44.00 +4.844E-01 -5.610E+01 +5.352E-01 +9.717E-01 +1.815E-01 +0.000E-39 +0.000E-39
  1 +1.539E-02 +1.777E+00 +8.485E+00 +8.729E+00 +41.00 +4.325E-01 -5.558E+01 +5.472E-01 +9.408E-01 +1.804E-01 +0.000E-39 +0.000E-39
  1 +2.732E-02 +1.827E+00 +8.527E+00 +8.794E+00 +38.00 +3.813E-01 -5.445E+01 +5.024E-01 +8.999E-01 +1.769E-01 +0.000E-39 +0.000E-39
  1 +4.259E-02 +1.880E+00 +8.566E+00 +8.860E+00 +35.00 +3.372E-01 -4.455E+01 +5.519E-01 +8.561E-01 +1.722E-01 +0.000E-39 +0.000E-39
  1 +6.118E-02 +1.934E+00 +8.602E+00 +8.925E+00 +32.00 +2.981E-01 -3.972E+01 +5.052E-01 +8.099E-01 +1.655E-01 +0.000E-39 +0.000E-39
  1 +8.302E-02 +1.991E+00 +8.635E+00 +8.991E+00 +29.00 +2.627E-01 -3.554E+01 +4.622E-01 +7.620E-01 +1.600E-01 +0.000E-39 +0.000E-39
  1 +1.081E-01 +2.049E+00 +8.665E+00 +9.056E+00 +26.00 +2.309E-01 -3.186E+01 +4.202E-01 +7.132E-01 +1.528E-01 +0.000E-39 +0.000E-39
  1 +1.362E-01 +2.108E+00 +8.692E+00 +9.122E+00 +23.00 +2.028E-01 -2.853E+01 +3.312E-01 +6.654E-01 +1.453E-01 +0.000E-39 +0.000E-39
  3 +1.675E-01 +2.169E+00 +8.716E+00 +9.187E+00 +20.00 +1.777E-01 -2.570E+01 +3.443E-01 +6.180E-01 +1.375E-01 +0.000E-39 +0.000E-39
  3 +5.601E-01 +2.907E+00 +8.985E+00 +9.972E+00 +20.00 +1.668E-01 -8.830E-01 +2.703E-01 +5.868E-01 +1.443E-01 +0.000E-39 +0.000E-39
  3 +9.527E-01 +3.645E+00 +9.253E+00 +1.076E+01 +20.00 +1.577E-01 -7.422E-01 +2.447E-01 +5.600E-01 +1.519E-01 +0.000E-39 +0.000E-39
  3 +1.345E+00 +4.383E+00 +9.522E+00 +1.154E+01 +20.00 +1.509E-01 -5.723E-01 +2.253E-01 +5.382E-01 +1.594E-01 +0.000E-39 +0.000E-39
  3 +1.738E+00 +5.121E+00 +9.790E+00 +1.233E+01 +20.00 +1.510E-01 +0.000E-39 +2.093E-01 +5.314E-01 +1.703E-01 +0.000E-39 +0.000E-39
  3 +2.130E+00 +5.858E+00 +1.006E+01 +1.311E+01 +20.00 +1.450E-01 -4.996E-01 +2.029E-01 +5.127E-01 +1.774E-01 +0.000E-39 +0.000E-39
  3 +2.523E+00 +6.596E+00 +1.033E+01 +1.390E+01 +20.00 +1.397E-01 -4.419E-01 +1.912E-01 +4.960E-01 +1.845E-01 +0.000E-39 +0.000E-39
  3 +2.916E+00 +7.334E+00 +1.060E+01 +1.468E+01 +20.00 +1.351E-01 -3.930E-01 +1.813E-01 +4.809E-01 +1.915E-01 +0.000E-39 +0.000E-39
  3 +3.308E+00 +8.072E+00 +1.086E+01 +1.547E+01 +20.00 +1.306E-01 -3.783E-01 +1.727E-01 +4.665E-01 +1.982E-01 +0.000E-39 +0.000E-39
  3 +3.701E+00 +8.810E+00 +1.113E+01 +1.625E+01 +20.00 +1.266E-01 -3.336E-01 +1.649E-01 +4.535E-01 +2.049E-01 +0.000E-39 +0.000E-39
  4 +4.093E+00 +9.548E+00 +1.140E+01 +1.704E+01 +20.00 +1.231E-01 -2.954E-01 +1.532E-01 +4.417E-01 +2.116E-01 +0.000E-39 +0.000E-39
  4 +4.102E+00 +9.563E+00 +1.141E+01 +1.705E+01 +14.00 +9.093E-02 -1.245E+02 +2.105E-01 +3.672E-01 +1.794E-01 +0.000E-39 +0.000E-39
  4 +4.108E+00 +9.573E+00 +1.141E+01 +1.707E+01 +10.00 +7.420E-02 -1.055E+02 +1.354E-01 +3.230E-01 +1.598E-01 +0.000E-39 +0.000E-39
  4 +4.112E+00 +9.578E+00 +1.141E+01 +1.707E+01  +8.00 +6.666E-02 -9.657E+01 +1.750E-01 +3.016E-01 +1.551E-01 +0.000E-39 +0.000E-39
  4 +4.123E+00 +9.594E+00 +1.141E+01 +1.709E+01  +2.00 +4.729E-02 -7.259E+01 +1.304E-01 +2.411E-01 +1.222E-01 +0.000E-39 +0.000E-39
  4 +4.135E+00 +9.609E+00 +1.141E+01 +1.710E+01  -4.00 +3.332E-02 -5.425E+01 +1.012E-01 +1.909E-01 +9.947E-02 +0.000E-39 +0.000E-39
  4 +4.148E+00 +9.625E+00 +1.141E+01 +1.712E+01 -10.00 +2.279E-02 -3.936E+01 +7.553E-02 +1.473E-01 +7.735E-02 +0.000E-39 +0.000E-39
  4 +4.162E+00 +9.640E+00 +1.141E+01 +1.713E+01 -16.00 +1.537E-02 -2.812E+01 +5.752E-02 +1.121E-01 +5.985E-02 +0.000E-39 +0.000E-39
  4 +4.177E+00 +9.655E+00 +1.140E+01 +1.715E+01 -22.00 +1.011E-02 -1.952E+01 +4.263E-02 +8.349E-02 +4.531E-02 +0.000E-39 +0.000E-39
  4 +4.192E+00 +9.669E+00 +1.139E+01 +1.716E+01 -28.00 +6.514E-03 -1.340E+01 +3.133E-02 +6.195E-02 +3.357E-02 +0.000E-39 +0.000E-39
  4 +4.208E+00 +9.683E+00 +1.139E+01 +1.718E+01 -34.00 +4.092E-03 -8.933E+00 +2.269E-02 +4.366E-02 +2.445E-02 +0.000E-39 +0.000E-39
  8 +4.223E+00 +9.695E+00 +1.138E+01 +1.720E+01 -40.00 +3.598E-03 +0.000E-39 +5.451E-03 +3.976E-02 +2.238E-02 +0.000E-39 +0.000E-39
  8 +4.244E+00 +9.710E+00 +1.136E+01 +1.722E+01 -48.00 +3.598E-03 +0.000E-39 +5.453E-03 +3.275E-02 +2.241E-02 +0.000E-39 +0.000E-39
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   8 +4.265E+00 +9.723E+00 +1.134E+01 +1.724E+01 -56.00 +3.598E-03 +0.000E-39 +5.443E-03 +3.974E-02 +2.244E-02 +0.000E-39 +0.000E-39
   8 +4.284E+00 +9.734E+00 +1.133E+01 +1.725E+01 -64.00 +3.598E-03 +0.000E-39 +5.433E-03 +3.973E-02 +2.247E-02 +0.000E-39 +0.000E-39
   8 +4.303E+00 +9.742E+00 +1.131E+01 +1.728E+01 -72.00 +3.598E-03 +0.000E-39 +5.421E-03 +3.972E-02 +2.249E-02 +0.000E-39 +0.000E-39
   8 +4.320E+00 +9.747E+00 +1.129E+01 +1.730E+01 -80.00 +3.598E-03 +0.000E-39 +5.410E-03 +3.971E-02 +2.252E-02 +0.000E-39 +0.000E-39
   8 +4.335E+00 +9.749E+00 +1.127E+01 +1.732E+01 -88.00 +3.598E-03 +0.000E-39 +5.397E-03 +3.970E-02 +2.255E-02 +0.000E-39 +0.000E-39
   8 +4.348E+00 +9.748E+00 +1.125E+01 +1.734E+01 -96.00 +3.598E-03 +0.000E-39 +5.385E-03 +3.970E-02 +2.257E-02 +0.000E-39 +0.000E-39

 I ST      X ST            Y ST           S ST           DTDS ST        THET ST        SECT  ALPHA

  26  +4.14835E+00  +7.47990E+00  +8.58500E+00  -6.66667E+00  +3.00000E+01      4   +60.00

 IW SN     XOW SN          YOW SN         XBW SN         YBW SN         SBW SN         THETW SN     SECT  ALPHA

   8  +4.24423E+00  +7.49854E+00  +3.69015E-02  +9.85328E-02  +1.07502E-01  +4.89372E+01      8   +60.00

 IL SN     XOL SN          YOL SN         XBL SN         YBL SN         SBL SN         THETL SN     SECT  ALPHA

  20  +8.30245E-02  +4.47960E-01  +4.08612E+00  +7.07111E+00  +8.17186E+00  +4.39372E+01      1   +60.00


 AT ALPHA =  +6.0000E+01 WINDWARD, RW =  +2.7633E-01 DELS =  +1.8342E-02 DSHOCK =  -1.3402E+00
 SIN(THETAW) NEG. FOR XB =  +2.7315E-02 RW =  +2.7633E-01 DELS =  +1.8342E-02 DSHOCK =  -1.3402E+00

 SEC    XO W        XB W        YB W        SB W     THETBW  PE/PS W     DP/DS W      QL W        QT W        RF W        QR W        XSI W

   4 +4.148E+00 +0.000E-39 +0.000E-39 +0.000E-39 +90.00 +1.000E+00 -4.879E-04 +1.573E+00 +0.000E-39 +0.000E-39 +2.018E-01 +1.834E-02
   4 +4.162E+00 +8.217E-04 +1.568E-02 +1.571E-02 +84.00 +9.891E-01 -9.725E+01 +1.550E+00 +1.122E+00 +8.305E-05 +1.398E-01 +1.870E-02
   4 +4.177E+00 +3.278E-03 +3.119E-02 +3.142E-02 +78.00 +9.568E-01 -1.903E+02 +1.506E+00 +1.659E+00 +3.243E-04 +2.688E-02 +1.978E-02
   4 +4.192E+00 +7.342E-03 +4.635E-02 +4.712E-02 +72.00 +9.045E-01 -2.749E+02 +1.339E+00 +1.775E+00 +5.931E-04 +0.000E-39 +2.159E-02
   4 +4.208E+00 +1.297E-02 +6.101E-02 +6.283E-02 +66.00 +8.346E-01 -3.476E+02 +1.343E+00 +1.992E+00 +9.981E-04 +0.000E-39 +2.411E-02
   8 +4.223E+00 +2.010E-02 +7.500E-02 +7.854E-02 +60.00 +7.500E-01 -4.051E+02 +1.259E+00 +2.109E+00 +1.450E-03 +0.000E-39 +2.735E-02
   8 +4.244E+00 +3.180E-02 +9.235E-02 +9.948E-02 +52.00 +6.210E-01 -4.539E+02 +1.106E+00 +2.123E+00 +2.045E-03 +0.000E-39 +3.274E-02
   8 +4.244E+00 +3.690E-02 +9.853E-02 +1.075E-01 +48.94 +5.685E-01 -4.633E+02 +1.045E+00 +2.088E+00 +2.240E-03 +0.000E-39 +3.512E-02
   8 +4.265E+00 +4.580E-02 +1.079E-01 +1.204E-01 +44.00 +4.844E-01 -4.675E+02 +9.281E-01 +1.989E+00 +2.524E-03 +0.000E-39 +3.930E-02
   8 +4.284E+00 +6.183E-02 +1.214E-01 +1.414E-01 +36.00 +3.478E-01 -4.449E+02 +7.233E-01 +1.727E+00 +2.774E-03 +0.000E-39 +4.688E-02
   8 +4.303E+00 +7.958E-02 +1.324E-01 +1.623E-01 +28.00 +2.493E-01 -2.832E+02 +5.453E-01 +1.443E+00 +2.828E-03 +0.000E-39 +5.524E-02
   8 +4.320E+00 +9.870E-02 +1.410E-01 +1.933E-01 +20.00 +1.758E-01 -2.124E+02 +4.083E-01 +1.170E+00 +2.730E-03 +0.000E-39 +6.403E-02
   8 +4.335E+00 +1.188E-01 +1.467E-01 +2.042E-01 +12.00 +1.213E-01 -1.573E+02 +2.989E-01 +9.236E-01 +2.517E-03 +0.000E-39 +7.277E-02
   8 +4.348E+00 +1.395E-01 +1.496E-01 +2.251E-01  +4.00 +8.138E-02 -1.137E+02 +2.133E-01 +7.085E-01 +2.223E-03 +0.000E-39 +8.094E-02
   8 +4.358E+00 +1.605E-01 +1.496E-01 +2.461E-01  -4.00 +5.274E-02 -7.959E+01 +1.475E-01 +5.256E-01 +1.881E-03 +0.000E-39 +8.800E-02
   8 +4.366E+00 +1.812E-01 +1.467E-01 +2.670E-01 -12.00 +3.322E-02 -5.411E+01 +9.951E-02 +3.810E-01 +1.534E-03 +0.000E-39 +9.355E-02
   9 +4.371E+00 +2.013E-01 +1.410E-01 +2.880E-01 -20.00 +2.009E-02 -3.535E+01 +6.483E-02 +2.662E-01 +1.199E-03 +0.000E-39 +0.000E-39
   9 +4.435E+00 +5.473E-01 +1.502E-02 +6.552E-01 -20.00 +2.009E-02 +0.000E-39 +4.825E-02 +2.258E-01 +2.732E-03 +0.000E-39 +0.000E-39
   9 +4.499E+00 +8.933E-01 +1.109E-01 +1.024E+00 -70.00 +2.009E-02 +0.000E-39 +4.482E-02 +2.065E-01 +4.255E-03 +0.000E-39 +0.000E-39
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AT ALPHA =  +6.0000E+01, LEEWARD, RW =  +1.6970E+01 DELS =  +1.8342E-02 BSHOCK =  -2.7396E+00
SIN(THETAW) NEG. FOR XB =  +4.0572E+00 RW =  +1.6970E+01 DELS =  +1.8342E-02 BSHOCK =  -2.7396E+00

SEC     XO L        XB L        YB L        SB L     THETBL  PE/PS L     DP/DS L       QL L        QT L        RE L        QR L        XSI L

  4 +4.148E+00 +0.000E-39 +0.000E-39 +0.000E-39 +90.00 +1.000E+00 -5.153E-04 +1.573E+00 +0.000E-39 +0.000E-39 +2.018E-01 +1.834E-02
  4 +4.135E+00 +8.217E-04 +1.568E-02 +1.571E-02 +84.00 +9.891E-01 -9.725E+01 +1.550E+00 +2.384E-01 +1.198E-05 +1.712E-01 +1.926E-02
  4 +4.123E+00 +3.278E-03 +3.119E-02 +3.142E-02 +78.00 +9.568E-01 -1.903E+02 +1.506E+00 +3.524E-01 +4.677E-05 +6.028E-02 +2.206E-02
  4 +4.112E+00 +7.342E-03 +4.635E-02 +4.712E-02 +72.00 +9.045E-01 -2.749E+02 +5.594E+00 +1.775E+00 +5.931E-04 +3.571E-02 +2.691E-02
  4 +4.102E+00 +1.297E-02 +6.101E-02 +6.283E-02 +66.00 +8.346E-01 -3.476E+02 +4.401E+00 +1.992E+00 +9.981E-04 +4.353E-02 +3.409E-02
  4 +4.093E+00 +2.010E-02 +7.500E-02 +7.854E-02 +60.00 +7.500E-01 -4.051E+02 +3.807E+00 +2.109E+00 +1.450E-03 +5.385E-02 +4.406E-02
  3 +3.701E+00 +4.127E-01 +7.550E-01 +8.637E-01 +60.00 +7.500E-01 +0.000E-39 +7.245E-01 +1.306E+00 +1.595E-02 +0.000E-39 +4.645E-01
  3 +3.308E+00 +8.053E-01 +1.435E+00 +1.649E+00 +60.00 +7.500E-01 +0.000E-39 +5.180E-01 +1.147E+00 +3.044E-02 +0.000E-39 +8.334E-01
  3 +2.916E+00 +1.198E+00 +2.115E+00 +2.434E+00 +60.00 +7.500E-01 +0.000E-39 +4.245E-01 +1.061E+00 +4.494E-02 +0.000E-39 +1.153E+00
  3 +2.523E+00 +1.590E+00 +2.795E+00 +3.219E+00 +60.00 +7.500E-01 +0.000E-39 +3.533E-01 +1.004E+00 +5.943E-02 +0.000E-39 +1.426E+00
  3 +2.130E+00 +1.983E+00 +3.475E+00 +4.005E+00 +60.00 +7.500E-01 +0.000E-39 +3.298E-01 +9.608E-01 +7.393E-02 +0.000E-39 +1.651E+00
  3 +1.738E+00 +2.376E+00 +4.155E+00 +4.790E+00 +60.00 +7.500E-01 +0.000E-39 +3.013E-01 +9.270E-01 +8.843E-02 +0.000E-39 +1.829E+00
  3 +1.345E+00 +2.768E+00 +4.835E+00 +5.575E+00 +60.00 +7.500E-01 +0.000E-39 +2.791E-01 +8.993E-01 +1.029E-01 +0.000E-39 +1.957E+00
  3 +9.527E-01 +3.161E+00 +5.515E+00 +6.360E+00 +60.00 +7.500E-01 +0.000E-39 +2.611E-01 +8.759E-01 +1.174E-01 +0.000E-39 +2.032E+00
  3 +5.601E-01 +3.553E+00 +6.195E+00 +7.145E+00 +60.00 +7.500E-01 +0.000E-39 +2.453E-01 +8.558E-01 +1.319E-01 +0.000E-39 +2.050E+00
  3 +1.675E-01 +3.946E+00 +6.875E+00 +7.931E+00 +60.00 +7.500E-01 +0.000E-39 +2.337E-01 +8.381E-01 +1.464E-01 +0.000E-39 +2.004E+00
  1 +1.362E-01 +3.980E+00 +6.931E+00 +7.996E+00 +57.00 +7.034E-01 -5.128E+01 +3.454E-01 +8.625E-01 +1.554E-01 +0.000E-39 +1.989E+00
  1 +1.081E-01 +4.017E+00 +6.985E+00 +8.061E+00 +54.00 +6.545E-01 -5.338E+01 +3.454E-01 +8.767E-01 +1.628E-01 +0.000E-39 +1.979E+00
  1 +8.302E-02 +4.057E+00 +7.037E+00 +8.127E+00 +51.00 +6.040E-01 -5.490E+01 +3.414E-01 +8.810E-01 +1.683E-01 +0.000E-39 +1.975E+00
  1 +8.302E-02 +4.086E+00 +7.071E+00 +8.172E+00 +48.94 +5.685E-01 -5.560E+01 +3.375E-01 +8.782E-01 +1.710E-01 +0.000E-39 +1.975E+00
  1 +6.118E-02 +4.100E+00 +7.086E+00 +8.192E+00 +48.00 +5.539E-01 -5.532E+01 +3.355E-01 +8.756E-01 +1.718E-01 +0.000E-39 +1.976E+00
  1 +4.259E-02 +4.145E+00 +7.134E+00 +8.258E+00 +45.00 +5.018E-01 -5.613E+01 +3.229E-01 +8.607E-01 +1.735E-01 +0.000E-39 +1.981E+00
  1 +2.732E-02 +4.192E+00 +7.179E+00 +8.323E+00 +42.00 +4.497E-01 -5.532E+01 +3.085E-01 +8.355E-01 +1.730E-01 +0.000E-39 +1.992E+00
  1 +1.539E-02 +4.242E+00 +7.221E+00 +8.389E+00 +39.00 +3.982E-01 -5.490E+01 +2.910E-01 +8.034E-01 +1.705E-01 +0.000E-39 +2.007E+00
  1 +6.848E-03 +4.294E+00 +7.261E+00 +8.454E+00 +36.00 +3.515E-01 -4.658E+01 +2.677E-01 +7.652E-01 +1.664E-01 +0.000E-39 +2.027E+00
  1 +1.713E-03 +4.348E+00 +7.298E+00 +8.520E+00 +33.00 +3.102E-01 -4.121E+01 +2.455E-01 +7.246E-01 +1.612E-01 +0.000E-39 +2.052E+00
  1 +0.000E-39 +4.404E+00 +7.333E+00 +8.585E+00 +30.00 +2.734E-01 -3.678E+01 +2.255E-01 +6.824E-01 +1.551E-01 +0.000E-39 +2.081E+00
  1 +1.713E-03 +4.461E+00 +7.364E+00 +8.650E+00 +27.00 +2.410E-01 -3.303E+01 +2.079E-01 +6.405E-01 +1.486E-01 +0.000E-39 +2.114E+00
  1 +6.848E-03 +4.520E+00 +7.392E+00 +8.715E+00 +24.00 +2.120E-01 -2.959E+01 +1.900E-01 +5.984E-01 +1.416E-01 +0.000E-39 +2.152E+00
  1 +1.539E-02 +4.581E+00 +7.417E+00 +8.781E+00 +21.00 +1.856E-01 -2.653E+01 +1.727E-01 +5.551E-01 +1.342E-01 +0.000E-39 +2.194E+00
  1 +2.732E-02 +4.642E+00 +7.439E+00 +8.847E+00 +18.00 +1.617E-01 -2.331E+01 +1.562E-01 +5.141E-01 +1.265E-01 +0.000E-39 +2.239E+00
  1 +4.259E-02 +4.705E+00 +7.457E+00 +8.912E+00 +15.00 +1.408E-01 -2.129E+01 +1.412E-01 +4.739E-01 +1.188E-01 +0.000E-39 +2.288E+00
  1 +6.118E-02 +4.769E+00 +7.473E+00 +8.978E+00 +12.00 +1.224E-01 -1.902E+01 +1.272E-01 +4.357E-01 +1.112E-01 +0.000E-39 +2.340E+00
  1 +8.302E-02 +4.833E+00 +7.485E+00 +9.043E+00  +9.00 +1.055E-01 -1.638E+01 +1.139E-01 +3.980E-01 +1.034E-01 +0.000E-39 +2.395E+00
  1 +1.081E-01 +4.898E+00 +7.493E+00 +9.109E+00  +6.00 +9.054E-02 -1.439E+01 +1.013E-01 +3.614E-01 +9.557E-02 +0.000E-39 +2.454E+00
  1 +1.362E-01 +4.963E+00 +7.498E+00 +9.174E+00  +3.00 +7.796E-02 -1.318E+01 +9.044E-02 +3.285E-01 +8.838E-02 +0.000E-39 +2.514E+00
  3 +1.675E-01 +5.029E+00 +7.500E+00 +9.240E+00  +0.00 +6.659E-02 -1.158E+01 +8.011E-02 +2.957E-01 +8.119E-02 +0.000E-39 +2.575E+00
  3 +5.601E-01 +5.814E+00 +7.500E+00 +1.002E+01  +0.00 +6.657E-02 +0.000E-39 +5.445E-02 +2.918E-01 +8.909E-02 +0.000E-39 +2.735E+00
  3 +9.527E-01 +6.599E+00 +7.500E+00 +1.081E+01  +0.00 +6.550E-02 -9.384E-02 +5.553E-02 +2.845E-01 +9.407E-02 +0.000E-39 +2.729E+00
  3 +1.345E+00 +7.384E+00 +7.500E+00 +1.160E+01  +0.00 +6.447E-02 -9.032E-02 +5.423E-02 +2.777E-01 +9.995E-02 +0.000E-39 +0.000E-39
  3 +1.738E+00 +8.169E+00 +7.500E+00 +1.238E+01  +0.00 +6.348E-02 -8.730E-02 +5.299E-02 +2.713E-01 +1.058E-01 +0.000E-39 +0.000E-39
  3 +2.130E+00 +8.955E+00 +7.500E+00 +1.317E+01  +0.00 +6.205E-02 -1.232E-01 +5.197E-02 +2.641E-01 +1.110E-01 +0.000E-39 +0.000E-39
  3 +2.523E+00 +9.740E+00 +7.500E+00 +1.395E+01  +0.00 +6.072E-02 -1.168E-01 +5.053E-02 +2.574E-01 +1.161E-01 +0.000E-39 +0.000E-39
  3 +2.916E+00 +1.052E+01 +7.500E+00 +1.474E+01  +0.00 +5.944E-02 -1.110E-01 +4.918E-02 +2.511E-01 +1.211E-01 +0.000E-39 +0.000E-39
  3 +3.308E+00 +1.131E+01 +7.500E+00 +1.552E+01  +0.00 +5.823E-02 -1.056E-01 +4.790E-02 +2.452E-01 +1.259E-01 +0.000E-39 +0.000E-39
  3 +3.701E+00 +1.210E+01 +7.500E+00 +1.631E+01  +0.00 +5.745E-02 -6.841E-02 +4.552E-02 +2.407E-01 +1.313E-01 +0.000E-39 +0.000E-39
  4 +4.093E+00 +1.288E+01 +7.500E+00 +1.709E+01  +0.00 +5.735E-02 +0.000E-39 +4.409E-02 +2.382E-01 +1.374E-01 +0.000E-39 +0.000E-39
  4 +4.102E+00 +1.290E+01 +7.499E+00 +1.711E+01  -6.00 +4.077E-02 -6.424E+01 +8.351E-02 +1.902E-01 +1.117E-01 +0.000E-39 +0.000E-39
  4 +4.112E+00 +1.291E+01 +7.497E+00 +1.712E+01 -12.00 +2.849E-02 -4.754E+01 +5.525E-02 +1.494E-01 +9.927E-02 +0.000E-39 +0.000E-39
  4 +4.123E+00 +1.293E+01 +7.493E+00 +1.714E+01 -18.00 +1.943E-02 -3.437E+01 +5.010E-02 +1.149E-01 +6.983E-02 +0.000E-39 +0.000E-39
  4 +4.135E+00 +1.294E+01 +7.487E+00 +1.715E+01 -24.00 +1.295E-02 -2.428E+01 +3.799E-02 +8.656E-02 +5.350E-02 +0.000E-39 +0.000E-39
  4 +4.148E+00 +1.296E+01 +7.480E+00 +1.717E+01 -30.00 +8.464E-03 -1.632E+01 +2.353E-02 +6.407E-02 +4.025E-02 +0.000E-39 +0.000E-39
  4 +4.162E+00 +1.297E+01 +7.471E+00 +1.719E+01 -36.00 +5.385E-03 -1.136E+01 +2.117E-02 +4.635E-02 +2.959E-02 +0.000E-39 +0.000E-39
  4 +4.177E+00 +1.298E+01 +7.461E+00 +1.720E+01 -42.00 +3.598E-03 +0.000E-39 +3.531E-03 +3.451E-02 +2.239E-02 +0.000E-39 +0.000E-39
  4 +4.192E+00 +1.299E+01 +7.450E+00 +1.722E+01 -48.00 +3.598E-03 +0.000E-39 +3.531E-03 +3.451E-02 +2.241E-02 +0.000E-39 +0.000E-39
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   4 +4.208E+00 +1.300E+01 +7.438E+00 +1.723E+01 -54.00 +3.598E-03 +0.000E-39 +3.531E-03 +3.460E-02 +2.243E-02 +0.000E-39 +0.000E-39
   8 +4.223E+00 +1.301E+01 +7.425E+00 +1.725E+01 -60.00 +3.598E-03 +0.000E-39 +3.531E-03 +3.459E-02 +2.245E-02 +0.000E-39 +0.000E-39
   8 +4.244E+00 +1.302E+01 +7.406E+00 +1.727E+01 -68.00 +3.598E-03 +0.000E-39 +3.530E-03 +3.459E-02 +2.248E-02 +0.000E-39 +0.000E-39
   8 +4.265E+00 +1.303E+01 +7.386E+00 +1.729E+01 -76.00 +3.598E-03 +0.000E-39 +3.530E-03 +3.458E-02 +2.251E-02 +0.000E-39 +0.000E-39
   8 +4.284E+00 +1.303E+01 +7.366E+00 +1.731E+01 -84.00 +3.598E-03 +0.000E-39 +3.530E-03 +3.457E-02 +2.253E-02 +0.000E-39 +0.000E-39
   8 +4.303E+00 +1.303E+01 +7.345E+00 +1.733E+01 -92.00 +3.598E-03 +0.000E-39 +3.530E-03 +3.456E-02 +2.256E-02 +0.000E-39 +0.000E-39

 I ST      X ST            Y ST            S ST          DTDS ST        THET ST      SECT  ALPHA

    31  +4.22335E+00  +7.50000E+00  +8.66354E+00  -6.66667E+00  +0.00000E-39      8    +90.00

 IW SN    XOW SN          YOW SN          XBW SN          YBW SN         SBW SN        THETW SN     SECT  ALPHA

     7  +4.31977E+00  +7.46491E+00  +3.69016E-02  +9.85329E-02  +1.07502E-01  +4.39372E+01     8    +90.00

 IL SN    XOL SN          YOL SN          XBL SN          YBL SN         SBL SN        THETL SN     SECT  ALPHA

     8  +4.13519E+00  +7.47135E+00  +3.69016E-02  +9.85328E-02  +1.07502E-01  +4.39372E+01     4    +90.00
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480

72f

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AT ALPHA =  +9.0000E+01 WINDWARD, RW =  +2.7533E-01 DELS =  +1.8342E-02 DSHOCK =  -2.5619E-02
THETAW LESS THAN LIMIT

SEC    XO W        XB W        YB W        SB W     THETBW  PE/PS W     DP/DS W      QL W        QT W        RE W        QR W       XSI W

  8 +4.223E+00 -0.000E-39 +0.000E-39 +0.000E-39 +90.00 +1.000E+00 +4.008E-05 +2.219E+00 +0.000E-39 +0.000E-39 +2.018E-01 +1.834E-02
  8 +4.244E+00 +1.460E-03 +2.088E-02 +2.094E-02 +82.00 +9.806E-01 -1.239E+02 +2.176E+00 +1.325E+00 +1.467E-04 +1.115E-01 +1.899E-02
  8 +4.265E+00 +5.811E-03 +4.135E-02 +4.189E-02 +74.00 +9.240E-01 -2.479E+02 +2.050E+00 +1.920E+00 +5.621E-04 +0.000E-39 +2.095E-02
  8 +4.284E+00 +1.297E-02 +6.101E-02 +6.283E-02 +66.00 +8.345E-01 -3.476E+02 +1.726E+00 +1.992E+00 +7.981E-04 +0.000E-39 +2.431E-02
  8 +4.303E+00 +2.279E-02 +7.949E-02 +8.378E-02 +58.00 +7.192E-01 -4.204E+02 +1.591E+00 +2.128E+00 +1.503E-03 +0.000E-39 +2.924E-02
  8 +4.320E+00 +3.509E-02 +9.642E-02 +1.047E-01 +50.00 +5.868E-01 -4.606E+02 +1.389E+00 +2.103E+00 +2.181E-03 +0.000E-39 +3.596E-02
  8 +4.320E+00 +3.690E-02 +9.853E-02 +1.075E-01 +48.94 +5.685E-01 -4.633E+02 +1.359E+00 +2.088E+00 +2.249E-03 +0.000E-39 +3.701E-02
  8 +4.335E+00 +4.963E-02 +1.115E-01 +1.257E-01 +42.00 +4.497E-01 -4.652E+02 +1.149E+00 +1.935E+00 +2.513E-03 +0.000E-39 +4.481E-02
  8 +4.348E+00 +6.612E-02 +1.244E-01 +1.466E-01 +34.00 +3.152E-01 -4.337E+02 +3.319E-01 +1.644E+00 +2.789E-03 +0.000E-39 +5.623E-02
  8 +4.358E+00 +8.424E-02 +1.348E-01 +1.676E-01 +26.00 +2.252E-01 -2.600E+02 +5.513E-01 +1.361E+00 +2.796E-03 +0.000E-39 +7.085E-02
  8 +4.366E+00 +1.036E-01 +1.427E-01 +1.885E-01 +18.00 +1.577E-01 -1.945E+02 +4.912E-01 +1.094E+00 +2.662E-03 +0.000E-39 +8.954E-02
  9 +4.371E+00 +1.240E-01 +1.477E-01 +2.094E-01 +10.00 +1.080E-01 -1.432E+02 +3.573E-01 +8.557E-01 +2.424E-03 +0.000E-39 +1.135E-01
  9 +4.435E+00 +4.866E-01 +2.117E-01 +5.776E-01 +10.00 +7.981E-02 -3.356E+00 +1.389E-01 +5.797E-01 +5.541E-03 +0.000E-39 +2.887E-01
  9 +4.499E+00 +8.492E-01 +2.756E-01 +9.458E-01 +10.00 +6.686E-02 -1.824E+00 +1.396E-01 +4.692E-01 +8.331E-03 +0.000E-39 +3.831E-01
  9 +4.563E+00 +1.212E+00 +3.395E-01 +1.314E+00 +10.00 +5.923E-02 -1.150E+00 +1.133E-01 +4.053E-01 +1.077E-02 +0.000E-39 +4.439E-01
  9 +4.627E+00 +1.574E+00 +4.035E-01 +1.682E+00 +10.00 +5.416E-02 -8.068E-01 +9.574E-02 +3.648E-01 +1.307E-02 +0.000E-39 +4.845E-01
  9 +4.691E+00 +1.937E+00 +4.674E-01 +2.050E+00 +10.00 +5.052E-02 -5.945E-01 +8.532E-02 +3.351E-01 +1.527E-02 +0.000E-39 +5.111E-01
  9 +4.755E+00 +2.300E+00 +5.313E-01 +2.419E+00 +10.00 +4.779E-02 -4.552E-01 +7.592E-02 +3.125E-01 +1.742E-02 +0.000E-39 +5.271E-01
  9 +4.819E+00 +2.662E+00 +5.953E-01 +2.787E+00 +10.00 +4.566E-02 -3.605E-01 +7.047E-02 +2.948E-01 +1.951E-02 +0.000E-39 +5.347E-01
  9 +4.883E+00 +3.025E+00 +6.592E-01 +3.155E+00 +10.00 +4.396E-02 -2.914E-01 +6.533E-02 +2.804E-01 +2.158E-02 +0.000E-39 +5.353E-01
  9 +4.947E+00 +3.387E+00 +7.232E-01 +3.523E+00 +10.00 +4.257E-02 -2.397E-01 +6.115E-02 +2.685E-01 +2.363E-02 +0.000E-39 +5.299E-01
 10 +5.010E+00 +3.750E+00 +7.871E-01 +3.891E+00  +0.00 +4.202E-02 -1.004E-01 +5.790E-02 +2.610E-01 +2.589E-02 +0.000E-39 +5.240E-01
 10 +5.010E+00 +4.125E+00 +7.871E-01 +4.266E+00  +0.00 +4.150E-02 -9.228E-02 +5.546E-02 +2.541E-01 +2.817E-02 +0.000E-39 +5.731E-01
 10 +5.010E+00 +4.500E+00 +7.871E-01 +4.641E+00  +0.00 +4.102E-02 -8.504E-02 +5.329E-02 +2.479E-01 +3.042E-02 +0.000E-39 +6.179E-01
 10 +5.010E+00 +4.875E+00 +7.871E-01 +5.016E+00  +0.00 +4.057E-02 -7.855E-02 +5.133E-02 +2.423E-01 +3.266E-02 +0.000E-39 +6.589E-01
 10 +5.010E+00 +5.250E+00 +7.871E-01 +5.391E+00  +0.00 +4.016E-02 -7.272E-02 +4.956E-02 +2.372E-01 +3.488E-02 +0.000E-39 +6.963E-01
 10 +5.010E+00 +5.625E+00 +7.871E-01 +5.766E+00  +0.00 +3.978E-02 -6.745E-02 +4.795E-02 +2.326E-01 +3.709E-02 +0.000E-39 +7.305E-01
 10 +5.010E+00 +6.000E+00 +7.871E-01 +6.141E+00  +0.00 +3.943E-02 -6.258E-02 +4.647E-02 +2.283E-01 +3.928E-02 +0.000E-39 +7.615E-01
 10 +5.010E+00 +6.375E+00 +7.871E-01 +6.516E+00  +0.00 +3.910E-02 -5.834E-02 +4.512E-02 +2.244E-01 +4.147E-02 +0.000E-39 +7.897E-01
 10 +5.010E+00 +6.750E+00 +7.871E-01 +6.891E+00  +0.00 +3.880E-02 -5.439E-02 +4.387E-02 +2.207E-01 +4.364E-02 +0.000E-39 +0.000E-39
 10 +5.010E+00 +7.125E+00 +7.871E-01 +7.266E+00  +0.00 +3.851E-02 -5.078E-02 +4.272E-02 +2.173E-01 +4.580E-02 +0.000E-39 +0.000E-39
 10 +5.010E+00 +7.500E+00 +7.871E-01 +7.641E+00  +0.00 +3.824E-02 -4.747E-02 +4.164E-02 +2.141E-01 +4.796E-02 +0.000E-39 +0.000E-39
 10 +5.010E+00 +7.875E+00 +7.871E-01 +8.016E+00  +0.00 +3.800E-02 -4.444E-02 +4.055E-02 +2.112E-01 +5.011E-02 +0.000E-39 +0.000E-39
 10 +5.010E+00 +8.250E+00 +7.871E-01 +8.391E+00  +0.00 +3.776E-02 -4.154E-02 +3.971E-02 +2.084E-01 +5.225E-02 +0.000E-39 +0.000E-39
 10 +5.010E+00 +8.625E+00 +7.871E-01 +8.766E+00  +0.00 +3.754E-02 -3.906E-02 +3.884E-02 +2.058E-01 +5.439E-02 +0.000E-39 +0.000E-39
 10 +5.010E+00 +9.000E+00 +7.871E-01 +9.141E+00  +0.00 +3.734E-02 -3.668E-02 +3.802E-02 +2.033E-01 +5.652E-02 +0.000E-39 +0.000E-39
 10 +5.010E+00 +9.375E+00 +7.871E-01 +9.516E+00  +0.00 +3.714E-02 -3.448E-02 +3.725E-02 +2.010E-01 +5.865E-02 +0.000E-39 +0.000E-39
 10 +5.010E+00 +9.750E+00 +7.871E-01 +9.891E+00  +0.00 +3.696E-02 -3.244E-02 +3.653E-02 +1.988E-01 +6.077E-02 +0.000E-39 +0.000E-39
 10 +5.010E+00 +1.012E+01 +7.871E-01 +1.027E+01  +0.00 +3.679E-02 -3.054E-02 +3.585E-02 +1.967E-01 +6.290E-02 +0.000E-39 +0.000E-39
 10 +5.010E+00 +1.050E+01 +7.871E-01 +1.064E+01  +0.00 +3.663E-02 -2.878E-02 +3.520E-02 +1.947E-01 +6.501E-02 +0.000E-39 +0.000E-39
 10 +5.010E+00 +1.087E+01 +7.871E-01 +1.102E+01  +0.00 +3.648E-02 -2.714E-02 +3.458E-02 +1.928E-01 +6.713E-02 +0.000E-39 +0.000E-39
 10 +5.010E+00 +1.125E+01 +7.871E-01 +1.139E+01  +0.00 +3.634E-02 -2.551E-02 +3.400E-02 +1.910E-01 +6.925E-02 +0.000E-39 +0.000E-39
  9 +4.947E+00 +1.161E+01 +7.232E-01 +1.176E+01 -10.00 +3.634E-02 +0.000E-39 +3.300E-02 +1.898E-01 +7.148E-02 +0.000E-39 +0.000E-39
  9 +4.883E+00 +1.198E+01 +6.592E-01 +1.213E+01 -10.00 +3.634E-02 +0.000E-39 +3.258E-02 +1.887E-01 +7.372E-02 +0.000E-39 +0.000E-39
  9 +4.819E+00 +1.234E+01 +5.953E-01 +1.250E+01 -10.00 +3.634E-02 +0.000E-39 +3.220E-02 +1.875E-01 +7.596E-02 +0.000E-39 +0.000E-39
  9 +4.755E+00 +1.270E+01 +5.313E-01 +1.286E+01 -10.00 +3.634E-02 +0.000E-39 +3.183E-02 +1.864E-01 +7.820E-02 +0.000E-39 +0.000E-39
  9 +4.691E+00 +1.306E+01 +4.674E-01 +1.323E+01 -10.00 +3.634E-02 +0.000E-39 +3.146E-02 +1.854E-01 +8.044E-02 +0.000E-39 +0.000E-39
  9 +4.627E+00 +1.343E+01 +4.035E-01 +1.360E+01 -10.00 +3.634E-02 +0.000E-39 +3.111E-02 +1.844E-01 +8.267E-02 +0.000E-39 +0.000E-39
  9 +4.563E+00 +1.379E+01 +3.395E-01 +1.397E+01 -10.00 +3.634E-02 +0.000E-39 +3.077E-02 +1.834E-01 +8.491E-02 +0.000E-39 +0.000E-39
  9 +4.499E+00 +1.415E+01 +2.756E-01 +1.434E+01 -10.00 +3.634E-02 +0.000E-39 +3.044E-02 +1.824E-01 +8.715E-02 +0.000E-39 +0.000E-39
  9 +4.435E+00 +1.451E+01 +2.117E-01 +1.471E+01 -10.00 +3.634E-02 +0.000E-39 +3.012E-02 +1.815E-01 +8.939E-02 +0.000E-39 +0.000E-39
  9 +4.371E+00 +1.488E+01 +1.477E-01 +1.507E+01 -10.00 +3.634E-02 +0.000E-39 +2.981E-02 +1.806E-01 +9.163E-02 +0.000E-39 +0.000E-39
  8 +4.366E+00 +1.490E+01 +1.427E-01 +1.509E+01 -18.00 +2.204E-02 -3.826E+01 +3.505E-02 +1.295E-01 +6.675E-02 +0.000E-39 +0.000E-39
  8 +4.358E+00 +1.492E+01 +1.348E-01 +1.512E+01 -26.00 +1.288E-02 -2.417E+01 +2.414E-02 +8.843E-02 +4.697E-02 +0.000E-39 +0.000E-39
  8 +4.348E+00 +1.493E+01 +1.244E-01 +1.514E+01 -34.00 +7.219E-03 -1.456E+01 +1.576E-02 +5.866E-02 +3.185E-02 +0.000E-39 +0.000E-39
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8 +4.335E+00 +1.495E+01 +1.115E-01 +1.516E+01 -42.00 +3.867E-03 -8.501E+00 +1.005E-02 +3.741E-02 +2.075E-02 +0.000E-39 +0.000E-39
8 +4.320E+00 +1.496E+01 +9.642E-02 +1.518E+01 -50.00 +3.598E-03 +0.000E-39 +3.553E-03 +3.549E-02 +1.976E-02 +0.000E-39 +0.000E-39
8 +4.303E+00 +1.498E+01 +7.949E-02 +1.520E+01 -58.00 +3.598E-03 +0.000E-39 +3.553E-03 +3.548E-02 +1.978E-02 +0.000E-39 +0.000E-39
8 +4.284E+00 +1.499E+01 +6.101E-02 +1.522E+01 -66.00 +3.598E-03 +0.000E-39 +3.553E-03 +3.547E-02 +1.981E-02 +0.000E-39 +0.000E-39
8 +4.265E+00 +1.499E+01 +4.135E-02 +1.524E+01 -74.00 +3.598E-03 +0.000E-39 +3.552E-03 +3.546E-02 +1.984E-02 +0.000E-39 +0.000E-39
8 +4.244E+00 +1.500E+01 +2.088E-02 +1.526E+01 -82.00 +3.598E-03 +0.000E-39 +3.552E-03 +3.545E-02 +1.987E-02 +0.000E-39 +0.000E-39
8 +4.223E+00 +1.500E+01 +3.912E-07 +1.528E+01 -90.00 +3.598E-03 +0.000E-39 +3.552E-03 +3.544E-02 +1.989E-02 +0.000E-39 +0.000E-39
4 +4.208E+00 +1.500E+01 +1.568E-02 +1.530E+01 -96.00 +3.598E-03 +0.000E-39 +3.552E-03 +3.543E-02 +1.991E-02 +0.000E-39 +0.000E-39
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AT ALPHA =  +9.0000E+01, LEEWARD, RW =  +2.7633E-01 DELS =  +1.8342E-02 BSHOCK =  +4.8575E-01

SEC      XO L          XB L          YB L          SB L      THETBL  PE/PS L      DP/DS L       QL L          QT L          RE L          QR L         XSI L

  8 +4.223E+00 -0.000E-39 +0.000E-39 +0.000E-39 +90.00 +1.000E+00 +4.008E-05 +2.219E+00 +0.000E-39 +0.000E-39 +2.018E-01 +1.834E-02
  4 +4.208E+00 +8.218E-04 +1.568E-02 +1.571E-02 +84.00 +9.891E-01 -9.725E+01 +2.194E+00 +1.122E+00 +8.305E-05 +1.398E-01 +1.870E-02
  4 +4.192E+00 +3.278E-03 +3.119E-02 +3.142E-02 +78.00 +9.568E-01 -1.903E+02 +2.123E+00 +1.659E+00 +3.243E-04 +2.691E-02 +1.980E-02
  4 +4.177E+00 +7.342E-03 +4.635E-02 +4.712E-02 +72.00 +9.045E-01 -2.749E+02 +1.835E+00 +1.775E+00 +5.931E-04 +0.000E-39 +2.167E-02
  4 +4.162E+00 +1.297E-02 +6.101E-02 +6.283E-02 +66.00 +8.346E-01 -3.476E+02 +1.776E+00 +1.992E+00 +9.981E-04 +0.000E-39 +2.439E-02
  4 +4.148E+00 +2.010E-02 +7.500E-02 +7.854E-02 +60.00 +7.500E-01 -4.051E+02 +1.664E+00 +2.109E+00 +1.450E-03 +0.000E-39 +2.803E-02
  4 +4.135E+00 +2.865E-02 +8.817E-02 +9.425E-02 +54.00 +6.545E-01 -4.449E+02 +1.519E+00 +2.134E+00 +1.903E-03 +0.000E-39 +3.274E-02
  4 +4.135E+00 +3.690E-02 +9.853E-02 +1.075E-01 +48.94 +5.685E-01 -4.633E+02 +1.377E+00 +2.088E+00 +2.249E-03 +0.000E-39 +3.765E-02
  4 +4.123E+00 +3.853E-02 +1.004E-01 +1.100E-01 +48.00 +5.539E-01 -4.652E+02 +1.357E+00 +2.074E+00 +2.306E-03 +0.000E-39 +3.866E-02
  4 +4.112E+00 +4.963E-02 +1.115E-01 +1.257E-01 +42.00 +4.497E-01 -4.652E+02 +1.150E+00 +1.935E+00 +2.613E-03 +0.000E-39 +4.602E-02
  4 +4.102E+00 +6.183E-02 +1.214E-01 +1.414E-01 +36.00 +3.478E-01 -4.449E+02 +9.596E-01 +1.727E+00 +2.774E-03 +0.000E-39 +5.508E-02
  4 +4.093E+00 +7.500E-02 +1.299E-01 +1.571E-01 +30.00 +2.706E-01 -3.037E+02 +7.756E-01 +1.512E+00 +2.827E-03 +0.000E-39 +6.620E-02
  3 +3.701E+00 +7.550E-01 +5.225E-01 +9.423E-01 +30.00 +2.529E-01 -8.000E-02 +2.319E-01 +1.022E+00 +1.651E-02 +0.000E-39 +2.587E-01
  3 +3.308E+00 +1.435E+00 +9.151E-01 +1.727E+00 +30.00 +2.527E-01 -9.256E-04 +2.039E-01 +9.051E-01 +3.026E-02 +0.000E-39 +3.554E-01
  3 +2.916E+00 +2.115E+00 +1.308E+00 +2.513E+00 +30.00 +2.527E-01 +3.942E-05 +1.736E-01 +8.398E-01 +4.402E-02 +0.000E-39 +4.361E-01
  3 +2.523E+00 +2.795E+00 +1.700E+00 +3.298E+00 +30.00 +2.527E-01 +2.158E-05 +1.518E-01 +7.953E-01 +5.777E-02 +0.000E-39 +5.110E-01
  3 +2.130E+00 +3.475E+00 +2.093E+00 +4.083E+00 +30.00 +2.527E-01 +2.553E-05 +1.356E-01 +7.621E-01 +7.153E-02 +0.000E-39 +5.831E-01
  3 +1.738E+00 +4.155E+00 +2.485E+00 +4.868E+00 +30.00 +2.527E-01 -0.000E-39 +1.252E-01 +7.357E-01 +8.528E-02 +0.000E-39 +6.537E-01
  3 +1.345E+00 +4.835E+00 +2.878E+00 +5.653E+00 +30.00 +2.527E-01 -0.000E-39 +1.152E-01 +7.141E-01 +9.904E-02 +0.000E-39 +7.234E-01
  3 +9.527E-01 +5.515E+00 +3.271E+00 +6.439E+00 +30.00 +2.527E-01 -0.000E-39 +1.039E-01 +6.957E-01 +1.128E-01 +0.000E-39 +7.925E-01
  3 +5.601E-01 +6.195E+00 +3.663E+00 +7.224E+00 +30.00 +2.527E-01 -0.000E-39 +1.029E-01 +6.799E-01 +1.265E-01 +0.000E-39 +8.611E-01
  3 +1.675E-01 +6.875E+00 +4.056E+00 +8.009E+00 +30.00 +2.527E-01 +0.000E-39 +9.773E-02 +6.650E-01 +1.403E-01 +0.000E-39 +9.294E-01
  1 +1.362E-01 +6.933E+00 +4.087E+00 +8.074E+00 +27.00 +2.221E-01 -3.035E+01 +1.149E-01 +6.227E-01 +1.340E-01 +0.000E-39 +9.424E-01
  1 +1.081E-01 +6.992E+00 +4.115E+00 +8.140E+00 +24.00 +1.945E-01 -2.757E+01 +1.044E-01 +5.793E-01 +1.272E-01 +0.000E-39 +9.616E-01
  1 +8.302E-02 +7.052E+00 +4.140E+00 +8.205E+00 +21.00 +1.701E-01 -2.482E+01 +9.454E-02 +5.371E-01 +1.203E-01 +0.000E-39 +9.874E-01
  1 +6.118E-02 +7.114E+00 +4.162E+00 +8.271E+00 +18.00 +1.484E-01 -2.222E+01 +8.549E-02 +4.960E-01 +1.132E-01 +0.000E-39 +1.020E+00
  1 +4.259E-02 +7.176E+00 +4.181E+00 +8.336E+00 +15.00 +1.288E-01 -1.983E+01 +7.536E-02 +4.560E-01 +1.061E-01 +0.000E-39 +1.060E+00
  1 +2.732E-02 +7.240E+00 +4.196E+00 +8.402E+00 +12.00 +1.114E-01 -1.752E+01 +5.879E-02 +4.172E-01 +9.890E-02 +0.000E-39 +1.108E+00
  1 +1.539E-02 +7.304E+00 +4.208E+00 +8.467E+00  +9.00 +9.581E-02 -1.559E+01 +6.127E-02 +3.798E-01 +9.171E-02 +0.000E-39 +1.165E+00
  1 +6.848E-03 +7.369E+00 +4.217E+00 +8.533E+00  +6.00 +8.257E-02 -1.331E+01 +5.454E-02 +3.456E-01 +8.495E-02 +0.000E-39 +1.231E+00
  1 +1.713E-03 +7.435E+00 +4.222E+00 +8.598E+00  +3.00 +7.082E-02 -1.218E+01 +4.349E-02 +3.131E-01 +7.834E-02 +0.000E-39 +1.309E+00
  1 +0.000E-39 +7.500E+00 +4.223E+00 +8.664E+00  +0.00 +5.965E-02 -1.057E+01 +4.233E-02 +2.799E-01 +7.132E-02 +0.000E-39 +1.399E+00
  1 +1.713E-03 +7.565E+00 +4.222E+00 +8.729E+00  -3.00 +5.033E-02 -9.138E+00 +3.707E-02 +2.502E-01 +6.487E-02 +0.000E-39 +1.504E+00
  1 +6.848E-03 +7.631E+00 +4.217E+00 +8.794E+00  -6.00 +4.244E-02 -7.972E+00 +3.244E-02 +2.232E-01 +5.888E-02 +0.000E-39 +1.625E+00
  1 +1.539E-02 +7.696E+00 +4.208E+00 +8.860E+00  -9.00 +3.562E-02 -5.835E+00 +2.325E-02 +1.982E-01 +5.319E-02 +0.000E-39 +1.766E+00
  1 +2.732E-02 +7.760E+00 +4.196E+00 +8.925E+00 -12.00 +2.967E-02 -5.904E+00 +2.445E-02 +1.749E-01 +4.775E-02 +0.000E-39 +1.931E+00
  1 +4.259E-02 +7.824E+00 +4.181E+00 +8.991E+00 -15.00 +2.458E-02 -5.035E+00 +2.108E-02 +1.537E-01 +4.255E-02 +0.000E-39 +2.124E+00
  1 +6.118E-02 +7.886E+00 +4.162E+00 +9.055E+00 -18.00 +2.032E-02 -4.235E+00 +1.317E-02 +1.346E-01 +3.799E-02 +0.000E-39 +2.353E+00
  1 +8.302E-02 +7.948E+00 +4.140E+00 +9.122E+00 -21.00 +1.673E-02 -3.629E+00 +1.559E-02 +1.174E-01 +3.369E-02 +0.000E-39 +2.627E+00
  1 +1.081E-01 +8.008E+00 +4.115E+00 +9.187E+00 -24.00 +1.362E-02 -3.043E+00 +1.327E-02 +1.016E-01 +2.963E-02 +0.000E-39 +2.958E+00
  1 +1.362E-01 +8.067E+00 +4.087E+00 +9.253E+00 -27.00 +1.106E-02 -2.543E+00 +1.129E-02 +8.762E-02 +2.597E-02 +0.000E-39 +3.365E+00
  3 +1.675E-01 +8.125E+00 +4.056E+00 +9.313E+00 -30.00 +8.957E-03 -2.120E+00 +9.599E-03 +7.537E-02 +2.269E-02 +0.000E-39 +3.875E+00
  3 +5.601E-01 +8.805E+00 +3.663E+00 +1.010E+01 -30.00 +8.957E-03 +0.000E-39 +5.515E-03 +7.416E-02 +2.461E-02 +0.000E-39 +5.552E+00
  3 +9.527E-01 +9.485E+00 +3.271E+00 +1.089E+01 -30.00 +8.957E-03 +0.000E-39 +5.500E-03 +7.306E-02 +2.652E-02 +0.000E-39 +7.228E+00
  3 +1.345E+00 +1.016E+01 +2.878E+00 +1.167E+01 -30.00 +8.957E-03 +0.000E-39 +5.485E-03 +7.205E-02 +2.843E-02 +0.000E-39 +8.904E+00
  3 +1.738E+00 +1.084E+01 +2.485E+00 +1.246E+01 -30.00 +8.957E-03 +0.000E-39 +5.471E-03 +7.112E-02 +3.034E-02 +0.000E-39 +0.000E-39
  3 +2.130E+00 +1.152E+01 +2.093E+00 +1.324E+01 -30.00 +8.957E-03 +0.000E-39 +5.457E-03 +7.025E-02 +3.226E-02 +0.000E-39 +0.000E-39
  3 +2.523E+00 +1.220E+01 +1.700E+00 +1.403E+01 -30.00 +8.957E-03 +0.000E-39 +5.443E-03 +6.945E-02 +3.417E-02 +0.000E-39 +0.000E-39
  3 +2.916E+00 +1.288E+01 +1.308E+00 +1.481E+01 -30.00 +8.957E-03 +0.000E-39 +5.428E-03 +6.870E-02 +3.608E-02 +0.000E-39 +0.000E-39
  3 +3.308E+00 +1.356E+01 +9.151E-01 +1.550E+01 -30.00 +8.957E-03 +0.000E-39 +5.415E-03 +6.799E-02 +3.799E-02 +0.000E-39 +0.000E-39
  3 +3.701E+00 +1.424E+01 +5.225E-01 +1.638E+01 -30.00 +8.957E-03 +0.000E-39 +5.401E-03 +6.733E-02 +3.991E-02 +0.000E-39 +0.000E-39
  4 +4.093E+00 +1.492E+01 +1.299E-01 +1.717E+01 -30.00 +8.957E-03 +0.000E-39 +5.387E-03 +6.670E-02 +4.182E-02 +0.000E-39 +0.000E-39
  4 +4.102E+00 +1.494E+01 +1.214E-01 +1.719E+01 -36.00 +5.751E-03 -1.203E+01 +1.193E-02 +4.859E-02 +3.095E-02 +0.000E-39 +0.000E-39
  4 +4.112E+00 +1.495E+01 +1.115E-01 +1.720E+01 -42.00 +3.598E-03 +0.000E-39 +2.293E-03 +3.461E-02 +2.239E-02 +0.000E-39 +0.000E-39
  4 +4.123E+00 +1.496E+01 +1.004E-01 +1.722E+01 -48.00 +3.598E-03 +0.000E-39 +2.293E-03 +3.451E-02 +2.241E-02 +0.000E-39 +0.000E-39
  4 +4.135E+00 +1.497E+01 +8.817E-02 +1.723E+01 -54.00 +3.598E-03 +0.000E-39 +2.293E-03 +3.460E-02 +2.243E-02 +0.000E-39 +0.000E-39
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 4 +4.148E+00 +1.498E+01 +7.500E-02 +1.725E+01 -60.00 +3.598E-03 +0.000E-39 +2.293E-03 +3.459E-02 +2.245E-02 +0.000E-39 +0.000E-39
 4 +4.162E+00 +1.499E+01 +6.101E-02 +1.726E+01 -66.00 +3.598E-03 +0.000E-39 +2.293E-03 +3.459E-02 +2.247E-02 +0.000E-39 +0.000E-39
 4 +4.177E+00 +1.499E+01 +4.635E-02 +1.728E+01 -72.00 +3.598E-03 +0.000E-39 +2.293E-03 +3.458E-02 +2.249E-02 +0.000E-39 +0.000E-39
 4 +4.192E+00 +1.500E+01 +3.119E-02 +1.730E+01 -78.00 +3.598E-03 +0.000E-39 +2.293E-03 +3.458E-02 +2.251E-02 +0.000E-39 +0.000E-39
 4 +4.208E+00 +1.500E+01 +1.568E-02 +1.731E+01 -84.00 +3.598E-03 +0.000E-39 +2.293E-03 +3.457E-02 +2.253E-02 +0.000E-39 +0.000E-39
 8 +4.223E+00 +1.500E+01 +3.912E-07 +1.733E+01 -90.00 +3.598E-03 +0.000E-39 +2.293E-03 +3.456E-02 +2.255E-02 +0.000E-39 +0.000E-39

  I ST      X ST           Y ST           S ST          DTDS ST        THET ST      SECT  ALPHA

 35  +4.29835E+00  +7.47990E+00  +8.74208E+00  -6.66667E+00  -3.00000E+01     8  +120.00

 IW SN     XOW SN         YOW SN         XBW SN         YBW SN         SBW SN       THETW SN     SECT  ALPHA

  7  +4.35817E+00  +7.41576E+00  +3.69015E-02  +9.85329E-02  +1.07502E-01  +4.89372E+01     8  +120.00

 IL SN     XOL SN         YOL SN         XBL SN         YBL SN         SBL SN       THETL SN     SECT  ALPHA

  7  +4.20767E+00  +7.49918E+00  +3.69014E-02  +9.85327E-02  +1.07502E-01  +4.89372E+01     4  +120.00
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AT ALPHA =  +1.2000E+02 WINDWARD, RW =  +2.7533E-01 DELS =  +1.8342E-02 BSHOCK =  +5.7912E-01

SEC   XO W        XB W        YB W        SB W     THETBW  PE/PS W    DP/DS W      QL W        QT W        RF W        QR W       XSI W

  8 +4.298E+00 -0.000E-39 +0.000E-39 +0.000E-39 +90.00 +1.000E+00 +4.008E-05 +3.133E+00 +0.000E-39 +0.000E-39 +2.018E-01 +1.834E-02
  8 +4.303E+00 +9.137E-05 +5.235E-03 +5.235E-03 +88.00 +9.983E-01 -4.635E+01 +3.132E+00 +5.844E-01 +9.290E-06 +1.798E-01 +1.838E-02
  8 +4.320E+00 +2.279E-03 +2.605E-02 +2.618E-02 +80.00 +9.573E-01 -2.231E+02 +3.004E+00 +1.487E+00 +2.253E-04 +2.819E-02 +1.935E-02
  8 +4.335E+00 +7.341E-03 +4.635E-02 +4.712E-02 +72.00 +8.695E-01 -3.550E+02 +2.389E+00 +1.966E+00 +6.793E-04 +0.000E-39 +2.168E-02
  8 +4.348E+00 +1.518E-02 +6.576E-02 +6.807E-02 +64.00 +7.533E-01 -4.059E+02 +2.552E+00 +2.165E+00 +1.251E-03 +0.000E-39 +2.551E-02
  8 +4.358E+00 +2.564E-02 +8.388E-02 +8.901E-02 +56.00 +6.380E-01 -3.433E+02 +2.156E+00 +2.156E+00 +1.815E-03 +0.000E-39 +3.109E-02
  8 +4.358E+00 +3.690E-02 +9.853E-02 +1.075E-01 +48.94 +5.685E-01 -1.627E+02 +1.840E+00 +2.088E+00 +2.249E-03 +0.000E-39 +3.776E-02
  8 +4.366E+00 +3.853E-02 +1.004E-01 +1.100E-01 +48.00 +5.539E-01 -4.652E+02 +1.899E+00 +2.074E+00 +2.306E-03 +0.000E-39 +3.878E-02
  9 +4.371E+00 +5.358E-02 +1.149E-01 +1.309E-01 +40.00 +4.153E-01 +0.000E-39 +1.353E+00 +1.873E+00 +2.585E-03 +0.000E-39 +4.908E-02
  9 +4.435E+00 +3.356E-01 +3.516E-01 +4.991E-01 +40.00 +4.153E-01 +0.000E-39 +5.553E-01 +1.433E+00 +1.024E-02 +0.000E-39 +1.206E-01
  9 +4.499E+00 +6.177E-01 +5.883E-01 +8.673E-01 +40.00 +4.153E-01 +0.000E-39 +4.929E-01 +1.283E+00 +1.779E-02 +0.000E-39 +1.349E-01
  9 +4.563E+00 +8.998E-01 +8.249E-01 +1.235E+00 +40.00 +4.153E-01 +0.000E-39 +4.114E-01 +1.195E+00 +2.534E-02 +0.000E-39 +1.341E-01
  9 +4.627E+00 +1.182E+00 +1.062E+00 +1.604E+00 +40.00 +4.153E-01 +0.000E-39 +3.504E-01 +1.135E+00 +3.289E-02 +0.000E-39 +1.269E-01
  9 +4.691E+00 +1.464E+00 +1.298E+00 +1.972E+00 +40.00 +4.153E-01 +0.000E-39 +3.246E-01 +1.089E+00 +4.044E-02 +0.000E-39 +1.164E-01
  9 +4.755E+00 +1.746E+00 +1.535E+00 +2.340E+00 +40.00 +4.153E-01 +0.000E-39 +2.977E-01 +1.052E+00 +4.799E-02 +0.000E-39 +1.039E-01
  9 +4.819E+00 +2.028E+00 +1.772E+00 +2.708E+00 +40.00 +4.153E-01 +0.000E-39 +2.765E-01 +1.022E+00 +5.554E-02 +0.000E-39 +9.024E-02
  9 +4.883E+00 +2.310E+00 +2.008E+00 +3.076E+00 +40.00 +4.153E-01 +0.000E-39 +2.594E-01 +9.960E-01 +6.310E-02 +0.000E-39 +7.573E-02
  9 +4.947E+00 +2.592E+00 +2.245E+00 +3.445E+00 +40.00 +4.153E-01 +0.000E-39 +2.450E-01 +9.737E-01 +7.065E-02 +0.000E-39 +6.063E-02
 10 +5.010E+00 +2.874E+00 +2.482E+00 +3.813E+00 +30.00 +4.153E-01 +0.000E-39 +2.328E-01 +9.541E-01 +7.820E-02 +0.000E-39 +4.544E-02
 10 +5.010E+00 +3.199E+00 +2.669E+00 +4.188E+00 +30.00 +4.153E-01 +0.000E-39 +2.221E-01 +9.364E-01 +8.589E-02 +0.000E-39 +9.502E-02
 10 +5.010E+00 +3.524E+00 +2.857E+00 +4.563E+00 +30.00 +4.153E-01 +0.000E-39 +2.127E-01 +9.205E-01 +9.358E-02 +0.000E-39 +1.443E-01
 10 +5.010E+00 +3.848E+00 +3.044E+00 +4.938E+00 +30.00 +4.153E-01 +0.000E-39 +2.045E-01 +9.060E-01 +1.013E-01 +0.000E-39 +1.934E-01
 10 +5.010E+00 +4.173E+00 +3.232E+00 +5.313E+00 +30.00 +4.153E-01 +0.000E-39 +1.971E-01 +8.929E-01 +1.090E-01 +0.000E-39 +2.424E-01
 10 +5.010E+00 +4.498E+00 +3.419E+00 +5.688E+00 +30.00 +4.153E-01 +0.000E-39 +1.905E-01 +8.808E-01 +1.167E-01 +0.000E-39 +2.912E-01
 10 +5.010E+00 +4.823E+00 +3.607E+00 +6.063E+00 +30.00 +4.153E-01 +0.000E-39 +1.845E-01 +8.696E-01 +1.243E-01 +0.000E-39 +3.399E-01
 10 +5.010E+00 +5.147E+00 +3.794E+00 +6.438E+00 +30.00 +4.153E-01 +0.000E-39 +1.790E-01 +8.592E-01 +1.320E-01 +0.000E-39 +3.885E-01
 10 +5.010E+00 +5.472E+00 +3.982E+00 +6.813E+00 +30.00 +4.153E-01 +0.000E-39 +1.740E-01 +8.496E-01 +1.397E-01 +0.000E-39 +4.370E-01
 10 +5.010E+00 +5.797E+00 +4.169E+00 +7.188E+00 +30.00 +4.153E-01 +0.000E-39 +1.594E-01 +8.405E-01 +1.474E-01 +0.000E-39 +4.854E-01
 10 +5.010E+00 +6.122E+00 +4.357E+00 +7.563E+00 +30.00 +4.153E-01 +0.000E-39 +1.551E-01 +8.320E-01 +1.551E-01 +0.000E-39 +5.338E-01
 10 +5.010E+00 +6.447E+00 +4.544E+00 +7.938E+00 +30.00 +4.153E-01 +0.000E-39 +1.511E-01 +8.240E-01 +1.628E-01 +0.000E-39 +5.822E-01
 10 +5.010E+00 +6.771E+00 +4.732E+00 +8.313E+00 +30.00 +4.153E-01 +0.000E-39 +1.575E-01 +8.164E-01 +1.705E-01 +0.000E-39 +6.305E-01
 10 +5.010E+00 +7.096E+00 +4.919E+00 +8.688E+00 +30.00 +4.153E-01 +0.000E-39 +1.540E-01 +8.092E-01 +1.782E-01 +0.000E-39 +6.787E-01
 10 +5.010E+00 +7.421E+00 +5.107E+00 +9.063E+00 +30.00 +4.153E-01 +0.000E-39 +1.508E-01 +8.024E-01 +1.859E-01 +0.000E-39 +7.270E-01
 10 +5.010E+00 +7.746E+00 +5.294E+00 +9.438E+00 +30.00 +4.153E-01 +0.000E-39 +1.478E-01 +7.959E-01 +1.936E-01 +0.000E-39 +7.752E-01
 10 +5.010E+00 +8.070E+00 +5.482E+00 +9.813E+00 +30.00 +4.153E-01 +0.000E-39 +1.449E-01 +7.898E-01 +2.013E-01 +0.000E-39 +8.233E-01
 10 +5.010E+00 +8.395E+00 +5.669E+00 +1.019E+01 +30.00 +4.153E-01 +0.000E-39 +1.422E-01 +7.839E-01 +2.089E-01 +0.000E-39 +8.715E-01
 10 +5.010E+00 +8.720E+00 +5.857E+00 +1.056E+01 +30.00 +4.153E-01 +0.000E-39 +1.396E-01 +7.782E-01 +2.155E-01 +0.000E-39 +9.195E-01
 10 +5.010E+00 +9.045E+00 +6.044E+00 +1.094E+01 +30.00 +4.153E-01 +0.000E-39 +1.372E-01 +7.728E-01 +2.243E-01 +0.000E-39 +9.677E-01
 10 +5.010E+00 +9.369E+00 +6.232E+00 +1.131E+01 +30.00 +4.153E-01 +0.000E-39 +1.349E-01 +7.676E-01 +2.320E-01 +0.000E-39 +1.016E+00
  9 +4.947E+00 +9.715E+00 +6.358E+00 +1.168E+01 +20.00 +4.153E-01 +0.000E-39 +1.328E-01 +7.627E-01 +2.396E-01 +0.000E-39 +1.170E+00
  9 +4.883E+00 +1.006E+01 +6.484E+00 +1.205E+01 +20.00 +4.153E-01 +0.000E-39 +1.307E-01 +7.580E-01 +2.471E-01 +0.000E-39 +1.285E+00
  9 +4.819E+00 +1.041E+01 +6.609E+00 +1.242E+01 +20.00 +4.153E-01 +0.000E-39 +1.288E-01 +7.534E-01 +2.547E-01 +0.000E-39 +1.399E+00
  9 +4.755E+00 +1.075E+01 +6.735E+00 +1.279E+01 +20.00 +4.153E-01 +0.000E-39 +1.269E-01 +7.491E-01 +2.622E-01 +0.000E-39 +1.514E+00
  9 +4.691E+00 +1.110E+01 +6.861E+00 +1.315E+01 +20.00 +4.153E-01 +0.000E-39 +1.251E-01 +7.448E-01 +2.698E-01 +0.000E-39 +1.629E+00
  9 +4.627E+00 +1.145E+01 +6.987E+00 +1.352E+01 +20.00 +4.153E-01 +0.000E-39 +1.234E-01 +7.407E-01 +2.773E-01 +0.000E-39 +1.743E+00
  9 +4.563E+00 +1.179E+01 +7.113E+00 +1.389E+01 +20.00 +4.153E-01 +0.000E-39 +1.217E-01 +7.367E-01 +2.849E-01 +0.000E-39 +1.858E+00
  9 +4.499E+00 +1.214E+01 +7.239E+00 +1.426E+01 +20.00 +4.153E-01 +0.000E-39 +1.202E-01 +7.329E-01 +2.924E-01 +0.000E-39 +1.973E+00
  9 +4.435E+00 +1.248E+01 +7.365E+00 +1.463E+01 +20.00 +4.153E-01 +0.000E-39 +1.186E-01 +7.292E-01 +3.000E-01 +0.000E-39 +2.087E+00
  9 +4.371E+00 +1.283E+01 +7.491E+00 +1.499E+01 +20.00 +4.153E-01 +0.000E-39 +1.172E-01 +7.255E-01 +3.075E-01 +0.000E-39 +2.202E+00
  8 +4.366E+00 +1.285E+01 +7.497E+00 +1.502E+01 +12.00 +4.667E-02 -1.903E+02 +5.168E-02 +2.135E-01 +1.066E-01 +0.000E-39 +2.334E+00
  8 +4.358E+00 +1.287E+01 +7.500E+00 +1.504E+01  +4.00 +2.900E-02 -4.827E+01 +4.313E-02 +1.552E-01 +7.930E-02 +0.000E-39 +2.537E+00
  8 +4.348E+00 +1.289E+01 +7.500E+00 +1.506E+01  -4.00 +1.723E-02 -3.102E+01 +3.015E-02 +1.085E-01 +5.672E-02 +0.000E-39 +2.839E+00
  8 +4.335E+00 +1.291E+01 +7.497E+00 +1.508E+01 -12.00 +9.854E-03 -1.919E+01 +2.058E-02 +7.325E-02 +3.917E-02 +0.000E-39 +3.293E+00
  8 +4.320E+00 +1.293E+01 +7.491E+00 +1.510E+01 -20.00 +5.397E-03 -1.138E+01 +1.387E-02 +4.763E-02 +2.603E-02 +0.000E-39 +4.006E+00
  8 +4.303E+00 +1.295E+01 +7.482E+00 +1.512E+01 -28.00 +3.598E-03 +0.000E-39 +2.175E-03 +3.552E-02 +1.969E-02 +0.000E-39 +5.222E+00
  8 +4.298E+00 +1.296E+01 +7.480E+00 +1.513E+01 -30.00 +3.598E-03 +0.000E-39 +2.175E-03 +3.551E-02 +1.969E-02 +0.000E-39 +5.666E+00
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 8 +4.284E+00 +1.297E+01 +7.471E+00 +1.514E+01 -36.00 +3.598E-03 +0.000E-39 +2.175E-03 +3.551E-02 +1.971E-02 +0.000E-39 +7.658E+00
 8 +4.265E+00 +1.298E+01 +7.458E+00 +1.516E+01 -44.00 +3.598E-03 +0.000E-39 +2.175E-03 +3.550E-02 +1.974E-02 +0.000E-39 +0.000E-39
 8 +4.244E+00 +1.300E+01 +7.442E+00 +1.518E+01 -52.00 +3.598E-03 +0.000E-39 +2.175E-03 +3.549E-02 +1.976E-02 +0.000E-39 +0.000E-39
 8 +4.223E+00 +1.301E+01 +7.425E+00 +1.520E+01 -60.00 +3.598E-03 +0.000E-39 +2.175E-03 +3.548E-02 +1.979E-02 +0.000E-39 +0.000E-39
 4 +4.208E+00 +1.302E+01 +7.411E+00 +1.522E+01 -66.00 +3.598E-03 +0.000E-39 +2.175E-03 +3.547E-02 +1.981E-02 +0.000E-39 +0.000E-39
 4 +4.192E+00 +1.302E+01 +7.396E+00 +1.524E+01 -72.00 +3.598E-03 +0.000E-39 +2.175E-03 +3.546E-02 +1.983E-02 +0.000E-39 +0.000E-39
 4 +4.177E+00 +1.303E+01 +7.381E+00 +1.525E+01 -78.00 +3.598E-03 +0.000E-39 +2.175E-03 +3.546E-02 +1.985E-02 +0.000E-39 +0.000E-39
 4 +4.162E+00 +1.303E+01 +7.366E+00 +1.527E+01 -84.00 +3.598E-03 +0.000E-39 +2.175E-03 +3.545E-02 +1.987E-02 +0.000E-39 +0.000E-39
 4 +4.148E+00 +1.303E+01 +7.350E+00 +1.528E+01 -90.00 +3.598E-03 +0.000E-39 +2.175E-03 +3.544E-02 +1.989E-02 +0.000E-39 +0.000E-39
 4 +4.135E+00 +1.303E+01 +7.334E+00 +1.530E+01 -96.00 +3.598E-03 +0.000E-39 +2.175E-03 +3.543E-02 +1.991E-02 +0.000E-39 +0.000E-39
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 AT ALPHA =  +1.2000E+02, LEEWARD, RW =  +2.7633E-01 DELS =  +1.8342E-02 BSHOCK =  -1.4148E+00
 SKIP CASE, YW IMAGINARY FOR RW =  +2.7633E-01 DELS =  +1.8342E-02 BSHOCK =  -1.4148E+00

 SEC     XO L         XB L         YB L         SB L      THETBL  PE/PS L     DP/DS L       QL L        QT L         RE L         QR L        XSI L

   8 +4.298E+00 -0.000E-39 +0.000E-39 +0.000E-39 +90.00 +1.000E+00 +4.008E-05 +3.138E+00 +0.000E-39 +0.000E-39 +2.018E-01 +1.834E-02
   8 +4.284E+00 +8.217E-04 +1.568E-02 +1.571E-02 +84.00 +9.844E-01 -1.333E+02 +3.089E+00 +1.118E+00 +8.276E-05 +1.231E-01 +1.870E-02
   8 +4.265E+00 +4.456E-03 +3.629E-02 +3.665E-02 +76.00 +9.183E-01 -2.959E+02 +2.881E+00 +1.764E+00 +4.284E-04 +0.000E-39 +2.030E-02
   8 +4.244E+00 +1.092E-02 +5.619E-02 +5.760E-02 +68.00 +8.133E-01 -3.932E+02 +2.711E+00 +2.095E+00 +9.588E-04 +0.000E-39 +2.318E-02
   8 +4.223E+00 +2.010E-02 +7.500E-02 +7.854E-02 +60.00 +6.933E-01 -3.917E+02 +2.351E+00 +2.185E+00 +1.541E-03 +0.000E-39 +2.732E-02
   4 +4.208E+00 +2.865E-02 +8.817E-02 +9.425E-02 +54.00 +6.138E-01 -3.051E+02 +2.056E+00 +2.148E+00 +1.944E-03 +0.000E-39 +3.121E-02
   4 +4.208E+00 +3.690E-02 +9.853E-02 +1.075E-01 +48.94 +5.685E-01 -1.627E+02 +1.835E+00 +2.088E+00 +2.249E-03 +0.000E-39 +3.500E-02
   4 +4.192E+00 +3.853E-02 +1.004E-01 +1.100E-01 +48.00 +5.539E-01 -4.652E+02 +1.334E+00 +2.074E+00 +2.306E-03 +0.000E-39 +3.575E-02
   4 +4.177E+00 +4.963E-02 +1.115E-01 +1.257E-01 +42.00 +4.497E-01 -4.652E+02 +1.516E+00 +1.935E+00 +2.613E-03 +0.000E-39 +4.086E-02
   4 +4.162E+00 +6.183E-02 +1.214E-01 +1.414E-01 +36.00 +3.478E-01 -4.449E+02 +1.339E+00 +1.727E+00 +2.774E-03 +0.000E-39 +4.646E-02
   4 +4.148E+00 +7.500E-02 +1.299E-01 +1.571E-01 +30.00 +2.706E-01 -3.037E+02 +1.034E+00 +1.512E+00 +2.827E-03 +0.000E-39 +5.241E-02
   4 +4.135E+00 +8.899E-02 +1.370E-01 +1.728E-01 +24.00 +2.097E-01 -2.452E+02 +8.730E-01 +1.303E+00 +2.795E-03 +0.000E-39 +5.853E-02
   4 +4.123E+00 +1.036E-01 +1.427E-01 +1.885E-01 +18.00 +1.599E-01 -1.957E+02 +7.007E-01 +1.103E+00 +2.680E-03 +0.000E-39 +6.461E-02
   4 +4.112E+00 +1.188E-01 +1.467E-01 +2.042E-01 +12.00 +1.210E-01 -1.570E+02 +5.547E-01 +9.221E-01 +2.513E-03 +0.000E-39 +7.040E-02
   4 +4.102E+00 +1.343E-01 +1.492E-01 +2.199E-01  +6.00 +8.933E-02 -1.227E+02 +4.299E-01 +7.547E-01 +2.290E-03 +0.000E-39 +7.564E-02
   4 +4.093E+00 +1.500E-01 +1.500E-01 +2.356E-01  +0.00 +6.548E-02 -9.516E+01 +3.309E-01 +6.113E-01 +2.050E-03 +0.000E-39 +8.009E-02
   3 +3.701E+00 +9.352E-01 +1.500E-01 +1.021E+00  +0.00 +3.106E-02 -1.230E+00 +1.114E-01 +2.784E-01 +5.622E-03 +0.000E-39 +0.000E-39
   3 +3.308E+00 +1.720E+00 +1.500E-01 +1.806E+00  +0.00 +2.181E-02 -5.395E-01 +7.204E-02 +1.951E-01 +7.931E-03 +0.000E-39 +0.000E-39
   3 +2.916E+00 +2.506E+00 +1.500E-01 +2.591E+00  +0.00 +2.183E-02 +0.000E-39 +5.345E-02 +1.817E-01 +1.139E-02 +0.000E-39 +0.000E-39
   3 +2.523E+00 +3.291E+00 +1.500E-01 +3.376E+00  +0.00 +1.896E-02 -2.159E-01 +5.422E-02 +1.563E-01 +1.354E-02 +0.000E-39 +0.000E-39
   3 +2.130E+00 +4.076E+00 +1.500E-01 +4.152E+00  +0.00 +1.687E-02 -1.616E-01 +4.622E-02 +1.382E-01 +1.546E-02 +0.000E-39 +0.000E-39
   3 +1.738E+00 +4.861E+00 +1.500E-01 +4.947E+00  +0.00 +1.527E-02 -1.250E-01 +4.040E-02 +1.246E-01 +1.721E-02 +0.000E-39 +0.000E-39
   3 +1.345E+00 +5.646E+00 +1.500E-01 +5.732E+00  +0.00 +1.401E-02 -1.014E-01 +3.596E-02 +1.139E-01 +1.883E-02 +0.000E-39 +0.000E-39
   3 +9.527E-01 +6.432E+00 +1.500E-01 +6.517E+00  +0.00 +1.298E-02 -8.351E-02 +3.246E-02 +1.052E-01 +2.035E-02 +0.000E-39 +0.000E-39
   3 +5.601E-01 +7.217E+00 +1.500E-01 +7.302E+00  +0.00 +1.212E-02 -7.015E-02 +2.953E-02 +9.802E-02 +2.179E-02 +0.000E-39 +0.000E-39
   3 +1.675E-01 +8.002E+00 +1.500E-01 +8.088E+00  +0.00 +1.140E-02 -5.935E-02 +2.728E-02 +9.196E-02 +2.316E-02 +0.000E-39 +0.000E-39
   1 +1.362E-01 +8.067E+00 +1.483E-01 +8.153E+00  -3.00 +9.249E-03 -2.130E+00 +2.744E-02 +7.920E-02 +2.029E-02 +0.000E-39 +0.000E-39
   1 +1.081E-01 +8.133E+00 +1.432E-01 +8.218E+00  -6.00 +7.426E-03 -1.802E+00 +2.275E-02 +6.753E-02 +1.753E-02 +0.000E-39 +0.000E-39
   1 +8.302E-02 +8.198E+00 +1.346E-01 +8.284E+00  -9.00 +5.932E-03 -1.433E+00 +1.380E-02 +5.749E-02 +1.524E-02 +0.000E-39 +0.000E-39
   1 +6.118E-02 +8.262E+00 +1.227E-01 +8.349E+00 -12.00 +4.728E-03 -1.216E+00 +1.553E-02 +4.875E-02 +1.314E-02 +0.000E-39 +0.000E-39
   1 +4.259E-02 +8.325E+00 +1.074E-01 +8.415E+00 -15.00 +3.761E-03 -9.957E-01 +1.282E-02 +4.124E-02 +1.130E-02 +0.000E-39 +0.000E-39
   1 +2.732E-02 +8.388E+00 +8.882E-02 +8.480E+00 -18.00 +3.598E-03 +0.000E-39 +3.373E-03 +3.987E-02 +1.104E-02 +0.000E-39 +0.000E-39
   1 +1.539E-02 +8.450E+00 +6.697E-02 +8.545E+00 -21.00 +3.598E-03 +0.000E-39 +3.867E-03 +3.981E-02 +1.112E-02 +0.000E-39 +0.000E-39
   1 +6.848E-03 +8.510E+00 +4.193E-02 +8.611E+00 -24.00 +3.598E-03 +0.000E-39 +3.352E-03 +3.975E-02 +1.121E-02 +0.000E-39 +0.000E-39
   1 +1.713E-03 +8.569E+00 +1.376E-02 +8.677E+00 -27.00 +3.598E-03 +0.000E-39 +8.355E-03 +3.969E-02 +1.129E-02 +0.000E-39 +0.000E-39
   1 +0.000E-39 +8.627E+00 +1.747E-02 +8.742E+00 -30.00 +3.598E-03 +0.000E-39 +3.350E-03 +3.963E-02 +1.138E-02 +0.000E-39 +0.000E-39

 I ST      X ST          Y ST           S ST         DTDS ST         THET ST      SECT  ALPHA

   39  +4.35326E+00  +7.42500E+00  +8.82062E+00  -6.66667E+00  -6.00000E+01     8  +150.00

 IW SN    XOW SN        YOW SN        XBW SN         YBW SN        SBW SN        THETW SN   SECT  ALPHA

   45  +4.37107E+00  +7.37605E+00  +7.38690E+00  +1.28291E+01  +1.49151E+01  +4.89372E+01     9  +150.00

 IL SN    XOL SN        YOL SN        XBL SN         YBL SN        SBL SN        THETL SN   SECT  ALPHA

    7  +4.28436E+00  +7.48703E+00  +3.59015E-02  +9.85330E-02  +1.07502E-01  +4.89372E+01     8  +150.00
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AT ALPHA =  +1.5000E+02 WINDWARD, RW =  +3.1389E+01 DELS =  +1.8342E-02 BSHOCK =  -3.1534E+00
SIN(THETAW) NEG. FOR XB =  +7.3869E+00 RW =  +3.1389E+01 DELS =  +1.8342E-02 BSHOCK =  -3.1534E+00

SEC    XO W        XB W        YB W        SB W      THETBW  PE/PS W     DP/DS W      QL W        QT W        PE W        QR W        XSI W

  8 +4.353E+00 -0.000E-39 +0.000E-39 +0.000E-39 +90.00 +1.000E+00 +4.008E-05 +3.002E+00 +0.000E-39 +0.000E-39 +2.018E-01 +1.834E-02
  8 +4.358E+00 +3.654E-04 +1.046E-02 +1.047E-02 +86.00 +9.951E-01 -5.510E+01 +2.987E+00 +7.613E-01 +3.077E-05 +1.887E-01 +1.875E-02
  8 +4.366E+00 +3.278E-03 +3.119E-02 +3.142E-02 +78.00 +9.568E-01 -1.903E+02 +2.872E+00 +1.429E+00 +2.591E-04 +6.123E-02 +2.208E-02
  9 +4.371E+00 +9.046E-03 +5.130E-02 +5.236E-02 +70.00 +8.830E-01 +0.000E-39 +2.600E+00 +1.859E+00 +7.203E-04 +4.013E-02 +2.908E-02
  9 +4.435E+00 +1.350E-01 +3.973E-01 +4.206E-01 +70.00 +8.830E-01 +0.000E-39 +5.855E-01 +1.225E+00 +5.786E-03 +1.371E-01 +1.597E-01
  9 +4.499E+00 +2.609E-01 +7.433E-01 +7.888E-01 +70.00 +8.830E-01 +0.000E-39 +4.941E-01 +1.081E+00 +1.085E-02 +9.667E-02 +2.852E-01
  9 +4.563E+00 +3.868E-01 +1.089E+00 +1.157E+00 +70.00 +8.830E-01 +0.000E-39 +4.059E-01 +1.001E+00 +1.592E-02 +0.000E-39 +4.056E-01
  9 +4.627E+00 +5.128E-01 +1.435E+00 +1.525E+00 +70.00 +8.830E-01 +0.000E-39 +3.525E-01 +9.471E-01 +2.098E-02 +0.000E-39 +5.210E-01
  9 +4.691E+00 +6.387E-01 +1.781E+00 +1.893E+00 +70.00 +8.830E-01 +0.000E-39 +3.159E-01 +9.070E-01 +2.605E-02 +0.000E-39 +6.314E-01
  9 +4.755E+00 +7.646E-01 +2.127E+00 +2.262E+00 +70.00 +8.830E-01 +0.000E-39 +2.888E-01 +8.753E-01 +3.111E-02 +0.000E-39 +7.368E-01
  9 +4.819E+00 +8.906E-01 +2.473E+00 +2.630E+00 +70.00 +8.830E-01 +0.000E-39 +2.676E-01 +8.493E-01 +3.518E-02 +0.000E-39 +8.373E-01
  9 +4.883E+00 +1.016E+00 +2.819E+00 +2.998E+00 +70.00 +8.830E-01 +0.000E-39 +2.505E-01 +8.274E-01 +4.124E-02 +0.000E-39 +9.330E-01
  9 +4.947E+00 +1.142E+00 +3.165E+00 +3.366E+00 +70.00 +8.830E-01 +0.000E-39 +2.363E-01 +8.084E-01 +4.631E-02 +0.000E-39 +1.024E+00
 10 +5.010E+00 +1.268E+00 +3.511E+00 +3.734E+00 +60.00 +7.500E-01 +0.000E-39 +2.858E-01 +9.744E-01 +5.894E-02 +0.000E-39 +1.173E+00
 10 +5.010E+00 +1.456E+00 +3.836E+00 +4.109E+00 +60.00 +7.500E-01 +0.000E-39 +2.691E-01 +9.559E-01 +7.587E-02 +0.000E-39 +1.324E+00
 10 +5.010E+00 +1.643E+00 +4.161E+00 +4.484E+00 +60.00 +7.500E-01 +0.000E-39 +2.551E-01 +9.393E-01 +8.279E-02 +0.000E-39 +1.469E+00
 10 +5.010E+00 +1.831E+00 +4.486E+00 +4.859E+00 +60.00 +7.500E-01 +0.000E-39 +2.430E-01 +9.244E-01 +8.971E-02 +0.000E-39 +1.609E+00
 10 +5.010E+00 +2.018E+00 +4.810E+00 +5.234E+00 +60.00 +7.500E-01 +0.000E-39 +2.325E-01 +9.107E-01 +9.664E-02 +0.000E-39 +1.742E+00
 10 +5.010E+00 +2.206E+00 +5.135E+00 +5.609E+00 +60.00 +7.500E-01 +0.000E-39 +2.232E-01 +8.982E-01 +1.036E-01 +0.000E-39 +1.869E+00
 10 +5.010E+00 +2.393E+00 +5.460E+00 +5.984E+00 +60.00 +7.500E-01 +0.000E-39 +2.150E-01 +8.867E-01 +1.105E-01 +0.000E-39 +1.991E+00
 10 +5.010E+00 +2.581E+00 +5.785E+00 +6.359E+00 +60.00 +7.500E-01 +0.000E-39 +2.075E-01 +8.759E-01 +1.174E-01 +0.000E-39 +2.105E+00
 10 +5.010E+00 +2.768E+00 +6.109E+00 +6.734E+00 +60.00 +7.500E-01 +0.000E-39 +2.009E-01 +8.660E-01 +1.243E-01 +0.000E-39 +2.216E+00
 10 +5.010E+00 +2.956E+00 +6.434E+00 +7.109E+00 +60.00 +7.500E-01 +0.000E-39 +1.949E-01 +8.566E-01 +1.313E-01 +0.000E-39 +2.320E+00
 10 +5.010E+00 +3.143E+00 +6.759E+00 +7.484E+00 +60.00 +7.500E-01 +0.000E-39 +1.893E-01 +8.479E-01 +1.382E-01 +0.000E-39 +2.417E+00
 10 +5.010E+00 +3.331E+00 +7.084E+00 +7.859E+00 +60.00 +7.500E-01 +0.000E-39 +1.842E-01 +8.396E-01 +1.451E-01 +0.000E-39 +2.508E+00
 10 +5.010E+00 +3.518E+00 +7.408E+00 +8.234E+00 +60.00 +7.500E-01 +0.000E-39 +1.795E-01 +8.318E-01 +1.520E-01 +0.000E-39 +2.593E+00
 10 +5.010E+00 +3.706E+00 +7.733E+00 +8.609E+00 +60.00 +7.500E-01 +0.000E-39 +1.751E-01 +8.245E-01 +1.589E-01 +0.000E-39 +2.572E+00
 10 +5.010E+00 +3.893E+00 +8.058E+00 +8.984E+00 +60.00 +7.500E-01 +0.000E-39 +1.711E-01 +8.175E-01 +1.659E-01 +0.000E-39 +2.745E+00
 10 +5.010E+00 +4.081E+00 +8.383E+00 +9.359E+00 +60.00 +7.500E-01 +0.000E-39 +1.673E-01 +8.108E-01 +1.729E-01 +0.000E-39 +2.810E+00
 10 +5.010E+00 +4.268E+00 +8.707E+00 +9.734E+00 +60.00 +7.500E-01 +0.000E-39 +1.637E-01 +8.045E-01 +1.797E-01 +0.000E-39 +2.870E+00
 10 +5.010E+00 +4.456E+00 +9.032E+00 +1.011E+01 +60.00 +7.500E-01 +0.000E-39 +1.604E-01 +7.984E-01 +1.866E-01 +0.000E-39 +2.922E+00
 10 +5.010E+00 +4.643E+00 +9.357E+00 +1.048E+01 +60.00 +7.500E-01 +0.000E-39 +1.573E-01 +7.926E-01 +1.936E-01 +0.000E-39 +2.967E+00
 10 +5.010E+00 +4.831E+00 +9.682E+00 +1.086E+01 +60.00 +7.500E-01 +0.000E-39 +1.543E-01 +7.870E-01 +2.005E-01 +0.000E-39 +3.006E+00
 10 +5.010E+00 +5.018E+00 +1.001E+01 +1.123E+01 +60.00 +7.500E-01 +0.000E-39 +1.515E-01 +7.817E-01 +2.074E-01 +0.000E-39 +3.037E+00
  9 +4.947E+00 +5.255E+00 +1.029E+01 +1.160E+01 +50.00 +5.868E-01 +0.000E-39 +1.571E-01 +8.201E-01 +2.416E-01 +0.000E-39 +3.193E+00
  9 +4.883E+00 +5.492E+00 +1.057E+01 +1.197E+01 +50.00 +5.868E-01 +0.000E-39 +1.543E-01 +8.150E-01 +2.493E-01 +0.000E-39 +3.262E+00
  9 +4.819E+00 +5.728E+00 +1.085E+01 +1.234E+01 +50.00 +5.868E-01 +0.000E-39 +1.517E-01 +8.101E-01 +2.569E-01 +0.000E-39 +3.322E+00
  9 +4.755E+00 +5.965E+00 +1.113E+01 +1.271E+01 +50.00 +5.868E-01 +0.000E-39 +1.492E-01 +8.054E-01 +2.646E-01 +0.000E-39 +3.373E+00
  9 +4.691E+00 +6.202E+00 +1.142E+01 +1.308E+01 +50.00 +5.868E-01 +0.000E-39 +1.469E-01 +8.008E-01 +2.723E-01 +0.000E-39 +3.415E+00
  9 +4.627E+00 +6.438E+00 +1.170E+01 +1.344E+01 +50.00 +5.868E-01 +0.000E-39 +1.446E-01 +7.963E-01 +2.799E-01 +0.000E-39 +3.448E+00
  9 +4.563E+00 +6.675E+00 +1.198E+01 +1.381E+01 +50.00 +5.868E-01 +0.000E-39 +1.424E-01 +7.920E-01 +2.876E-01 +0.000E-39 +3.470E+00
  9 +4.499E+00 +6.912E+00 +1.226E+01 +1.418E+01 +50.00 +5.868E-01 +0.000E-39 +1.404E-01 +7.879E-01 +2.953E-01 +0.000E-39 +3.483E+00
  9 +4.435E+00 +7.148E+00 +1.254E+01 +1.455E+01 +50.00 +5.868E-01 +0.000E-39 +1.384E-01 +7.839E-01 +3.029E-01 +0.000E-39 +3.484E+00
  9 +4.371E+00 +7.385E+00 +1.283E+01 +1.492E+01 +50.00 +5.868E-01 +0.000E-39 +1.365E-01 +7.799E-01 +3.106E-01 +0.000E-39 +3.474E+00
  9 +4.371E+00 +7.387E+00 +1.283E+01 +1.492E+01 +48.94 +5.685E-01 -4.633E+02 +3.445E-01 +7.786E-01 +3.121E-01 +0.000E-39 +3.471E+00
  8 +4.366E+00 +7.400E+00 +1.284E+01 +1.494E+01 +42.00 +4.497E-01 -4.552E+02 +3.003E-01 +7.441E-01 +3.106E-01 +0.000E-39 +3.475E+00
  8 +4.358E+00 +7.416E+00 +1.285E+01 +1.496E+01 +34.00 +3.152E-01 -4.337E+02 +2.475E-01 +6.520E-01 +2.845E-01 +0.000E-39 +3.523E+00
  8 +4.353E+00 +7.425E+00 +1.286E+01 +1.497E+01 +30.00 +2.669E-01 -3.002E+02 +2.175E-01 +6.036E-01 +2.680E-01 +0.000E-39 +3.565E+00
  8 +4.348E+00 +7.434E+00 +1.287E+01 +1.498E+01 +26.00 +2.252E-01 -2.601E+02 +1.941E-01 +5.542E-01 +2.500E-01 +0.000E-39 +3.618E+00
  8 +4.335E+00 +7.454E+00 +1.287E+01 +1.500E+01 +18.00 +1.577E-01 -1.945E+02 +1.453E-01 +4.561E-01 +2.118E-01 +0.000E-39 +3.760E+00
  8 +4.320E+00 +7.474E+00 +1.288E+01 +1.502E+01 +10.00 +1.080E-01 -1.432E+02 +1.127E-01 +3.645E-01 +1.739E-01 +0.000E-39 +3.951E+00
  8 +4.303E+00 +7.495E+00 +1.288E+01 +1.504E+01  +2.00 +7.197E-02 -1.029E+02 +3.502E-02 +2.828E-01 +1.383E-01 +0.000E-39 +4.191E+00
  8 +4.284E+00 +7.516E+00 +1.288E+01 +1.506E+01  -6.00 +4.584E-02 -7.034E+01 +5.193E-02 +2.109E-01 +1.057E-01 +0.000E-39 +4.478E+00
  8 +4.265E+00 +7.536E+00 +1.288E+01 +1.508E+01 -14.00 +2.850E-02 -4.755E+01 +4.470E-02 +1.533E-01 +7.867E-02 +0.000E-39 +4.806E+00
  8 +4.244E+00 +7.556E+00 +1.287E+01 +1.510E+01 -22.00 +1.696E-02 -3.059E+01 +3.127E-02 +1.072E-01 +5.630E-02 +0.000E-39 +5.165E+00
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8 +4.223E+00 +7.575E+00 +1.286E+01 +1.513E+01 -30.00 +9.707E-03 -1.894E+01 +2.147E-02 +7.243E-02 +3.889E-02 +0.000E-39 +5.543E+00
4 +4.208E+00 +7.588E+00 +1.285E+01 +1.514E+01 -36.00 +6.248E-03 -1.293E+01 +1.531E-02 +5.289E-02 +2.985E-02 +0.000E-39 +0.000E-39
4 +4.192E+00 +7.600E+00 +1.284E+01 +1.516E+01 -42.00 +3.905E-03 -8.575E+00 +1.240E-02 +3.758E-02 +2.089E-02 +0.000E-39 +0.000E-39
4 +4.177E+00 +7.611E+00 +1.283E+01 +1.517E+01 -48.00 +3.598E-03 +0.000E-39 +2.257E-03 +3.549E-02 +1.975E-02 +0.000E-39 +0.000E-39
4 +4.162E+00 +7.621E+00 +1.282E+01 +1.519E+01 -54.00 +3.598E-03 +0.000E-39 +2.257E-03 +3.549E-02 +1.977E-02 +0.000E-39 +0.000E-39
4 +4.148E+00 +7.630E+00 +1.281E+01 +1.520E+01 -60.00 +3.598E-03 +0.000E-39 +2.257E-03 +3.548E-02 +1.979E-02 +0.000E-39 +0.000E-39
4 +4.135E+00 +7.637E+00 +1.279E+01 +1.522E+01 -66.00 +3.598E-03 +0.000E-39 +2.257E-03 +3.547E-02 +1.981E-02 +0.000E-39 +0.000E-39
4 +4.123E+00 +7.643E+00 +1.278E+01 +1.524E+01 -72.00 +3.598E-03 +0.000E-39 +2.267E-03 +3.546E-02 +1.983E-02 +0.000E-39 +0.000E-39
4 +4.112E+00 +7.647E+00 +1.276E+01 +1.525E+01 -78.00 +3.598E-03 +0.000E-39 +2.257E-03 +3.546E-02 +1.985E-02 +0.000E-39 +0.000E-39
4 +4.102E+00 +7.649E+00 +1.275E+01 +1.527E+01 -84.00 +3.598E-03 +0.000E-39 +2.257E-03 +3.545E-02 +1.987E-02 +0.000E-39 +0.000E-39
4 +4.093E+00 +7.650E+00 +1.273E+01 +1.528E+01 -90.00 +3.598E-03 +0.000E-39 +2.257E-03 +3.544E-02 +1.989E-02 +0.000E-39 +0.000E-39
3 +3.701E+00 +7.650E+00 +1.195E+01 +1.607E+01 -90.00 +3.598E-03 +0.000E-39 +2.255E-03 +3.509E-02 +2.092E-02 +0.000E-39 +0.000E-39
3 +3.308E+00 +7.650E+00 +1.116E+01 +1.585E+01 -90.00 +3.598E-03 +0.000E-39 +2.255E-03 +3.475E-02 +2.194E-02 +0.000E-39 +0.000E-39
3 +2.916E+00 +7.650E+00 +1.037E+01 +1.764E+01 -90.00 +3.598E-03 +0.000E-39 +2.254E-03 +3.444E-02 +2.296E-02 +0.000E-39 +0.000E-39
3 +2.523E+00 +7.650E+00 +9.590E+00 +1.842E+01 -90.00 +3.598E-03 +0.000E-39 +2.252E-03 +3.414E-02 +2.398E-02 +0.000E-39 +0.000E-39
3 +2.130E+00 +7.650E+00 +8.805E+00 +1.921E+01 -90.00 +3.598E-03 +0.000E-39 +2.251E-03 +3.386E-02 +2.500E-02 +0.000E-39 +0.000E-39
3 +1.738E+00 +7.650E+00 +8.019E+00 +1.999E+01 -90.00 +3.598E-03 +0.000E-39 +2.250E-03 +3.359E-02 +2.603E-02 +0.000E-39 +0.000E-39
3 +1.345E+00 +7.650E+00 +7.234E+00 +2.078E+01 -90.00 +3.598E-03 +0.000E-39 +2.259E-03 +3.333E-02 +2.705E-02 +0.000E-39 +0.000E-39
3 +9.527E-01 +7.650E+00 +6.449E+00 +2.156E+01 -90.00 +3.598E-03 +0.000E-39 +2.253E-03 +3.308E-02 +2.807E-02 +0.000E-39 +0.000E-39
3 +5.601E-01 +7.650E+00 +5.664E+00 +2.235E+01 -90.00 +3.598E-03 +0.000E-39 +2.257E-03 +3.285E-02 +2.909E-02 +0.000E-39 +0.000E-39
3 +1.675E-01 +7.650E+00 +4.879E+00 +2.313E+01 -90.00 +3.598E-03 +0.000E-39 +2.255E-03 +3.252E-02 +3.011E-02 +0.000E-39 +0.000E-39
1 +1.362E-01 +7.648E+00 +4.813E+00 +2.320E+01 -93.00 +3.598E-03 +0.000E-39 +2.255E-03 +3.250E-02 +3.020E-02 +0.000E-39 +0.000E-39
```

```
AT ALPHA =  +1.5000E+02, LEEWARD, RW =  +2.7633E-01 DELS =  +1.8342E-02 3S4D3( =  -1.4148F+00
THETAW LESS THAN LIMIT

SEC     XO L         XB L         YB L         SB L      THETBL  PF/PS L     DP/DS L      QL L         QT L         RE L         QR L         XSI L

  8 +4.353E+00 -0.000E-39 +0.000E-39 +0.000E-39 +90.00 +1.000E+00 +4.008E-05 +3.002E+00 +0.000E-39 +0.000E-39 +2.018E-01 +1.834E-02
  8 +4.348E+00 +3.654E-04 +1.046E-02 +1.047E-02 +86.00 +9.951E-01 -6.510E+01 +2.937E+00 +8.838E-01 +3.708E-05 +1.595E-01 +1.850E-02
  8 +4.335E+00 +3.278E-03 +3.119E-02 +3.142E-02 +78.00 +9.568E-01 -1.903E+02 +2.872E+00 +1.659E+00 +3.243E-04 +2.688E-02 +1.978E-02
  8 +4.320E+00 +9.046E-03 +5.130E-02 +5.236E-02 +70.00 +8.830E-01 -3.007E+02 +2.455E+00 +1.859E+00 +7.203E-04 +0.000E-39 +2.234E-02
  8 +4.303E+00 +1.756E-02 +7.042E-02 +7.330E-02 +62.00 +7.796E-01 -3.878E+02 +2.302E+00 +2.081E+00 +1.297E-03 +0.000E-39 +2.617E-02
  8 +4.284E+00 +2.865F-02 +8.817E-02 +9.425E-02 +54.00 +6.545E-01 -4.449E+02 +2.051E+00 +2.134E+00 +1.903E-03 +0.000E-39 +3.121E-02
  8 +4.284E+00 +3.690E-02 +9.853E-02 +1.075E-01 +48.94 +5.685E-01 -4.633E+02 +1.363E+00 +2.088E+00 +2.249E-03 +0.000E-39 +3.500E-02
  8 +4.265E+00 +4.210E-02 +1.042E-01 +1.152E-01 +45.00 +5.192E-01 -4.675E+02 +1.748E+00 +2.036E+00 +2.422E-03 +0.000E-39 +3.739E-02
  8 +4.244E+00 +5.765E-02 +1.182E-01 +1.351E-01 +38.00 +3.813E-01 -4.539E+02 +1.386E+00 +1.803E+00 +2.739E-03 +0.000E-39 +4.455E-02
  8 +4.223E+00 +7.500E-02 +1.299E-01 +1.571E-01 +30.00 +2.735E-01 -3.056E+02 +1.053E+00 +1.519F+00 +2.839E-03 +0.000E-39 +5.241E-02
  4 +4.208E+00 +8.899E-02 +1.370E-01 +1.728E-01 +24.00 +2.121E-01 -2.475E+02 +8.555E-01 +1.311E+00 +2.809E-03 +0.000E-39 +5.853E-02
  4 +4.192E+00 +1.036F-01 +1.427E-01 +1.885E-01 +18.00 +1.617E-01 -1.985E+02 +5.324E-01 +1.110E+00 +2.695E-03 +0.000E-39 +6.461E-02
  4 +4.177E+00 +1.188E-01 +1.467E-01 +2.042E-01 +12.00 +1.223E-01 -1.534E+02 +5.401E-01 +9.284E-01 +2.528E-03 +0.000E-39 +7.040E-02
  4 +4.162E+00 +1.343E-01 +1.492E-01 +2.199E-01  +6.00 +9.031E-02 -1.238E+02 +4.183E-01 +7.599E-01 +2.304E-03 +0.000E-39 +7.564E-02
  4 +4.148E+00 +1.500E-01 +1.500E-01 +2.355E-01  -0.00 +6.625E-02 -9.609E+01 +3.222E-01 +6.160E-01 +2.064E-03 +0.000E-39 +8.009E-02
  4 +4.135E+00 +1.657E-01 +1.492E-01 +2.513F-01  -6.00 +4.700E-02 -7.233E+01 +2.407E-01 +4.862E-01 +1.791E-03 +0.000E-39 +8.358E-02
  4 +4.123E+00 +1.812E-01 +1.467E-01 +2.570E-01 -12.00 +3.312E-02 -5.397E+01 +1.790E-01 +3.802E-01 +1.532E-03 +0.000E-39 +0.000E-39
  4 +4.112E+00 +1.964E-01 +1.427E-01 +2.827E-01 -18.00 +2.265E-02 -3.916E+01 +1.296E-01 +2.902F-01 +1.273E-03 +0.000E-39 +0.000E-39
  4 +4.102E+00 +2.110E-01 +1.370E-01 +2.985E-01 -24.00 +1.527E-02 -2.797E+01 +9.274E-02 +2.184E-01 +1.038E-03 +0.000E-39 +0.000E-39
  4 +4.093E+00 +2.250E-01 +1.299E-01 +3.142E-01 -30.00 +1.003E-02 -1.949E+01 +5.498E-02 +1.609E-01 +8.259E-04 +0.000E-39 +0.000E-39
  3 +3.701E+00 +9.050E-01 +2.627E-01 +1.099E+00 -30.00 +1.003E-02 +0.000E-39 +4.499E-02 +1.252E-01 +2.890E-03 +0.000E-39 +0.000E-39
```

430->

72

```
 2334 LINES OUTPUT.
     $IBSYS
     $PAUSE
     OPER. ACTION PAUSE

     ..CONTINUING

     $PAUSE
     OPER. ACTION PAUSE

     ..CONTINUING

     $IBSYS
000000000000Q00000080001I-0101GQ0000080001F000000IBSYST-000010000027534000000000 )
    1 LINES OUTPUT THIS JOB.
```

III. COMPUTATIONS

A. BLOCK DIAGRAM

The block diagram for Program 1885 is shown in Figure 11. The overall program is divided into five basic calculations:

1. The body geometry routine, depicted in Figure 11a, computes the body coordinates at zero angle-of attack, locates the stagnation point at angle of attack, defines the wind axes, and thereafter computes the body coordinates in the transformed axis system. The array of body coordinates so generated is thereafter utilized to compute the pressure and heating distributions.

2. The pressure distribution routine, depicted in Figure 11b, computes the pressures utilizing several calculation models by testing the local slope, curvature, and previous pressure value. The local slope and curvature are given in the coordinate tables.

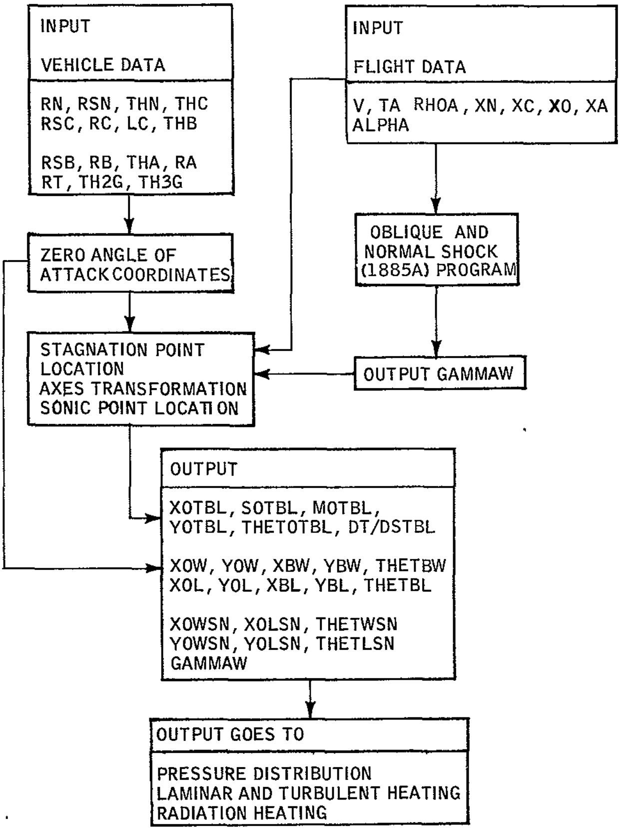
3. The laminar and turbulent heating routine, depicted in Figure 11c, utilizes the pressure distributions, surface distance information from the coordinate tables, and thermochemical data from the oblique and normal shock routine to evaluate the appropriate heat-transfer relationships.

4. The oblique and normal shock routine, depicted in Figure 11d, evaluates all the necessary flow conditions behind oblique waves assuming equilibrium thermodynamics.

5. The radiation heating routine, depicted in Figure 11e, requires that the shock layer thickness be defined everywhere and that the radiation intensities be determined at the body and at the shock.

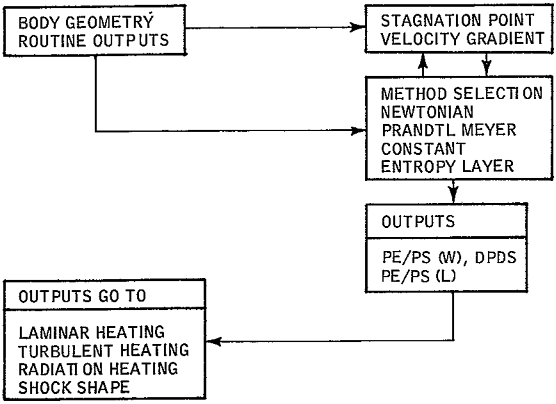
B. SYMBOLS

		Units
a	exponent on Lewis Number in stagnation point heating equation	--
C_p	specific heat at constant pressure	$ft^2/sec^2 - {}^oK$
h_D	dissociation enthalpy	ft^2/sec^2
h_w	static enthalpy behind oblique wave	ft^2/sec^2
H	stagnation enthalpy	ft^2/sec^2



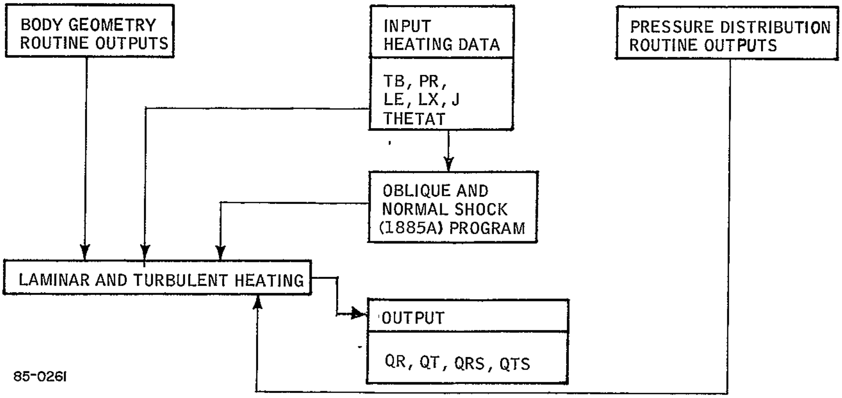
85-0259

Figure 11a BLOCK DIAGRAM FOR PROGRAM 1885 -- BODY GEOMETRY ROUTINE



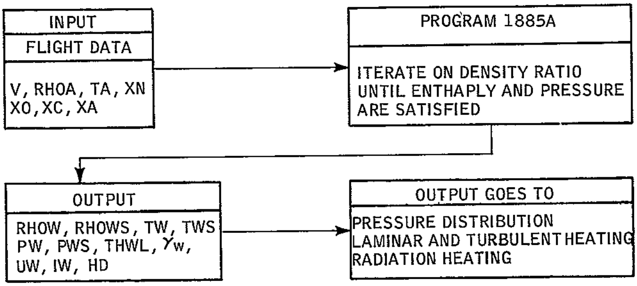
85-0260

Figure 11b



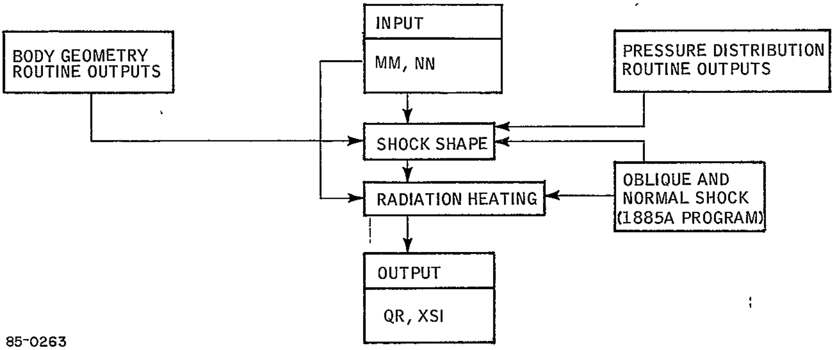
85-0261

Figure 11 c



85-0262

Figure 11d



85-0263

Figure 11e

I_b	radiation intensity at edge of boundary layer	Btu/ft^3- sec
I_w	radiation intensity behind oblique shock	Btu/ft^3- sec
j	index for body shape; $j = 1$ is axisymmetric; 0 is two dimensional	--
L	Lewis Number	--
LC	cylinder length	feet
M	mean molecular weight of atmosphere	--
m	polynomial exponent for radiation profile	--
M_a	flight Mach number	--
n	polynomial exponent for mass flow profile	--
P_a	ambient pressure	lb/ft^2
P_e	pressure at edge of boundary layer	lb/ft^2
P_o	reference pressure; $P_o = 2116.2$	lb/ft^2
P_w	pressure behind oblique shock	lb/ft^2
P_{ws}	stagnation pressure behind oblique shock	lb/ft^2
P_s	stagnation pressure behind normal shock	lb/ft^2
P_e^*	sonic point pressure	lb/ft^2
P_T	stagnation pressure at edge of boundary layer	lb/ft^2
q_L	laminar heat rate	Btu/ft^2- sec
q_{LS}	stagnation point heat rate	Btu/ft^2- sec
q_T	turbulent heat rate	Btu/ft^2- sec
q_R	radiative heating rate	Btu/ft^2-sec

R	universal gas constant; $R = 89500$	$\mathrm{ft}^2/\mathrm{sec}^2$-°K
RA	radius of rear spherical cap	feet
RB	radius of flare	feet
RC	radius of cylinder; reference radius	feet
RN	radius of nose cap	feet
RSB	toroidal radius at flare base	feet
RSC	toroidal radius of fore cone base	feet
RSN	toroidal radius following nose cap	feet
RT	base radius of truncated after body	feet
S_o	surface distance in zero angle-of-attack coordinates measured from stagnation point	feet
S_b	surface distance in wind coordinates measured from stagnation point	feet
S_{os}	surface distance from zero angle-of-attack stagnation point to stagnation point at angle of attack	feet
S_b^*	surface distance to sonic point	feet
T_a	ambient atmospheric temperature	°K
T_b	body surface temperature	°K
T_e	temperature at edge of boundary layer	°K
T_o	reference temperature; $T_o = 273.16$	°K
T_w	temperature behind oblique shock	°K
T_{ws}	stagnation temperature behind oblique shock	°K
T_s	stagnation temperature behind normal shock	°K

T_T	stagnation temperature at edge of boundary layer	^oK
U_e	velocity at edge of boundary layer	ft/sec
U_w	velocity behind normal shock	ft/sec
V	flight velocity	ft/sec
x_o, y_o	body coordinates at zero angle of attack	feet
x_b, y_b	body coordinates in wind axes	feet
x_b^*, y_b^*	sonic point coordinates in wind axes	feet
x_{os}, y_{os}	angle-of-attack stagnation point coordinates measured in zero angle of attack coordinates	feet
Z	compressibility factor; number moles per initial mole	--
α	angle of attack	degrees
β	pressure gradient parameter	--
γ_a	ratio of specific heats for ambient atmosphere	--
γ_w	adiabatic exponent behind oblique shock	
γ_s	adiabatic exponent behind normal shock	
γ_e	adiabatic exponent at edge of boundary layer	
ρ_a	ambient density of atmosphere	slug/ft^3
ρ_w	density behind oblique shock	slug/ft^3
ρ_e	density at edge of boundary layer	slug/ft^3
ρ_{ws}	stagnation density behind oblique shock	slug/ft^3
ρ_s	stagnation density behind normal shock	slug/ft^3
ρ_b	density at body surface	slug/ft^3
ρ_{bs}	density at body surface at stagnation point	slug/ft^3

ρ_T	stagnation density at edge of boundary layer	slug/ft^3
θ_b	angle corresponding to local body slope	degrees
θ_w	oblique shock angle	degrees
θ_{wL}	flow deflection angle behind oblique shock	degrees
μ_b	viscosity evaluated at (T_b)	lb-sec/ft^2
μ_e	viscosity evaluated at (T_e)	lb-sec/ft^2
μ_s	viscosity evaluated at (T_s)	lb-sec/ft^2
ξ	coordinate normal to body surface	feet
ξ_w	shock standoff distance normal to body	feet
σ	Prandtl Number	--

C. EQUATIONS

The equations for generating each section of the shape are summarized below:

1. Shape Generation Equations

Section 1. (Nosecap)

Coordinates	Formula	Independent Variable Limits	
x_o	$x_o = 0$	$\theta_o = 90, \ \theta_1 = \theta_N$	
$x_o \rightarrow x_1$	$x = R_N(1 - \sin\theta)$	$\theta_1 \leq \theta \leq \theta_o$	
x_1	$x_1 = R_N(1 - \sin\theta_N)$		(1)
y_o	$y_o = 0$		
$y_o \rightarrow y_1$	$y = R_N \cos\theta$		
y_1	$y_1 = R_N \cos\theta_N$		

Section 2.(Torus) Ind. Var (θ)

$x_1 \rightarrow x_2$ $x = x_1 + R_{SN}(\sin\theta_N - \sin\theta),\ \theta_1 = \theta_N$

x_2 $x_2 = x_1 + R_{SN}(\sin\theta_N - \sin\theta_2)$ (2)

$\theta_2 \leq \theta \leq \theta_N$

$y_1 \rightarrow y_2$ $y = y_1 + R_{SN}(\cos\theta - \cos\theta_N),\ \theta_2 = \theta_c$ cone

y_2 $y_2 = y_1 + R_{SN}(\cos\theta_2 - \cos\theta_N),\ \theta_2 = \beta$ tension shell

→ $\theta_2 = \theta_{2G}$ general shell

Section 3. (Cone)

Cone: Input $\theta_c = \theta_2$

$x_2 \rightarrow x_3$ $x = x_2 + (y - y_2)\cot\theta_2$

x_3 $x_3 = x_2 + (y_3 - y_2)\cot\theta_2$ (3)

$y_2 \rightarrow y_3$ $y = y$ $y_2 \leq y \leq y_3$

y_3 $y_3 = R_c - R_{sc}(1 - \cos\theta_2)$

Section 3.

Tension Shell:

$$y = \left\{ y_3^2 + (y_2^2 - y_3^2) \frac{\ln\left(\dfrac{1+\cos\theta}{\sin\theta}\right)}{\ln\left(\dfrac{1+\cos\beta}{\sin\beta}\right)} \right\}^{1/2} \qquad \beta \leq \theta \leq 90 \tag{4}$$

$$x - x_2 = \int_{y_2}^{y} \cot\theta \, dy \qquad y_2 \leq y \leq y_3$$

$$\frac{dS}{d\theta} = \frac{-\left(y_2^2 - y_3^2\right)}{2y(\sin^2\theta)\ \ln\left(\dfrac{1+\cos\beta}{\sin\beta}\right)} \qquad y_3 = R_c - R_{sc}$$

Section 3. , General Shape: Input Coordinates

$$\left.\begin{array}{l}\text{Table of } x\\ \text{Table of } y\end{array}\right\}\quad 25 \text{ points}$$

First pair of coordinates are x_2, y_2 (5)

Last pair of coordinates are x_3, y_3

Also, θ_{2G}, θ_{3G}.

$$y_3 = R_c - R_{sc}\,(1 - \cos\,\theta_{3G})$$

$$y_2 = y_1 + R_{SN}\,(\cos\,\theta_{2G} - \cos\,\theta_N)$$

Section 4. (Torus)

Coordinates	Formula	Independent Variable Limits	
$x_3 \rightarrow x_4$	$x = x_3 + R_{sc}\,(\sin\,\theta_3 - \sin\,\theta)$		
x_4	$x_4 = x_3 + R_{sc}\,\sin\,\theta_3$	$0 \leq \theta \leq \theta_3$	(6)
$y_3 \rightarrow y_4$	$y = y_3 + R_{sc}\,(\cos\,\theta - \cos\,\theta_3)$	$\theta_3 = \theta_c$, cone	
y_4	$y_4 = R_c$	$\theta_3 = 90$, tension shell	
		$\theta_3 = \theta_{3G}$, Gen. Shell	

Section 5. (Cylinder)

	Ind. Var. (X)		
$x_4 \rightarrow x_5$	$x = x$	$x_4 \leq x \leq x_4 + \Delta x$	
x_5	$x_5 = x_4 + \Delta x$	$\Delta x \leq L_c$	(7)
$y_4 \rightarrow y_5$	$y = R_c$		

Section 6. (Flare) Ind. Var. (y)

$x_5 \rightarrow x_6$	$x = x_5 + (y - R_c)\,\cot\,\theta_B$		
x_6	$x_6 = x_5 + (y_6 - R_c)\,\cot\,\theta_B$		
$y_5 \rightarrow y_6$	$y = y$	$y_5 \leq y \leq y_6$	(8)
y_6	$y_6 = R_B - R_{SB}\,(1 - \cos\,\theta_B)$		

Section 7. (Torus)

$$\begin{array}{llll}
x_6 \rightarrow x_7 & x = x_6 + R_{SB}(\sin\theta_B - \sin\theta) & & \\
x_7 & x_7 = x_6 + R_{SB}\sin\theta_B & 0 \leq \theta \leq \theta_B & (9) \\
y_6 \rightarrow y_7 & y = y_6 + R_{SB}(\cos\theta - \cos\theta_B) & & \\
y_7 & y_7 = R_B & &
\end{array}$$

Section 8. (Torus)

$$\begin{array}{llll}
x_7 \rightarrow x_8 & x = x_7 - R_{SB}\sin\theta & & \\
 & & & (10) \\
x_8 & x_8 = x_7 - R_{SB}\sin\theta_A & \theta_A \leq \theta \leq 0 & \\
y_7 \rightarrow y_8 & y = y_7 - R_{SB}(1-\cos\theta) & & \\
y_8 & y_8 = y_7 - R_{SB}(1-\cos\theta_A) & &
\end{array}$$

Section 9. (Aft Cone)

$$\begin{array}{llll}
x_8 \rightarrow x_9 & x = x_8 + (y - y_8)\cot\theta_A & & \\
x_9 & x_9 = x_8 + (y_9 - y_8)\cot\theta_A & y_9 \leq y \leq y_8 & (11) \\
y_8 \rightarrow y_9 & y = y & & \\
y_9 & y_9 = R_A\cos\theta_A\text{ , or } y_9 = R_T\text{ (optional)} & &
\end{array}$$

Section 10. (Aft Cap)

$$\begin{array}{llll}
x_9 \rightarrow x_{10} & x = x_9 + R_A(\sin\theta_A - \sin\theta) & & \\
x_{10} & x_{10} = x_9 + R_A(\sin\theta_A + 1) & -90 \leq \theta \leq \theta_A & (12) \\
y_9 \rightarrow y_{10} & y = R_A\cos\theta & & \\
y_{10} & y_{10} = 0 & &
\end{array}$$

Section 10. (Truncated Base)

$$\begin{array}{ll}
x = x_9 & \\
y = y & 0 \leq y \leq R_T \\
y_{10} = 0 & \\
y_9 = R_T &
\end{array}$$

2. Surface Distance Equations

Section 1.

	Formula	Limits	
S_o	$S_o = 0$		
$S_o \rightarrow S_1$	$S = R_N \dfrac{(90 - \theta_N)}{57.3}$	$\theta_N \leq \theta \leq 90$	(13)
S_1	$S_1 = R_N \dfrac{(90 - \theta_N)}{57.3}$		

Section 2.

	Formula	Limits	
$S_1 \rightarrow S_2$	$S = S_1 + R_{SN} \dfrac{(\theta_N - \theta)}{57.3}$	$\theta_2 \leq \theta \leq \theta_1$	(14)
S_2	$S_2 = S_1 + R_{SN}(\theta_N - \theta_2)/57.3$		

Section 3.

	Formula	Limits	
$S_2 \rightarrow S_3$	$S = S_2 + \dfrac{(x - x_2)}{\cos\theta_2}$	$x_2 \leq x \leq x_3$	(15)
S_3	$S_3 = S_2 + \dfrac{(x_3 - x_2)}{\cos\theta_2}$	$\theta_2 = \theta_c$	

$$S = S_2 + \int_{y_2}^{y_3} \frac{dy}{\sin\theta} \qquad (16)$$

Section 4.

	Formula	Limits	
$S_3 \rightarrow S_4$	$S = S_3 + R_{SC}(\theta_3 - \theta)/57.3$	$0 \leq \theta \leq \theta_3$	(17)

Section 5.

	Formula	Limits	
$S_4 \rightarrow S_5$	$S = S_4 + (x - x_4)$	$x_4 \leq x \leq x_5$	(18)

Section 6.

$S_5 \rightarrow S_6$ $\qquad S = S_5 + (x - x_5)/\cos\theta_B \qquad x_5 \leq x \leq x_6 \qquad (19)$

Section 7.

$S_6 \rightarrow S_7$ $\qquad S = S_6 + R_{SB}\dfrac{(\theta_B - \theta)}{57.3} \qquad 0 < \theta < \theta_6 \qquad (20)$

Section 8.

$S_7 \rightarrow S_8$ $\qquad S = S_7 - R_{SB}(\theta/57.3) \qquad \theta_A \leq \theta \leq 0 \qquad (21)$

Section 9.

$S_8 \rightarrow S_9$ $\qquad S = S_8 + (y - y_8)/\sin\theta_A \qquad y_9 \leq y \leq y_8 \qquad (22)$

Section 10.

$S_9 \rightarrow S_{10}$ $\qquad S = S_9 + R_{SA}(\theta_A - \theta)/57.3 \qquad -90 \leq \theta \leq \theta_9 \qquad (23)$

or $\qquad S = S_9 + (R_T - y) \qquad 0 \leq y \leq R_T$

3. Axes Transformation

$$y_b = |(y_o - y_{os})\cos\alpha + (x_o - x_{os})\sin\alpha| \qquad (24)$$

$$x_b = (x_o - x_{os})\cos\alpha - (y_o - y_{os})\sin\alpha \qquad (25)$$

Body slope and surface distance at angle of attack.

4. Windward Meridian

Proceeding from $x_o = x_{os}$ in direction of increasing (x_o),

$\theta_b = \theta_o + \alpha$

$+y_o$ used $\qquad (27)$

$S_b = S_o - S_{os}$

When $(x_o)_{max}$ is reached, reverse direction to decreasing (x_o), and use,

$\theta_b = \alpha - \theta_o - 180$

$-y_o$ used $\qquad (28)$

$S_b = 2(S_o)_{max} - S_{os} - S_o$

5. Leeward Meridian

Proceeding from $x_o = x_{os}$ in direction of decreasing (x_o)

$\theta_b = 180 - \theta_o - \alpha$

$+y_o$ used (29)

$S_b = S_{os} - S_o$

When $(x_o = 0)$ is reached, reverse direction increasing (x_o), and use,

$\theta_b = \theta_o - \alpha$

$-y_o$ used (30)

$S_b = S_{os} + S_o$

6. Sonic Point Location

$$\theta_b^* = \sin^{-1} \left[\frac{2}{\gamma_S + 1} \right]^{\frac{\gamma_S}{2(\gamma_S - 1)}} \qquad (31)$$

7. Equation and Logic for Stagnation Point Location

Test each section for all possible cases of $\alpha + \theta_o = 90$. Select stagnation point at maximum $\bar{x}_\alpha$,

$$\bar{x}_\alpha = y_{os} \sin \alpha - x_{os} \cos \alpha , \qquad (32)$$

8. Oblique Shock Equations

$$M = 28\ X_N + 32\ X_O + 44\ X_C + 40\ X_A \qquad (33)$$

$$C_p = (R/M)\ (3.5\ X_N + 3.5\ X_O + 2.5\ X_A) \qquad (34)$$

$$H = (V^2/2) + C_p\ T_a \qquad (35)$$

$$M_a = \frac{V}{\left[\dfrac{C_p\ T_a}{\dfrac{C_p M}{R} - 1} \right]^{1/2}} \qquad (36)$$

$$\gamma_a = \frac{(C_p M/R)}{[(C_p M/R) - 1]} \tag{37}$$

$$\frac{h_w\ M}{R\ T_o} = \frac{H\,M}{R\ T_o}\left\{1 - \frac{V^2}{2H}\left[\left(\frac{\rho_a}{\rho_w}\right)^2 \sin^2\ \theta_w + \cos^2\ \theta_w\right]\right\} \tag{38}$$

$$\frac{P_w}{P_o} = \frac{\rho_a\ V^2}{P_o}\ \sin^2\ \theta_w\ \left(1 - \frac{\rho_a}{\rho_w}\right) + \frac{P_a}{P_o} \tag{39}$$

9. Oblique Shock Solution

$$\rho_w = \frac{P_w\ M}{Z\,R\,T_w} \tag{40}$$

$$\left(\frac{U_w}{V}\right)^2 = \cos^2\ \theta_w + \left(\frac{\rho_a}{\rho_w}\right)^2\ \sin^2\ \theta_w \tag{41}$$

$$\cot\ \theta_{wl} = \frac{\cos^2\ \theta_w + (\rho_a/\rho_w)\sin^2\ \theta_w}{\sin\ \theta_w\ \cos\ \theta_w\ (1 - \rho_a/\rho_w)} \tag{42}$$

$$\gamma_w = \frac{\rho_w/\rho_a + 1}{\rho_w/\rho_a - 1} \tag{43}$$

$$\frac{\rho_{ws}}{\rho_a} = \frac{\rho_w}{\rho_a}\ \left(\frac{P_{ws}}{P_w}\right)^{\frac{1}{\gamma_w}} \tag{44}$$

$$\frac{P_{ws}}{P_o} = \frac{P_w}{P_o}\ \left[\frac{1}{1 - \frac{V^2}{2H}\ \left(\frac{U_w}{V}\right)^2}\right]^{\frac{\gamma_w}{\gamma_w - 1}} \tag{45}$$

Start oblique shock calculation at $\theta_w = 90$ degrees When $I_w \leq$ INSTØP cease calculation of I_w at smaller θ_w's At this time the value of γ_w is taken as

$\theta_w < \theta_w'$

$$\gamma_w = \gamma_w' + \frac{(\gamma_w' - \gamma_a)}{(\theta_w' - \mu_a)}(\theta_w - \theta_w') \tag{46}$$

where θ_w' is first angle where $I_w \leq$ INSTØP and γ_w' is corresponding γ_w.

$$\mu_a = \sin^{-1}\frac{1}{M_a} \tag{47}$$

$$\frac{\rho_w}{\rho_a} = \frac{(\gamma_w + 1) M_a{}^2 \sin^2\theta_w}{[(\gamma_w - 1) M_a^2 \sin^2\theta_w + 2]} \tag{48}$$

I_w is taken as zero for $\theta_w < \theta_w'$

Remainder of shock variables via Equations (38), (39), (40), (41), (42), and (44)

10. Equations for Pressure Distribution $\quad 0 \leq S_b \leq S_b^*$

$$\frac{P_e^*}{P_s} = \left(\frac{2}{\gamma_s + 1}\right)^{\frac{\gamma_s}{\gamma_s - 1}} \tag{49}$$

$$\frac{P_e}{P_s} = 1 - \frac{\rho_s}{\rho_a}\left(\frac{\rho_a V^2}{2 P_s}\right)\left(\frac{S_b^*}{V}\cdot\frac{du}{ds}\right)^2\left(\frac{S_b}{S_b^*}\right)^2 + \left[\frac{P_e^*}{P_s} - 1 + \frac{\rho_s}{\rho_a}\left(\frac{\rho_a V^2}{2P_s}\right)\left(\frac{S_b^*}{V}\frac{du}{ds}\right)^2\right]\left(\frac{S_b}{S_b^*}\right)^4 \tag{50}$$

$$\frac{P_e}{P_s} = \sin^2\theta_b \tag{51}$$

11. Pressure Distribution $S_b > S_b^*$

Equations for

Newtonian

$$\frac{P_e}{P_s} = \sin^2 \theta_b + \frac{P_a}{P_s} \cos^2 \theta_b \tag{52}$$

PC: Pressure is constant = last value

Prandtl - Meyer: Use table look up

P_e/P_s initial val. → initial ν_i

$$\nu_j = \nu_i + (\theta_i - \theta_j) \tag{53}$$

$\nu_j \rightarrow P_e/P_s$

Pressure Limit

$$\frac{P_e}{P_s} > \frac{P_a}{P_s} \tag{54}$$

Entropy Layer

$$\frac{P_i}{P_s} = \frac{P_i}{P_s} + \left(\frac{dp}{dx}\right)_i (x_j - x_i) \frac{1}{P_s} \tag{55}$$

Entropy Layer Equations,

$j = 0$

$$\frac{d(P_e/P_s)}{dx_b} = \frac{\gamma_s}{B_2} \cdot \left(\frac{P_e}{P_s}\right)^{\frac{\gamma_s + 1}{\gamma_s}} \cdot \left[\operatorname{Tan} \theta_b - \sqrt{\frac{\frac{P_e}{P_s} - \frac{P_a}{P_s}}{1 - \frac{P_e}{P_s} - \frac{P_a}{P_s}}}\,\right] \tag{56}$$

$$B_2 = (\gamma_s - 1) \left(\frac{P_{eb}}{P_s}\right)^{\frac{1 - \gamma_s}{\gamma_s}} \cdot \int_0^{y_{bb}} \frac{P_e}{P_s} \, dy_b$$

$j = 1$

$$\frac{d(P_e/P_s)}{dx_b} = \frac{\gamma_s}{B_1}\left(\frac{P_e}{P_s}\right)^{\frac{\gamma_s+1}{\gamma_s}} \cdot \left\{ \frac{ y_{bb}\tan\theta_b + \tan^2\theta_b\,(x - x_{bb}) \,.}{\sqrt{\dfrac{\dfrac{P_e}{P_s} - \dfrac{P_a}{P_s}}{1 - \dfrac{P_e}{P_s} - \dfrac{P_a}{P_s}} \left\{ 2B_1\left(\dfrac{P_e}{P_s}\right)^{-\frac{1}{\gamma_s}} + [y_{bb} + \tan\theta_b\,(x_b - x_{bb})]^2 \right\}}} \right\} \qquad (57)$$

$$B_1 = (\gamma_s - 1)\left(\frac{P_{eb}}{P_s}\right)^{\frac{1-\gamma_s}{\gamma_s}} \int_0^{Y_{bb}} \frac{P_e}{P_s}\, y_b\, dy_b$$

(bb) subscripts refer to start of straight section ($\frac{d\theta}{ds} = 0$) and to conditions there.

12. Stagnation Point Velocity Gradient

An average stagnation point velocity gradient is needed to evaluate heating. A velocity gradient is obtained for both the windward and leeward meridians. For

$$0 \leq \alpha < 90 - \theta_N \qquad \text{and} \qquad (180 + \theta_A) < \alpha \leq 180$$

$$\left(\frac{du}{ds}\right)_s = \left(\frac{du}{ds}\right)_s = \frac{1}{2}\left(\frac{du}{ds}\right)_{wind} + \frac{1}{2}\left(\frac{du}{ds}\right)_{lee} \qquad (58)$$

For $(90 - \theta_N) \leq \alpha \leq (180 + \theta_A)$

$$\left(\frac{du}{ds}\right)_s = \frac{1}{2}\,\overline{\frac{du}{ds}}_s + \frac{1}{2}\,\frac{\sin\alpha}{(y_{os})}\sqrt{\frac{3\rho_a}{\rho_s}} \qquad (59)$$

509<

489

where (y_{os}) is the value of y_o in zero angle of attack corresponding to the new stagnation point.

13. Laminar Heating

$$q_{LS} = \frac{0.76}{\sigma^{0.6}} \left(\frac{\rho_{bs} \quad \mu_b}{\rho_s \; \mu_s} \right)^{0.1} \sqrt{\rho_s \; \mu_s} \quad \frac{H}{778} \sqrt{\left(\frac{du}{ds}\right)_s} \tag{60}$$

$$\left[1 + (L^a - 1) \frac{h_D}{H} \right]$$

$$\frac{q_L}{q_{LS}} = \frac{{y_b}^j \; \rho_b \; \mu_b \; U_e}{(1.068) \sqrt{2\xi}} \quad \frac{(1 + 0.096 \sqrt{\beta}}{\sqrt{2 \; \rho_{bs} \; \mu_b \left(\frac{du}{ds}\right)_{W,L}}} \quad \sqrt{\frac{2}{j+1}} \tag{61}$$

$$\frac{q_L}{(q_{LS})_{\alpha = 0}} = \left(\frac{q_L}{q_{LS}}\right) \times \frac{q_{LS}}{(q_{LS})_{\alpha = 0}} \tag{62}$$

$$\rho_{bs} = \frac{P_s \, M}{R \; T_b} \tag{63}$$

$$\mu = \mu\,(T) \qquad \text{Table took up} \tag{64}$$

$$\rho_b = \frac{P_e \;\; M}{R \; T_b} \tag{65}$$

14. Equations Modified by THETAT Input

$$U_e = \sqrt{2\,H} \quad \sqrt{1 - \frac{T_e}{T_T}} \tag{66}$$

$$T_T = T_{ws}\,(\text{THETATT}) \tag{67}$$

$$\frac{T_e}{T_T} = \left(\frac{P_e}{P_s} \quad \frac{P_s}{P_T} \right)^{\frac{\gamma_e - 1}{\gamma_e}} \tag{68}$$

49D

$$\gamma_e = \gamma_w \text{ (THETATT)} \tag{69}$$

$$P_{T'} = P_{ws} \text{ (THETATT)} \tag{70}$$

$$\frac{\rho_e}{\rho_T} = \left(\frac{P_e}{P_s} \; \frac{P_s}{P_T} \right)^{\frac{1}{\gamma_e}} \tag{71}$$

$$\rho_T = \rho_{ws} \text{ (THETATT)} \tag{72}$$

15. Reynold's Number

$$Re = \frac{\rho_e \, U_e \, S_b}{\mu_e} \tag{73}$$

16. Laminar Heating Parameters

$$\xi = \int_{s_1}^{s_j} \rho_b \, \mu_b \, U_e \, y_b^{2j} \, dS_b + \xi_1 \tag{74}$$

For,

$S_b \le \dot{S}_1$

$$\left\{ \; \xi = \rho_{bs} \; \mu_b \left(\frac{dU}{dS} \right) \frac{S_b^{\,2j+2}}{(2j+2)} \right. \tag{75}$$

1 /dU\

$$\beta = \frac{-2\,\xi}{(\rho_e \, U_e^3 \, \rho_b \, \mu_b \, y_b^{\,2j})} \; \frac{d\,P_e}{d\,S_b} \quad , \quad \beta \ge 0 \tag{76}$$

17. Turbulent Heating

$$q_T = \frac{C_f}{2\,(778)} \, \rho_e \, U_e \, H \tag{77}$$

$$C_f = C_{f_i} \cdot \frac{C_f}{C_{f_i}} \tag{78}$$

$$C_{f_i} = \frac{0.0296 \; (2)^{0.2j}}{\sigma^{2/3} \; \mathrm{Re}^{0.2}} \tag{79}$$

$$\frac{C_f}{C_{f_i}} = \left(\frac{\rho^*}{\rho_e}\right)^{0.8} \left(\frac{\mu^*}{\mu_e}\right)^{0.2} \tag{80}$$

$$\mu^* = \mu\,(T^*) \tag{81}$$

$$\frac{\rho^*}{\rho_e} = \frac{T_e}{T^*} \tag{82}$$

$$T^* = T_e \left\{ 1 + 1/2 \left(\frac{T_b}{T_e} - 1\right) + 0.22 \; (\sigma)^{1/3} \left(\frac{T_T}{T_e} - 1\right) \right\} \tag{83}$$

18. Radiation Heating

$$q_R = \frac{\xi_w}{2} \left[\frac{m}{m+1} \; I_b + \frac{1}{m+1} \; I_w \right] \tag{84}$$

19. Shock Shape

$$\xi_w = \frac{(x_b + \Delta_s) \cos \theta_w - y_b \, (1 - \sin \theta_w)}{\cos \theta_b - \sin(\theta_w - \theta_b)} \tag{85}$$

where,

x_b, y_b, are taken as

$$x_b = x_b^* \;\text{ and }\; y_b = y_b^* \left\{ \begin{array}{l} \dfrac{d\theta}{dS} < 0 \qquad 0 \leq S < S_b^*, \text{ or} \\ \hline \dfrac{d\theta}{dS} = 0 \;\text{ and }\; x_b^* \leq (\Delta_{so}) \end{array} \right.$$

$$x_b = x_{bb} \;\text{ and }\; y_b = y_{bb} \left\{ \dfrac{d\theta}{dS} = 0 \;\text{ and }\; x_b^* > (\Delta_{so}) \right.$$

$$R_w = \frac{\xi_w \cos \theta_b + y_b}{\cos \theta_w} \tag{86}$$

$j = 1$

$$C_1 \xi_w^2 + C_2 \xi_w + C_3 = 0$$

(Positive Root)

$$C_1 = 2 \cos \theta_b \left\{ \frac{1}{2} \frac{\rho_e}{\rho_a} \frac{U_e}{V} + \frac{1}{n+2} \left[\frac{\rho_w}{\rho_a} \frac{U_w}{V} \cos (\theta_{wL} - \theta_b) - \frac{\rho_e}{\rho_a} \frac{U_e}{V} \right] \right\} - \cos^2 \theta_b \tag{87}$$

$$C_2 = 2y_b \left\{ \frac{\rho_e}{\rho_a} \frac{U_e}{V} + \frac{1}{n+1} \left[\frac{\rho_w}{\rho_a} \frac{U_w}{V} \cos (\theta_{wL} - \theta_b) - \frac{\rho_e}{\rho_a} \frac{U_e}{V} \right] \right\} - 2y_b \cos \theta_b$$

$$C_3 = - y_b^2$$

$j = 0$

$$\xi_w = \frac{y_b}{\frac{\rho_e}{\rho_a} \frac{U_e}{V} + \frac{1}{n+1} \left[\frac{\rho_w}{\rho_a} \frac{U_w}{V} \cos (\theta_{wL} - \theta_b) - \frac{\rho_e}{\rho_a} \frac{U_e}{V} \right] - \cos \theta_b} \tag{88}$$

Determination of ξ_w :

$$Y_w^2 (1 - B\tan^2 \theta_b) + Y_w [2R_w \tan \theta_b + 2B(X_b + \Delta_s) \tan \theta_b + 2BY_b \tan^2 \theta_b]$$

$$-2R_w [X_b + \Delta_s + Y_b \tan \theta_b] - B(X_b + \Delta_s)^2 - BY_b^2 \tan^2 \theta_b - 2B(X_b + \Delta_s) Y_b \tan \theta_b = 0 \tag{89}$$

$$\mathrm{Tan}\ \theta_w = \frac{2R_w + 2B [X_b + \Delta_s - (Y_w - Y_b) \tan \theta_b]}{2 Y_w} \tag{90}$$

Evaluate B at first point where $\theta_b \leq 0$.

$$B = \frac{(Y_b + \xi) \tan \theta_w - R_w}{(X_b + \Delta_s)} \tag{91}$$

$$\text{Tan}\ \theta_w = \frac{(Y_b + \xi)}{X_b + \Delta_s} - \frac{R_w}{(Y_b + \xi)} \tag{92}$$

$$\xi(\theta_w, 0) \text{ from equations 87, 88} \tag{93}$$

Solve for $\xi_w, \theta_w, (S_b)$

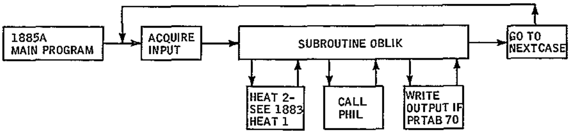
$$\xi_w = \frac{Y_w - Y_b}{\cos\theta_b} \tag{94}$$

IV. IBM ROUTINES

A. PROGRAM FLOW

The program flow for the A and B parts of Program 1885 is illustrated in Figure 12 below.

1885A PROGRAM FLOW



1885B PROGRAM FLOW

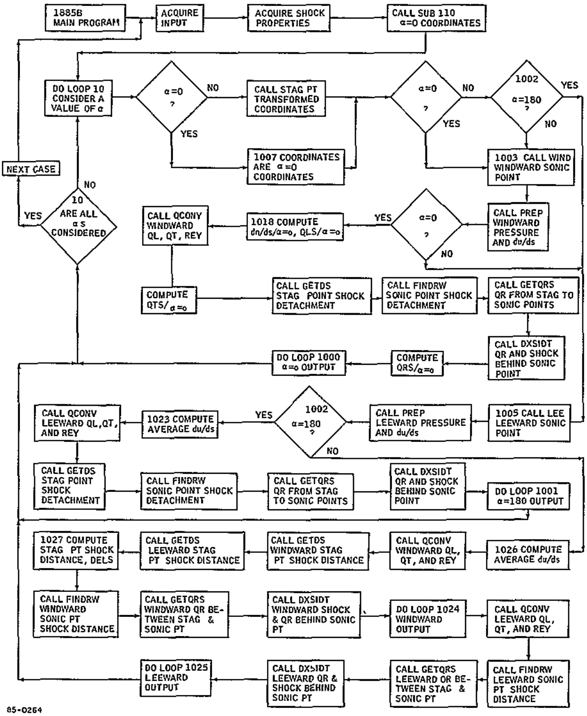


Figure 12 PROGRAM FLOW

B. COMMON STORAGE

Common data in 1885B is transferred between subroutines and the main program for two primary purposes, the first for computing zero angle-of-attack coordinates, (SUB110) and for computing the derivatives $\frac{d(P_e/P_s)}{dx}$ (PREP) or $\frac{d\xi}{dS}$ (DXSIDT), where the ADM4RB and DEREQB predictor-corrector system is used to solve numerically one or the other of these differential equations. Note that the CØMMØN DATA variables XMEMØ and THETAC appear in equivalence statements, and are thus the first items in common storage core locations.

ALPHA	α	Program Input	SUB110 Input	Array of angles of attack.
BETA	β	Program Input	SUB110 Input	Tension shell angle.
CTHSTT		DXSIDT	DEREQB Input	Value of cos (THSTRT) at start of integration interval.
DATE		Program Input	In to SUB110	Identification number.
DN1		Not currently used.		
DN2		Program Input	PREP Input	Lower bound for accuracy in integrating $d(P_e/P_s)/dx$.
DTDSO	$\frac{d\theta_{o_1}}{dS_{o1}}$	SUB110	SUB110 Output	Array of $\frac{d\theta_{o_1}}{dS_{o1}}$ for $\alpha = 0$ coordinates.
DTDSST		DXSIDT	DEREQB Input	Value of $\frac{d\theta_b}{dS_b}$ at start of integration interval.
DTDSTB	$\frac{d\theta_i}{dS_i}$	Program Input	SUB110 Input	Array of $\frac{d\theta_i}{dS_i}$ for general shape.
GAMS	γ_s	Program Input or 1885A	DEREQB Input	Value of γ_s for calculation Input.
GM IØG		Main	DEREQB Input	$(\gamma_s - 1)/\gamma_s$

GP1ØG		Main	DEREQB Input	$(\gamma_s + 1)/\gamma_s$
GSØB	γ_s/B	PREP	DEREQB Input	γ_s/B_1 or γ_s/B_2 used to integrate $d(P_e/P_s)/ds$
HAMB	H	Program Input or 1885A	DEREQB Input	Enthalpy used to compute U_e/V, etc., for shock and radiation.
ICASE	CASE	Program Input	In to SUB110	Identification number.
ILINE		Main	SUB110 In & Out	The page number on printing $\alpha = 0$ coordinates.
IO1		SUB110	SUB110 Output	Sentinel 1, 2, 3, if section 3 is cone, tension shell, or general shape.
IO2		SUB110	SUB110 Output	Sentinel 1, 2, if section 10 is sphere of flat base.
IOTBL		Program Input	SUB110 Input	If = 1, $\alpha = 0$ coordination are printed.
IPAGE		Main	SUB110 In & Out	Page number on printing $\alpha = 0$ coordinates.
JFLØW	X_J	Program Input	DEREQB Input	Sentinel for 1-D or 2-D flow.
JOMAX		SUB110	SUB110 Output	Number of points in $\alpha = 0$ coordinate tables.
KINDEQ		DXSIDT or PREP	DEREQB Input	If 0, integrate $\frac{d(P_e/P_s)}{dx}$, if >0, integrate $d\xi/dS_b$.
M	M_{o_1}	SUB110	SUB110 Output	Array of section numbers for $\alpha = 0$ coordinates.
NALPHA		Program Input	SUB110 Input	Number of angles of attack on the array ALPHA.
NUMBER		Program Input	In to SUB110	Identification number.

ØØGS		Main	DEREQB Input	$1/\gamma_s$.
PAPØS		PREP	DEREQB Input	Value of P_A/P_S as a lower pressure limit for $d(P_e/P_s)/dX$ integration.
PIR		Main	SUB110 Input	deg/rad.
PSTART		DXSIDT	DEREQB Input	Value of P_e/P_s at start of integration interval.
PSTØP		DXSIDT	DEREQB Input	Value of P_e/P_s at end of integration interval.
RA	R_A	Program Input	In to SUB110	Aft cap radius.
RAD		Main	DEREQB Input	rad/deg.
RB	R_B	Program Input	In to SUB110	Flare and aft cone base radius.
RC	R_C	Program Input	In to SUB110	Cylinder and cone base radius.
REYT		Not currently used.		
RHØA	ρ_A	Program Input or 1885A	DEREQB Input	Ambient density.
RN	R_N	Program Input	In to SUB110	Nose radius.
RSB	R_{SB}	Program Input	In to SUB110	Toroidal radius.
RSC	R_{SC}	Program Input	In to SUB110	Toroidal radius at base of cone.
RSN	R_{SN}	Program Input	In to SUB110	Toroidal radius aft of nose.

RSØRA	ρ_s/ρ_A	Program Input or 1885A	DEREQB Input	Value of ρ_s/ρ_A for calculation.
RT	R_T	Program Input	In to SUB110	Base truncation radius.
RTBL	Y_i	Program Input	SUB110 Input	Array of y_i for general shape.
SECTN		Main	SUB110 Input	Section number for labeling.
SO	S_{o_i}	SUB110	SUB110 Output	Array of S_o for $\alpha = 0$ coordinates.
SQ2HV2		Main	DEREQB Input	$(2H/V^2)^{1/2}$
SSTART		PREP or DXSIDT	DEREQB Input	Value of S_b at start of integration interval.
SSTØP		DXSIDT	DEREQB Input	Value of S_b at end of integration interval.
TA	T_A	Program Input or 1885A	DEREQB	Ambient temperature.
TABLE		Program Input or 1885A	DEREQB Input	Two-dimensional array of oblique and normal shock properties.
TANTB		PREP	DEREQB Input	Value of tan (θ_b) at start of straight section for $d(P_e/P_s)/dx$ integration.
TANTB2		PREP	DEREQB Input	TANTB^2
TB	T_B	Program Input	DEREQB Input	Body temperature.
THET		GETTWG	DEREQB Output	Value of θ_b corresponding to S_b in integrating $d\xi/dS_b$.

THETAA	θ_A	Program Input	In to SUB110	Aft cone angle.
THETAC	θ_C	Program Input	In to SUB110	Fore core angle.
THETAN	θ_N	Program Input	In to SUB110	Nose cap angle.
THETAO	θ_{o_i}	SUB110	SUB110 Output	Array of θ_o for $\alpha = 0$ coordinates.
THETB	θ_B	Program Input	In to SUB110	Flare angle.
THET2G	θ_{2_G}	Program Input	SUB110 Input	Angle at first point on general shape.
THET3G	θ_{3_G}	Program Input	SUB110 Input	Angle at last point on general shape.
THSTRT		DXSIDT	DEREQB Input	Value of θ_b at start of integration interval.
THWGS		GETTWG	DEREQB Output	Value of θ_W corresponding to ξ from $d\xi/dS_b$.
THWLIM		Main	GETTWG Input	$1.1 \, \mathrm{Sin}^{-1} \left(\frac{1}{MACH} \right)$, lower limit to θ_w for $d\xi/dS_b$.
TW0BB		PREP	DEREQB Input	2B, or $2B_2$ used to integrate $d(P_e/P_s)/dx$
UP1		Not currently used.		
UP2		Program Input	PREP Input	Upper bound for accuracy in integrating $d(P_e/P_s)/dx$.
V	V	Program Input or 1885A	DEREQB Input	Vehicle velocity.
XA	X_A	Program Input or 1885A	DEREQB Input	Mole fraction of Argon in undissociated mixture.

XC	x_C	Program Input or 1885A	DEREQB Input	Mole fraction of $CØ_2$ in undissociated mixture.
XGB		Not currently used.		
XLC	L_C	Program Input	In to SUB110	Cylinder length.
XMEMØ	MEMØ	Program Input	In to SUB110	Identification number.
XMMX	MM	Program Input	FINDRW or DXSIDT Input	Used by FINDRW or DXSIDT to compute QR.
XN	N	Program Input	In to SUB110	Array of divisions per body segment.
XNN	x_N	Program Input or 1885A	DEREQB Input	Mole fraction of N_2 in undissociated mixture.
XNNX	NN	Program Input	DEREQB Input	Used to compute shock shape.
XO	x_{o_i}	SUB110	SUB110 Output	Array of x_o for $\alpha = 0$ coordinates.
XØ	$x_Ø$	Program Input or 1885A	DEREQB Input	Mole fraction of $Ø_2$ in undissociated mixture.
XSTART		PREP	DEREQB Input	Value of x_b at start of straight section for $d(P_e/P_s)/dx$ integration.
XTBL	x_i	Program Input	SUB110 Input	Array of x_i for general shape.
YGB		Not currently used.		
YO	y_{o_i}	SUB110	SUB110 Output	Array of y_o for $\alpha = 0$ coordinates.
YSTART		PREP or DXSIDT	DEREQB Input	Value of Y_b at start of integration interval.

C. 1885A SUBROUTINES

CALLING SEQUENCES

ØBLIK	Variable Input or Output Source	RHØA, Sa, ambient density Input Program Input	XA, argon mole fraction in atmosphere Input Program Input	XC, CO_2 mole fraction in atmosphere Input Program Input	XN, N_2 mole fraction in atmosphere Input Program Input
XØ, O_2 mole fraction in atmosphere Input Program Input	XPL, print sentinel for converged iteration Input Program Input	XPE, print sentinel for each iteration Input Program Input	DELAL, movement in wave angle table Input Program Input	TA, Ta, ambient temperature Input Program Input	V, velocity Input Program Input
TABLE, table of oblique shock data Output ØBLIK	IGØØF, sentinel > 1 if solution impossible Output ØBLIK	PATAB, print sentinel Input Program Input	PA, ambient pressure Output ØBLIK	HA, ambient enthalpy Output ØBLIK	AM, Mach number Output ØBLIK
XM, mean molecular weight of atmosphere Output ØBLIK	HDHS90, dissociation energy for normal shock Output ØBLIK	QINSTP, lowest radiation intensity Input Program Input			
PHIL	Variable Input or Output Source	TABLE, table of shock data Input/Output ØBLIK/PHIL	ITH, index of last TABLE computed intensity Input ØBLIK	DELAL, increment in ϕ_w Input Program Input	IGOOF, sentinal > 1 if solution impossible Output PHIL

Calling sequences for all other subroutines are as in Section 1883

1. ØBLIK

Purpose: To perform the oblique shock calculation and prepare a table of shock data, TABLE.

Method· TABLE is a two-dimensional array 46 x 13. The 13 columns contain the variables θ_W (THW), ρ_W/ρ_a (DENINV), $\rho_W U_W/\rho_a V$ (DENINV· UWØV), θ_{WL} (THWL), γ_W (GAMW), T_W(T), P_W/P_o (PRS), H_W/H (ENT· R·TO/(XM· HH)), ρ_{WS}/ρ_A (RWSØRA), P_{WS}/P_o (PWSØPØ), TWS (T·HMØRT Z/ENT), IW (2·QSUM/DEL), and IB (2·QSUM/DEL), where IB is evaluated at the enthalpy ENTB.

After initializing TABLE, defining output names (ZNAMI and ZNAM2), ØBLIK computes ambient conditions and selects the proper set of tables of temperature and enthalpy for the atmosphere. This is done before HVST is called after statement 1001. A loop from 1002 to the statement before 1024 then decrements the value of θ_W in decrements of DELAL until the lower limit in θ_W is reached and solved (If test before 1006), or until the wave intensity [TABLE(ITH, 12)]is less than the input INSTØP (test after 2005).

The first θ_W is for the normal shock (90 degrees), and the calculation is done in the same way as described in Program 1883. Provision for this special case is made by the IF test before statement 1017. For all other values of an iteration on the density ratio is performed, convergence being determined by two successive values of the density ratios differ by less than 1 percent (IF test before Statement 1022). The iteration for such value $90 > \theta_W \geq$ THWL is as follows. Given a first guess for the density ratio (DENR) from the preceding computation, the pressure and enthalpy are expressed as PRS and ENT (after Statement 1021) in terms of DENR, θ_W, and the ambient condition. HEAT2 is called which, as in 1883, converges on the pressure and enthalpy and in the process computes a new density ratio which, for convergence, approaches the estimated value. Corresponding to the last iteration is the radiation QSUM, which is simply related to IW [TABLE(ITH, 12)] . After convergence, IB [TABLE(ITH, 13)] is computed at the converged pressure PRS and a new enthalpy ENTB by HEAT2 before Statement 2004. If the problem fails to converge for the normal shock (test of 2000) IGØØF is set to 1 and control passed to the math program for the next case. If no convergence is obtained for other values of θ_W, a transfer is made to Statement 1004 which sets the tabular value of THW [TABLE(ITH, 1)] = 0, and the increments of the computation IINT. At the conclusion of the calculation subroutine PHIL is called if IINT > 0. This subroutine searches for values of THW which are zero and if there are any provides linear interpolation for the 12 shock property columns with θ_W as the independent variable. The output for each iteration (XPE>1) for every converged iteration (XPL>1) is provided by the tests between 1022 and 1024 and the Statements between 1009 and 1016.

If the body radiation intensity drops below the input INSTØP, a transfer is made out of the loop to Statement 1024. DØ loop 1028 provides an interpolation between the ambient γ(GAMA) and the last γ_W (GAMW) computed by the iterative procedure, using THW as the independent variable. All shock properties, except IW (which is set to 0) and IB (which is still computed until it also falls below INSTØP, then set to zero for smaller θ_W) are then expressed in terms of the interpolated value of γ (GAMI), the θ_W, and the ambient conditions.

2. PHIL

Purpose: To interpolate values of the shock properties using θ_W as the independent variable.

Method: Where TABLE(ITH, 1) are zero the solution was not found by iteration, the TABLE(ITH, 2-13) are linearly interpolated between successive successful iteration. If successive successful values are not found in TABLE(ITH, 1), IGØØF is set to 1 and control is returned to DBLIK, then the math program for the next case.

3. HEAT 2

Purpose: Described in Section 1883.

Method: Same as 1883, but the detachment distance is now computed and is always set = 0.1 by DBLIK.

All other subroutines are the same as 1883.

D. 1885 B SUBROUTINES

CALLING SEQUENCE

LEE	Variable Input or Øutput Sources	KKL, Section identification array Øutput LEE	XIL, X_o array corres to X_b Øutput I EE	YIL, Y_o array corres to Y_b Øutput LEE	XBL, X_b array Øutput LEE
YBL, Y_b array Øutput LEE	SBL, S_b array Øutput LEE	THETBL, array Øutput LEE	ISTAG, No of stag pt in XIL array Input STAGPT	IGOOF, If = 0, calculation o k Øutput LEE	XI stag pt Input LEE
Y1 stag pt Input STAGPT	S1 stag pt Input STAGPT	DTDSI, stag pt Input STAGPT	THETA stag pt Input STAGPT	M1 stag pt Input STAGPT	INØ, number of entries in XIL Øutput LEE
ALPH current Input Program Input	ISØNL, number at sonic pt in XIL Øutput LEE	THEBST, sonic point Input MAIN	DTDSL array Øutput LEE		

PREP	Variable Input or Output Source	X, X_b array Input WIND or LEE	Y, Y_b array Input WIND or LEE	S, S_b array Input WIND or LEE	DTDS, $d\theta_b/dS_b$ Input WIND or LEE
THETS, θ_b array Input WIND or LEE	ISØNQ, number of sonic pt, in table Input WIND or LEE	PRE, array of Pe/Ps Output PREP	THEBSQ, sonic θ_b^* Input MAIN	RSØRAQ, ρ_s/ρ_A Input Prog Input or 1885A	PWSQ, P_s Input Prog Input or 1885A
V, velocity Input Prog Input or 1885A	RHOA, ρ_A Input Prog Input or 1885A	IPTSQ, number of points in X array Input WIND or LEE	GAMS γ_s Input Prog Input or 1885A	RC, R_C Input Prog Input	JFLOW, j flow sentinal Input Prog Input
KKW, body identification array Input WIND or LEE	DSY, Δ_s array $\gamma^*_{\epsilon=0}$ Input MAIN	RWY, $(R_w/\gamma^*)_{\epsilon=0}$ array Input MAIN	RSA ρ_s/ρ_a array with DSY, RWY Input MAIN	RARST, ρ_a/ρ_s array with XSYST & DUTB Input MAIN	XSYST, X*/Y* array for DUTB Input MAIN
DUTB, $\frac{V_T}{V}\ \frac{du}{ds}$ 2-D array Input MAIN	GMTB, γ array with PMPSTB Input MAIN	PMPSTB, PMPSTB array with GMTB Input MAIN	XNT, ν array for Prandtl-Meyer Input MAIN	XNTI, P_e/P_s array, XNGM(1), Prandtl-Meyer Input MAIN	XNT2 P_e/P_s array XNGM(2), Prandtl-Meyer Input MAIN
XNT3, Pe/Ps array, XNGM(3), Prandtl-Meyer Input MAIN	XNT4, Pe/Ps array XNGM(r), Prandtl-Meyer Input MAIN	XNGM, ν array for use in Prandtl-Meyer Input MAIN	DPØDS $\frac{d\,Pe/Ps)ds}{ds}$ array Øutput PREP	PA, P_A Input Prog Input or 1885A	DUDSSS, $du/_{ds}$ at stag pt Øutput PREP
XIW, non-trans X_1 geometry array Input Sub110	UP2, upper (limit to d(Pe/Ps)/dx integration Input Prog Input or MAIN	DN2, lower limit to d(Pe/Ps)/dx integration Input Prog Input or MAIN	IGØØF, if ≤ 0 computation satisfactory Output PREP		

QCØNV	Variable Input or Output Source	PREW, p_e/p_s array Input PREP	XMULPS, factor = Ps/PT Input MAIN	RHOBS, ρ_{BS} Input MAIN	TB, T_B Input Program
XMAMB, mean molecular weight Input Program Input or 1885A	RHOT, ρ_T Input MAIN	GAME, γ_e Input MAIN	XMUBB μ_{T_B} Input MAIN	YBW, Y_B array Input WIND or LEE	VISC, Viscocity table (with TMPVS) Input MAIN
TMPVS, temp table (with visc) Input MAIN	HAMB, enthalpy H Input Program Input or 1885A	TT, T_T Input Program Input or 1885A	DPDSW, d(Pe/Ps)/ds array Input PREP	QLW, QL array Output QCØNV	QTW, QT array Output QCØNV
INØW, number of entries th XBW Input WIND or LEE	REW, REY array Output QCØNV	JFLOW, flow Input Program Input	QLSAO, $(QLS)/_{\alpha=0}$ normalization Input MAIN	QLSW, QL'normalizing factor Input MAIN	PWS, P_S Input Program Input or 1885A
SBW, S_b array Input WIND or LEE	ISONW, number of sonic pt th XBW Input WIND or LEE	DUDSW, du/ds windward or leeward Input PREP	SIGMA, input PN, Prandtl Number Input Program Input	QTSTAO, (QTS) $\alpha = 0$ normalization Input MAIN	RYNORM, REY normalization Input MAIN
DTDSW, $d\theta_b/dS_b$ Array Input WIND or LEE					

QRNMAD	Variable	INØW, number of entries in QRAD	QRAD, or array	QRADNM, normalization factor
	Input or Øutput	Input	Input-Øutput	Input
	Source	WIND or LEE	GETQRS & DXSIDT QRNMAD	MAIN

QRCLER	Variable	INOW, number of X_b's in array	QRAD, QR array	STAND, array
	Input or Output	Input	Output	Output
	Source	WIND or LEE	QRCLER	QRCLER

GETTØT	Variable Input or Output Source	TI, Indep. Variable Input Calling Program	TTB, Indep Variable array Input Calling Program	PD, 1st dep. variable Output GETTØT	PTB, 1st dep variable array Input Calling Program
ROD, 2nd dep variable Output GETTØT	ROTB, 2nd dep. variable array Input Calling program	TTD, 3rd dep. variable Output GETTØT	TTAB, 3rd dep variable array Input Calling program	GAD, 4th dep. variable Output GETTØT	GATB, 4th dep. variable array Input Calling program

HDPRN	Variable Input or Output Source	ICASE Input Program input	IPAGE Input Main	ILINE Input Program input	NUMBER Input Main
MEMØ Input Program input	DATE Input Program input	KPRINT Output HDPRNI			

DERQ5	Variable Input or output Source	NZ Input ADAMS4	XEQ Input ADAMS 4	XIND Input ADAMS 4	DXEQ Output DERQ5
L Input ADAMS4	PAR Input Dummy variable	NPAR Input Dummy variable			

TABLES	Variable Input or Output Source	RASDØY Output TABLES	EPDØY Output TABLES	DØY Output TABLES	TMPVS Output TABLES
VISC Output TABLES	DSY Output TABLES	RWY Output TABLES	RSA Output TABLES	DUTB Output TABLES	RARST Output TABLES
XSYST Output TABLES	GMTB Output TABLES	PMPSTB Output TABLES	XNGM Output TABLES	XNT Output TABLES	XNTI Output TABLES
XNT2 Output TABLES	XNT3 Output TABLES	XNT4 Output TABLES			

WIND	Variable Input or Output Source	KKW, Section identification array Output WIND	X1W, X_o array, corres to X_b Output WIND	X1W, array corres. to Output WIND	XBW, X_b array Output WIND
YBW, Y_b array Output WIND	SBW, S_b array Output WIND	THETBW, Output WIND	ISTAG, No of stag pt in X_I, etc Input STAGPT	IGØØF, If = 0 calculation O K Output WIND	X1 stag pt Input STAGPT
Y1 stag pt Input STAGPT	S1 stag pt Input STAGPT	DTDS1 stag pt Input STAGPT	THETA1 plus stag pt Input STAGPT	M1 = 0 sections, plus stag. pt Input STAGPT	INØ, number of entries in XIW Output WIND
ALPH 1 current Input Program Input	ISØNW, number at sonic pt in XIw Output WIND	THEBST, sonic point Input MAIN	DTDSW, array Output WIND		

GETNU

Variable	XNT, dependent variable array	XNT1, independent variable array	XNU, dependent variable	PØPT, independent variable
Input or Output	Input	Input	Output	Input
SOURCE	PREP	PREP	GETNU	PREP

ACØSH

Variable	ARG, argument of $\cosh^{-1}$	ANS, $\cosh^{-1}$(ARG)	IGOOF, if ≥ 0, calculation O.K.
Input or Output	Input	Output	Output
SOURCE	Calling Program	ACØSH	ACØSH

The subroutine SUB110 receives all input and provides all output through CØMMØN DATA. In addition to their calling sequences, the following subroutines use CØMMØN for some input and output; GETTWG, PREP, WIND, LEE, STAGPT, DXSIDT, and DEREQB.

Subroutine UN08 has no calling sequence.

The calling sequences for the general purpose routines ADAMS4 and ARTLU are explained in the section on special routines.

FINDRW	Variable Input or Øutput Source	XIW, X_o corres to X_b array Input WIND or LEE	XIW, Y_o corres to X_b array Input WIND or LEE	XBW, X_b array Input WIND or LEE	YBW, Y_b array Input WIND or LEE
SBW, S_b array Input WIND or LEE	THETBW, array Input WIND or LEE	DTDSW, array Input WIND or LEE	KKW, Section I. D array Input WIND or LEE	ISØNW, Index of sonic pt MX_b Input WIND or LEE	INØW, number of entries MX_b Input WIND or LEE
RSØRA, Input Prog Input or 1885A	DOY, 2D array of Input MAIN	RASDØY, array for DØY Input MAIN	IGØØF, if ≤ 0, calculation o k Øutput FINDRW	IFLOW, flow sentinel Input Prog Input	INDDUM, index of Y_T in YWB Input GETDS
DELS, Input GETDS	THW, 1st col of table Input Prog Input or 1885A	RUØRV, column 3 of table Input Prog Input or 1885A	THWL, column 4 of table Input Prog Input or 1885A	XNNX, NN used to compute Input Prog Input	PREW, array Input PREP
HAMB, enthalpy Input Prog Input or 1885A	GAMS, Input Prog Input or 1885A	V, velocity Input Prog Input or 1885A	THETAW, at Y_T Øutput FINDRW	RW, R_w, radius of bow wave Øutput FINDRW	XSI2, at Y_T Øutput FINDRW
TDUM1, comunm 5 of TABLE Input Prog Input or 1885A	TDUM2, column 6 of TABLE Input Prog Input or 1885A	BSHOCK, B_SSHOCK Parameter Øutput FINDRW	THWLIM Smallest Input MAIN		

GETB	Variable Input or Øutput Source	PRE, array Input PREP	Y, Y_b array Input WIND or LEE	GAMS, Input Prog Input or 1885A	RC, R_c Input Program Input
MS, number of section on which I falls Input PREP	MB 2EL, number of section of end of B_1 B2 integration Øutput GETB	I, index of pt in Y considered Input PREP	JJJJ, flow index (JFLOW) Input Program Input	BB, B_1 or B_2 for $d(P_e/P_s)/dx$ calc. Øutput PREP	M, array of section I, D Input WIND or LEE
THET, array Input WIND or LEE	ISTOP, index of last pt in integration of Øutput PREP				

GETDS	Variable Input or Øutput Sources	XIW, X_o corres to XBW Input WIND or LEE	YIW, Y_o array corres to YBW Input WIND or LEE	XBW, X_b array Input WIND or LEE	YBW, Y_b array Input WIND or LEE
SBW, S_b array Input WIND or LEE	THETBW, array Input WIND or LEE	KKW, Section I D array Input WIND or LEE	ISØNW, number of sonic pt. in XBW Input WIND or LEE	INØW, number of entries in XBW Input WIND or LEE	ALPHAI, Input Program Input
RSORA, Input Prog Input or 1885A	RN, R_N Input Program Input	JFLØW, flow sential Input Program Input	DØY, 2D array of Input MAIN	RASDOY, array for DØY Input MAIN	EPDOY, array for DØY Input MAIN
IGØØF, if ≤ 0, calculation o k Øutput GETDS	DTDSW array Input WIND or LEE	DELS, , stag pt detachment Øutput GETDS	INDDUM, index of Øutput GETDS		

GETPRE

Variable	XNT, independant variable table	XNT1, dependent variable table	XNU, independent variable	PRES, dependent variable
Input or Output	Input	Input	Input	Input
Source	PREP	PREP	PREP	GETPRE

GETQRS

Variable	XBW, X_b array	YBW, Y_b array	THETBW,	RW, R_w at Y_T
Input or Output	Input	Input	Input	Input
Source	WIND or LEE	WIND or LEE	WIND or LEE	FINDRW

DELS, from stag pt	BSHOCK, B_s shock shape parameter	QRAD, QR array	STAND, array	THW O_w array	TIW I_w array	PREW P_e/P_s array
Input	Input	Output	Output	Input	Input	Input
GETDS	Program Input or FINDRW	GETQRS	GETQRS	Program Input or 1885A	Program Input or 1885A	PREP
TPR P_w/P_o array	TIB I_B array	XMMX, MM to compute QR	TRW array	PWS, P_S Input Program	INOW, No of points in XBW array	RC, R_C radius
Input	Input	Input	Input	Input	Input	Input
Program Input or 1885A	Program Input or 1885A	Program Input	Program Input or 1885A	Program Input or 1885A	WIND or LEE	Program Input
THWLIM, θ_{wLIMIT} smallest value of θ_w						
Input						
MAIN						

1885B SUBROUTINE DESCRIPTIONS

1. PREP

Purpose· To compute the pressure distribution and velocity gradient for the body.

Method· The pressure distribution is divided into two parts, one the area between stagnation point and sonic point, and two the area aft of the sonic point.

If there is no straight section before the sonic point, (see tests near Statement 1000), and if the ratio X/Y sonic point $\geq (1 - \sin(\theta_b^*))/\cos(\theta_b^*)$, then the forward pressure distribution is assumed Newtonian (DØ LØØP 1003). The velocity gradient is computed with JGØ = 1 by the correlation using the input tables DUTB, XSYST, and RARST. (Statements 1008 to 1021).

If there is no straignt section, but X/Y sonic point $< \frac{1 - \sin(\theta_b^*)}{\cos \theta_b^*}$, then the above velocity gradient is computed (1008 to 1021), but with JGØ = 2, which then uses du/ds to compute a polynomial distribution (Statements 1024 to 1026).

If a straight section exists before the sonic point, then a polynomial pressure distribution is computed,
if $\frac{d\theta}{dS} = 0$ at stagnation point; then du/ds is computed by the correlation at Statement 1007. Otherwise du/ds is computed as above.

After the distribution to the sonic point is computed (by Statement 1027) the DØ 1067 loop beginning after Statement 2008 computes all the following pressures. First, however, a table lookup is done to compute the pressure ration PMØPS, a function of γ_S. Statements 2000 to 2008 establish indexes used with the Prandtl-Meyer calculation. After the DØ1067 the Statements 3002 to 2013 are used to assure that the first pressure computed on Section 5 or a flatbased section 10 is done by Prandtl-Meyer. If the $d\theta/ds > 0$, for the current point, the pressure is computed by the Newtonian approximation (1028). If $d\theta/ds = 0$, $\theta < 0$, the pressure is constant (1031). If $d\theta/ds = 0$, $\theta \geq 0$, then a test is made (1032). If the previous pressure was $\leq$ PMØPS, the Entropy-Layer formulation is used (Statements 1033 to 3008). This involves the use of the ADAMS4 integration system to integrate the differential equation $d(P_e/Ps)/dx$. This derivative involves a constant BB, which itself is an integral from the stagnation point to the beginning of the straight section. Subroutine GETB computes this constant, and the quantity MB2EL assures that it is computed only once per straight section.

If $d\theta/ds = 0$, and the previous pressure was > PMØPS at Statement 1032, then constant pressure is assumed (Statement 1031).

If $d\theta/ds < 0$, a test is made at Statement 1040. If the previous pressure > PMØPS, Newtonian is assumed (1028). Otherwise, Prandtl-Meyer is assumed (Statements 1041 to 1064).

As each pressure PRE_i is computed, so is its derivative $DPØDS_i$. If the pressure ever becomes less then P_A/P_S (PAØPS), then the pressure is held constant at PAØPS (loop 1005) for the rest of the body.

2. QRCLER

Purpose: To set each entry of the arrays QRAD and STAND to zero before the calculation QR_i and XSI_i are initiated.

Method: DØ LØØP 1000.

3. QCØNV

Purpose: To compute the heating quantities QL_i, QT_i, and REY_i for each point on the body.

Method: The distributions QL_i, QT_i, and REY_i are computed by the DØ LØØP 1011. Between entry and the DØ 1011, all constants independent of the body are computed. The QL_i computed uses the term BETA (1004, 1003), involving the trapezoidal integration of the function $\rho_b u_e \gamma_i^{2j}$, and ξ (not related to the shock ξ). When the surface distance $S_{b_i} \leq 0.2\ S_{b,\,sonic}$, a limiting form of ξ and BETA is provided (Statements 1000 to 1001). If $S_{b_i} > 0.2\ S_{b,\,sonic}$, then the ξ and BETA are computed between 1001 and 1004, where the trapezoidal integration also is done. The QL_i, QT_i, and REY_i are computed between Statements 1002 and 1011.

4. GETTØT

Purpose: To perform table look-up using columns of the table of normal and oblique shock properties TABLE

Method: It was necessary to write GETTØT because two columns of independent variables on TABLE, θ_W (column 1) and PW/PO (column 7) are monotonically decreasing and thus not suitable for ARTLU. The maximum number of dependent variables is 4, when the subroutine is called by the MAIN program to compute "total" conditions. When it is called with fewer dependent variables of interest (e. g. by FINDRW, GETQRS), dummy variables are included.

5. WIND

Purpose: To compute the transformed body coordinates for the wind ward side at angle of attack, and include in these tables the coordinates of the sonic point.

Method: The DO LOOP 1012 first transforms the zero angle-of-attack coordinates by using the input values of α (ALPHI), and the XBRAL and YBRAL included in the zero angle-of-attack tables by STAGPT as the alpha = 0 coordinates of the stagnation point of the body at the current α. The difference in definition of x_b, y_b, θ_b done at the Statement 1002 reflects the fact that the windward side must go around the $\alpha = 0$ rearward point and back up the other ($\alpha = 0$) side. The table is considered complete whenever $|\theta_b| > 90$ (Statement 1010), or y_b passes through zero (1006). The statements between 1014 and 1029 compute the co-ordinate of the sonic point ($\theta_b = \theta_b{}^*$). If the sonic point falls on a straight section, it is defined to be the start of that section (1023). Otherwise an interpolation is done using $d\theta/ds$ of the section containing the sonic point (DO LOOP 1020), and the sonic point coordinates are computed at Statement 1026. The DO LOOP 1027 rearranges the x_b, y_b, etc., tables so that the sonic point co-ordinates fall in their proper sequence, with index = ISONW. Proper sequence is determined by the fact that the SBW table must be monotonically increasing.

6. LEE

Purpose: Same as WIND above, but for leeward side.

Method: Same as WIND above, except for co-ordinate definitions at Statements 1002 to 1005.

7. GETDS

Purpose: To compute the detachment distance of the bow wave normal to the body at the stagnation point.

Method: GETDS computes the detachment Δ_s by choosing among several correlations involving the density ratio ρ_A/ρ_s and body geometry.

If there are no straight sections between the stagnation point and the sonic point, and JFLOW = 0, then the Δ_s is computed from a simple algebraic evaluation involving $\cosh^{-1}$ (between Statements 1001 to 1008). For the purposes of $\cosh^{-1}$ only, if the inverse of the argument is ≥ 1, it is set to a limit 3/3.1.

If there were no straight sections and JFLØW > 0, then the Δ_s is computed from a correlation involving the tables RASDØY, EPDØY, and DØY. The table DØY is $\Delta_s/Y_T = f(\epsilon, \rho_A/\rho_s)$, Y_T here is defined as $y_b{}^*$ at the sonic point, ρ_A/ρ_s = RAØ RS, and ϵ = EPSLT = $x_b{}^*/y_b{}^*$ at the sonic point.

If there is a straight section before the sonic point, and JFLØW ≤ 0, the ΔS is computed from the function using $\cosh^{-1}$, but with the (DTDSMP) redefined between Statements 1020 and 1026. If JFLØW > 0 and $x_b{}^* \geq \Delta_{so}$, then the correlation from tables DØY, EPDØY, and RASDØY is performed with Y_T and ϵ = EPSLT redefined between Statements 1028 and 1032. If JFLØW > 0 and $x_b{}^* < \Delta_{so}$, DELS = $\Delta_{so} - x_b{}^*$ at Statement 1037.

The index INDDUM is either the index of the sonic point or the beginning of a straight section, depending on which point was used to determine Y_T.

8. GETQRS

Purpose: To compute the radiation QRAD and normal detachment distance STAND along the meridion.

Method: The detachment distance STAND_i and QRAD_i are computed in DØ LØØP 1010 by solving a quadratic which is a function of RW, the body coordinates and the shock parameter BSHOCK, between the DØ 1010 and Statement 1033. Given the distance and the pressure distribution, subroutine GETTØT is used to look up the intensities, first from the wave angle THWW and then from the local pressure PARG. Three dummies are used in each table, look up (see GETTØT). The QRAD_i is computed prior to 1010.

9. STAGPT

Purpose: To locate in the zero angle-of-attack co-ordinates the co-ordinates of the new stagnation point at $\alpha \neq 0$, and place this point in the tables.

Method: In the IF LØØP between 1030 and 1029, the program finds all points for which the local body angle $\theta_b + \alpha = 90$. It does this by seeking a change of sign in the residual. If the point is not identical to a point in the $\alpha = 0$ tables, $d\theta/ds$ is computed and the co-ordinates are interpolated (1022 to 1025). If the point is identical to a point in the $\alpha = 0$ table, this fact is noted (1026). If the point falls on a straight section, the new stagnation point is arbitrarily defined to be at the middle of the straight section (1003 to 1007).

For each candidate for the stagnation point, the quantity XBRAL is computed (1027). The point which maximizes this quantity is defined to be the stagnation point (1028 to 1029). The statements between 1033 and 1040 are used to define the arrays X1, Y1, etc., which contain the $\alpha = 0$ co-ordinates (X0, Y0, etc.) plus the stagnation point, whose index in X1, etc. is ISTAG. It is placed in the co-ordinate tables in such fashion that S1 is monotonically increasing.

10. GETB

Purpose: To compute the constants B1 or B2 used in computing the pressures by integrating the differential equation $d(P_e/P_s)/dx$

Method: GETB computes BB which involves an integral of the pressures and geometry between the stagnation point and the beginning of the straight section on which the ith (current) point lies. Since the integral is only to the start of the section, ISTØP, the index of the starting point in the x_b table, and MB2EL, the identification number of the straight section are computed in the DO 1003 loop. These quantities are used to guarantee that the calculation is done once for each straight section on which the entropy layer equations are used, and not once for each output point on the section. The integration is done trapezoidally in DØ LØØP 1008. The integrand depends on JJJJ, which is the flow index JFLOW. The argument BB in the calling sequence is the value of either B1 or B2, whichever is appropriate.

11. QRNMAD

Purpose: To normalize the array QRAD by QRADNM.

Method: If QRADNM is > 0, each entry in QRAD is divided by it in DØ LØØP 1002.

12. GETPRE

Purpose: Given a value of ν (XNU) and a ν table (XNT), to compute a corresponding Pressure (PRES) from the table XNT1.

Method: Linear interpolation in DØ LØØP 1002 and Statement 1003.

13. FINDRW

Purpose: To compute the bow wave radius RW, and the parameter BSHOCK by computing the detachment distance and wave angle (XSI2 and THETAW) at the body point whose index is INDDUM, and at the first point where $\theta_w \leq 0$.

Method: FINDRW computes the shock-shape parameters RW and BSHOCK by computing the shock angle and detachment distance at two points on the body, the first (IC0MP = 0) defined as the point on the geometry tables with index INDDUM, and the second (IC0MP = 1) being the most forward point with $\theta_b \leq 0$. The point indexed by INDDUM is either the sonic point or the start of a straight section if it occurs ahead of the sonic point and if $x_b^* \geq$ DELTST as defined by Statement 1003.

The method of iteration is to compute for a point on the body and a value of θ_w (initially set to θ_b) two values of detachment distance XSI1 and XSI2. When IC0MP = 0, XSI1 is obtained from Statement 1071, and when IC0MP > 0 from the (largest) positive root of a quadratic (Statements 1044 to 1047). XSI2 is always obtained from the (largest) positive root of the quadratic computed between 1052 and 1057. If the relative difference between XSI1 and XSI2 is $\leq 10^{-4}$, the computation has converged (after 1022). If it has not converged, then the value of THET = θ_w is modified until a change of sign in the residual indicates a near root (Statement 1026). At this time the $\Delta\theta_w$ is decreased and the successive approximations continued. If a successive redidual is larger in absolute value than the former value (divergence) the sign of $\Delta\theta_w$ is changed (1029). If this happens twice, then the residual has passed through a minimum without finding a root, and transfer is made to Statement 1041 which sets IG00F = 1 and prints the message CANN0T FIND THETA F0R RW 0R B, SKIP CASE. Control then is passed to the main program. If no solution is found in 600 iterations, IG00F is set to 1 and the return is executed (1034 et. seq.). After the first pass (IC0MP = 0) RW is computed and the reference geometry is changed to the most forward point at which $\theta_b \leq 0$ (Statements 1038 to 1070). After the second pass (IC0MP = 1), the shock shape parameter BSH0CK is computed (1070) and a normal RETURN is executed.

14. <u>GETNU</u>

Purpose: Given a value of pressure P0PT and a pressure table XNTI, to compute a corresponding ν from the table XNT.

Method: Linear interpolation in D0 L00P 1002 and statement 1003.

15. <u>AC0SH</u>

Purpose: To compute $\cosh^{-1}$ (ARG).

Method: Expansion in D0 L00P 1000 for ARG > 1.

16. DERQ5

Purpose: To compute the derivatives $d(P_e/P_s)/dx$ or $d\xi/dS_b$.

Method: $d(P_e/P_s)/dx$ is computed between 1002 and 1008 by using the current values of P_e/P_s (PRS), X (XIND), and data in CØMMØN storage computed by PREP. DERQ5 is called by the predictor-corrector routine ADAMS4.

17. SUB110

Purpose: To compute $\alpha = 0$ coordinates

Method: SUB110 computes $\alpha = 0$ body data in the large DØ LØØP 20. For each of 10 segments, the input array N (XN) contains a number. For each of the segments but 3 and 10 this should be of the form X where X is an integer giving the number of increments in the section. For the third section X. 1 is a cone, X. 2 is a tension shell, and X. 3 is a general shape (statement 50), X still being the number of increments. For Section 10 X. 1 is an aft sphere, and X. 2 is a flat base (statement 120). The index J1 counts the points, and the total number of points in each X0, Y0, etc. array is JOMAX. The appropriate equations for each section are determined by the computed GØTØ at statement 10, and if $XN_i = 0$, the i^{th} section is omitted. If the input sentinel IOTBL $\neq$ 1, the co-ordinates are printed out (statement 131).

18. ADAMS4

Purpose: To numerically integrate differential equations by a predictor-corrector method.

Method: See the writeup of ADAMS4 in the section special subroutines.

19. TABLES

Purpose: To define tables used in the computations.

Method: Each element of each table is set to the appropriate numerical value in an arithmetic statement.

20. HDPRNI

Purpose: To print identification material at the beginning of each case.

Method: The appropriate "WRITE" and "FORMAT" statements are used.

21. UNO8

Purpose: To define logical tape 8 as the binary input-output tape SYSUT5.

Method: UNO8 is a MAP subroutine containing the necessary FILE information.

E. 1885 A MAIN PROGRAM

Purpose: To acquire input for the oblique shock calculation and prepare a binary tape of shock data for Program 1885B.

Method: Having acquired the values of the input, control is passed to subroutine OBLIK which performs the shock calculation. If a binary tape is to be prepared for 1885B, the tape is rewound for a first case (XFIRST = 0, Statement 1001) and not rewound for successive cases until ILAST is input > 0 (Statement 1005).

F. 1885 B MAIN PROGRAM

Purpose: The purpose of the main program is to acquire tables and input used by the calculation, provide output, and control the order of the calculations of the heating and pressure distribution at each angle of attack for both leeward and windward sides.

Method: Common data, dimension statements, and definition of the Namelist array INPUT occur in the MAIN program before input is acquired. CALL TABLES provides the constant tables to be used by the program. Preset variables are then set, and the data read in through the Namelist array INPUT. The CALL SUB110 statement provides for the computation and subsequent output of the zero angle of attack coordinates.

The statements between CALL SUB110 and 1035 provide for oblique and normal shock data to be read from TAPE 38, if the input quantity TAPE (XTP) > O, implying that these data are to come from an 1885A calculation. After Statement 1035 pertinent gas properties are defined from these data taken at wave angle (θ_w) = 90 degrees.

In the statements preceding 1017, "total conditions", P_T, ρ_T, T_T, γ_e are defined at θ_w = 90 or by table look-up (CALL GETTØT) at θ_w = THETAT (THTØT), depending on the input TTØ. Before the DØ 10 statement further gas properties are defined, as is the Reynolds number normalization RYNØRM.

The DØ LØØP 10 extends to the end of the MAIN program, and controls as a monitor the sequence of calculations performed for each angle of attack. The first entry of the array ALPHA must be 0. The flow diagram (Section

A above) should be helpful, as the entire function of the MAIN program in this loop to control the logic. Since the leeward and windward sides of the vehicle at angle of attack are nearly independant of each other, there are virtually no significant equations in the loop.

When $\alpha = 0$ or 180, the body is symmetric and only one side need be computed. At $\alpha = 0$ it is the windward side, Statements 1018 to 1000, in which four normalizing factors are computed, QLSAO and DUDSAO for QL, QTNØRM for QT, and QRADNM for QRAD, if the radiation is to be computed (CØMQRD > 0 in the input).

When $\alpha = 180$, the same sequence is performed for the leeward side, Statements 1023 to 1001, using the previously computed normalization.

When $0 < \alpha < 180$, calculations are performed in the proper sequence first for the windward side and then for the leeward side, and all but the coordinates are computed between Statements 1026 and 1025. When both sides are computed two averages must be found, one a mean value of du/ds (DUDSD) between Statements 1026 and 1022, which assures continuity of heating at the stagnation point (common to windward and leeward sides), and the other is the detachment distance (DELS) from the stagnation point, which is computed between Statements 4002 and 1029.

There are several co-ordinate tables used. XO, YO, SO, DTDSO, THETAO, and M in CØMMØN are the zero angle-of-attack coordinates. The tables X1, Y1, S1, DTDS1, THETA1, and M1 are these tables plus one additional point, the stagnation point at the current value of α. The tables XBW, YBW, SBW, THETBW, and KKW are the body coordinates of the windward side after the translation and rotation implied by the angle of attack, and the tables X1W and Y1W are the $\alpha = 0$ coordinates from which the body coordinates were transformed. On the leeward side the tables are analagous to the above seven, except the letter "W" is replaced by "L".

For each side of the body, the sequence is as follows

1) Obtain the stagnation point coordinates in the $\alpha = 0$ reference by calling STAGPT (Statement 1009) if $\alpha \neq 0$, acquiring the tables X1, Y1, etc., and the index of the stagantion point ISTAG.

2) Obtain the windward (leeward) body coordinates by transforming X1, Y1, etc., to XBW (XBL), YBW (YBL), etc., by calling subroutine WIND (LEE). The first point in XBW (XBL) will be the stagnation point at the current α, and in addition the coordinate tables include the coordinates of the sonic point, whose index is ISØNW (ISØNL). There are INØW (INØL) entries in each of these tables.

3) Compute the pressure distribution and du/ds for the windward (leeward) side by calling PREP to obtain the array PREW (PREL), and the quantities DUDSW (DUDSL).

4) From this point the windward and leeward sides data are completely indepedent. CALL QC0NV provides for the computation of the heating data QLW, QTW, and REY. This is provided as output for the windward side, and when the leeward calculation is made the distributions are stored in the same arrays.

5) If C0MQRD in input is ≤ 0, go to Step 10.

6) If RW0, BSH0CT, DELT are input, SKIP to Step 9.

7) Obtain the detachment distance DELS from the stagnation point, which is provided by GETDS.

8) Obtain the shock detachment distance XSI2 and the shock angle THETAW from the point whose index is INDDUI from the windward side and INDDU2 from the Leeward side. This point is either the sonic point or the start of a straight section if there is such a section between the stagnation point and the sonic point. Also obtain the bow wave radius RW, and shock parameter BSH0CK, these quantities coming from the subroutine FINDRW.

9) Obtain the radiation heating (QRAD) and detachment distance (STAND), (Windward or leeward). This is done by subroutine GETQRS.

10) Provide the pressure and heating quantities as output for the windward and leeward side.

Most of the subroutines have as an argument the sentinal IG00F, which if >0 indicates that the computation is unsatisfactory and the next angle of attack is considered.

G. 1885A SIGNIFICANT EQUATIONS

1. Main

None.

2. PHIL

None.

3. ØBLIK

ρ_w/ρ_a = DENINV from iteration of IW $\geq$ INSTØP

$= (\mathrm{GAMI} + 1) + \mathrm{AM}^2 \cdot \sin^2\theta_w / \{(\mathrm{GAMI} - 1) \cdot \mathrm{AM}^2 \cdot \sin^2\theta_w + 2\}$

GAMI interpolated when IW $<$ INSTØP

$\rho_w U_w/\rho_a V$ = DENINV + UWØV ,

$\mathrm{UW\O V} = [\cos^2\theta_w + \mathrm{DENR}^2 \sin^2\theta_w]^{1/2}$, DENR = 1/DENINV

$$\theta_{WL} = \tan^{-1}\left\{\frac{[\sin\theta_w \cos\theta_w (1 - \mathrm{DENR})]}{[\cos^2\theta_w + \mathrm{DENR} \cdot \sin^2\theta_w]}\right\}$$

γ_w = (DENINV + 1.)/(DENINV − 1) if IW $\geq$ INSTØP

= GAMI , interpolated if IW $<$ INSTØP

T_w = T from HEAT2 iteration if IW $\geq$ INSTØP

= HWMRTZ · R · TO/XM if IW $<$ INSTØP , where HWMRTZ =

HMØRTZ $\{1 - V^2 \times 0.5\,[\mathrm{DENR}^2 \times \sin^2\theta_w + \cos^2\theta_w]/\mathrm{HH}\}$

HMØRTZ and HH from ambient condition (after 1001).

P_w/P_o = PRS = RHØR $\cdot\, V^2 \times \sin^2\theta_w (1 - \mathrm{DENR})/P_o + \mathrm{PA}/P_o$

HW/H = ENT $\cdot$ R $\cdot$ T_o /(XM HH) when ENT = f(DENR) if IW $\geq$ INSTØP

= HWMRTZ R T_o/(XM HH) if IW $<$ INSTØP

ρ_{ws}/ρ_a = DENINV$\cdot$ (PWSØPϕ/PRS)$^{(1/\mathrm{GAMW})}$

$$\mathrm{PWS\O P\O} = \mathrm{PRS}\left[\frac{1}{\left[1 - \frac{V^2}{2 * \mathrm{HH}}\left(\frac{U_w}{V}\right)^2\right]}\right]^{\frac{\mathrm{GAMW}}{\mathrm{GAMW}-1}} \quad \text{if IW} \geq \text{INSTØP}$$

$$\mathrm{PWS\O P\O} = \mathrm{PW\O PZ}\left[\frac{1}{\left[1 - \frac{V^2}{2 \cdot \mathrm{HH}}\left(\frac{U_w}{V}\right)^2\right]}\right]^{\frac{\mathrm{GAMI}}{\mathrm{GAMI}-1}} \quad \text{if IW} < \text{INSTØP}$$

P_{ws}/P_o = PWS0P0 , see above

TWS = T · HM0RTZ/ENT if IW $\geq$ INST0P

= T · HM0RTZ/HWM0RTZ if IW < INST0P

IW from HEAT2 = $\frac{2 \cdot \text{QSUM}}{\text{DEL}}$ evaluated at P = PRS and H = ENT if IW $\geq$ INSTOP

= 0 if IW < INST0P

IB from HEAT2 = $\frac{2 \cdot \text{QSUM}}{\text{DEL}}$ evaluated at P = PRS and

$$H = \text{ENTB} = \text{HM0RTZ}\ (\text{PRS/PWS0P0})^{[(\text{GAMMA} - 1)/\text{GAMMA})]}$$

PWS0P0 and GAMMA here evaluated only at $\theta_w = 90$

H. 1885B SIGNIFICANT EQUATIONS

1. MAIN

STATEMENT NUMBERS

$$\text{REYA} = \text{RYN0RM} = \frac{\text{RH0A}\ \ V \cdot 2 \cdot \text{RC}}{\text{XMUAAA}}\ ,\ \text{XMUAAA} = \mu|_{TA} \qquad 1017$$

$$\theta_b^* = \text{THEBST} = \text{ASIN}\left[\left(\frac{2}{\text{GAMS} + 1}\right)^{\frac{\text{GAMS}}{\text{GAMS} - 1}}\right] \qquad 1017$$

$$QL_s|_{\alpha=0} = \text{QLSAO} = \frac{0.76}{\text{SIGMA}^{0.6}} \cdot \left(\frac{\text{RH0BS} \cdot \text{XMUBBB}}{\text{RH0SS} \cdot \text{XMUSSS}}\right)^{0.1} (\text{RH0SS} \cdot \text{XMUSSS})^{0.5}$$

$$\cdot \frac{\text{HAMB}}{778.} \cdot (\text{DUDSAO})^{0.5} \cdot [1 + (\text{EL}^{\text{ALPQ}} - 1) \cdot \text{HDHS90}] \qquad 1018$$

$$\rho_{BS} = \text{RH0BS} = \frac{\text{PWS} \cdot \text{XMAMB}}{89516 \cdot \text{TB}}\ ,\ \mu_B = \text{XMUBBB} = \mu|_{TB}\ ,$$

$$\mu_s = \text{XMUSSS} = \mu|_{TWS}\ ,\ \left.\frac{du}{ds}\right|_{\alpha=0} = \text{DUDSAO},\ \text{HDHS90} = \left.\frac{H_D}{H_s}\right|_{\theta_w=90}$$

$$QT_s\Big|_{\alpha=0} = \text{QT (ISØNW)}\Big|_{\alpha=0} \qquad 2012$$

$$QRS\Big|_{\alpha=0} = \text{QRADNM} = \text{QRAD}(1)\Big|_{\alpha=0} \qquad 2014$$

$$\frac{du_\ell}{ds} = \text{DUDSD} = \frac{1}{2}\ \text{DUDSW} + \frac{1}{2}\ \text{DUDSL}\ , \qquad 1020$$

$$\frac{du}{ds}\bigg|_s = \text{DUDSD} = \frac{\overline{du}}{ds} \quad \text{if} \quad \begin{array}{c} \alpha - 90 - \theta_N < 0 \quad \text{and} \\ 180 + \theta_A - \alpha < 0 \end{array} \qquad 1020$$

$$\frac{du}{ds}\bigg|_s = \frac{1}{2}\ \frac{\overline{du}}{ds} + \frac{0.5 \sin\alpha}{\text{YIW}(1)} \left(\frac{3}{\text{RSØRA}}\right)^{1/2} , \quad \alpha \text{ otherwise than above} \qquad 1021$$

YIW(1) is $\alpha = 0$ value of y_o for the stag. pt. at the current α

2. PREP

$$P_e/P_s = \text{PRE(I)} = \sin^2(\theta_b)$$

$$\frac{dP_e/P_s}{dS} = \text{DPØDS(I)} = \text{PWS} \cdot \sin(2\theta_b)\ \frac{d\theta_b}{dS_b} \qquad \text{Newtonian, } S_b \le S_b^* \qquad 1003$$

$$C_1 = \text{CØED1} = \frac{\text{RHØA}\ \ V^2}{2\ \text{PWS}}\ \ \text{RSØRA} \cdot \ \ S_b^*\left(\frac{\text{DUDS}}{V}\right)^2$$

$$C_2 = \text{CØED2} = \text{Sin}^2(\theta_b{}^*) - 1 + \text{CØED1}$$

$$\frac{P_e}{P_s} = \text{PRE(I)} = 1 - \text{CØED1} \cdot \left(\frac{S_b}{S_b^*}\right)^2 + \text{CØED2} \cdot \left(\frac{S_b}{S_b^*}\right)^4 \quad \text{Polynomial, } S_b \le S_b^*$$

$$\frac{d(P_e/P_s)}{dS} = \text{DPØDS(I)} = -2 \cdot \text{CØED1} \cdot \text{PWS}\ \frac{S_b}{S_b^{*\,2}} \qquad 1026$$

$$+\ 4 \cdot \text{CØ ED2} \cdot \text{PWS} \cdot \frac{S_b^3}{S_b^{*4}}$$

$$P_e/P_s = \text{PRE}(I) = \sin^2(\theta_b) + \text{PAØPS} \cdot \cos^2(\theta_b)$$

Newtonian, $S_b > S_b^*$

$$\frac{d(P_e/P_s)}{dS} = \text{DPØDS}(I) = \text{PWS} \cdot \sin(2\theta_b)\frac{d\theta_b}{dS_b}$$

The entropy-layer pressure formulation is done by integrating a differential equation, Statement 3003. See DEREQB and GETB significant equations.

The Prandtl-Meyer pressures are obtained by two dimensional table look ups (GETNU and GETPRE subroutines) and the logic between Statements 1042 and 1066.

3. QCØNV

$$\text{QL}_1 = \text{QLW}(I) = \text{YBW}^{\text{JFLØW}} \cdot \text{RØB} \cdot \text{UED} \cdot \left[(1. + 0.096\sqrt{\text{BETA}}) / \sqrt{2 \cdot \text{XSI}}\right] \frac{\text{QLSW}}{\text{QLSAO}}$$

$$\cdot \frac{\text{XMUBBB}}{(\text{RHØBS} \cdot \text{XMUBBB} \cdot \text{DUDSW} \cdot (\text{JFLØW} + 1))^{1/2} \cdot 1.068} \qquad 1002$$

$$\rho_B = \text{RØB} = \text{PREW}(I) \cdot \frac{\text{XMAMB} \cdot \text{PWS}}{89516 \cdot \text{TB}}$$

$$U_e = \text{UED} = \text{DUDSW} \cdot \text{SBW}(I), \qquad S_b < S_1 \qquad 1000$$

$$= \left(1. - \text{PREW}(I)^{\frac{\text{GAME} - 1}{\text{GAME}}}\right) \sqrt{2 \cdot \text{HAMB}}, \quad S_b > S_1 \quad . \qquad 1001$$

$$\beta = \text{BETA} = 0.5, \qquad S_b < S_1 \qquad 1000$$

$$\beta = -\frac{2}{\text{XMUBBB}} \cdot \frac{\text{DPDSW}(I) \cdot \text{XSI}}{\text{RØE} \cdot \text{UED}^3 \cdot \text{RØB} \cdot Y_b^{2\text{JFLØW}}}, \quad S_b > S_i \quad \frac{d(P_e/P_s)}{dS} < 0 \qquad 1004$$

$$= 0 \qquad S_b > S_1, \quad \frac{d(P_e/P_s)}{dS} \geq 0 \qquad 1003$$

$$\xi = \mathrm{XSI} = \mathrm{RHØBS} \cdot \mathrm{XMUBBB} \cdot \mathrm{DUDSW} \cdot \frac{1}{2\,\mathrm{JFLØW}+2}\,, \quad S_b \leq S_1 \qquad 1000$$

$$= \mathrm{XSISUB} + \mathrm{XMUBBB} \cdot \int_{S_1}^{S_b} \mathrm{RØB} \cdot \mathrm{UED} \cdot Y_b^{2\mathrm{JFLØW}}\, dS \qquad 1001$$

where

$S_1 = S_b$ evaluated at second output point

XSISUB = ξ evaluated at largest SBW(I) $< S_2$

$\rho_e = \mathrm{RØE} = \mathrm{RHØT} \quad \mathrm{PREW(I)}^{1/\mathrm{GAME}}$

$\mathrm{REY}_1 = \mathrm{REW(I)} = \mathrm{RØE} \quad \mathrm{UED} \quad \mathrm{SBW(I)}/(\mathrm{XMUE} \cdot \mathrm{RYNØRM})$

$$\mathrm{XMUE} = \mu_{\mathrm{TE}}, \quad \mathrm{TE} = \mathrm{TT} \cdot \left(\mathrm{PREW(I)}^{\frac{\mathrm{GAME}-1}{\mathrm{GAME}}}\right)$$

$$\mathrm{QT}_i = \mathrm{QTW(I)} = 0.0296 \left(\frac{2^{0\ 2}(\mathrm{JFLØW})}{\mathrm{SIGMA}^{2/3}}\right) \cdot \mathrm{RSRE}^{0.8} \cdot \left(\frac{\mathrm{XMUST}}{\mathrm{XMUE}}\right)^{0.2} \quad \mathrm{REY}^{0.2}$$

$$\cdot \ \mathrm{RØE} * \mathrm{UED} \cdot \frac{\mathrm{HAMB}}{(1556 + \mathrm{QTSTAD})} \qquad 1006$$

$$\mathrm{RSRE} = \mathrm{TE}/\mathrm{TSTR}$$

$$\mathrm{TSTR} = \mathrm{TE} \quad \left[1 + \frac{1}{2}\left(\frac{\mathrm{TB}}{\mathrm{TE}} - 1\right) + 0.22 \cdot \mathrm{SIGMA}^{1/3} \quad \left(\frac{\mathrm{TT}}{\mathrm{TE}} - 1\right)\right]$$

4. WIND

$$y_b = \mathrm{YBW(I)} = (y_{o_1} - \mathrm{YBRAL}) \cdot \cos(\alpha) + (x_{o_1} - \mathrm{XBRA2}) \cdot \sin(\alpha), \quad x_{o_1} < x_{o_{\mathrm{largest}}}$$

$$= (-y_{o_1} - \mathrm{YBRAL}) \cdot \cos(\alpha) + (x_{o_1} - \mathrm{XBRAL}) \cdot \sin(\alpha), \text{ after } x_{o_1} = x_{o_{\mathrm{largest}}}$$

$$x_b = \mathrm{XBW(I)} = (x_{o_1} - \mathrm{XBRAL}) \cdot \cos(\alpha) - (y_{o_1} - \mathrm{YBRAL}) \cdot \sin(\alpha), \quad x_{o_1} < x_{o_{\mathrm{largest}}}$$

$$= (x_{o_1} - \mathrm{XBRAL}) \cdot \cos(\alpha) - (-y_{o_1} - \mathrm{YBRAL}) \cdot \sin(\alpha), \text{ after } x_{o_1} = x_{o_{\mathrm{largest}}}$$

XBRAL, YBRAL, SBRAL = values of x_o, y_o, and S_o for stagnation point of current α, in zero angle of attack system.

$$\theta_b = \text{THETBW(I)} = \theta_{o_1} + \alpha \qquad x_{o_1} < x_{o_{\text{largest}}}$$

$$= \alpha - \theta_{o_1} - 180, \qquad \text{after} \qquad x_{o_i} = x_{o_{\text{largest}}}$$

$$S_b = \text{SBW(I)} = S_{o_1} - \text{SBRAL} \qquad x_o < x_{o_{\text{largest}}}$$

$$= 2\, S_{o_{\text{largest}}} - \text{SBRAL} - S_{o_1} \qquad \text{after} \qquad x_{o_1} = x_{o_{\text{largest}}}$$

5. LEE

$$y_b = \text{YBL(I)} = (y_{o_1} - \text{YBRAL}) \cos(\alpha) + (x_{o_1} - \text{XBRAL}) \cdot \sin(\alpha), \qquad x_{o_1} > 0$$

$$= (-y_{o_1} - \text{YBRAL}) \cdot \cos(\alpha) + (x_{o_1} - \text{XBRAL}) \sin(\alpha) \qquad \text{after} \qquad x_{o_1} = 0$$

$$x_b = \text{XBL(I)} = (x_{o_i} - \text{XBRAL}) \cdot \cos(\alpha) - (y_{o_1} - \text{YBRAL}) \cdot \sin(\alpha) \qquad x_{o_1} > 0$$

$$= (x_{o_1} - \text{XBRAL}) \cdot \cos(\alpha) - (-y_{o_1} - \text{YBRAL}) \cdot \sin(\alpha) \qquad \text{after} \qquad x_{o_1} = 0$$

$$\theta_b = \text{THETBL(I)} = 180 \cdot - \theta_{o_1} - \alpha \qquad x_{o_1} > 0$$

$$= \theta_{o_1} - \alpha \qquad \text{after} \qquad x_{o_i} = 0$$

$$S_b = \text{SBL(I)} = \text{SBRAL} - S_{o_1} \qquad x_{o_1} > 0$$

$$= \text{SBRAL} + S_{o_1} \qquad \text{after} \qquad x_{o_1} = 0$$

6. GETDS

$$\text{DELS} = \text{RAØRS} \cdot \text{EF}$$

$$\text{EF} = \text{ACØSH} \frac{1}{\sqrt{3\ \text{RAØRS}}} \cdot - \text{DTDSMP} \cdot \frac{1}{\sqrt{1-3\ \text{RAØRS}}} \qquad 1007$$

$$\text{if} \quad \frac{d\theta_b}{dS_b} < 0, \quad 0 \leq S_b \leq S_b^*, \quad \text{and JFLOW} \leq 0$$

$$\text{DTDSMP} = 1/\left.\frac{d\theta_b}{ds_b}\right|_{\text{current stag point}}$$

IF $\frac{d\theta_b}{ds_b} = 0,\ 0 \le S_b \le S_b^*$, and JFLØW < 0, the equation is the same but

$$= -\text{RN} \text{ if } \alpha = 0, \qquad 1025$$

$$\text{DTDSMP} = -\frac{\text{Y1W(1)}}{\sin(\alpha)} \text{ if } \alpha \neq 0, \qquad 1026$$

where Y1W(1) is the y coordinate of the stagnation point for the current α in the zero angle of attack system

$$\text{DTDSMP} = 1/\left.\frac{d\theta_b}{dS_b}\right|_{\text{current stag point}} \text{ if } \left.\frac{d\theta_b}{dS_b}\right|_{\text{current stag point}} \neq 0 \qquad 1036$$

If JFLØW > 0, DELS is computed from a two dimensional table look up (1009 to 1018) for $\frac{\Delta s}{Y_T}(\epsilon, \rho_A/\rho_s)$, where Y_T and ϵ are either referenced to the sonic point (1008) or the beginning of a straight section if there is such a section in $0 \le S_b \le S_b^*$ (1028 to 1031, if $X_b^* \ge \Delta_{so}$. If $X_b^* < \Delta_{so}$, DELS = $\Delta_{so} - X_b^*$ at 1037.

7. GETQRS

If $\theta_w = 90$, ξ = STAND (I) =

$$\text{XBW (I)} - \left\{\frac{-\text{RW} + \text{SQRTF}(\text{RW}^2 + \text{BSHØCK YBW (I)}^2}{\text{BSHØCK}} - \text{DELS}\right\} \qquad 1036$$

If $\theta_w \neq 90$, compute Y_w = YW = pos root of the quadratic given by

$$A = 1 - \text{BSHØCK TANN}^2$$

$$B = 2\,\text{RW} \cdot \text{TANN} + 2\ \text{BSHØCK DM TANN} + 2 \cdot \text{BSHØCK YBW (I) TANN}^2$$

$$C = 2\,\text{RW}\ \{\text{DM} + \text{YBW (I)} \cdot \text{TANN}\} - \text{BSHØCK} \cdot \text{DM}^2 - \text{BSHØCK YBW(I)}^2\ \text{TANN}^2$$

$$- 2 \cdot \text{BSHØCK} \cdot \text{DM YBW (I)} \cdot \text{TANN}$$

where,

$\text{TANN} = \tan(\theta_{w_1}), \ \text{DM} = \text{XBW(I)} - \text{DELS}$ 1040-1003

$\text{SSS} = \text{STAND (I)} = \dfrac{[\text{YW} - \text{YBW (I)}]}{\cos(\text{THWT})}$ if $\text{BSHØCK} \leq 0$ 1025

$$\text{SSS} = \text{STAND (I)} = \frac{\text{AINT} + \text{ARGUI} \cdot \text{DM} - \text{YBW (I)}}{\cos(\text{THWT}) + \text{ARGUI} \cdot \sin(\text{THWT})} \quad \text{if BSHØCK} > 0$$

where,

$$\text{AINT} = \text{YBW}(\text{I}-1) + \text{STAND}(\text{I}-1) \cdot \cos(\text{THETBW}(\text{I}-1) - \text{ARGUI}\,[\text{XBW}(\text{I}-1) - \text{STAND}(\text{I}-1) \cdot \sin(\text{THET BW}(\text{I}-1) + \text{DELS}]$$

$$\text{ARGUI} = \text{SQRTF (BSHØCK)}$$

$$\theta_w = \text{THWW} = \tan^{-1} \frac{2 \cdot \text{RW} + 2 \cdot \text{BSHØCK} \cdot [\text{DM} - (\text{YW} - \text{YBW(I)}) \cdot \text{TANN}}{2 \cdot \text{YW}}$$

$$\text{P} = \text{PARG} = \text{PREW (I)} \cdot \frac{\text{PWS}}{2116} \quad \cdot$$

$$\text{QRAD}_1 = \text{QRAD (I)} = \frac{1}{2} \ \text{STAND (I)} \ \frac{\text{XMMX}}{\text{XMMX}+1} \cdot \text{XINB} + \frac{1}{\text{XMMX}} \cdot \text{XINW}$$

$\text{XINB} = \text{table}\,(1, 12) \mid \theta_w = \text{THT}, \ \text{XINW} = \text{table}\,(1, 13) \mid p = \text{PARG},$

independent variable tables being TABLE (1, 1) and (1, 7), respectively.

8. STAGPT

$\text{XBRAL} = \text{YBR} \cdot \sin(\alpha) - \text{XBR} \cdot \cos(\alpha),$ 1027

XBR, YBR are x and y co-ordinates in the zero angle of attack system of a point where $\theta_b + \alpha = 90$. The stagnation point is that which maximizes XBRAL, and the candidates are found by the IF LØØP from 1030 to 1008.

9. GETB

$$BB = (GAMS - 1) \cdot (PRCØN)^{\frac{(1 - GAMS)}{GAMS}} \cdot XINT$$

$$PRCØN = \frac{P_e}{P_s} \quad \text{at start of straight section}$$

$$XINT = \int_o^{y_{ss}} PRE \; dy_b \; , \; y_{ss} = y_b \; \text{at start of straight section, JFLØW} \leq 0$$

$$XINT = \int_o^{y_{ss}} PRE \cdot y_b \, dy_b \; , \text{JFLOW} > 0.$$

10. FINDRW

ξ_2 = XSI2 = largest root of $C_1 \xi^2 + C_2 \xi + \phi = 0$, If J FLØW > 0 1014

where

$$C_1 = 2 \cdot TBR \left[.5 \cdot REØRA \cdot UEØV + \frac{1}{XNNX + 2} \cdot TERM \right] - 2 \cdot YB \cdot TBR$$

TBR = cos (TB), TB = θ_b = body angle

$$\rho_e / \rho_a = REØRA = RSØRA \cdot PREW\,(I)^{\left(\frac{1}{GAMS}\right)}$$

$$U_e / V = \left\{ \frac{2 \cdot HAMB}{V^2} \left[1 - PREW\,(I)^{\frac{(GAMS - 1)}{GAMS}} \right] \right\}^{1/2}$$

TERM = RURV · CØSF (TWL – TB) – REØRA · UEØV

TWL and RURV = θ_{wL} and ρ_U/ρ_{aV} evaluated from oblique data at θ_w = THET

YB = body y

$$\xi_2 = \text{XSI2} = (\text{If J FLØW} \le 0)\ \text{YB}/\left[\text{REØRA} \cdot \text{UEØV} + \frac{1}{\text{XNNX} + 1} \quad \text{TERM} - \text{TBR}\right]$$

For the forward point, (ICØMP = 0)

$$\frac{\xi_1 = \text{XSI1} = [(\text{XB} + \text{DELS}) \cos(\text{THETR}) - \text{YB} \cdot (1 - \sin(\text{THETR}))]}{\text{TBR} - \sin(\text{THET} - \text{TB})} \qquad 1071$$

where

THETR = θ_w of iteration, XB = body X - coordinate, DELS = detachment distance

$$\text{RW} = [\text{XSI2} \cdot \text{TBR} + \text{YB}] / \cos(\text{THETAW}),\ \text{THETAW} = \text{converged } \theta_w \qquad 1066$$

For the most forward point with $\theta_b \le 0$ (ICØMP = 1)

$$\xi_1 = \text{XSI1} = \text{largest root of } A\xi^2 + B\xi + C$$

$$A = 1/(\text{XB} + \text{DELS})$$

$$B = 2 \cdot \text{YB} \cdot A - \tan(\text{THETR})$$

$$C = \text{YB}^2 \cdot A - \text{RW} - \text{YB} \cdot \tan(\text{THETR})$$

$$\text{BSHØCK} = [(\text{YB} + \text{XSI2}) \cdot \text{TANTR} - \text{RW}]/(\text{XB} + \text{DELS}),\ \text{TANTR} = \tan(\text{THETR}),$$

$$\text{THETR} = \text{converged } \theta_w .$$

11. ACØSH

$$\text{ACOSH}(\text{ARG}) = \ln(2 \cdot \text{ARG}) - \frac{1}{2} \cdot \frac{1}{2\,\text{ARG}^2} - \frac{1}{2} \cdot \frac{3}{4} \cdot \frac{1}{4\,\text{ARG}^4} - \cdots$$

12. DERQ5

$$\frac{d(P_e/P_S)}{dx} = \tan\theta_b - \sqrt{\frac{P_e/P_S - P_A/P_S}{1 - P_e/P_S - P_A/P_S}}, \qquad 1006$$

P_A/P_S = PA0PS P_e/P_S = XEQ(1)

JFL0W > 0.

$$\frac{d\,(P_e/P_S)}{dx} = \frac{\text{GAMS}}{\text{BB}} \cdot \left(\frac{P_e}{P_S}\right)^{\frac{\text{GAMS}+1}{\text{GAMS}}} \cdot \text{XTERM}$$

$$\text{XTERM} = y_{ss} \cdot \tan\theta_b + \tan^2\theta_b\,(x - x_{ss}) - \sqrt{\text{ARG}}$$

$$\text{ARG} = \left[\frac{P_e/P_S - P_A/P_S}{1 - P_e/P_S - P_A/P_S}\right]\left[2 \cdot \text{BB} \cdot \left(\frac{P_e}{P_S}\right)^{-\frac{1}{\text{GAMS}}} + \left(y_{ss} + \tan\theta_b\,(x - x_{ss})\right)^2\right]$$

x_{ss}, y_{ss}, θ_b : x_b, y_b, θ_b at start of straight section, x = independent variable.

13. SUB110

The zero angle of attack co-ordinate equations are obvious by inspection, and have been documented in Program 1882.

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PROGRAM 1886

PRELIMINARY STRUCTURES WEIGHT PROGRAM (1886)

CONTENTS

ILLUSTRATIONS

TABLES

I. INTRODUCTION

A. GENERAL DESCRIPTION

The purpose of this program is to determine the unit area structural weight requirements for shells to resist the critical aerodynamic loads incurred during entry. The general inputs include:

1. The aerodynamic load in terms of the peak pressure which may occur on each section of the vehicle.

2. The mechanical properties of the material, including modulus of elasticity, yield stress, Poisson's ratio, and density.

3. Geometric parameters describing the size and shape of the elemental sections, including spherical caps, conical frustra, cylinders, and the tension shell.

4. The following types of construction can be handled by the program:

   a. Cylinders and conical frustra-honeycomb or ring stiffened.

   b. Spherical caps--honeycomb or monocoque

   c. Tension shell--monocoque

5. The program treats the case of a hot structure, using the thin skin assumption, for which the convective and radiative heating tables and a stagnation enthalpy table are required as input. Additional material properties must be specified for this case, including the specific heat, and emissivity. The variation of material properties with temperature is handled by input values. The program will obtain the unit area weight necessary to resist the combined aerodynamic and thermal loads.

6. The design criteria utilized include buckling and/or yield stress criteria, and allowable temperature rise.

B. CALCULATION MODEL

1. Honeycomb Sandwich

The calculation model for the honeycomb analysis is described in detail in Reference 1, and hence only a brief summary is given here. The analyses considered five modes of failure: (1) general instability; (2) yielding of face sheets, (3) core crushing; (4) dimpling of face sheets; and (5) wrinkling.

Since little test data and theoretical analysis are available on the buckling of sandwich spherical caps, derivation of the general instability criteria was limited to transformation of isotropic buckling data $^{2-4}$ to sandwich shells; the data was correlated as shown in Figure 1. Transformation of these data employed the use of equivalent bending and extensional rigidity moduli for sandwich shells. The equivalent extensional (B) and bending (D) rigidities have the form:

$$B = \frac{2\,E_f t_f}{(1 - \nu_f^2)}$$

$$D = \frac{E_f t_f t_c^2}{2\,(1 - \nu_f^2)}$$

where E_f, ν_f and t_f are the modulus of elasticity, Poisson ratio and thickness of the face sheets and t_c is the core height. The experimental data for the buckling of homogeneous spherical shells was taken from References 2, 3, and 4. The spherical cap geometry is depicted in Figure 2.

The conical and cylindrical sandwich analyses were based on the approach of Reference 5 utilizing the equivalent rigidities discussed above. The conical shell geometry used is depicted in Figure 3.

The honeycomb calculated provides an optimum face sheet, and core height to resist buckling with minimum weight. The optimum values to prevent buckling are compared with those required for the yield or minimum gauge criteria, then the honeycomb sandwich is re-analyzed with the heavier face sheets and the results given for the core height and total unit weight.

The calculation model allows for the combined interaction of lateral pressure and axial loads. The effects of body forces due to the deceleration experienced during entry, for example, are also included in the calculation model. The body forces due to the heat shield are included. The inclusion of the body forces results in an iterative solution as the effect depends on the structural weight which is, of course, unknown initially. Besides the buckling criteria of Reference 5, the meridional (σ_ξ) and circumferential (σ_θ) stresses are incorporated into an elastic yield criteria, wherein the allowable stress is given by

$$\sigma_y = \sqrt{\sigma_\theta^2 + \sigma_\xi^2 - \sigma_\theta\,\sigma_\xi} \quad .$$

In the case of forward facing cones, it is possible that the maximum stress will not be at the base of the cone due to the body forces; hence, the resultant stress (σ_y) is tested over the whole length of the cone to ascertain its maximum value.

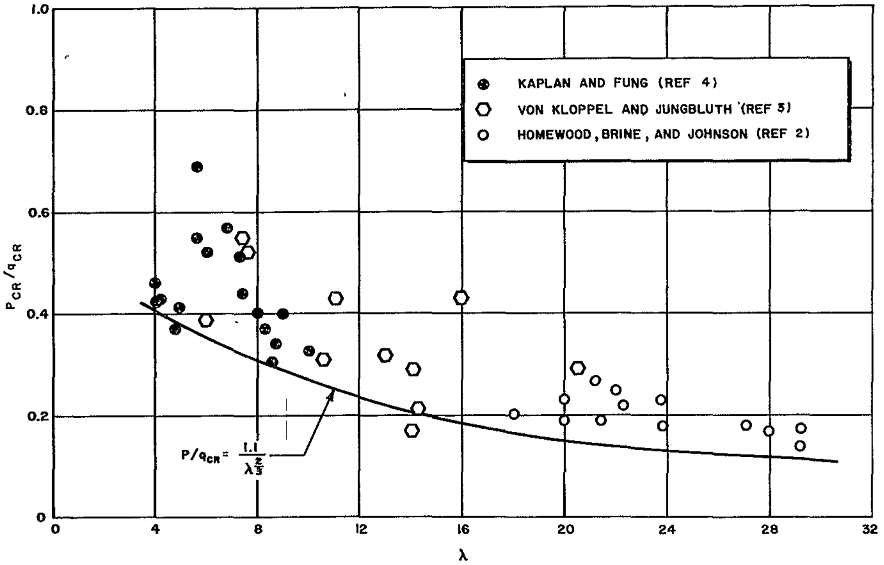

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Figure 1 EXPERIMENTAL BUCKLING OF SPHERICAL SHELLS

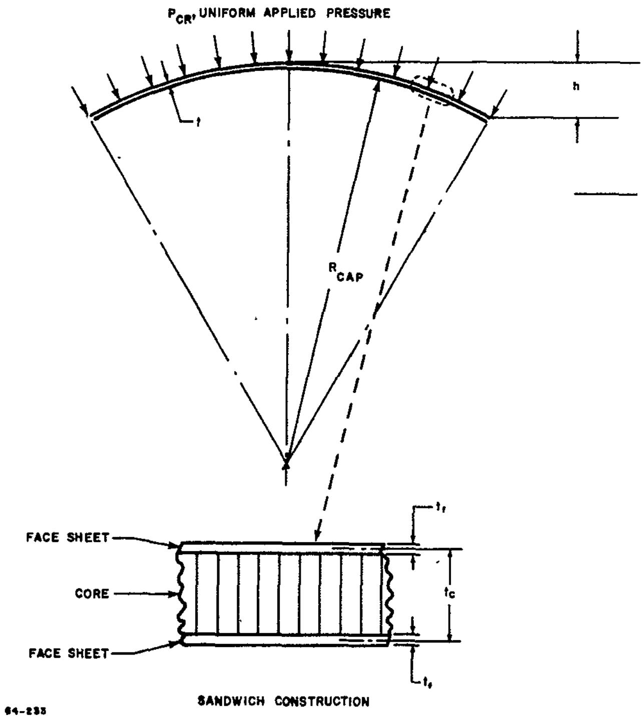

Figure 2 SPHERICAL CAP GEOMETRY

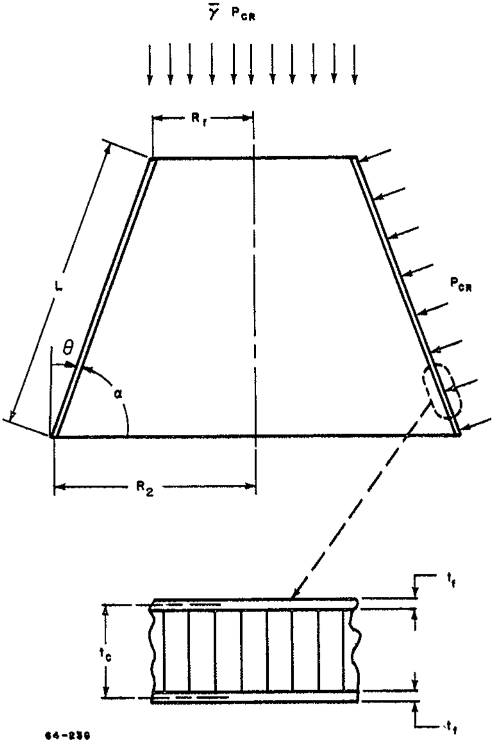

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Figure 3 CONICAL SANDWICH SHELL GEOMETRY

2. Ring-Stiffened

The calculation model for the ring-stiffened analysis is that suggested in Reference 5. The method of solution is based on an application of the principle of minimum potential energy of an equivalent orthotropic shell, utilizing a set of displacement relationships to describe the deflected shape.[5] The range of application of shell geometries is approximately given by,

$$10^2 < 2\left(\frac{L}{R_2}\right)^2 \frac{\cos\theta}{\left(1+\frac{R_1}{R_2}\right)} \frac{R_2}{t} < 10^4$$

where (L) is the slant length, (R_1) and (R_2) are the minimum and maximum radii, (t) is the shell thickness, and (θ) is the cone angle of the shell section.

A particular stiffener geometry, that of a (Z) section as shown in Figure 4, is fixed in the program. The effective width of the stiffener is controlled by input, as well as the proportions of the stiffener.

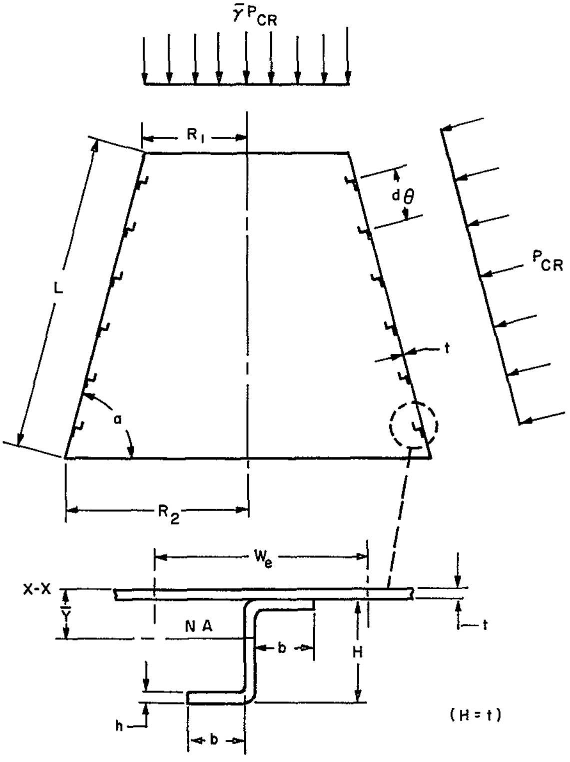
The solution is programmed so as to satisfy local and overall stability and to solve for the number of rings which minimize the total shell weight. Tests are provided to ensure minimum gauge and yeild criteria are satisfied.

The program provides for the option of either specifying the stiffener height and satisfying both local (inter-bay) and general stability, which in general will require different shell thicknesses or the program can solve for the stiffener height which yields equal shell thickness requirements for local and general stability. The calculation model assumes that the stiffeners have the same thickness as the shell. The spacing between stiffeners is limited to a value not smaller than the effective width.

The calculation model provides for lateral pressure and axial loads as well as for body forces. The body forces include those due to the structure as well as those arising due to a heat shield attached to the structure. The inclusion of the body forces results in an iterative solution as the body force depends on the structural weight which is unknown initially.

The method of solution starts by considering a shell without rings and satisfying the buckling, yield stress and miniumum gage limitations. If the minimum gage and/or yield stress limits are not excluded then rings are added in a sequence controlled by input, i.e., rings may be added one at a time or in a progressive manner given by the expression

$$N_K = N_J\,(NFAC) + NTERM$$



64- 887

Figure 4 RING STIFFENED CONE GEOMETRY

where NFAC and NTERM are program input integers. Each ring configuration solution is tested against the limits on minimum gage and/or yield stress and if either of these two conditions are excluded, the calculation stops, with the last weight being evaluated on the largest of the thickness requirements.

The yield stress criteria is based on the combined criteria wherein the maximum stress is given by

$$\sigma_y = \sqrt{\sigma_\xi^2 + \sigma_\theta^2 - \sigma_\theta \, \sigma_\xi} \quad .$$

In the case of forward facing cones, it is possible that the maximum stress will not be at the base of the cone due to the body forces, hence, the resultant stress (σ_y) is tested over the whole length of the cone to ascertain its maximum value.

3. Tension Shell

The calculation model for the tension shell utilizes the membrane equations to determine the stress distribution in the shell, as done in Reference 6. The calculation model assumes that the vehicle mass all exists forward of the tension shell. Two options are provided, one being the case of a Newtonian pressure distribution and zero hoop stress and the second being the more general case wherein the coordinates are input, and the hoop tension is taken as a fraction of the meridional tension, i.e., $N_\theta = aN_\phi$.

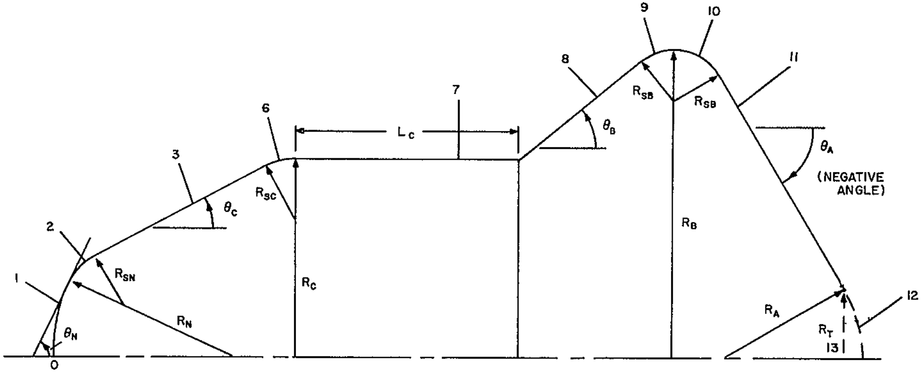
Along with the tension shell analysis, the compression ring weight is evaluated using the criteria of lateral stability as derived in Reference 7, and that of buckling of a long cylinder in compression as suggested in Reference 8. A circular cross section is used to estimate the compression ring weight.

4. Monocoque

An option is provided to compute the weight of spherical caps of monocoque construction. The approach is empirical, utilizing the buckling data correlated in Figure 1 and the shell model in Figure 2. General instability and yielding modes of failure are considered, and the resulting shell thickness is compared with practical minimum gage limitations.

5. Geometry

The overall vehicle geometry for which the program is intended is shown in Figures 5 and 6. The toroidal sections defined by RSN, RSC, and RSB cannot be handled with the program; however, these parameters are required as input to define the fore and aft radii of each conical section. The tension shell geometry considered is shown in Figure 6 wherein the tension shell replaces Section 23, as shown in Figure 5.



SECTION	
1	NOSE SPHERE
2	R_{SN} TORUS
3	CONE (SEE FIGURE 6 FOR ADDITIONAL OPTIONS)
6	R_{SC} TORUS
7	CYLINDER
8	FLARE
9	FORE R_{SB} TORUS
10	AFT R_{SB} TORUS
11	AFT CONE
12	AFT SPHERE (R_A)
13	BASE (R_T)

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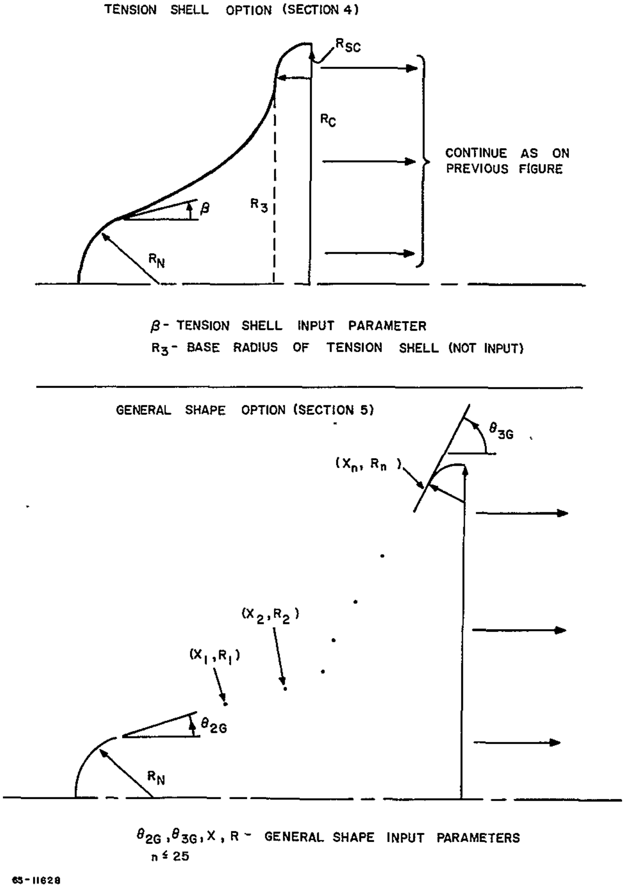
Figure 5 VEHICLE SHAPE PARAMETERS



β - TENSION SHELL INPUT PARAMETER

R_3 - BASE RADIUS OF TENSION SHELL (NOT INPUT)

$\theta_{2G}, \theta_{3G}, X, R$ - GENERAL SHAPE INPUT PARAMETERS

$n \leq 25$

Figure 6 TENSION SHELL AND GENERAL SHAPE PARAMETERS

6. Body Forces

The calculation model provides for the inclusion of body forces resulting from the structure and the heat shield during entry.

The formulation of the sandwich buckling analysis for cones can handle a limited range of body forces when the body forces cause a tensile stress. The limitations are due to the fact that K_1 and K_2 must be greater than zero as the equations are formulated. The limits take the form

$$\frac{(WHS + W)G}{144 P_{CR} \sin\theta} < 1 + \frac{\bar{\gamma}(1 - \beta)^2}{\beta(1 - \beta + \beta/3 + \beta/2\pi)^2} .$$

$$\frac{(WHS + W) G \sin\theta}{144 P_{CR}} < 1$$

In general, these limits are automatically fulfilled for entry vehicles where the fore body pressures are sufficiently large to decelerate the payload internal structure and afterbody as well as the heat shield and structure of the forebody.

7. Hot Structures

The option to compute the temperature rise for a specified heat pulse is contained within the program. Both the convective and radiation heat pulses may be input. Provision is made to account for the hot wall reduction on the convective heating and for reradiation. The structure is assumed to be at a uniform temperature equal to the surface temperature. In the event the structure temperature rise exceeds the allowable input value, the structural weight is increased. The material properties are treated as a function of temperature.

C. LIMITATIONS

The following basic limitations exist in the program:

1. The effects of bending and edge conditions are not treated.

2. The sandwich core is assumed rigid so that transverse shear deformation has a negligible influence on the buckling load; consequently the results would not be valid for a weak core.

3. The sandwich construction must have equal face sheet thicknesses.

4. Axisymmetric loading is assumed.

II. USAGE

A. INPUT DEFINITIONS

Name	Preset Values	Symbol	Parameter	Units
A	0.	a	Ratio of Circumferential to meridional stress for tension shell.	--
BETA	0.	β	Leading edge angle for tension shell.	degrees
CASE	0.		Identification number of the form XX.XX.	
CBAR	1.		An empirical factor which modifies the value of used in the calculation model for combined loadings.	
CPTAB	0.	C_p	Specific heat table.	Btu/lb-°F
DATE	4.01		Identification number of the form XX.XX.	--
DELKI	0.		Additive term in calculation of K_1.	$in.^3$
DELK2	0.		Additive term in calculation of K_2.	inches
DELTAU	0.1		Time increment used for integration of temperature rise equation.	seconds
DTHDY	0.	$d\theta/dY$	Derivative of body angle with radial coordinates for general shape.	rad/ft
EF	0.	E_f	Modulus of elasticity for honeycomb face sheets and monocoque skin.	$lb/in.^2$
EFTAB	0.	E_f	Face sheet modulus table.	$lb/in.^2$

Name	Preset Values	Symbol	Parameter	Units
EM	0.	m	Effective width factor.	--
EN	0.	n	Stiffener proportionality factor.	--
EMISTR	0.	ϵ	Emissivity of structure.	--
EPS	0.01		Thickness iteration factor.	
ER	0.	E_R	Modulus of elasticity for compression ring.	lb/in.^{2}
GAMF	0.	ν_f	Poisson ratio for honeycomb face sheets and monocoque skin.	--
G	0.		Deceleration.	Earth g
GAMR	0.	ν_R	Poisson's ratio for core ribbon.	--
GAMBAR	0.	$\bar{\gamma}$	Axial load factor.	--
GFTAB	0.	ν_f	Face sheet Poisson's ratio table.	--
GRTAB	0.	ν_r	Ribbon Poisson's ratio table.	--
HS	0.	H	Height of stiffener.	inches
HTBL	0.	HM/RT_o	Stagnation enthalpy table.	--
HTST	0.		Hot-structure option sentinel.	--
HTØP	1.		Stiffener optimization sentinel.	--
KADHES	0.	K	Honeycomb adhesive weight.	lb/ft^2
LC	0.	LC	Cylinder length.	feet

Name	Preset Values	Symbol	Parameter	Units
MEM0	0.		Identification number of of the form XX. XX.	--
M0N	0.		Monocoque option sentinel.	--
NFAC	2.		Constants which specify ring frequency.	--
NTERM	0.		($N_K = N_j$ NFAC + NTERM)	--
PCR	0.	P_{CR}	Aerodynamic pressure.	lb/in.^{2}
QCMULT	0.		Convective heat pulse multiplier.	--
QRMULT	0.		Radiative heat pulse multiplier.	--
QTBL	0.	q_c	Convective heating table.	Btu/ft^{2}sec
RA	0.	R_A	Aft Cap radius.	feet
RB	0.	R_B	Base radius.	feet
RC	0.	R_C	Cylinder radius.	feet
RN	0.	R_N	Nose Cap radius.	feet
R0CMAX	0.	ρ_{max}	Maximum core density.	lb/ft^3
R0CMIN	0.	ρ_{min}	Minimum core density.	lb/ft^3
R0F	0.	ρ_f	Density of honeycomb face sheet and monocoque skin.	lb/ft^3
R0R	0.	ρ_R	Density of core ribbon.	lb/ft^3
R0RG	0.	ρ_g	Density of compression ring skin.	lb/ft^3
RSB	0.		Shoulder radius.	--

Name	Preset Values	Symbol	Parameter	Units
RSC	0.	R_{SC}	Shoulder radius.	feet
RSD	0.		Ring-stiffened option sentinel.	--
RSN	0.	R_{SN}	Shoulder radius	feet
RT	0.	R_T	Truncation radius at base.	feet
RTBL	0.		Radiative heating table.	Btu/ft^{2}sec
SECTN	0.		Ordered array of section numbers.	
SGFTAB	0.	σ_f	Face-sheet yield stress table.	lbs/in.^{2}
SGRTAB	0.	σ_r	Ribbon yield stress table.	lb/in.^{2}
SIGCYF	0.	σ_f	Yield stress of honeycomb face sheet.	lb/in.^{2}
SIGCYR	0.	σ_r	Yield stress of core ribbons.	lb/in.^{2}
SIGRG	0.	σ_g	Yield stress of compression ring skin.	lb/in.^{2}
TCMAX	0.	$t_{c_{max.}}$	Maximum core thickness.	inches
TCMIN	0.	$t_{c_{min}}$	Minimum core thickness.	inches
TEMPA	0.		Maximum allowable structural temperature.	°F
TEMPI	0.		Initial structural temperature.	°F

Name	Preset Values	Symbol	Parameter	Units
TFMIN	0. 01	$t_{f_{min}}$	Minimum honeycomb face sheet and monocoque skin thickness.	inches
THA	0.	θ_A	Afterbody cone angle.	degrees
THB	0.	θ_B	Flare angle.	degrees
THC	0.	θ_C	Forebody cone angle.	degrees
THN	0.	θ_N	Nosecap angle.	degrees
TH2G	0.	θ_{2G}	Initial angle for general tension shell.	degrees
TH3G	0.	θ_{3G}	Final angle for general tension shell.	degrees
TIME	0.		Time.	seconds
TINIT	0.		Initial temperature at which structural properties are selected.	°F
TSTØP	0.		Maximum thermal design time during which $T_W \leq T_{W\,max}$	°F
TTAB	0.	t	Temperature table.	°F
WHS	0.		Unit heat shield weight.	lb/ft^2
XA, XN, XC, XØ	0.		Mole fractions of argon, nitrogen, carbon dioxide, and oxygen in the atmosphere.	--
X, R	0.	X, R	Coordinates for general shell.	feet

B. INPUT PROCEDURES

1. General

a. Decimal points may be used on all numerical input data, although they are not necessary on integer values.

b. RC must always be specified.

c. If RB is not specified, then RB=RC.

d. Contour angles (θ) are measured relative to free stream and a positive value indicates an increasing body radius whereas a negative value indicates a decreasing body radius.

e. If several cases are run on a single memo, only changed inputs need be specified following the first case.

f. Input QTBL, HTBL, and RTBL as a function of TIME. For each value of TIME input there must be corresponding values of QTBL, HTBL, and RTBL (maximum of 150 values in each table). In stacking cases, it is necessary to add at least one 0. value at the end of the TIME table if the number of entries is decreased. This 0. value is used internally as an indication of the end of the table.

2. Shell Geometry

The section numbers and section parameters are identical to those of Programs 1881, 1882, and so forth. Although tori cannot be handled by the program, the tori parameters are nevertheless required in many cases to compute the fore and aft section radii.

SECTIØNS

The vehicle sections are specified by an ordered list of numbers which identify them and place them in the desired sequence. The number list is given below, and the corresponding sections are further described by Figures 5 and 6.

Number	Section	Input Required
1.	NOSE SPHERE	RN, THN
2.	TORUS	RSN
3.	CONE	THC
4.	TENSION SHELL	BETA
5.	GENERAL SHAPE	TH2G, TH3G, X, R
6.	TORUS	RSC, RC
7.	CYLINDER	LC
8.	FLARE	THB
9.	TORUS	RSB, RB
10.	TORUS	RSB
11.	AFTCØNE	THA
12.	AFTSPHERE	RA
13.	BASE	RT

3. Construction Options

a. Monocoque analysis for the spherical cap for flat base is used when the option sentinel MØN = 1 is specified.

b. Ring-stiffened analysis for the conical and cylindrical sections is used when the option sentinel RSD = 1 is specified.

c. The hot structure analysis is utilized when the option sentinel HTST = 1 is specified.

d. The program will use honeycomb if and only if, no option sentinels are specified.

e. Ring depth optimized if HTØP = 2.0.

4. Design Factors

a. Conical Shell Buckling

The calculation model for an unstiffened cylinder under external pressure reduces to the expression

$$PCR = \frac{0.92\, E_f\, t_f^{5/2}}{R_c^{3/2}\, L_c} = (P_e)$$ Reference 9

which agrees precisely with equation (3) of Reference 9. The data summary given in Reference 9 indicates that the theoretical critical pressure is too large, and should be reduced, and a design factor of (0.8) is reasonable. Calculations using Program 1886 for cones under hydrostatic pressure are summarized:

$\beta = 1 - \frac{R_1}{R_2}$	P_{cr}/P_e θ_c = 30 degrees	P_{cr}/P_e θ_c = 60
0.1	0.99	0.97
0.3	1.00	0.98
0.5	1.05	1.02
0.7	1.12	1.08
0.8	1.20	1.14
0.9	1.18	1.15
1.0	1.18	1.16

Using the recommended design criteria of Reference 9 would require factors on the aerodynamic pressure ranging from (1.2) at small values of (β) to (1.5) at large values of (β).

b. Interaction Effects

The calculation model for buckling under combined lateral pressure and axial loading yields a theoretical interaction curve similar to those presented in Reference 9. Typical results obtained from Program 1886 are given in the following table for cylinder with $t/_R = 0.01$

$\bar{\gamma}$	P_{CR}/P_{cro}	$F/2\pi E_f t_f^2$
0	1.00	0.00
4	0.88	0.08
10	0.81	0.18
20	0.61	0.27
40	0.43	0.38
100	0.22	0.48
200	0.11	0.48
400	0.05	0.48

where F is the axial load and P_{cro} is the critical lateral buckling pressure with zero axial load.

The agreement with experiment for small values of $(\bar{\gamma})$ is reasonably good; however, a correction factor is needed at large values. An empirical correction factor is formulated for cylinders in Reference 10 which is a function of the (t/R) ratio. In order to facilitate an empirical correction to the program model, an additional optional input, designated CBAR is provided, which modifies the value of $\bar{\gamma}$ used in the equations, such that

$$(\bar{\gamma})_{used} = \text{CBAR}\ (\bar{\gamma})_{input} \quad .$$

The value of CBAR is preset to 1.0.

c. Spherical Cap Buckling

The empirical correlation of available buckling data used in Program 1886 is shown in Figure 1. The value of λ for sandwich shells is generally smaller than for monocoque shells, being given by

$$\lambda = 2(1-\nu_f)^{1/4} \left(\frac{h}{t_c}\right)^{1/2} \quad .$$

Hence, it appears that the formulation utilized results in smaller knockdown factors, due to imperfections, for sandwich shells than for monocoque shells.

5. Input Forms

An input form is provided for the user. All the information shown is keypunched provided the variable is specified All numerical values have decimal points.

C. OUTPUT DEFINITIONS

Name	Parameter	Units
AG	Area of general shell.	ft^2
AT	Area of tension shell.	ft^2
H	Height of stiffener.	inches
N	Number of stiffeners.	--
RØC	Core density.	lb/ft^3
RR	Radius of compression ring.	inches
SIGH	Circumferential stress.	$lb/in.^2$
SIGM	Meridional stress.	$lb/in.^2$
SIGMH	Resultant yield stress criteria.	$lb/in.^2$
T3	Thickness of tension and for general shell adjacent to compression ring.	inches
TC	Core height required.	inches
TCY	Face sheet thickness required to satisfy yield criteria.	inches
TF	Face sheet thickness used.	inches
TFØPT	Face sheet thickness designed for optimum under buckle criteria.	inches
TIME	Time at which TWMAX occurs.	seconds
TNG	Thickness of face sheet based on local and general stability.	inches
TNL	Thickness of face sheet based on local stability.	inches

D. SAMPLE PROBLEM

1. Statement of Problem

Determine the external structural weight for a blunt cone configuration using the heating and loads obtained from the sample trajectory problem of Program 1880. A heat shield is to be used on the forebody, but the afterbody is to be a heat sink.

2. Computer Input Forms

The necessary input computer forms, shown in the following pages, contain all the necessary input. The nosecap and forecone are considered to be of aluminum honeycomb construction. The aft cone is of stiffened beryllium and the flat base section is of beryllium honeycomb.

3. Output

The program output is given on the succeeding pages. The nosecap is designed on minimum gage for the face sheets and core height. The face sheets of the forecone are minimum gage, but the core height is 0.479 inch. The afterbody design indicates a minimum weight for 64 stiffeners of 0.17 inch height. The maximum temperature achieved by the afterbody is 1168°F, which satisfies the allowable temperature limit. The weight required for the heating (temperature limit) is seen to be larger (WTQ > WT) than that required for the structural loads; hence weight reductions can be achieved by increasing the allowable temperature. The base cover is designed on minimum gage considerations.

The total skin weight is then

Section	Weight (pounds)
Nose	0.7
Forecone	104.6
Aft Cone	52.1
Base	18.3
Total	175.7 pounds

The weight calculated does not include the torus section; Program 1888 provides for inclusion of the complete shell.

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DIGITAL COMPUTER INPUT REQUEST FORM		PROBLEM NO 1886			PROGRAMMER		
		TITLE Structural Preliminary Design Program					
MEMO NO	SECTION NO	WORK ORDER NO	(E240 USE ONLY)	REQUESTED BY	EXT	EST TIME	PAGE 1 OF 6 PAGES

$INPUT

DATE = ____________,
A = ____________,
BETA = ____________,
CBAR = ____________,
DELK1 = ____________,
DELK2 = ____________,
DELTAU = ____________,
DTHDY = ____________,
EF = ____________,
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GAMF = ____________,
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DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO.	MEMO NO	SECTION NO.	CONTINUATION SHEET PAGE 2 OF 6 PAGES

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RAD 2 0964
5 63

DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO	MEMO NO	SECTION NO	CONTINUATION SHEET PAGE 3 OF 6 PAGES

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DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO	MEMO NO	SECTION NO	CONTINUATION SHEET PAGE 4 OF 6 PAGES

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DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO	MEMO NO.	SECTION NO	CONTINUATION SHEET PAGE 5 OF 6 PAGES

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RAD 2 0964
5-63

DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO.	MEMO NO.	SECTION NO	CONTINUATION SHEET PAGE 6 OF 6 PAGES

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RAD P 0963
5 63

DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO 1886				PROGRAMMER		
	TITLE Structural Preliminary Design Program						
MEMO NO PL-179	SECTION NO W610	WORK ORDER NO W305-050-0005	(E240 USE ONLY)	REQUESTED BY P. Levine	EXT 2996	EST TIME	PAGE 1 OF 7 PAGES

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$INPUT

DATE    =  4.1     ,  MEM0    =         ,  CASE    =         ,
A       =          ,  LC      =         ,  SIGCYF  =  40000. ,
BETA    =          ,  M0N     =         ,  SIGCYR  =  40000. ,
CBAR    =  1.0     ,  NFAC    =  2.0    ,  SIGRG   =         ,
DELK1   =          ,  NTERM   =         ,  TCMAX   =  3 0    ,
DELK2   =          ,  PCR     =  1.67   ,  TCMIN   =  0.25   ,
DELTAU  =  0 1     ,  QCMULT  =         ,  TEMPA   =  1200.  ,
DTHDY   =          ,  QRMULT  =         ,  TEMPI   =  100.   ,
EF      =  8 E6    ,  RA      =         ,  TFMIN   =  .01    ,
EM      =          ,  RB      =         ,  THA     =  -80.   ,
EN      =          ,  RC      =  7.5    ,  THB     =         ,
EMISTR  =          ,  RN      =  1 25   ,  THC     =  60     ,
EPS     =  01      ,  R0CMAX  =  10.    ,  THN     =  60.    ,
ER      =          ,  R0CMIN  =  1.     ,  TH2G    =         ,
G       =  25.8    ,  R0F     =  172.   ,  TH3G    =         ,
GAMF    =  .33     ,  R0R     =  172.   ,  TINIT   =  100    ,
GAMR    =  .33     ,  R0RG    =         ,  TST0P   =  411 6  ,
GAMBAR  =          ,  RSB     =  0.15   ,  WHS     =  1.0    ,
HS      =          ,  RSC     =  0.15   ,  XA      =  0.     ,
HT0P    =  1.0     ,  RSD     =         ,  XC      =  0.2    ,
HTST    =          ,  RSN     =         ,  XN      =  0.8    ,
KADHES  =  .20     ,  RT      =  3.75   ,  X0      =  0.     ,

CPTAB  =  4      ,  5      ,  57     ,  .61    ,  .65    ,
          67     ,  .7     ,  73     ,  .76    ,         ,

EFTAB  =  44.E6  ,  42.E6  ,  40.E6  ,  37.E6  ,  32.E6  ,
          26.E6  ,  15.E6  ,  8.E6   ,  1.E6   ,         ,
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5-63

DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO	MEMO NO	SECTION NO	CONTINUATION SHEET
	1886	PL-179	W610	PAGE 2 OF 7 PAGES

GFTAB =	10*.024,	,	,	,	,
	,	,	,	,	,
GRTAB =	10*.32,	,	,	,	,
	,	,	,	,	,
SECTN =	1 0,	3.0,	,	,	,
	,	,	,	,	,
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	32000.,	20000.,	10000.,	1000.,	,
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	90000,	85000.,	70000.,	10000.,	,
TTAB =	0,	200.,	400.,	600,	800.,
	1000.,	1200.,	1400.,	1600.,	0.,
R =	,	,	,	,	,
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HTBL =	127.5,	130.9,	131.1,	131.4,	131.7,
	132.0,	132.2,	132.5,	132.7,	132.9,
	133.0,	133.1,	133.0,	132.8,	132.3,
	131.4,	129 9,	128.0,	126.4,	122.8,
	116 7,	108.2,	98.6,	89 4,	80.7,

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5 63

DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO	MEMO NO	SECTION NO	CONTINUATION SHEET
	1886	PL-179	W610	PAGE 3 OF 7 PAGES

HTBL (Continued) =
72.5, 64.7, 57.4, 50.5, 44.1,
38.2, 32.7, 27.6, 23.1, 19.0,
15.3, 12.9, 10.8, 8.9, 7.2,
5.8, 4.7, 3.9, 3.7, 4.0,

QTBL =
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2.3, 2.8, 3.4, 4.1, 5.1,
6.2, 7.6, 9.4, 11.4, 14.1,
16.8, 20.3, 23.8, 27.2, 28.3,
29.4, 30.4, 28.7, 26.4, 23.8,

RAD 2 0964
5-63

DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO 1886	MEMO NO PL-179	SECTION NO W610	CONTINUATION SHEET PAGE 4 OF 7 PAGES

QTBL (Continued)	=	21.1,	18.5,	15.9,	13.5,	11.2,
		9.2,	7.4,	5.8,	4.4,	3.2,
		2.3,	1.7,	1.2,	0.8,	0.6,
		0 3,	0.2,	0.1,	0.,	0.
RTBL	=	45 * 0,				

RAD 2-0934
5 63

DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO	MEMO NO	SECTION NO	CONTINUATION SHEET
	1886	PL-179	W610	PAGE 5 OF 7 PAGES

RTBL (Continued) =
____, ____, ____, ____, ____,
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TIME = 0. , 83.59 , 91.01 , 98.59 , 106.29 ,
114.11 , 122.04 , 130.15 , 138.41 , 146.83 ,
155.43 , 164.26 , 173.32 , 182.60 , 192.13 ,
201.94 , 212.11 , 221.42 , 229.50 , 236.71 ,
243.49 , 250.18 , 256.24 , 261.31 , 265.89 ,

RAO 2 C267
5 65

DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO 1886	MEMO NO PL-179	SECTION NO W610	CONTINUATION SHEET PAGE 6 OF 7 PAGES

TIME (Continued) = 270 19 , 274.35 , 278.41 , 282.47 , 286.62 ,
290.91 , 295.42 , 300.24 , 305.47 , 311.25 ,
317 80 , 323.33 , 329.62 , 336.92 , 345.61 ,
356.33 , 370.26 , 389.41 , 426.40 , 473.00 ,

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RAD 2 0964
5-63

DIGITAL COMPUTER INPUT REQUEST FORM	PROBLEM NO	MEMO NO	SECTION NO	CONTINUATION SHEET
	1886	PL-179	W610	PAGE 7 OF 7 PAGES

```
$INPUT
CASE        =  2.0    ,
SECTN       =  11.    ,
EM          =  30.    ,
EPS         =   05    ,
HTØP        =  2 0    ,
HTST        =  1.0    ,
PCR         =  8 3E-3 ,
QCMULT      =  0 1    ,
RØF         =  116.   ,
RØR         =  500    ,
RSD         =  1 0    ,

$


$INPUT
CASE        =  3.0    ,
SECTN       =  13.    ,
HTØP        =  0.0    ,
HTST        =  0.0.   ,
QCMULT      =  0.05   ,
RSD         =  0.0    ,

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                         * MEMORY MAP *

 SYSTEM                                 00000 THRU  02717
 FILE BLOCK ORIGIN                      02720
 FILES         1.      UNIT05
               2.      UNIT06             .
 FILE LIST ORIGIN                       02750
 PRE-EXECUTION INITIALIZATION           02754
 CALL ON OBJECT PROGRAM                 02777
 OBJECT PROGRAM                         03004 THRU  41547

       DECK  ORIGIN        CONTROL SECTIONS  (/NAME/=NON-0 LENGTH, (LOC)=DELETED, *=NOT REFERENCED)

   1. SSTIFS  03004        ///     /(76252)    STIFS    06034
   2. 1886    06050        ///     /(76252)    ......   07064 *
   3. SBUCKL  07100        ///     /(76252)    BUCKLE   11325
   4. SMONOC  11341        ///     /(76252)    MONOC    12754
   5. CNOSE   12770        NOSE      13615
   6. SRING   14017        RING      14211
   7. SCONE   14270        CONE      15511
   8. STENSN  15773        TENSON    16661
   9. SBASE   16766        BASE      17241
  10. SGNRLS  17374        GNRLSH    20050
  11. SCYLND  20202        CYLIND    21212
  12. SHOTST  21443        HOTSTR    22033
  13. SARTLU  22166        ARTLU     22400
  14. .LXCON  22551        .LXSTR    22551 *   .LXSTP   22555      .LXOUT   22623      .LXRTN   22635      IBEXIT   22635 *
                           .LXCAL    22640 *   .LXERR   22640      .DBCLS   23022 *    .LXARG   23171      .LO      23214 *
                           .CLSE     23222     .LFBL    23223 *    .LUNB    23224      .DFOUT   23225
  15. .IODEF  23231        .DEFIN    23231     .ATTAC   23235 *    .CLOSE   23237      .OPEN    23241      .READ    23243
                           .WRITE    23245     .BSR     23255 *    .REAOR   23265      .RELES   23267 *    .LAREA   23300
                           .LFBLK    23316     .LTSX    23321 *    .AREA1   23333      .LUNBL   23341      .ENTRY   23345
                           .GOA      23400     .GO      23404      .DERR    23420      .NOPXI   23421      .COMXI   23423
                           .EX34     23445
  16. .LXSL    23452       .LXSEL    23452     LXCSEL   23453      .LXTST   23456 *    .LXOVL   23516 *    .LXRCT   23527 *
                           .LXIND    23576 *   .LXDIS   23601 *    .LXFLG   23602 *    .LTCH    23603
  17. .FPTRP   23611       .FFPT.    23611 *   .FPOUT   23750      .FPARG   23767      /.COUNT/ 23771 *    OVFLOW   24042 *
  18. .ERAS.   24051       E.1       24051     E.2      24052      E.3      24053      E.4      24054
  19. .XCC.    24055       CC.1      24055     CC.2     24056      CC.3     24057      CC.4     24060
  20. XIT      24061       EXIT      24061     .EXIT.   24061 *
  21. FXEM     24062       .FXEM.    24062     .FXOUT   24417      .FXARG   24425      /.OPTW./ 24501
  22. FOUT     24512       .FOUT.    24512
  23. FCNV     25054       .FCON.    25054     .FCNV.   25077      .ENDFS   25112      .CNVSW   25114      .FDX1    25120
                           .FDX2     25121     .DBC     25123      .DBC8    25244      .DBC9    25247      .DBC10   25254
                           .DBC20    25302     .QDSW    25312      .DDFIX   25321      .FIXSW   25327      .DDBC    25404
                           .DDRS1    25656     .DDRS2   25660      .D1      25663      .D2      25665      .FERR2   25752 *
                           .ANPT     26006     .ONPT    26023      .LNTP    26077      .AOUT    26146      .DFLT    26164
                           .FLT      26320     .DEXPN   26410      .FXD     26411      .HOUT    26541      .INTG    26611
                           .LOUT     26727     .OOUT    26746      .XCF     26777      .TEST    27504      .KOUNT   27507
                           .LIST     27512     .DONE    27523      .OUTBF   27567      .BUF     27615      .QSTO    27616
                           .WIDTH    27617     .GAIN    27620      .GAIN1   27621      .FBDBF   27631      .DDDFL   27654
                           .DDFLG    27655     .MQD     27656      .PEX     27657      .FEXP    27660      .DIG     27661
  24. FIOS     27701       .FIOS.    27701     .FSEL.   30041      .FILR.   30045      .FRTB.   30054 *    .FRTD.   30061
                           .FILL.    30064     .FCLS    30066 *    .FOPN    30072 *    REOF     30076 *    .TOUT.   30241
                           .REED     30247 *   .BIN     30250 *    .FCT     30251      .FCKSZ   30253 *
  25. FIOH     30335       .FIOH.    30335     .FFIL.   31124      .FRTN.   31151 *
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              IBLDR                                                12/01/64

  26. FWRD     31336       .FWRD.  31336
  27. FWRU     31362       .FWRU.  31362
  28. FWRO     31406       .FWRO.  31406     .FREST   31711 *
  29. FROU     32013       .FROU.  32013
  30. UNO5     32054       .UNO5.  32054
  31. UNO6     32055       .UNO6.  32055     .BUFSZ   32056
  32. FIOU     32061       .FIOU.  32061     .CTUIO   32534     .NMLST   32557     .NAME.   33662     .INTAP   33663
  33. JTNQR    34306       ATANQR  34364     ATANQ    34373 *   ATANQD   34402 *
  34. JRSIM    34411       ARSIMP  34452
  35. FLOG     34503       ALOG10  34503 *   ALOG     34505
  36. FXPF     34644       EXP     34644
  37. FSCN     34764       COS     34764     SIN      34766
  38. FSQR     35175       SQRT    35175
  39. FATN     35302       ATAN2   35302     ATAN     35304 *
  40. FXP2     35510       .XP2.   35510
  41. FXP3     35626       .XP3.   35626
  42. .IOCS    35753       .L(0)   35753     .MONSW   35773     .TEOR    36042     .DEFI.   36122     .JOINX   36166 *
                           .CLOS.  36205     .ATTC.   36220     .SH1     36432 *   .SH9     36474 *   .OPEN.   36515
                           .OP4    36543 *   .OP7     36574 *   .OP9.2   36610 *   .RLSE.   36662     .RER2.   36662
                           .READ.  36663     .RER1.   36706     .WRIT.   36710     .MNT1A   37076 *   .EOFEX   37157 *
                           .FEEIT  37227     .GTIOX   37250     .RW7     37366 *   .RE7     40005 *   .ENDTR   40446
                           .SEL59  40450 *   .BSR.    41061     .EOTOF   41206     .ETOF3   41214 *   .SWITC   41243
                           .TCHEX  41544     .BASIO   41547 *
  43. .IOCSM   41550
  44. //       76252

 I/O BUFFERS                         41550 THRU  76153

 UNUSED CORE                         76154 THRU  76251


 $INPUT

 DATE   =          0.40100000E 01,

 MEMO   =          0.00000000E-38,

 CASE   =          0.00000000E-38,

 SECTN  =                1,             3,             0,             0,             0,             0,             0,
                         0,             0,             0,             0,             0,             0,

 MON    =                0,

 RSD    =                0,

 HTOP   =                1,

 HTST   =                0,

 GAMF   =          0.33000000E 00,

 EF     =          0.80000000E 07,

 ROF    =          0.17200000E 03,

 SIGCYF =          0.40000000E 05,

 GAMR   =          0.33000000E 00,

 ER     =          0.00000000E-38,

 ROR    =          0.17200000E 03,

 SIGCYR =          0.40000000E 05,

 KADHES =          0.20000000E 00,

 PCR    =          0.16700000E 01,

 TFMIN  =          0.10000000E-01,

 TCMIN  =          0.25000000E 00,

 TCMAX  =          0.30000000E 01,

 ROCMIN =          0.10000000E 01,

 ROCMAX =          0.10000000E 02,

 GAMBAR =          0.00000000E-38,

 CBAR   =          0.10000000E 01,

 WHS    =          0.10000000E 01,

 G      =          0.25800000E 02,

 HS     =          0.00000000E-38,

 EM     =          0.00000000E-38,
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EN     =        0.00000000E-38,
NFAC   =                 2,
NTERM  =                 0,
EPS    =        0.10000000E-01,
RN     =        0.12500000E 01,
RSN    =        0.00000000E-38,
THN    =        0.60000000E-02,
RA     =        0.00000000E-38,
THA    =        0.80000000E-02,
THC    =        0.60000000E 02,
RB     =        0.00000000E-38,
RSB    =        0.15000000E 00,
THB    =        0.00000000E-38,
RC     =        0.75000000E 01,
RSC    =        0.15000000E 00,
LC     =        0.00000000E-38,
RT     =        0.37500000E-01,
BETA   =        0.00000000E-38,
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TH2G   =        0.00000000E-38,
TH3G   =        0.00000000E-38,
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SIGRG  =        0.00000000E-38,
DTHDY  =        0.00000000E-38,
DELTAU =        0.10000000E 00,
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EMISTR =          0.00000000E-38,
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QRMULT =          0.00000000E-38,
XN     =          0.80000000E 00,
XO     =          0.00000000E-38,
XA     =          0.00000000E-38,
XC     =          0.20000000E 00,
TEMPI  =          0.10000000E 03,
TEMPA  =          0.12000000E 04,
TINIT  =          0.10000000E 03,
TSTOP  =          0.41160000E 03,
DELK1  =          0.00000000E-38,
DELK2  =          0.00000000E-38,
TIME   =          0.00000000E-38,     0.83590000E 02,     0.91010000E 02,     0.98590000E 02,     0.10629000E 03,
                  0.11411000E 03,     0.12204000E 03,     0.13015000E 03,     0.13841000E 03,     0.14683000E 03,
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 TTAB   =      0.00000000E-38,   0.20000000E 03,   0.40000000E 03,   0.60000000E 03,   0.80000000E 03,
               0.10000000E 04,   0.12000000E 04,   0.14000000E 04,   0.16000000E 04,   0.00000000E-38,

 CPTAB  =      0.40000000E 00,   0.50000000E 00,   0.57000000E 00,   0.61000000E 00,   0.65000000E 00,
               0.67000000E 00,   0.70000000E 00,   0.73000000E 00,   0.76000000E 00,   0.00000000E-38,

 EFTAB  =      0.44000000E 08,   0.42000000E 08,   0.40000000E 08,   0.37000000E 08,   0.32000000E 08,
               0.26000000E 08,   0.15000000E 08,   0.80000000E 07,   0.10000000E 07,   0.00000000E-38,

 SGFTAB =      0.60000000E 05,   0.58000000E 05,   0.52000000E 05,   0.46000000E 05,   0.40000000E 05,
               0.32000000E 05,   0.20000000E 05,   0.10000000E 05,   0.10000000E 04,   0.00000000E-38,

 GFTAB  =      0.24000000E-01,   0.24000000E-01,   0.24000000E-01,   0.24000000E-01,   0.24000000E-01,
               0.24000000E-01,   0.24000000E-01,   0.24000000E-01,   0.24000000E-01,   0.24000000E-01,

 GRTAB  =      0.32000000E 00,   0.32000000E 00,   0.32000000E 00,   0.32000000E 00,   0.32000000E 00,
               0.32000000E 00,   0.32000000E 00,   0.32000000E 00,   0.32000000E 00,   0.32000000E 00,

 SGRTAB =      0.95000000E 05,   0.95000000E 05,   0.95000000E 05,   0.92000000E 05,   0.90000000E 05,
               0.90000000E 05,   0.85000000E 05,   0.70000000E 05,   0.10000000E 05,   0.00000000E-38,

 $ END



 DATE=    4.01     MEMO=    0.00     CASE=    0.00


 SECTION     1


 SANDWICH CONSTRUCTION

      TC Y          ROC             W              TF              TC             WT
   1.31241E-04   1.00000E 00   5.07500E-01    1.00000E-02   2.50000E-01   6.67511E-01

      SIGMH
   -5.24965E 02



 SECTION     3


 SANDWICH CONSTRUCTION

      TC Y          ROC             W              TF              TC             WT
   2.76586E-03   1.00000E 00   5.26615E-01    1.00000E-02   4.79382E-01   1.04572E 02

      SIGMH         SIGH          SIGM
   1.10634E 04  -1.27668E 04  -5.98852E 03
```

```
 $INPUT
 DATE   =          0.40100000E 01,
 MEMO   =          0.00000000E-38,
 CASE   =          0.20000000E-01,
 SECTN  =                 11,           0,           0,           0,           0,           0,           0,
                           0,           0,           0,           0,           0,           0,
 MON    =                  0,
 RSD    =                  1,
 HTOP   =                  2,
 HTST   =                  1,
 GAMF   =          0.33000000E 00,
 EF     =          0.80000000E 07,
 ROF    =          0.11600000E 03,
 SIGCYF =          0.40000000E 05,
 GAMR   =          0.33000000E 00,
 ER     =          0.00000000E-38,
 ROR    =          0.50000000E 03,
 SIGCYR =          0.40000000E 05,
 KADHES =          0.20000000E 00,
 PCR    =          0.83000000E-02,
 TFMIN  =          0.10000000E-01,
 TCMIN  =          0.25000000E 00,
 TCMAX  =          0.30000000E 01,
 ROCMIN =          0.10000000E 01,
 ROCMAX =          0.10000000E 02,
 GAMBAR =          0.00000000E-38,
 CBAR   =          0.10000000E 01,
 WHS    =          0.00000000E-38,
 G      =          0.25800000E 02,
 HS     =          0.00000000E-38,
 EM     =          0.30000000E 02,
```

```
EN      =         0.00000000E-38,
NFAC    =                  2,
NTERM   =                  0,
EPS     =         0.50000000E-01,
RN      =         0.12500000E 01,
RSN     =         0.00000000E-38,
THN     =         0.60000000E 02,
RA      =         0.00000000E-38,
THA     =         0.80000000E 02,
THC     =         0.60000000E 02,
RB      =         0.00000000E-38,
RSB     =         0.15000000E 00,
THB     =         0.00000000E-38,
RC      =         0.75000000E-01,
RSC     =         0.15000000E 00,
LC      =         0.00000000E-38,
RT      =         0.37500000E 01,
BETA    =         0.00000000E-38,
A       =         0.00000000E-38,
TH2G    =         0.00000000E-38,
TH3G    =         0.00000000E-38,
X       =         0.00000000E-38,    0.00000000E-38,    0.00000000E-38,    0.00000000E-38,    0.00000000E-38,
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R       =         0.00000000E-38,    0.00000000E-38,    0.00000000E-38,    0.00000000E-38,    0.00000000E-38,
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RORG    =         0.00000000E-38,
SIGRG   =         0.00000000E-38,
DTHDY   =         0.00000000E-38,
DELTAU  =         0.10000000E 00,
```

```
EMISTR =         0.00000000E-38,
QCMULT =         0.10000000E 00,
QRMULT =         0.00000000E-38,
XN     =         0.80000000E 00,
XO     =         0.00000000E-38,
XA     =         0.00000000E-38,
XC     =         0.20000000E-00,
TEMPI  =         0.10000000E 03,
TEMPA  =         0.12000000E-04,
TINIT  =         0.10000000E 03,
TSTOP  =         0.41160000E 03,
DELK1  =         0.00000000E-38,
DELK2  =         0.00000000E-38,
TIME   =         0.00000000E-38,   0.83590000E 02,   0.91010000E 02,   0.98590000E 02,   0.10629000E 03,
                 0.11411000E 03,   0.12204000E 03,   0.13015000E 03,   0.13841000E 03,   0.14683000E 03,
                 0.15543000E 03,   0.16426000E 03,   0.17332000E 03,   0.18260000E 03,   0.19213000E 03,
                 0.20194000E 03,   0.21211000E 03,   0.22142000E 03,   0.22950000E 03,   0.23671000E 03,
                 0.24349000E 03,   0.25018000E 03,   0.25624000E 03,   0.26131000E 03,   0.26589000E 03,
                 0.27019000E 03,   0.27435000E 03,   0.27841000E 03,   0.28247000E 03,   0.28662000E 03,
                 0.29091000E 03,   0.29542000E 03,   0.30024000E 03,   0.30547000E 03,   0.31125000E 03,
                 0.31780000E 03,   0.32333000E 03,   0.32962000E 03,   0.33692000E 03,   0.34561000E 03,
                 0.35633000E 03,   0.37026000E 03,   0.38941000E 03,   0.42640000E 03,   0.47300000E 03,
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QTBL   =         0.10000000E 00,   0.10000000E 01,   0.12000000E 01,   0.15000000E 01,   0.18000000E 01,
                 0.23000000E 01,   0.28000000E 01,   0.34000000E 01,   0.41000000E 01,   0.51000000E 01,
                 0.62000000E 01,   0.76000000E 01,   0.94000000E 01,   0.11400000E 02,   0.14100000E 02,
```

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```
              0.16800000E 02,   0.20300000E 02,   0.23800000E 02,   0.27200000E 02,   0.28300000E 02,
              0.29400000E 02,   0.30400000E 02,   0.28700000E 02,   0.26400000E 02,   0.23800000E 02,
              0.21100000E 02,   0.18500000E 02,   0.15900000E 02,   0.13500000E 02,   0.11200000E 02,
              0.92000000E 01,   0.74000000E 01,   0.58000000E 01,   0.44000000E 01,   0.32000000E 01,
              0.23000000E 01,   0.17000000E 01,   0.12000000E 01,   0.80000000E 00,   0.60000000E 00,
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RTBL    =     0.00000000E-38,   0.00000000E-38,   0.00000000E-38,   0.00000000E-38,   0.00000000E-38,
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HTBL    =     0.12750000E 03,   0.13090000E 03,   0.13110000E 03,   0.13140000E 03,   0.13170000E 03,
```

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```
             0.13200000E 03,   0.13220000E 03,   0.13250000E 03,   0.13270000E 03,   0.13290000E 03,
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             0.13140000E 03,   0.12990000E 03,   0.12800000E 03,   0.12640000E 03,   0.12260000E 03,
             0.11670000E 03,   0.10820000E 03,   0.98600000E 02,   0.89400000E 02,   0.80700000E 02,
             0.72500000E 02,   0.64700000E 02,   0.57400000E 02,   0.50500000E 02,   0.44100000E 02,
             0.38200000E 02,   0.32700000E 02,   0.27600000E 02,   0.23100000E 02,   0.19000000E 02,
             0.15300000E 02,   0.12900000E 02,   0.10800000E 02,   0.89000000E 01,   0.72000000E 01,
             0.58000000E 01,   0.47000000E 01,   0.39000000E 01,   0.37000000E 01,   0.40000000E 01,
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 TTAB   =    0.00000000E-38,   0.20000000E 03,   0.40000000E 03,   0.60000000E 03,   0.80000000E 03,
             0.10000000E 04,   0.12000000E 04,   0.14000000E 04,   0.16000000E 04,   0.00000000E-38,

 CPTAB  =    0.40000000E 00,   0.50000000E 00,   0.57000000E 00,   0.61000000E 00,   0.65000000E 00,
             0.67000000E 00,   0.70000000E 00,   0.73000000E 00,   0.76000000E 00,   0.00000000E-38,

 EFTAB  =    0.44000000E 08,   0.42000000E 08,   0.40000000E 08,   0.37000000E 08,   0.32000000E 08,
             0.26000000E 08,   0.15000000E 08,   0.80000000E 07,   0.10000000E 07,   0.00000000E-38,

 SGFTAB =    0.60000000E 05,   0.58000000E 05,   0.52000000E 05,   0.46000000E 05,   0.40000000E 05,
             0.32000000E 05,   0.20000000E 05,   0.10000000E 05,   0.10000000E 04,   0.00000000E-38,

 GFTAB  =    0.24000000E-01,   0.24000000E-01,   0.24000000E-01,   0.24000000E-01,   0.24000000E-01,
             0.24000000E-01,   0.24000000E-01,   0.24000000E-01,   0.24000000E-01,   0.24000000E-01,

 GRTAB  =    0.32000000E 00,   0.32000000E 00,   0.32000000E 00,   0.32000000E 00,   0.32000000E 00,
             0.32000000E 00,   0.32000000E 00,   0.32000000E 00,   0.32000000E 00,   0.32000000E 00,

 SGRTAB =    0.95000000E 05,   0.95000000E 05,   0.95000000E 05,   0.92000000E 05,   0.90000000E 05,
             0.90000000E 05,   0.85000000E 05,   0.70000000E 05,   0.10000000E 05,   0.00000000E-38,

 $ END


 DATE=     4.01     MEMO=     0.00     CASE=     2.00


 SECTION     11

    N     TNL          TNG            W            H           TCY         SIGMH        SIGH         SIGM         WT
    0  1.000000E-02 1.204077E-01 1.163341E 00 1.000000E 00 4.346337E-03 7.906099E 02 -9.045376E 02 -3.453915E 02 1.497972E 02
    1  8.851068E-02 8.851068E-02 8.632951E-01 3.972142E-01 3.267364E-03 8.085273E 02 -9.250158E 02 -3.530742E 02 1.111046E 02
    2  7.209250E-02 7.209250E-02 7.076373E-01 3.405616E-01 2.708730E-03 8.229407E 02 -9.414879E 02 -3.592459E 02 9.107170E 01
    4  5.299461E-02 5.299461E-02 5.265356E-01 3.073568E-01 2.058782E-03 8.508866E 02 -9.734252E 02 -3.712114E 02 6.776423E 01
    8  3.895591E-02 3.895591E-02 3.945414E-01 2.635200E-01 1.585074E-03 8.911879E 02 -1.019486E 03 -3.884882E 02 5.077680E 01
   16  2.720436E-02 2.720436E-02 2.844912E-01 2.259355E-01 1.190121E-03 9.581763E 02 -1.096048E 03 -4.172167E 02 3.661353E 01
   32  1.804793E-02 1.804793E-02 1.989396E-01 1.937114E-01 8.830890E-04 1.071692E 03 -1.225789E 03 -4.659058E 02 2.560319E 01
   64  1.260354E-02 1.260354E-02 1.526366E-01 1.748245E-01 7.170941E-04 1.246168E 03 -1.425238E 03 -5.409860E 02 1.965050E 01

 MINIMUM WEIGHT   W=   1.526866E-01      WT=   1.965050E 01

 TIME= 0.32329660E 03     TEMP= 0.11679241E 04     WQ= 0.40512287E 00     WTQ= 0.52138618E 02
```

604<

```
$INPUT
DATE   =          0.40100000E 01,
MEMO   =          0.00000000E-38,
CASE   =          0.30000000E 01,
SECTN  =                  13,                0,                0,                0,                0,                0,                0,
                           0,                0,                0,                0,                0,                0,
MON    =                   0,
RSO    =                   0,
HTOP   =                   0,
HTST   =                   0,
GAMF   =          0.33000000E 00,
EF     =          0.80000000E 07,
ROF    =          0.11600000E 03,
SIGCYF =          0.40000000E 05,
GAMR   =          0.33000000E 00,
ER     =          0.00000000E-38,
ROR    =          0.50000000E 03,
SIGCYR =          0.40000000E 05,
KADHES =          0.20000000E 00,
PCR    =          0.83000000E-02,
TFMIN  =          0.10000000E-01,
TCMIN  =          0.25000000E 00,
TCMAX  =          0.30000000E 01,
ROCMIN =          0.10000000E 01,
ROCMAX =          0.10000000E 02,
GAMBAR =          0.00000000E-38,
CBAR   =          0.10000000E 01,
WHS    =          0.00000000E-38,
G      =          0.25800000E 02,
HS     =          0.00000000E-38,
EM     =          0.30000000E 02,
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 EN      =         0.00000000E-38,
 NFAC    =                  2,
 NTERM   =                  0,
 EPS     =         0.50000000E-01,
 RN      =         0.12500000E 01,
 RSN     =         0.00000000E-38,
 THN     =         0.60000000E-02,
 RA      =         0.00000000E-38,
 THA     =         0.80000000E-02,
 THC     =         0.60000000E-02,
 RB      =         0.00000000E-38,
 RSB     =         0.15000000E 00,
 THB     =         0.00000000E-38,
 RC      =         0.75000000E-01,
 RSC     =         0.15000000E 00,
 LC      =         0.00000000E-38,
 RT      =         0.37500000E 01,
 BETA    =         0.00000000E-38,
 A       =         0.00000000E-38,
 TH2G    =         0.00000000E-38,
 TH3G    =         0.00000000E-38,
 X       =         0.00000000E-38,     0.00000000E-38,     0.00000000E-38,     0.00000000E-38,     0.00000000E-38,
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 R       =         0.00000000E-38,     0.00000000E-38,     0.00000000E-38,     0.00000000E-38,     0.00000000E-38,
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 RORG    =         0.00000000E-38,
 SIGRG   =         0.00000000E-38,
 DTHDY   =         0.00000000E-38,
 DELTAU  =         0.10000000E 00,
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EMISTR =        0.00000000E-38,
QCMULT =        0.50000000E-01,
QRMULT =        0.00000000E-38,
XN     =        0.80000000E 00,
XO     =        0.00000000E-38,
XA     =        0.00000000E-38,
XG     =        0.20000000E 00,
TEMPI  =        0.10000000E 03,
TEMPA  =        0.12000000E 04,
TINIT  =        0.10000000E 03,
TSTOP  =        0.41160000E 03,
DELK1  =        0.00000000E-38,
DELK2  =        0.00000000E-38,
TIME   =        0.00000000E-38,   0.83590000E 02,   0.91010000E 02,   0.98590000E 02,   0.10629000E 03,
                0.11411000E 03,   0.12204000E 03,   0.13015000E 03,   0.13841000E 03,   0.14683000E 03,
                0.15543000E 03,   0.16426000E 03,   0.17332000E 03,   0.18260000E 03,   0.19213000E 03,
                0.20194000E 03,   0.21211000E 03,   0.22142000E 03,   0.22950000E 03,   0.23671000E 03,
                0.24349000E 03,   0.25018000E 03,   0.25624000E 03,   0.26131000E 03,   0.26589000E 03,
                0.27019000E 03,   0.27435000E 03,   0.27841000E 03,   0.28247000E 03,   0.28662000E 03,
                0.29091000E 03,   0.29542000E 03,   0.30024000E 03,   0.30547000E 03,   0.31125000E 03,
                0.31780000E 03,   0.32333000E 03,   0.32962000E 03,   0.33692000E 03,   0.34561000E 03,
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QTBL   =        0.10000000E 00,   0.10000000E 01,   0.12000000E 01,   0.15000000E 01,   0.18000000E 01,
                0.23000000E 01,   0.28000000E 01,   0.34000000E 01,   0.41000000E 01,   0.51000000E 01,
                0.62000000E 01,   0.76000000E 01,   0.94000000E 01,   0.11400000E 02,   0.14100000E 02,
```

```
                  0.16800000E 02,   0.20300000E 02,   0.23800000E 02,   0.27200000E 02,   0.28300000E 02,
                  0.29400000E 02,   0.30400000E 02,   0.28700000E 02,   0.26400000E 02,   0.23800000E 02,
                  0.21100000E 02,   0.18500000E 02,   0.15900000E 02,   0.13500000E 02,   0.11200000E 02,
                  0.92000000E 01,   0.74000000E 01,   0.58000000E 01,   0.44000000E 01,   0.32000000E 01,
                  0.23000000E 01,   0.17000000E 01,   0.12000000E 01,   0.80000000E 00,   0.60000000E 00,
                  0.30000000E 00,   0.20000000E 00,   0.10000000E 00,   0.00000000E-38,   0.00000000E-38,
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RTBL   =          0.00000000E-38,   0.00000000E-38,   0.00000000E-38,   0.00000000E-38,   0.00000000E-38,
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HTBL   =          0.12750000E 03,   0.13090000E 03,   0.13110000E 03,   0.13140000E 03,   0.13170000E 03,
```

```
              0.13200000E 03,   0.13220000E 03,   0.13250000E 03,   0.13270000E 03,   0.13290000E 03,
              0.13300000E 03,   0.13310000E 03,   0.13300000E 03,   0.13280000E 03,   0.13230000E 03,
              0.13140000E 03,   0.12990000E 03,   0.12800000E 03,   0.12640000E 03,   0.12280000E 03,
              0.11670000E 03,   0.10820000E 03,   0.98600000E 02,   0.89400000E 02,   0.80700000E 02,
              0.72500000E 02,   0.64700000E 02,   0.57400000E 02,   0.50500000E 02,   0.44100000E 02,
              0.38200000E 02,   0.32700000E 02,   0.27600000E 02,   0.23100000E 02,   0.19000000E 02,
              0.15300000E 02,   0.12900000E 02,   0.10800000E 02,   0.89000000E 01,   0.72000000E 01,
              0.58000000E 01,   0.47000000E 01,   0.39000000E 01,   0.37000000E 01,   0.40000000E 01,
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 TTAB    =    0.00000000E-38,   0.20000000E 03,   0.40000000E 03,   0.60000000E 03,   0.80000000E 03,
              0.10000000E 04,   0.12000000E 04,   0.14000000E 04,   0.16000000E 04,   0.00000000E-38,

 CPTAB   =    0.40000000E 00,   0.50000000E 00,   0.57000000E 00,   0.61000000E 00,   0.65000000E 00,
              0.67000000E 00,   0.70000000E 00,   0.73000000E 00,   0.76000000E 00,   0.00000000E-38,

 EFTAB   =    0.44000000E 08,   0.42000000E 08,   0.40000000E 08,   0.37000000E 08,   0.32000000E 08,
              0.26000000E 08,   0.15000000E 08,   0.80000000E 07,   0.10000000E 07,   0.00000000E-38,

 SGFTAB  =    0.60000000E 05,   0.58000000E 05,   0.52000000E 05,   0.46000000E 05,   0.40000000E 05,
              0.32000000E 05,   0.20000000E 05,   0.10000000E 05,   0.10000000E 04,   0.00000000E-38,

 GFTAB   =    0.24000000E-01,   0.24000000E-01,   0.24000000E-01,   0.24000000E-01,   0.24000000E-01,
              0.24000000E-01,   0.24000000E-01,   0.24000000E-01,   0.24000000E-01,   0.24000000E-01,

 GRTAB   =    0.32000000E 00,   0.32000000E 00,   0.32000000E 00,   0.32000000E 00,   0.32000000E 00,
              0.32000000E 00,   0.32000000E 00,   0.32000000E 00,   0.32000000E 00,   0.32000000E 00,

 SGRTAB  =    0.95000000E 05,   0.95000000E 05,   0.95000000E 05,   0.92000000E 05,   0.90000000E 05,
              0.90000000E 05,   0.85000000E 05,   0.70000000E 05,   0.10000000E 05,   0.00000000E-38,

 $ END



 DATE=    4.01     MEMO=    0.00     CASE=    3.00


 SECTION    13


 SANDWICH CONSTRUCTION

      TC Y            ROC          W             TF            TC           WT
                  1.00000E 00   4.14167E-01   1.00000E-02   2.50000E-01   1.82973E-01



     1763 LINES OUTPUT.
         $IBSYS
         $PAUSE
         OPER. ACTION PAUSE

         ..CONTINUING

         $IBSYS
         $PAUSE
         OPER. ACTION PAUSE

         ..CONTINUING

    00000000000000000000800011-0101GQ00000800001F000000IBSYST-0000100000113740000000 )
       1 LINES OUTPUT THIS JOB.
```

III. COMPUTATIONS

A BLOCK DIAGRAM

The block diagram for Program 1886 is shown in Figure 7. It can be seen from the block diagram that the inputs provide for dealing with conical, spherical, and the tension and general shells with options for considering various construction approaches and for testing the structure to ascertain whether it is suitable as a hot structure

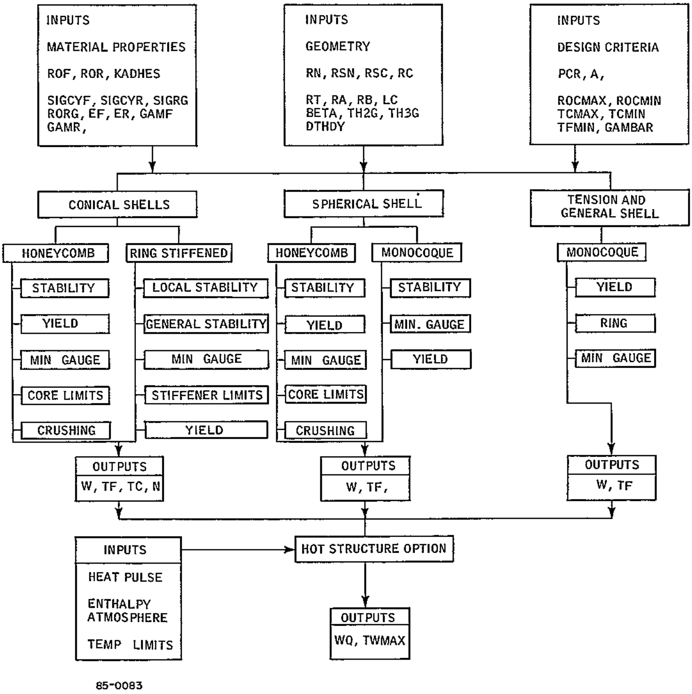

Figure 7 BLOCK DIAGRAM FOR PROGRAM 1886

B. SYMBOLS

Symbol	Parameter	Units
a	ratio of circumferential to meridianal stress	--
AT	area of tension shell	ft^2
AG	area of general shell	ft^2
A_T	stiffener area	in.^{2}
D	bending rigidity of shell	lb-in.
D_θ	equivalent orthotropic shell bending rigidity of ring-stiffened shell	lb-in.
E_f	modulus of elasticity of face sheets	lb/in.^{2}
E_R	modulus of elasticity for compression ring	lb/in.^{2}
h	height of spherical shell	inches
H	height of stiffener	inches
KAD	unit weight allowable for adhesives	lb/ft^2
I_x	stiffener moment of inertia about neutral axis	in.^{4}
I_θ	effective stiffener moment of inertia	in.^{4}
L_o	slant length of cone	inches
L_c	cylinder length	inches
m	effective width factor or stiffener	--
n	proportionality factor for stiffener	--
N	number of rings	--
P	stability parameter [5]	--
P_{CR}	critical pressure load	lb/in.^{2}
S	stability parameter [5]	--

T	temperature	$^\circ$R
t_c	core height	inches
t_f	face sheet thickness	inches
t_{copt}	optimized core height for buckling criteria	inches
t_{cy}	face sheet thickness required for yield criteria	inches
t_R	wall thickness of compression ring	inches
t_1, t_3, t_4	stability parameters	--
R_1, R_2	minimum and maximum radii of conical shell	inches
R_2, R_3	minimum and maximum radius for tension and general shell	inches
y	radial coordinate	inches
R_{SC}	toroidal radius following tension or general shell	inches
RR	radius of compression ring	inches
RC	maximum radius of tension or general shell combined with torus	inches
R_{CAP}	spherical cap radius	inches
q_c	convective heat rate	Btu/ft^2-sec
q_R	radiative heat rate	Btu/ft^2-sec
H_w	enthalpy of gas at wall	Btu/lb
H_s	stagnation enthalpy	Btu/lb
C_p	specific heat	Btu/lb-$^\circ$F
W_e	effective width	inches
W	unit area weight	lb/ft^2
WR	total compression ring weight	pounds
WTG	total general shell weight	pounds

WTT	total tension shell weight	pounds
ν_f	Poisson's Ratio	--
σ_{cy}	yield stress of face sheets	lb/in.^{2}
ρ_f	face sheet density	lb/ft^3
ρ_c	core density	lb/ft^3
σ_{CR}	yield stress of core ribbon	lb/in.^{2}
β	cone parameter, also tension shell angle (degrees)	--
ρ_R	density of core ribbon	lb/ft^3
θ	local body slope angle	degrees
θ_{3G}	last angle on general shell	degrees
τ	time	seconds
ϵ	emissivity	

C. EQUATIONS

1. Sandwich Construction - - Spherical Cap

a. Face Sheets

$$t_{f\ opt} = \left(\frac{3\,K_2}{4\,K_1}\right)^{4/7} \tag{1}$$

$$t_f = 0.36\,(1-\nu_f^2)^{2/3}\left(\frac{P_{CR}}{E_f}\right)\frac{h^{1/3}}{t_c^{\,4/3}}\quad R_{CAP}^2 \tag{2}$$

$$t_{cy} = \frac{P_{CR}\ R_{CAP}}{4\sigma_{cy}} \tag{3}$$

b. Core

$$t_{c\ opt} = \frac{12\,K_2}{\rho_c} \left[\frac{4\,K_1}{3\,K_2}\right]^{3/7} \qquad (4)$$

$$t_c = 0.465\ (1 - \nu_f^2)^{1/2} \left(\frac{P_{CR}}{E_f}\right)^{3/4} \frac{h^{1/4}}{t_f^{3/4}}\ R_{CAP}^{3/2} \qquad (5)$$

$$\rho_c = 0.22\ \rho_R \left(\frac{P_{CR}}{\sigma_{CR}}\right)^{0.588} \qquad (6)$$

c. Weight

$$W_{opt} = 7/3\ K_1 \left[\frac{3\,K_2}{4\,K_1}\right]^{4/7} + KAD \qquad (7)$$

$$W = K_1\, t_f + \frac{1}{12}\ \rho_c\, t_c + KAD \qquad (8)$$

$$K_1 = \rho_f/6 \qquad (9)$$

$$K_2 = \frac{\rho_c}{12} \left[0.465\ (1 - \nu_f^2)^{1/2} \left(\frac{P_{CR}}{E_f}\right)^{3/4} h^{1/4}\ R_{CAP}^{3/2}\right] \qquad (10)$$

$$h = R_{CAP}\ (1 - \sin\theta_{CAP}) \qquad (11)$$

$$\bar{P}CR = P_{AERO} \pm \frac{(W + WHS)}{144}\ G$$

2. Sandwich Construction--Conical Section

a. Face Sheet

$$t_{f\ opt} = \frac{4.89}{\rho_f} \left[C_1^{0.414}\ \ C_2^{0.586}\right] \qquad (12)$$

$$t_f = \frac{P\ \ k}{18.6\ (A\ t_c^{1/2})^{2.84}} \qquad (13)$$

$$t_{cy} = \frac{P_{CR}\ R_2}{4\sigma_{cy}\ \cos\theta_c}\left\{3 + (1 - \bar{\gamma})^2\ \left(\frac{R_1}{R_2}\right)^4\right\}^{1/2} \tag{14}$$

b. Core

$$t_{c\ opt} = 1\ 156\left(\frac{C_1}{C_2}\right)^{0.414} \tag{15}$$

$$t_c = 0.127\ \left(\frac{P\ k}{t_f\ A^{2.84}}\right)^{0.704} \tag{16}$$

c. Weight

$$W_{opt} = 1\ 971\ \ C_1^{0.414}\ \ C_2^{0.586} + KAD \tag{17}$$

$$W = \frac{1}{6}\ \rho_f\ t_f + \frac{1}{12}\ \rho_c\ t_c + KAD \tag{18}$$

t_1, t_3, t_4 evaluated from table 1.

$$A = \left(\frac{\lambda K_1}{k^{3/2}\ K_2}\right)\left(\frac{2 t_1\ t_3\ t_4}{2 t_3 - \nu_f^2}\right)^{1/4} \tag{19}$$

$$k = \frac{R_2\ (1 - \beta/2)}{\cos\ \theta_c} \tag{20}$$

$$\beta = \left[1 - \left(\frac{R_1}{R_2}\right)\right] \tag{21}$$

$$K_2 = K\left[1 \pm \frac{(WHS + W)\ G}{144\ P_{CR}}\ \sin\theta_c\right] \tag{22}$$

$$K_1 = \frac{K^3}{2\left(1 - \frac{\beta}{2}\right)^2} \left\{ 1 - \beta + \frac{\beta^2}{3} + \frac{\beta^2}{2\pi^2} - (1-\bar{\gamma})(1-\beta)^2 \right.$$

$$\left. \pm \frac{\beta}{\sin\theta_c} \frac{(WHS + W)\,G}{(144)\,P_{CR}} \left(1 - \beta + \frac{\beta}{3} + \frac{\beta}{2\pi^2}\right) \right\} \qquad (23)$$

$$\lambda = \frac{\pi \sin\theta_c}{R_2\,\beta} \qquad (24)$$

$$C_1 = \frac{P\,k\,\rho_f}{111.9\ A^{2\ 84}} \qquad (25)$$

$$C_2 = \rho_c/12 \qquad (26)$$

$$\rho_c = 0.22\ \rho_R \left(\frac{P_{CR}}{\sigma_{cyR}}\right)^{0.588} \qquad (27)$$

$$P = \left(\frac{32\,t_1\,t_3\,\lambda^2\ K_1{}^3}{k^7}\right) \frac{(1-\nu_f{}^2)}{(2\,t_3 - \nu_f{}^2)} \quad \frac{P_{CR}}{E_f} \qquad (28)$$

TABLE I

EVALUATION OF THE CONSTANTS T_1, T_3, T_4 as a FUNCTION OF THE GEOMETRIC PARAMETER β

β	t_1	t_3	t_4
0.00	0.50000	0.50000	0.50000
0.10	0.50074	0.50018	0.50027
0.20	0.50334	0.50081	0.50470
0.25	0.50554	0.50134	0.50803
0.35	0.51242	0.50300	0.51621
0.40	0.51748	0.50417	0.52532
0.50	0.53223	0.50749	0.54946
0.55	0.54273	0.50985	0.56400
0.60	0.55625	0.51276	0.58430
0.65	0.57382	0.51638	0.61134
0.70	0.59704	0.52093	0.64769
0.75	0.62853	0.52670	0.69795
1.00	0.62853	0.52670	0.69795

3. Sandwich Construction--Cylindrical Section

a. Face Sheet

$$t_{f\ opt} = \frac{4.7\ X_1^{2/5}\ X_2^{3/5}}{\rho_f} \qquad (29)$$

$$t_f = \frac{1.75}{P_B\ 3.87\ E_f \cdot t_c^{1.5}} \left\{ P_{CR} \cdot R_C^{3/2}\ \ L_C \cdot (1-\nu_f^2)^{3/4} \right\} \qquad (30)$$

$$t_{cy} = \frac{P_{CR}\ R_C}{2\,\sigma_f} \qquad (31)$$

b. Core Thickness

$$t_{c\ opt} = 1.176 \left(\frac{X_1}{X_2}\right)^{2/5} \qquad (32)$$

$$t_c = 0.404 \left(\frac{P_{CR}\ \ R_C^{3/2}\ L_c}{E_f\ \ t_f}\right)^{2/3} (1-\nu_f^2)^{1/2} \left(\frac{1.75}{P_B}\right)^{2/3} \qquad (33)$$

c. Weight

$$W_{opt} = 1.959\ X_1^{2/5}\ X_2^{3/5} + KAD$$

or

$$W = \frac{\rho_f\ t_f}{6} + \frac{\rho_c\ t_c}{12} + KAD \qquad (34)$$

$$X_1 = \frac{\rho_f\ P_{CR}\ R_C^{3/2}\ (L_C)}{23.2\ \ E_f} (1-\nu_f^2)^{3/4} \left(\frac{1.75}{P_B}\right)$$

and

$$X_2 = \rho_c/12 \qquad (35)$$

$$P_B = \frac{\left[\frac{3+S}{1+S} + 1\right]}{\left[\frac{3+S}{1+S}\right]^{1/2} \left[\left(\frac{3+S}{1+S}\right)^{1/4} + \frac{S}{2}\right]} \tag{36}$$

$$S = \frac{2.22\, t_c^{1/2} \cdot R_c^{1/2} \cdot}{L_c (1 - \nu_f^2)^{1/4}} \left[\bar{\gamma} + \frac{L_c}{R_c} \, \frac{(WHS + W)\, G}{(144)\, P_{CR}}\right] \tag{37}$$

$$\rho_c = 0.22 \, \rho_R \left(\frac{P_{CR}}{\sigma_{CR}}\right)^{0.588} \tag{38}$$

4. Monocoque Spherical Cap

$$t_f = 1.20 \left(\frac{P_{CR}}{E_f}\right)^{3/7} (1 - \nu^2)^{2/7} \left(\frac{h}{R_{CAP}}\right)^{1/7} R_{CAP} \tag{39}$$

$$t_{cy} = \frac{P_{CR}\, R}{2\, \sigma_{cy}} \tag{40}$$

$$h = R_{CAP} \, (1 - \cos \theta_{CAP}) \tag{41}$$

$$W = \frac{\rho_f \, t_f}{12} \tag{42}$$

$$P_{CR} = P_{AERO} \pm \frac{(W + WHS)\, G}{144}$$

5. Ring Stiffened Conical and Cylindrical Sections

$$P_{CR}(S) = \frac{P(S)\,\pi\,(D_\theta/D)^{3/4}\,t_4\,t^{5/2}\,[12\,(2t_3 - \nu_f^2\,]^{1/4}\,E_f}{6\,(1 - \nu_f^2)\,L\,K_2\,K^{1/2}\,(8\,t_1\,t_3\,t_4)^{1/4}} \qquad (43)$$

$$K = R_2\,\frac{(1 - \beta/2)}{\cos\,\theta_c} \qquad (44)$$

$$\beta = \left[1 - \left(\frac{R_1}{R_2}\right)\right] \qquad (45)$$

$$D = \frac{E_f\,t_f^3}{(12)(1 - \nu^2)} \qquad (46)$$

$$D_\theta = (N + 1)\,\frac{I_\theta\,E_f}{L_o} \qquad (47)$$

$$L_o = \frac{R_2 - R_1}{\sin\,\theta} \qquad \theta > 0 \qquad (48)$$

$$L_o = L_C \qquad \theta = 0 \qquad (49)$$

$$L = \frac{L_o}{N + 1} \qquad (50)$$

$$P = \frac{\left[\dfrac{3 + S}{1 + S} + 1\right]}{\left(\dfrac{3 + S}{1 + S}\right)^{1/2}\left[\left(\dfrac{3 + S}{1 + S}\right)^{1/4} + \dfrac{S}{2}\right]} \qquad (51)$$

$$S = B\left(\frac{D_\theta}{D}\right)^{1/4}\,t_f^{1/2} \qquad (52)$$

$$B = \frac{2\pi\,K_1\,K^{1/2}}{K_2\,L\,K^2}\;\frac{[8\,t_1\,t_3\,t_4]^{1/4}}{[12\,(2t_3 - \nu^2)]^{1/4}} \qquad (53)$$

$$K_1 = \frac{K^3}{2\left(1 - \frac{\beta}{2}\right)^2} \left\{ 1 - \beta + \frac{\beta^2}{3} + \frac{\beta^2}{2\pi^2} - (1 - \bar{y})(1 - \beta)^2 \right.$$

$$\left. \pm \frac{L}{R_2} \frac{(WHS + W)\,G}{(144)\,P_{CR}} \left(1 - \beta + \frac{\beta}{3} + \frac{\beta}{2\pi^2}\right) \right\} \tag{54}$$

$$K_2 = K \left[1 \pm \frac{(WHS + W)\,G}{(144)\,P_{CR}} \sin \theta_c \right] \tag{55}$$

$$I_\theta = I_x - A_T \bar{y}^2 \tag{56}$$

$$W_e = m t_f, \quad \text{and} \quad b = nH \tag{57}$$

$$I_x = \frac{m t_f^4}{3} + t_f H (2n + 1) \left(\frac{H}{2} + t_f\right)^2 + \left(\frac{nH + t_f}{12}\right) H^3 - \frac{nH\,(H - 2t_f)^3}{12} \tag{58}$$

$$AT = t_f H (2n + 1) + m t_f^2 \tag{59}$$

$$\bar{y} = \frac{\frac{m t_f^3}{2} + t_f H (2n + 1)(H/2 + t_f)}{AT} \tag{60}$$

$$W = \frac{\pi \rho_f t_f (R_1 + R_2) L_o + 2\pi H t_f (2n + 1)\, \rho \left[NR_2 - \frac{NL_o \sin\theta}{2} \right]}{12\,\pi\,(R_1 + R_2)\,L_o} \tag{61}$$

6. Monocoque Tension Shell

$$t_{f3} = \frac{P_{CR}\,R_3}{C_1\,\sigma_f} \tag{62}$$

$$C_1 = \frac{2}{\left[1 - (R_2/R_3)^2\right]} \ln \left(\frac{1 + \cos\beta}{\sin\beta}\right) \tag{63}$$

$$W = \frac{W_{TT}}{AT} \tag{64}$$

$$W_{TT} = 2\pi \frac{\rho_f}{1728} \int_{\theta=\beta}^{\theta=\pi/2} \frac{t_f}{\sin\theta} \; y\left(\frac{dy}{d\theta}\right) d\theta \qquad (65)$$

$$AT = \frac{2\pi}{144} \int_{\theta=\beta}^{\theta=\pi/2} \frac{1}{\sin\theta} \; y\left(\frac{dy}{d\theta}\right) d\theta \qquad (66)$$

$$y \frac{dy}{d\theta} = \frac{-(R_2^2 - R_3^2)}{2 \sin\theta \ln\left(\frac{1+\cos\beta}{\sin\beta}\right)} \qquad (67)$$

$$t_f = \frac{R_3 \, t_3}{y} \qquad (68)$$

$$y = \left\{ R_3^2 + (R_2^2 - R_3^2) \frac{\ln\left(\frac{1+\cos\theta}{\sin\theta}\right)}{\ln\left(\frac{1+\cos\beta}{\sin\beta}\right)} \right\}^{1/2} \qquad (69)$$

7. Monocoque General Tension Shell

$$W = \frac{WTG}{AG} \qquad (70)$$

$$WTG = \frac{2\pi \, \rho_f}{1728} \int_{R_2}^{R_3} \frac{t_f \, y \, dy}{\sin\theta} \qquad (71)$$

$$AG = \frac{2\pi}{144} \int_{R_2}^{R_3} \frac{y \, dy}{\sin\theta} \qquad (72)$$

$$\cot\theta = \frac{x_j - x_i}{y_j - y_i} \qquad (73)$$

$$t_f = t_{f3} \frac{R_3^{1-a}}{y^{1-a}} \tag{74}$$

$$t_{f3} = \frac{-P_{CR}}{\left[-\sin\theta_{3G}\left(\frac{d\theta}{dy}\right)_3 + \frac{a\cos\theta_{3G}}{R_3}\right]\sigma_{cy}} \tag{75}$$

8. Compression Ring

$$WSCST = \frac{WR\,(144)}{2\pi\, R_{SC}\left[\frac{R_3\ \theta_3}{57.3} + R_{SC}\left(\sin\theta_3 - \frac{\theta_3\cos\theta_3}{57.3}\right)\right]} \tag{76}$$

$$WR = \frac{4\pi^2\ RR}{1728}\ t_R\ \rho_R\ (R_C - RR) \tag{77}$$

$$RR = \left(\frac{R_C^{\ 3}}{1.7\ \pi}\ \sqrt{\frac{2\pi\,(0.3)\ t_3\ \sigma_f}{E_R\ R_C}}\right)^{1/3} \tag{78}$$

9. Hot Structures

$$W\ C_p\ \frac{dT}{d\tau} = q_c\left(1 - \frac{H_w}{H_s}\right) + q_R - \epsilon\left(\frac{T_w}{1200}\right)^4 \tag{79}$$

10. Base Section

$$PCR = (P_{CR})_{aero} + \frac{(WHS + W)\,G}{144} \tag{80}$$

Monocoque

$$W = \rho_f \cdot \frac{t_f}{12} \tag{81}$$

$$t_f = \sqrt{\frac{3}{8}\quad \frac{R_T^{\ 2}\quad P_{CR}\cdot(3+\nu)}{\sigma_f}} \tag{82}$$

622<

Honeycomb

$$W = \frac{1}{12} \rho_c \cdot t_c + ZK + \frac{1}{6} \rho_f \cdot t_f \tag{83}$$

$$\rho_c = 0.22 \cdot \rho_r \cdot \left(\frac{P_{CR}}{\sigma_R} \right)^{0.58} \tag{84}$$

$$Z1 = \frac{\rho_f}{16} \tag{85}$$

$$Z3 = \frac{1}{16} \quad \frac{[P_{CR} \cdot (R_T)^2] (3 + \nu)}{(\sigma_f)} \tag{86}$$

$$(t_f)_{opt} = \sqrt{\frac{Z3}{Z1}} \tag{87}$$

$$(t_c)_{opt} = \frac{Z3}{t_f} \tag{88}$$

$$t_f = \frac{(P_{CR} \cdot R_T{}^2)(3 + \nu)}{16 (\sigma_f) t_c} \tag{89}$$

11. Yield Criteria

a. Cones, Cylinders

$$N_\theta = - \frac{\left[P_{CR} - \frac{(WHS + W)}{144} G \sin \theta \right] R}{\cos \theta} \tag{90}$$

b. Cones

$$N_\phi = \frac{-P_{CR}}{2 R \cos \theta} \left[R^2 + R_1{}^2 (\bar{\gamma} - 1) \right] + \frac{G (R^2 - R_1^2)(WHS + W)}{2 R \sin \theta \cos \theta (144)} \tag{91}$$

c. Cylinders

$$N_\phi = \frac{- P_{CR} R_C \bar{\gamma}}{2} - \frac{G (L_C)(WHS + W)}{(144)} \tag{92}$$

d. M-H Criteria

$$N_y^2 = N_\theta^2 + N_\phi^2 - N_\theta \ N_\phi \tag{93}$$

e. Elastic Yield Requirements (sandwich construction)

$$t_f \geq \frac{(N_y)\,\max}{2\,\sigma_f} \tag{94}$$

f. Combined stress

$$\text{SIGMH} = \frac{(N_y)\,\max}{2\,t_f} \tag{95}$$

g. Meridional stress

$$\text{SIGM} = \frac{N_\phi}{2\,t_f} \tag{96}$$

h. Circumferential stress

$$\text{SIGH} = \frac{N_\theta}{2\,t_f} \tag{97}$$

IV. IBM ROUTINES

A. PROGRAM FLOW

Given vehicle geometry, structural material properties, and pressure loads, Program 1886 computes the weight of the external structure on each segment of the vehicle which will survive reentry. The segments of the vehicle may include a spherical nose cap, cones, cylinders, rear spherical cap, tension shell, and general shell. The program flow diagram is shown in Figure 8.

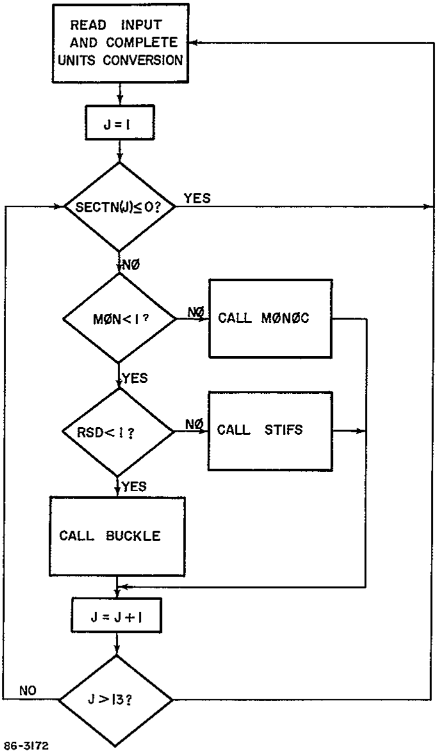

Figure 8 Flow Diagram For Program 1886

B. MAIN PRØGRAM

1. Purpose

The purpose of the main program is to acquire the program input, and make any necessary units conversions before transfering control to the appropriate subroutine for the calculation of the structural weight.

2 Method

Initially the types and dimensions of main program variables are specified and common storage is set up for the transmission of data to subroutines BUCKLE, MØNØC, and STIFS.

In the first executable statements of the program tables of BT (the geometric Parameter β) and of the dependent variables T1T, T3T, and T4T are defined element by element in arithmetic statements.

In the DØ 10 loop CØMMØN data (from SECTN through DELK2) is preset to 0. Since most of the program input variables appear in CØMMØN, this loop zeros out a large portion of the namelist data. The remainder of the input is preset in the data and arithmetic statements immediately following Statement 10.

The data is read in through the namelist array INPUT and immediately written on the output tape. The vehicle radii are then converted to inches, and the angles to radians for internal use If RB and TINIT have not been specified, they are taken to be RC and TEMPI, respectively.

In the DØ 30 loop NTAU, the number of elements in the array TIME, is calculated (by searching for the first 0 beyond the first element of the array).

Then for each vehicle section specified in the array SECTN, the DØ 100 loop transfers control to one of the subroutines BUCKLE, MØNØC, or STIFS according to the following criteria: if MØN $\geq$ 1, subroutine MØNØC is called; if MØN $<$ 1 and RSD $\geq$ 1, subroutine STIFS is called; if MØN$<$ 1 and RSD $<$ 1, subroutine BUCKLE is called The first value of SECTN $\leq$0 encountered terminates the current case. Control is then transferred back to the READ statement for processing the next case.

3. CØMMØN STØRAGE

The variables in CØMMØN STØRAGE are those input variables (with units modified if necessary) which must be transmitted to one of the subroutines BUCKLE, MØNØC, or STIFS. Unless a modification is specified, the CØMMØN variable is precisely the input value.

Variable	Definition (if not directly input)
SECTN	
HTST	
HT0P	
GAMFI	GAMF
GFTAB	
EFI	EF
EFTAB	
R0F	
SGFI	SIGCYF
SGFTAB	
GAMRI	GAMR
GRTAB	
ER	
R0R	
SGRI	SIGCYR
SGRTAB	
KADHES	
PCR	
TFMIN	
TCMIN	
TCMAX	
R0CMIN	
R0CMAX	
GAMBAR	
CBAR	
WHS	
G	
HS	
EM	
EN	
NFAC	
NTERM	
EPS	
RNI	12. · RN
RSNI	12. · RSN
THNR	THN · (π /180)
RAI	12. · RA
THAR	THA · (π /180)
THCR	THC · (π /180)
RBI	12. · RB for RB> 0; 12. *RC for RB$\leq$ 0.
RSBI	12. · RSB
THBR	THB · (π / 180)
RCI	12. · RC
RSCI	12. · RSC
XLCI	12. · LC

RTI	12.*RT
BETA	
A	
TH2G	
TH3G	
RØRG	
SIGRG	
DTHDY	
DELTAU	
EMISTR	
QCMULT	
QRMULT	
XN	
XØ	
XA	
XC	
TEMPI	
TEMPA	
X	
R	
TTAB	
CPTAB	
TIME	
HTBL	
QTBL	
RTBL	
TINITL	TINIT if TINIT>0; TEMPI if TINIT $\leq$ 0
TSTØP	
NTAU	Number of values in TIME array
DELK1	
DELK2	
JJJ	Index of current vehicle section
IGØ	SECTN (JJJ), ie identification of current section
DPC	GAMBAR*CBAR
BT	Table of geometric parameter β
T1T	Table of t_1
T3T	Table of t3
T4T	Table of t4

C. SUBRØUTINE CALLING SEQUENCES

1. NØSE	Variable	Input or Output	Variable	Input or Output
	R	INPUT	WØPT	OUTPUT
	THETA	INPUT	W	OUTPUT
	PCR	INPUT	WT	OUTPUT
	GAMF	INPUT	TFUSED	OUTPUT
	EF	INPUT	TCUSED	OUTPUT

1. NØSE	Variable	Input or Output	Variable	Input or Output
(Cont'd)				
	RØF	INPUT	SIGMH	OUTPUT
	SGF	INPUT	ICHK	OUTPUT
	GAMR	INPUT		OUTPUT
	SGR	INPUT		
	RØR	INPUT		
	TCMX	INPUT		
	TCMN	INPUT		
	TFMN	INPUT		
	RØMX	INPUT		
	RØMN	INPUT		
	ZK	INPUT		
	WHS	INPUT		
	G	INPUT		
	IGØ	INPUT		
	TCY	ØUTPUT		
	RØC	ØUTPUT		
2. CØNE				
	GAMF	INPUT	WHS	INPUT
	EF	INPUT	G	INPUT
	RØF	INPUT	SINTH	INPUT
	SGF	INPUT	CØSTH	INPUT
	GAMR	INPUT	IGØ	INPUT
	SGR	INPUT	DELZ1	INPUT
	RØR	INPUT	DELZ2	INPUT
	PCR	INPUT	TCY	ØUTPUT
	DPC	INPUT	RØC	ØUTPUT
	ZK	INPUT	WØPT	ØUTPUT
	RØMX	INPUT	W	ØUTPUT
	RØMN	INPUT	WT	ØUTPUT
	TCMX	INPUT	TFUSED	ØUTPUT
	TCMN	INPUT	TCUSED	ØUTPUT
	TFMN	INPUT	SIGMH	ØUTPUT
	BT	INPUT	SIGH	ØUTPUT
	T1T	INPUT	SIGM	ØUTPUT
	T3T	INPUT	ICHK	ØUTPUT
	T4T	INPUT		
	R1	INPUT		
	R2	INPUT		
3. CYLIND				
	RC	INPUT	TCY	ØUTPUT
	GAMF	INPUT	RØC	ØUTPUT
	EF	INPUT	WØPT	ØUTPUT
	RØF	INPUT	W	ØUTPUT

3. CYLIND	Variable	Input or Output	Variable	Input or Output
(Concl'd)	SGF	INPUT	WT	0UTPUT
	GAMR	INPUT	TFUSED	0UTPUT
	SGR	INPUT	TCUSED	0UTPUT
	R0R	INPUT	SIGMH	0UTPUT
	PCR	INPUT	SIGH	0UTPUT
	DEL	INPUT	SIGM	0UTPUT
	R0MN	INPUT	ICHK	0UTPUT
	R0MX	INPUT		
	TCMN	INPUT		
	TCMX	INPUT		
	TFMN	INPUT		
	ZK	INPUT		
	DPC	INPUT		
	WHS	INPUT		
	G	INPUT		
	DELK1	INPUT		
	DELK2	INPUT		
4. BASE				
	RT	INPUT	R0C	0UTPUT
	GAMF	INPUT	ICHK	0UTPUT
	R0F	INPUT		
	R0R	INPUT		
	SGF	INPUT		
	SGR	INPUT		
	PCR	INPUT		
	R0MX	INPUT		
	R0MN	INPUT		
	TCMX	INPUT		
	TCMN	INPUT		
	TFMN	INPUT		
	ZK	INPUT		
	WHS	INPUT		
	G	INPUT		
	W0PT	0UTPUT		
	W	0UTPUT		
	WT	0UTPUT		
	TFUSED	0UTPUT		
	TCUSED	0UTPUT		
5. TENSI0N				
	BETA	INPUT		
	RC	INPUT		
	RSC	INPUT		
	RSN	INPUT		
	RN	INPUT		

5. TENSIØN (Concl'd)	Variable	Input or Output	
	PCR	INPUT	
	THN	INPUT	
	SIGCYF	INPUT	
	RØF	INPUT	
	WTENST	ØUTPUT	
	WTT	ØUTPUT	
	AT	ØUTPUT	
	T3	ØUTPUT	
	WR	OUTPUT	
	RR	ØUTPUT	
	TR	ØUTPUT	
	WSCST	ØUTPUT	
	ER	INPUT	
	RØRG	INPUT	
	SIGRG	INPUT	
	TFMN	INPUT	

6. GNRLSH	Variable	Input or Output	Variable	Input or Output
	X	INPUT	TFMN	INPUT
	Y	INPUT	DTHDY3	INPUT
	A	INPUT		
	SIGCYF	INPUT		
	RØF	INPUT		
	TH2D	INPUT		
	TH3D	INPUT		
	PCR	INPUT		
	RØRG	INPUT		
	ER	INPUT		
	SIGRG	INPUT		
	RSC	INPUT		
	RC	INPUT		
	WR	ØUTPUT		
	TR	ØUTPUT		
	RR	ØUTPUT		
	WSCST	ØUTPUT		
	T3	ØUTPUT		
	WGENST	ØUTPUT		
	WTG	ØUTPUT		
	AG	ØUTPUT		

7. RING			
	THD	INPUT	
	R3	INPUT	
	T3	INPUT	
	RSC	INPUT	

7. RING	Variable	Input or Output		
(Concl'd)	ER	INPUT		
	SIGRG	INPUT		
	RC	INPUT		
	SIGCYF	INPUT		
	RØRG	INPUT		
	WR	ØUTPUT		
	RR	ØUTPUT		
	TR	ØUTPUT		
	WSCST	ØUTPUT		
8. HØTSTR	Variable	Input or Output	Variable	Input or Output
	XN	INPUT	W	INPUT
	XØ	INPUT	WSTAR	ØUTPUT
	XC	INPUT		
	XA	INPUT		
	TTAB	INPUT		
	TEMPI	INPUT		
	NTAU	INPUT		
	TAU	INPUT		
	TAUMAX	INPUT		
	QC	INPUT		
	QR	INPUT		
	HGØRT	INPUT		
	FR	INPUT		
	FC	INPUT		
	CPTAB	INPUT		
	DELTAU	INPUT		
	EMISS	INPUT		
	TEMPA	INPUT		
	EPS	INPUT		
	TAUT	ØUTPUT		
	TW	ØUTPUT		

D. SUBROUTINES, DESCRIPTIØNS

1. Subroutine BUCKLE

a. Purpose

The purpose of subroutine BUCKLE is to control the computation of the structure weights for sections having a honeycomb construction, and to provide the program output for those sections.

b. Method

Subroutine BUCKLE receives all of its input data from the main program through CØMMØN. It does not redefine any of this data, or transmit any information back to the main program.

At the first executable statement of BUCKLE the variable ICHK is set to 12345. Any subsequent change in ICHK will be an indication of computational difficulty, and appropriate action will be taken to inform the user of the situation (error messages and the deletion of further computation on the particular section). PI is defined, and the identification number of the current section is written on the output tape, logical tape 6.

There are two possible paths for the computation to take, depending on whether or not the section is to be run under the hot structures option (for which HTST is input as 1.)

If HTST $\neq$ 1, control is transferred immediately to statement 250 where a computed GØ TØ on the section number picks the correct method of computing the weight. For all sections but tori the appropriate data is supplied to one of the subroutines NOSE, CONE, TENSON, GNRLSH, CYLIND, or BASE which will carry out the actual computation. For the tori, which cannot in reality be handled by the program, the unit section weight is taken as the weight of the immediately preceding section; however, this weight is then multiplied by the torus area in finding the total weight. The weights, face sheet and core thicknesses, and core densities are placed in arrays from which they are finally printed on the output tape. For tori the weights are printed between statements 21 and 25, and return is made to the main program. For the other sections the block of statements between 255 and 2684 provides for writing all the output. This block is entered either at statement 255 or 260 after the return from the particular section subroutine. The computed GØ TØ at 261 controls setting up the correct headings to print only the information applicable for a particular section. The IF test at statement 2645 checks for nonconvergence of the weight iteration. If nonconvergence is detected, an error message is written. Return is then made to the main program.

In the case of a hot structure not only does the final weight depend upon the temperature rise computed by the program, but the material properties used in the honeycomb analysis are themselves a function of temperature. This second dependence makes an iterative scheme necessary to handle the weight computation. The numerical method used is standard false position applied to the temperature, the initial guesses being TINIT and TEMPA. To ensure convergence it is necessary that the actual temperature lie between TINIT and TEMPA. (If TINIT is not specified, it is taken to be TEMPI.) At Statement 230 the temperature TEMP is set to TINIT to start the process. Then NN (the number of iterations), WQ, and FTMP1 are initialized. At 245 the material properties corresponding to TEMP are looked up in tables EFTAB, SGFTAB, GFTAB, GRTAB, and SGRTAB, and control is transferred to the appropriate subroutine for a weight computation. After a transfer back to 260 the hot structures option switches control to 269 where subroutine HØTSTR calculates the maximum temperature TWMAX and, if necessary, the increased weight WQ. After the return form HØTSTR an IF test checks the difference between the original temperature TEMP and TWMAX. If the relative difference is less than 1 percent the iteration is terminated immediately, and control is passed to the output block at Statement 261. If the difference is greater than 1 percent, control is passed back to Statement 240 where NN is updated. The statements following 240 provide, in general for saving the last two temperature estimates TMP1 and TMP2 which bracket the root, along with the differences FTMP1 and FTMP2 between these estimates and their corresponding values of TWMAX. On this first pass TMP1 and FTMP1 are presumably set to TINIT and TINIT-TWMAX. A second pass is then made through the entire computation sequence with TEMP set to the value TEMPA. At 242 TMP2 will be set to TEMPA and FTMP2 to TEMPA-TWMAX. Then the false position algorithm computes a new projected temperature from TMP1, TMP2, FTMP1, and FTMP2 at statement 2425, and tests to make sure that TEMPA is not exceeded. (A value of TEMP>TEMPA results in an error message and return to the main program.) The iteration now continues until the relative difference between TEMP and TWMAX is less than 1 percent. The results are then printed and a return is made to the main program. (If convergence has not occurred within 10 iterations, the process is terminated and the last values printed out.)

2. Subroutine MØNØC

a. Purpose

The purpose of subroutine MØNØC is to calculate the structure weights of those sections having a monocoque construction and to provide the program output for these sections.

b. Method

Subroutine MØNØC receives all of its input data from the main program through CØMMØN. It does not redefine any of this data, or transmit any information back to the main program.

Like BUCKLE subroutine MØNØC can be called either with or without the hot structures option. However, unlike BUCKLE, MØNØC can handle a vehicle section only if it is a spherical cap or flat base (i.e. one of Sections 1, 12, or 13).

If HTST 1, there is a single level search performed for the weight, taking account of the inertia of the heat shield and structure. After the section number has been written out, control switches down to Statement 250 where an initial value of the unit weight WSTAR is computed using minimum gage thickness, and NIT, the number of iterations, is initialized. The computed GØ TØ on the section number results in an error message and return for any section other than 1, 12, or 13.

For the nose sphere or aft sphere the radius R, the shell height H, and a sign factor PFAC are set at statements 1 and 12, respectively. For either of these sections transfer is then made to Statement 300 where SMATM, an expression appearing in the pressure computations, is calculated, and the face sheet thickness SMAT is set initially to minimum gage. The search method between Statements 400 and 600, looks for a change of sign (from positive to negative) of the expression PCR-PTEST. Until such a change is detected, the statements are repeated with SMAT being increased by the factor EPSP1 $(1+f)$. A value of WSTAR is computed to correspond to each SMAT. (A maximum of 500 such increases in SMAT is allowed before an error message and return terminates calculations for the section.) Once the sign change has been detected, a final value of pressure P and yield thickness TY are calculated beginning at Statement 750. The final thickness is taken as the maximum of SMAT and TY, and WSTAR is again computed using this maximum. The total weight W and yield stress criteria SIGMH are then computed. Transfer is made to Statement 850 for the printout of results and return to the main program.

In the case of a flat base a first order iteration scheme is used to compute the unit weight rather than a search. The radius R is set to RT, and the initial estimate for WSTAR (using minimum gage thickness) is stored in W1. W1 will be used to keep track of the last previous iterate, and thus updated on each pass. The pressure and face sheet thickness are computed. An IF test ensures that the thickness is at least minimum gage, and a new weight WSTAR is calculated at Statement 132. If the relative difference between W1 and WSTAR is less than 1 percent, the last value of WSTAR is taken as the unit weight and a transfer is made to Statement 137 for the computation of the total weight, printout of results, and return to the main program. If the difference is greater than 1 percent transfer is made back to Statement 130 for the next iteration. Failure attain convergence within 25 iterations results in an error message at Statement 136 and return to the main program.

If HTST = 1, the same false position iteration scheme used in subroutine BUCKLE finds the weight as a function of temperature. This iteration is performed outside the iteration or search described above, thus making the entire iterative scheme a two-level process. The call to subroutine H0TSTR is now at Statement 810.

3. Subroutine STIFS

a. Purpose

The purpose of subroutine STIFS is to calculate the structure weights of those sections having a ring-stiffened construction, and to provide the program output for these sections.

b. Method

Subroutine STIFS receives all of its data from the main program through C0MM0N. It does not redefine any of this data, or transmit any information back to the main program.

STIFS can be called with or without the hot structures option. It handles a vehicle section that is a cone, cylinder, flare forecone, or aftcone (Sections 3, 7, 8, 11). At Statement 200 a computed G0 T0 tests that the current section is indeed one of these four. If not, a transfer to Statement 2000 results in an error message and immediate return to the main program. If the section can be handled, values of R1, R2, RTHETA, and XKFAC are calculated from the appropriate geometry parameters, beginning at one of the Statements 5551, 5552, 5553, or 5554. Transfer is then made to Statement 5555 where several variables depending on the vehicle geometry are calculated, and the section number and a heading are written out. The program flow beyond Statement 65 depends upon whether or not the section is a hot structure, and whether HT0P has been specified as 1. or 2.

Consider first the case HTST = 0, HT0P = 1. The object will be to find a thickness (t) satisfying both local and general stability conditions and a number (N) of rings which will minimize the structure weight. Since the inertia of the heat shield and structure are to be taken into consideration, an iterative method is again necessary in the weight calculations. In STIFS this iteration is carried out for each number (N) of rings considered.

Since HTST = 0, the test following Statement 65 transfers control down to 68 where N, the current number of rings, is set to 1 (although the N = O case will actually be handled first), and the control parameters ITEST and IG0T0 are initialized to 1. Since HT0P = 1, H is set to the input value HS. Between Statements 683 and 9 an additional block of variables is initialized including TL the thickness required for local stability, TG the thickness required for general stability, and SMAT, which is always the current thickness being used in the calculations. The block of statements between 9 and 15 performs the major computations of the routine.

Initially the case N = O is considered. (The routine recognizes this case by the fact that ITEST is still 1.) The computed GØ TØ before Statement 155 transfers control to 155 where PAS, the pressure just computed at Statement 15 is tested against the input value PA(PCR). If PA>PAS, TG is increased by the factor EPSP (1. + EPS), SMAT is set equal to TG and a transfer back to statement 12 begins a repetition of the computations. The loop thus formed is retraced until finally PAS ≥ PA, the variable M keeping track of the number of iterations. At Statement 17 the total weight WN and the unit weight WSTAR are calculated as a function of the current TG.

The computed GØTØ at Statement 20 transfers control to 28 since IGØTØ is still 1. Here the first order iteration procedure necessitated by structural inertia considerations tests for convergence of the unit weight WSTAR. WSTAR is compared with W1, the last previous iterate. (W1 was initialized to 0. just after Statement 5555 to take care of the first pass.) Ten iterations are allowed for obtaining convergence of the weight. On each iteration the looping process to obtain TG is repeated. The transfer back to statement 85 ensures that all the necessary reinitialization is included. Convergence is defined as a relative difference of less than 1 percent between W1 and WSTAR. If convergence is not reached within 10 iterations, an error message is written at Statement 295, and return is made to the main program. If convergence is attained, IGØTØ is reset to 2 at Statement 301.

The block of statements between 302 and 312 calculates the yield stress criteria. If the section is one of the cones, its entire length must be searched for the point of maximum allowable stress XNYMAX. XNYMAX is initially set to 0, and R to R2, the largest value of the cone radius. In the DO 305 loop a value of XNY is calculated at each of 10, equally-spaced points along the length of the cone as R decreases to R1, the smallest cone radius. XNYMAX is defined as the maximum of the 10 XNY values obtained in the loop. Values of XNTH and XNPHI to be used in evaluating the stress components are also calculated corresponding to XNYMAX. If the section is a cylinder, XNTH, XNPHI, and XNYMAX are evaluated directly. In either case TCY, the minimum thickness satisfying yield requirements, is calculated at Statement 308, and tested against TG. If TCY>TG, TG is reset to TCY, and the weights must be recalculated at Statement 17 to correspond to the new thickness. In this case the computed GØTØ brings control back to Statement 312 since IGØTØ is now 2. Here the stress component calculations are completed, the minimum weight WGTMIN is set to the current weight value, TL is set equal to TG, and the N = O results are printed. (ISW was set to 1 following Statement 5555, since HTST = O).

At 321 the N = 1 case is begun. (Statement 32 which ordinarily will compute the next N is skipped since N was set to 1 at the beginning of the routine.) The IF test on DN checks to see that the maximum number of rings is not exceeded. Initializations are completed, ITEST is set to 2 and IGØTØ to 3, and control is transferred back to the computation block at Statement 10. The computed GØTØ with ITEST = 2 chooses the test at Statement 16. This test and the statements starting at Statement 36 decrease TL (which was set to the TG obtained for the last N) by the factor EPSM**M($(1.-EPS)^M$), until PA $\geq$ PAS or TL $<$ TM. The weights are then computed at Statement 17, and the transfer to Statement 37 (IGØTØ = 3) sets up conditions for the general stability calculations. By the time the transfer back to Statement 9 takes place ITEST has been reset to 1 and IGØTØ to 4. The same general stability loop is repeated as in the O-ring case, TG being increased by EPSP until PAS $\geq$ PA.

The transfer from Statement 20 is now to Statement 39 where the first order iteration is begun for the N = 1 case. Both the TL and TG loops must be repeated for each iteration, as is indicated by the transfer to Statement 322 each time the relative difference between W1 and WSTAR is greater than 1 percent. When convergence has been attained, the stress calculations are repeated starting at Statement 302, but with IGØTØ now 5. Thus, when the stress calculations have been completed, the test on IGØTØ before Statement 318 brings control down to Statement 397 where the current weight is tested against WGTMIN the running minimum. WGTMIN is reset if the current WN is smaller. The results for N = 1 are printed, and the computations for the next N are begun at statement 32 where N is calculated as a function of its current value and the input parameters NFAC and NTERM.

The computations are repeated in this same manner for each new N until N exceeds the maximum allowable value XLØ/EM/TG. Then at Statement 43 the current minimum weight is taken as the final result. The unit and total weights are printed at statement 44, and return is made to the main program.

If HTØP = 2, the stiffener height (H) is intialized to 1. at Statement 682 before the computations begin. The N = O calculations, and the iterations for TL when N>O proceed exactly as in the HTØP = 1 case. However, when N>1 and the general stability calculations are set up starting at Statement 37, ITEST is set to 3 instead of 1. The computed GØTØ in the calculation block picks the test at 163. The object now is to find the value of H for which PA = PAS. If initially PA>PAS, ITEST is set to 5 and H is increased by the factor EPSP until a change of sign in PA-PAS occurs. (On the second and succeeding passes the test at 168 is used.) If initially PA< PAS, ITEST is set to 4, and H is decreased by the factor EPSM until a sign change in PA-PAS is detected. (On the second and succeeding passes the test at 169 is used.) Then the weight is calculated at Statement 17 as in the HTØP = 1 case. The remainder of the program logic is not affected by HTØP.

In cases where HTST = 1 false position iteration on the temperature is used in the weight calculations as in subroutines BUCKLE and MØNØC. This iteration is performed outside all the other computations carried out by the routine. The iteration loop itself extends from statement 67 to the IF test at 577. The variable ISW which has the value 2 initially, suppresses the printing of results until convergence has been achieved. Then the final iteration is repeated with ISW reset to 1 to obtain the printout.

4. Subroutine NØSE

a. Purpose

The purpose of subroutine NØSE is to calculate the honeycomb structure weights for the nosesphere and aftsphere sections (Sections 1 and 12) of the vehicle when specific geometry conditions and material properties are given.

b. Method

First order iteration is used to compute the weight, taking into account the inertia of the heat shield and structure. This iteration starts at Statement 800 after several terms that are to be constant during the looping process have been calculated, and the weights W and WØPT and the number of iterations NIT have been initialized to 0. At 800 W1 which will be the value of the last previous iterate is set equal to W. Then the pressure P, depending on W, is calculated and its sign tested.

If $P \leq 0$, the face sheet thickness and core height are taken as minimum gage. The weight (W), total weight (WT), and yield stress criteria (SIGMH) are computed, and an immediate return to the calling routine is executed.

If $P > 0$, the iteration continues. The core density (RØC) is calculated, and tested to make sure that it lies between the minimum and maximum values specified in the program input. If RØC < RØMN (RØCMIN), it is set to RØMN; if RØC > RØMX (RØCMAX), it is set to RØMX. Then TCY the face sheet thickness required to satisfy yield criteria is computed. TEST1 is defined as the larger of TCY and TFMN (TFMIN). Next TFØPT, the optimum face sheet thickness satisfying buckling criteria is computed and compared with TEST1.

Case (1). TFØPT > TEST1

Control is transferred to Statement 6 for the computation of TCØPT, the optimum core height. TCØPT is then checked to ensure that it lies between TCMN (TCMIN) and TCMX (TCMAX).

a. TCMN ≤ TCØPT ≤ TCMX

TFUSED and TCUSED are set to TFØPT and TCØPT, respectively, and the weight is computed as WØPT. (This is the only case in which WØPT is computed, and only if the final iteration computes a value of WØPT will a nonzero WØPT be returned to the calling routine.) W is set equal to WØPT and transfer is made to Statement 103.

b. TCØPT < TCMN

A value TF of the face sheet thickness is computed as a function of TCMN at Statement 7. TFUSED is defined as the larger of TF and TEST1, and TCUSED is set to TCMN. The weight (W) is then computed as a function of TFUSED and TCUSED at Statement 100.

c. TCØPT > TCMX

TFUSED is set to TFØPT and TCUSED is set to TCMX at Statement 14. Then W is computed as a function of TFUSED and TCUSED at Statement 100.

Case (2). TFØPT ≤ TEST1

TFUSED is set to TEST1 at Statement 16. TCUSED is computed as a function of TFUSED, then redefined as TCMN or TCMX if it lies, respectively, below or above the allowable range. (W) is then calculated at Statement 100.

In all cases the relative difference between W and W1 is checked at Statement 103. If this difference is less than 1 percent, the iteration is terminated, the total weight (WT) and the yield stress criteria (SIGMH) are computed, and a return to the calling routine is executed. If the difference is greater than 1 percent, the number of iterations NIT is updated at Statement 105, and tested against 10. If NIT < 10, a new iteration is begun at Statement 800. If NIT ≥ 10, ICHK is set to 1 as an error indication, and the last results obtained are returned to the calling routine.

5 Subroutine CØNE

a. Purpose

The purpose of subroutine CØNE is to calculate the honeycomb structure weights for the cone, flare fore cone, and aftcone sections (Sections 3, 8, and 11) of the vehicle, when specific geometry conditions and material properties are given.

b. Method

Subroutine CØNE uses the same first order iteration scheme used in NØSE, and the same logical procedure for obtaining the final values of TFUSED and TCUSED. (See the description of subroutine NØSE for details.) As far as program flow is concerned, the major difference between the two routines lies in the calculation of the maximum allowable stress XNYMAX. Immediately after Statement 800 (the beginning of the iteration loop), XNYMAX is initialized to 0., and R set to R2, the maximum value of the cone radius. In the DØ 805 loop a value of XNY is calculated at each of 10 equally-spaced points along the length of the cone as R decreases to R1, the minimum cone radius. XNYMAX is defined as the maximum of the 10 XNY values obtained in the loop. For the cones the circumferential stress (SIGH) and the meridional stress (SIGM) are calculated in addition to the resultant yield stress criteria (SIGMH) (XNYMAX/(2. TFUSED)).

6. Subroutine CYLIND

a. Purpose

The purpose of subroutine CYLIND is to calculate the honeycomb structure weight for the cylindrical section (Section 7) of the vehicle, when specific geometry conditions and material properties are given.

b. Method

The logical flow of subroutine CYLIND is essentially identical to that of subroutine NØSE. The first order iteration loop extends from Statement 3 to the GØ TØ 3 statement following 250. No loop is required for the calculation of the yield stress criteria as in CYLIND. However, the circumferential stress SIGH and the meridional stress SIGM are computed along with SIGMH before the return to the calling routine.

7. Subroutine BASE

a. Purpose

The purpose of subroutine BASE is to calculate the honeycomb structure weight for the BASE section (Section 13) of the vehicle, when specific geometry conditions and material properties are given.

b. Method

The first order iteration scheme is the same as in subroutine NØSE. The iteration loop starts at Statement 800 and ends at 240. However, the procedure for obtaining TFUSED and TCUSED is somewhat simpler since no-face sheet thickness is computed to satisfy yield criteria. TFUSED is defined on each iteration as the larger of TFØPT and TFMN (TFMIN). TCUSED, after being calculated as a function of TFUSED, is tested against TCMN (TCMIN) and TCMX (TCMAX). If TCUSED < TCMN it is redefined to be TCMN; if TCUSED > TCMX, it is redefined as TCMX. In either of these two cases TFUSED is then redefined to correspond at Statement 9.

8. Subroutine TENS0N

a. Purpose

The purpose of subroutine TENS0N is to compute the structural weight and area of the tension shell (Section 4).

b. Method

Simpson's rule is used to calculate the total weight WTT and the area AT. In the D0 60 loop the integrands W and A are calculated at 25 equally-spaced points between the initial angle BETA and $\pi/2$. Subroutine ARSIMP is then called twice to apply the Simpson's Rule formula. The unit weight WTENST is calculated as the total weight divided by the area, and subroutine RING is called to obtain the structural weight thickness and radius of the compression ring. Return is then made to the calling routine.

9. Subroutine GNRLSH

a. Purpose

The purpose of subroutine GNRLSH is to compute the structural weight and area of the general shell (Section 5).

b. Method

The Trapezoidal rule is used to calculate the total weight WTG and the area AG. In the 3-statement loop starting at Statement 10 the number of values of the coordinates X and Y which have been input are counted. The counting procedure assumes that a 0. follows the last value of the Y array. (Therefore, special care must be taken in stacking cases). Between Statements 123 and 60 an array AFUNCT of integrands for the area and an array WFUNCT of integrands for the total weight are generated. (Each element in these arrays corresponds to a point in the original X and Y arrays.) The trapezoidal rule is applied to AFUNCT and WFUNCT in the 5 statements starting at 61. The results of the integration WTG and AG are multiplied by appropriate factors, and the unit weight WGENST is calculated. A call to subroutine RING obtains the structural weight, thickness, and area of the compression ring. Return is then made to the calling routine.

10. Subroutine RING

a. Purpose

The purpose of subroutine RING is to compute the structural weight, thickness, and radius of the compression ring.

b. Method

Straightforward evaluation of the formulas in arithmetic statements.

11. Subroutine HØTSTR

a. Purpose

The purpose of subroutine HØTSTR is to compute the maximum structural temperature TWMAX, and increase the structure weight if necessary to ensure that TWMAX is no greater than the input value TEMPA.

b. Method

Starting with W supplied by the calling routine, the initial temperature TEMPI, and the initial time value TAU(1) (input as TIME (1)), the routine calculates the temperature rise DELTAT in successive intervals of time (each of length DELTAU). The heating factors QCI, QRI, and HGØRI which are used in the expression for DELTAT are looked up in tables QC, QR, and HGØRT (input as QTBL, RTBL, and HTBL, respectively) for each new point in time. Should TAUMAX (TSTØP) be specified as larger than the final value of the TAU table, these heating factors are set to 0. in the region beyond the ends of the tables.

After DELTAT has been computed, its sign is tested to check for a change from positive to negative, signifying a maximum temperature point. If DELTAT is initially negative, two sign changes must be encountered before it is assumed that the maximum temperature has been found. The computed GØ TØ controlled by IDEL at Statement 40 handles such a case.

If a particular value of DELTAT is positive, of if DELTAT is negative, but there has been no previous positive value, the current time TAUT in increased by DELTAU, and checked to make sure that it is less than TAUMAX.

If TAUT < TAUMAX, TW the current temperature is computed at Statement 60, and checked against TEMPA. If TW < TEMPA, the transfer to Statement 25 continues the process at the new time value. If TW ≥ TEMPA, WSTAR, the current weight, is increased by the factor EPSP1 (1. + EPS), and the process is restarted at the initial point in time and temperature.

If TAUT ≥ TAUMAX, (i.e., no maximum is found within the specified time interval), the temperature and weight at the final time point are taken as the result. A return to the calling routine is executed.

When a change in the sign of DELTAT from positive to negative is detected, an immediate return is made to the calling routine with the current values of weight, time, and temperature.

E. SIGNIFICANT EQUATIØNS

1. MAIN Program

$$\text{DPC} = \text{GAMBAR} \cdot \text{CBAR}$$

2. BUCKLE

$$\text{TEMP} = \text{TMP1} - \text{FTMP1}\left(\frac{\text{TMP1} - \text{TMP2}}{\text{FTMP1} - \text{FTMP2}}\right)$$

(False position algorithm for hot structures temperature iteration.)

3. MØNØC

$$\text{TEMP} = \text{TMP1} - \text{FTMP1}\left(\frac{\text{TMP1} - \text{TMP2}}{\text{FTMP1} - \text{FTMP2}}\right)$$

a. Spherical Caps

nose sphere	$R = RN$	$H = R(1 - \sin(THN))$
aftsphere	$R = RA$	$H = R(1 + \sin(THA))$

$$\text{PTEST} = \mp \frac{(\text{WHS} + \text{WSTAR})G}{144} + E\left(\frac{\text{SMAT}}{\text{SMATM}}\right)^{7/3}$$

where SMAT is the current t_f.

$$\mathrm{SMATM} = 1\ 2\,(1 - \mathrm{XNU}^2)^{2/7} \left(\frac{\mathrm{H}}{\mathrm{R}}\right)^{1/7} \mathrm{R}$$

$$\mathrm{WSTAR} = \frac{\mathrm{RHO} \cdot \mathrm{SMAT}}{12}$$

$$\mathrm{P} = \mathrm{PCR} \pm \frac{(\mathrm{WHS} + \mathrm{WSTAR})\,\mathrm{G}}{144}$$

$$\mathrm{TY} = \frac{\mathrm{P} \cdot \mathrm{R}}{2 \cdot \mathrm{SGF}}$$

$$\mathrm{SIGMH} = \left[- \mathrm{PCR} \mp \frac{(\mathrm{WHS} + \mathrm{WSTAR})\,\mathrm{G}}{144} \right] \frac{\mathrm{R}}{2 \cdot \mathrm{SMAT}}$$

$$\mathrm{W} = \frac{\mathrm{WSAR}\,(2\pi)\,\mathrm{H} \cdot \mathrm{R}}{144}$$

b. base

$$\mathrm{P} = \mathrm{PCR} + \frac{(\mathrm{WHS} + \mathrm{WSTAR})\,\mathrm{G}}{144}$$

$$\mathrm{SMAT} = \left[\frac{0.375\,(\mathrm{R})^2\ \mathrm{P}\,(3 + \mathrm{XNU})}{\mathrm{SGF}} \right]^{1/2}$$

$$\mathrm{WSTAR} = \frac{\mathrm{RHO} \cdot \mathrm{SMAT}}{12}$$

$$\mathrm{W} = \frac{\mathrm{WSTAR}\quad \pi \mathrm{R}^2}{144}$$

4. STIFS

$$\mathrm{TEMP} = \mathrm{TMP1} - \mathrm{FTMP1}\left(\frac{\mathrm{TMP1} - \mathrm{TMP2}}{\mathrm{FTMP1} - \mathrm{FTMP2}}\right)$$

$$\mathrm{BETAG} = 1 - \frac{\mathrm{R1}}{\mathrm{R2}}$$

$$\mathrm{BETA} = \frac{\mathrm{BETAG}}{\mathrm{DN} + 1}$$

$$\mathrm{XL\emptyset} = \begin{cases} \dfrac{\mathrm{R2} - \mathrm{R1}}{\mathrm{SINT}} & \text{Cones} \\ \mathrm{XLC} & \text{Cylinder} \end{cases}$$

$$\mathrm{TTT} = (8 \cdot \mathrm{T1} \quad \mathrm{T3} \cdot \mathrm{T4})^{1/4}$$

$$\mathrm{XK} = \mathrm{R2}\left(1 - \frac{\mathrm{BETA}}{2}\right) \Big/ \mathrm{C\emptyset ST}$$

$$\mathrm{XK1} = \frac{\mathrm{XK}^3}{2\left(1 - \dfrac{\mathrm{BETA})}{2}\right)^2} [\mathrm{GAMBAR} + \mathrm{BETA}\,(1 - 2 \cdot \mathrm{GAMBAR})$$

$$+ \mathrm{BETA}^2(\mathrm{GAMBAR} - 0\ 61600607) + \frac{\mathrm{XL}}{\mathrm{R2}}\,\mathrm{XKTM}\,(1 - 0.61600607 \quad \mathrm{BETA})]$$

$$+ \mathrm{DELK1}$$

$$\mathrm{XK2} = \mathrm{XK}\,(1 + \mathrm{XKTM} \cdot \mathrm{SINT}) + \mathrm{DELK2}$$

where,

$$\mathrm{XKTM} = \pm \frac{(\mathrm{WHS} + \mathrm{W})\,\mathrm{G}}{144 \cdot \mathrm{PA}}$$

$$\mathrm{B} = \frac{2\pi \cdot \mathrm{XK1} \quad \mathrm{TTT}}{\mathrm{XL}\,[12(2 \quad \mathrm{T3} - \mathrm{XNU}^2)]^{1/4} \quad \mathrm{XK}^{3/2} \cdot \mathrm{XK2}}$$

$$S = B(\mathrm{DTHØD})^{1/4}(\mathrm{SMAT})^{1/2}$$

$$PS = \frac{WS1 + 1}{(WS1)^{1/2}\left(WS1^{1/4} + \frac{S}{2}\right)}$$

where,

$$WS1 = \frac{3 + S}{1 + S}$$

$$\mathrm{RHØT} = \frac{\mathrm{RØF \quad SMAT}}{1728}$$

$$WS2 = 1 - XNU^2$$

$$PAS = \frac{\pi(PS)(\mathrm{DTHØD})^{3/4} \cdot T4\,(\mathrm{SMAT})^{5/2}\,[12\,(2 \quad T3 - XNU^2)]^{1/4} \cdot E}{6\,(WS2)\,XL \quad XK2 \cdot XK^{1/2} \cdot TTT}$$

$$WN = \pi \cdot \mathrm{RHØT}\left[(R1 + R2)\,\mathrm{XLØ} + 2 \cdot H(2 \cdot EN + 1) \cdot DN \cdot \left(R2 - \mathrm{XLØ} \cdot \frac{\mathrm{SINT}}{2}\right)\right]$$

$$\mathrm{WSTAR} = \frac{WN \cdot 144}{PI(R1 + R2)\,\mathrm{XLØ}}$$

cones:

$$\mathrm{XNTH} = \left[-PA \mp \frac{(\mathrm{WHS} + \mathrm{WSTAR}) \cdot G \cdot \mathrm{SINT}}{144}\right] \frac{R}{\mathrm{CØST}}$$

$$\mathrm{XNPHI} = \left[-PA\left(R^2 + R1^2\,(\mathrm{GAMBAR} - 1)\right) \mp \frac{G\,(R^2 - R1^2)\,(\mathrm{WHS} + \mathrm{WSTAR})}{144 \quad \mathrm{SINT}}\right] \frac{1}{2 \cdot R \cdot \mathrm{CØST}}$$

$$\mathrm{XNY} = [(\mathrm{XNTH})^2 + (\mathrm{XNPHI})^2 - \mathrm{XNTH} \cdot \mathrm{XNPHI}]^{1/2}$$

XNYMAX is the largest value of XNY. XNTHM, XNPHIM correspond cylinders:

$$XNTHM = -PA \;\; RC$$

$$XNPHIM = -\frac{PA \;\; RC \;\; GAMBAR}{2} - \frac{G \cdot XLC\,(WHS + WSTAR)}{144}$$

$$XNYMAX = [(XNTHM)^2 + (XNPHIM)^2 - XNTHM \cdot XNPHIM]^{1/2}$$

$$TCY = \frac{XNYMAX}{SGF}$$

$$SIGMH = \frac{XNYMAX}{TG}$$

$$SIGH = \frac{XNTHM}{TG}$$

$$SIGM = \frac{XNPHIM}{TG}$$

$$D = \frac{E \cdot TLC}{12 \cdot WS2}$$

$$THT = TL \cdot H\,(2 \cdot EN + 1)$$

$$AT = THT + EM \cdot TLS$$

$$YBAR = \left[\frac{EM \cdot TLC}{2} + THT\left(\frac{H}{2} + TL\right)\right]\frac{1}{AT}$$

$$XIX = \frac{EM \;\; TLC \cdot TL}{3} + THT\left(\frac{H}{2} + TL\right)^2 + (EN \;\; H + TL)\,\frac{H^3}{12}$$

$$- \frac{EN \cdot H\,(H - 2 \cdot TL)^3}{12}$$

$$\text{XITH} = \text{XIX} - \text{AT} \cdot \text{YBAR}^2$$

$$\text{DTH} = \frac{(\text{DN} + 1) \cdot \text{XITH} \cdot \text{E}}{\text{XLØ}}$$

$$\text{DTHØD} = \frac{\text{DTH}}{\text{D}}$$

5. NØSE

$$\text{H} = \text{R}\Big(1 - \sin\,(\text{THEATA})\Big)$$

$$\text{P} = \text{PCR} \pm \frac{(\text{WHS} + \text{W})\ \text{G}}{144}$$

$$\rho_c = \text{RØC} = 0\ 22 \cdot \text{RØR} \left(\frac{\text{P}}{\text{SGR}}\right)^{0\ 588}$$

$$t_{cy} = \text{TCY} = \frac{\text{P} \cdot \text{R}}{4(\text{SGF})}$$

$$\text{Z1} = \frac{\text{RØF}}{6}$$

$$\text{Z2} = \text{Z2T} \cdot \text{RØC} \cdot \text{P}^{3/4}$$

where,

$$\text{Z2T} = \frac{0.465\ \sqrt{1 - \text{GAMF}^2} \cdot \text{H}^{1/4} \cdot \text{R}^{3/2}}{12 \cdot \text{EF}^{3/4}}$$

$$t_{fopt} = \text{TFØPT} = \left(0.75\ \frac{\text{Z2}}{\text{Z1}}\right)^{4/7}$$

$$t_{copt} = \text{TCØPT} = \frac{12 \cdot \text{Z2}}{\text{RØC}} \left(\frac{4}{3}\ \frac{\text{Z1}}{\text{Z2}}\right)^{3/7}$$

$$t_f = \text{TSUBF(TC)} = \frac{\text{TFTM}\cdot\text{P}}{\text{TC}^{4/3}}$$

where,

$$\text{TFTM} = \frac{0.36(1-\text{GAMF}^2)^{2/3}\ \text{H}^{1/3}\cdot\text{R}^2}{\text{EF}}$$

$$t_c = \text{TSUBC(TF)} = \text{TCTM}\left(\frac{\text{P}}{\text{TF}}\right)^{3/4}$$

where,

$$\text{TCTM} = \frac{0.465\sqrt{1-\text{GAMF}^2}\quad \text{H}^{1/4}\ \ \text{R}^{3/2}}{\text{EF}^{3/4}}$$

$$\text{W} = \text{WEIGT(TF, TC)} = \text{Z1}\cdot\text{TF} + \frac{\text{R0C}\cdot\text{TC}}{12} + \text{ZK}$$

$$\text{WT} = \text{W}\cdot\frac{\pi\text{R}^2}{72}\left(1-\sin\text{(THETA)}\right)$$

$$\text{SIGMH} = \left[-\text{PCR} \mp \frac{(\text{WHS}+\text{W})\text{G}}{144}\right]\frac{\text{R}}{4\ \text{TFUSED}}$$

where TFUSED is the value of t_f chosen by the routine.

6. C0NE

$$\text{B} = 1-\frac{\text{R1}}{\text{R2}}$$

$$\text{ZLAMD} = \frac{\pi\cdot\text{SINTH}}{\text{R2}\cdot\text{B}}$$

$$\text{ZLILK} = \frac{\text{R1}+\text{R2}}{2\ \text{C0STH}}$$

$$\text{RØC} = 0.22 \cdot \text{RØR} \left(\frac{\text{PCR}}{\text{SGR}}\right)^{0.588}$$

$$\text{XNTH} = \left[- \text{PCR} \mp \frac{(\text{WHS} + \text{W})\ \text{G}\ \ \text{SINTH}}{144}\right] \frac{\text{R}}{\text{CØSTH}}$$

$$\text{XNPHI} = \frac{1}{2\text{R} \cdot \text{CØSTH}} \left[- \text{PCR}\ \ (\text{R}^2 + \text{R1}^2 \cdot (\text{DPC} - 1)) \mp \frac{\text{G}\ (\text{R}^2 - \text{R1}^2)(\text{WHS} + \text{W})}{144\ \text{SINTH}}\right]$$

$$\text{XNY} = \sqrt{(\text{XNTH})^2 + (\text{XNPHI})^2 - \text{XNTH}\ \ \text{XNPHI}}$$

$$\text{TCY} = \frac{\text{XNYMAX}}{2 \cdot \text{SGF}}$$

where XNYMAX is the largest value of XNY.

$$\text{Z2} = \text{ZLILK}\ (1 + \text{ZTERM} \cdot \text{SINTH}) + \text{DELZ2}$$

where,

$$\text{ZTERM} = \frac{(\text{WHS} + \text{W})\ \text{G}}{144\ \ \text{PCR}} \ .$$

$$\text{Z1} = \text{ZLILK}^3 \left[\text{DPC} + \text{B}\ (1 - 2 \cdot \text{DPC}) + \text{B}^2\ (\text{DPC} - 0.61600607) \mp \frac{\text{B} \cdot \text{ZTERM} \cdot (1 - 0.61600607 \cdot \text{B})}{\text{SINTH}}\right] \frac{1}{2\left(1 - \frac{\text{B}}{2}\right)^2} + \text{DELZ1}$$

$$A = ATM \left(\frac{Z1}{Z2}\right)$$

where,

$$ATM \ \frac{ZLAMD}{ZLILK^{3/2}} \left(\frac{2 \cdot TI \cdot T3 \cdot T4}{2 \quad T3 - GAMF^2}\right)^{1/4}$$

$$P = PTM \left(\frac{Z1}{Z2}\right)^2 \cdot Z1$$

where,

$$PTM = \frac{32 \cdot T1 \quad T3 \cdot ZLAMD^2}{(ZLILK)^5} \left(\frac{1 - GAMF^2}{2 \cdot T3 - GAMF^2}\right) \left(\frac{PCR}{EF}\right)$$

$$C1 = \frac{P \cdot ZLILK \quad RØF}{111.9 \ A^{2\ 84}}$$

$$C2 = \frac{RØC}{12}$$

$$t_{fopt} = TFØPT = \frac{4\ 89}{ROF} \ (C1)^{0.414} \cdot (C2)^{0.586}$$

$$t_{copt} = TCØPT = 1.156 \left(\frac{C1}{C2}\right)^{0.414}$$

$$t_f = TSUBF\ (TC) = \frac{P \quad ZLILK}{18.6\ (A \sqrt{TC})^{2.84}}$$

$$t_c = TSUBC\ (TF) = 0.127 \left(\frac{P \quad ZLILK}{TF \quad A^{2.84}}\right)^{0.704}$$

$$WEIGT\ \ (TF, TC) = \frac{RØF \cdot TF}{6} + \frac{RØC \quad TC}{12} + ZK$$

$$\mathrm{WT} = \frac{\mathrm{W}\,(\mathrm{R1} + \mathrm{R2})\,(\mathrm{R2} - \mathrm{R1})\,\pi}{\mathrm{SINTH}\quad 144}$$

$$\mathrm{SIGMH} = \frac{\mathrm{XNYMAX}}{2 \cdot \mathrm{TFUSED}}$$

$$\mathrm{SIGH} = \frac{\mathrm{XNTHM}}{2\quad \mathrm{TFUSED}}$$

$$\mathrm{SIGM} = \frac{\mathrm{XNPHIM}}{2 \cdot \mathrm{TFUSED}}$$

where TFUSED is the value of t_f chosen by the routine.

7. <u>CYLIND</u>

$$\rho_c = \mathrm{RØC} = 0.22\,(\mathrm{RØR})\left(\frac{\mathrm{PCR}}{\mathrm{SGR}}\right)^{0.588}$$

$$\mathrm{X2} = \frac{\mathrm{RØC}}{12}$$

$$\mathrm{X1} = \frac{\mathrm{X1T}}{\mathrm{PB}}$$

where,

$$\mathrm{PB} = \frac{(\mathrm{ST} + 1)}{\sqrt{\mathrm{ST}}\left(\mathrm{ST}^{1/4} + \frac{\mathrm{S}}{2}\right)}\left(1 + \frac{\mathrm{DELK2}}{\mathrm{RC}}\right)$$

$$\mathrm{ST} = \frac{3 + \mathrm{S}}{1 + \mathrm{S}}$$

$$\mathrm{XNTH} = -\,\mathrm{PCR} \cdot \mathrm{RC}$$

$$\mathrm{XNPHI} = -\,\frac{\mathrm{PCR} \cdot \mathrm{RC}\quad \mathrm{DPC}}{2} - \frac{\mathrm{G}\,(\mathrm{DEL})\,(\mathrm{WHS} + \mathrm{W})}{144}$$

$$\text{XNY} = [(\text{XNTH})^2 + (\text{XNPHI})^2 - (\text{XNTH})\,(\text{XNPHI})]^{1/2}$$

$$t_{cy} = \text{TCY} = \frac{\text{XNY}}{2\,(\text{SGF})}$$

$$t_{fopt} = \text{TFØPT} = \frac{4.7\,(\text{X1})^{0.4}\,(\text{X2})^{0.6}}{\text{RØF}}$$

$$\text{TCØPT} = 1.176 \left(\frac{\text{X1}}{\text{X2}}\right)^{0.4}$$

$$\text{S} = \text{STM}\,(\text{TCUSED})^{1/2} \left[\text{DPC} + \frac{\text{DELK1}}{\text{RC}^3} + \frac{\text{DEL}\,(\text{WHS} + \text{W})\,\text{G}}{(\text{RC})\,(144)\,(\text{PCR})}\right]$$

where,

$$\text{STM} = \frac{2\ 22\,(\text{RC})^{1/2}}{\text{DEL}\,(1 - \text{GAMF}^2)^{1/4} \left(1 + \dfrac{\text{DELK2}}{\text{RC}}\right)}$$

$$t_f = \text{TSUBF}\,(\text{TC}) = \frac{\text{TFTM}}{(\text{TC})^{3/2}\,(\text{PB})}$$

where,

$$\text{TFTM} = \frac{\text{PCR}\,(\text{RC})^{3/2}\,(\text{DEL})\,(1 - \text{GAMF}^2)^{3/4}\,(0.45219638)}{\text{EF}}$$

$$t_c = \text{TSUBC}\,(\text{TF}) = \frac{\text{TCTM}}{(\text{TF}\quad\text{PB})^{2/3}}$$

where,

$$\text{TCTM} = 0.404 \left[\frac{\text{PCR}\,(\text{RC})^{3/2}\,(\text{DEL})\,(1.75)}{\text{EF}}\right]^{2/3} (1 - \text{GAMF}^2)^{1/2}$$

$$\text{W} = \text{WEIGT}\quad(\text{TF, TC}) = \frac{\text{RØF}\quad\text{TF}}{6} + \frac{\text{RØC} \cdot \text{TC}}{12} + \text{ZK}$$

$$\text{WT} = \frac{\text{W} \cdot \text{RC} \cdot \text{DEL}\quad\pi}{72}$$

$$\text{SIGMH} = \frac{\text{XNY}}{2\,(\text{TFUSED})}$$

$$\text{SIGH} = \frac{\text{XNTH}}{2\ (\text{TFUSED})}$$

$$\text{SIGM} = \frac{\text{XNPHI}}{2\ (\text{TFUSED})}$$

8. BASE

$$\text{P} = \text{PCR} + \frac{(\text{WHS} + \text{W})\ \text{G}}{144}$$

$$\text{RØC} = 0.22 \cdot \text{RØR} \left(\frac{\text{P}}{\text{SGR}}\right)^{0.588}$$

$$\text{Z1} = \frac{\text{RØF}}{6}$$

$$\text{Z3} = \text{Z3T} \quad \text{P}$$

where

$$\text{Z3T} = \frac{\text{RT}^2\ (3. + \text{GAMF})}{16\ \ \text{SGF}} \ .$$

$$\text{TEØPT} = \sqrt{\frac{\text{Z3}}{\text{Z1}}}$$

$$\text{TCUSED} = \frac{\text{Z3}}{\text{TFUSED}}$$

$$\text{TFUSED} = \frac{\text{Z3}}{\text{TCUSED}}$$

$$\text{W} = \frac{\text{RØC} \cdot \text{TCUSED}}{12} + \text{ZK} + \text{Z1} \cdot \text{TFUSED}$$

$$\text{WT} = \frac{\text{W} \cdot \pi\ \text{RT}^2}{144}$$

9. TENSØN

$$R3 = RC - RSC$$

$$R2 = RN \cdot \sin(THN) + RSN\,(\cos(BETA) - \cos(THN))$$

$$XLØGB = \log_e \left[\frac{1 + \cos(BETA)}{\sin(BETA)}\right]$$

$$C1 = \frac{2 \cdot XLØGB}{1 - \left(\frac{R2}{R3}\right)^2}$$

$$T3 = \frac{PCR \cdot R3}{C1 \cdot SIGCYF}$$

$$YCALC = \sqrt{R3^2 + \frac{(R2^2 - R3^2) \cdot \log_e \left(\frac{1 + CØSTH}{SINTH}\right)}{XLØGB}}$$

$$T = \frac{R3 \quad T3}{YCALC}$$

$$YDYDT = - \frac{(R2^2 - R3^2)}{SINTH \cdot 2 \cdot XLØGB}$$

$$A(I) = \frac{YDYDT}{SINTH} \qquad I = 1, 2, \ldots 25$$

$$W(I) = T \quad A(I) \qquad I = 1, 2, \ldots 25$$

$$WTT = \frac{2\pi \cdot RØF}{1728} \int_{BETA}^{\pi/2} W$$

$$AT = \frac{2\pi}{144} \int_{BETA}^{\pi/2} A$$

10. GNRLSH

$$T3 = \frac{-(PCR)(12)}{\left[-\sin(TH3G)(DTHDY3) + \frac{A\cos(TH3G)}{Y3}\right] SIGCYF}$$

$$XNUM = Y(J) - Y(J-1)$$

$$DEN0M = X(J) - X(J-1)$$

$$THETA = \tan^{-1}\left(\frac{XNUM}{DEN0M}\right)$$

$$SINTH = \sin(THETA)$$

$$T = \frac{T3\,(Y3)^{1-A}}{Y(J)^{1-A}}$$

where Y3 is the last element of the Y-array.

$$AFUNCT(J) = \frac{Y(J)}{SINTH}$$

$$WFUNCT(J) = T \quad AFUNCT(J)$$

$$WTG = 2\pi \cdot R0F \int_{Y(1)}^{Y3} WFUNCT$$

$$AG = 2\pi \int_{Y(1)}^{Y3} AFUNCT$$

$$WGENST = WTG/AG$$

$$R3 = 12 \cdot Y3$$

11. RING

$$RR = \left(\frac{RC^3 \cdot WS1}{1.7 \cdot \pi}\right)^{1/3}$$

where,

$$WS1 = \sqrt{\frac{(2\pi)(0.3) \cdot T3 \cdot SIGCYF}{ER \cdot RC}}$$

$$TR = \sqrt{\frac{R3 \cdot T3 \cdot SIGCYF}{0.6\pi\,(ER)}}$$

$$WR = \frac{\pi^2 \cdot RR \cdot TR \cdot RØRG\,(RC - RR)}{432}$$

$$WSCST = \frac{WR \cdot 144}{2\pi \cdot RSC \cdot WS2}$$

where,

$$WS2 = R3 \cdot TH3 + RSC\left(\sin(TH3) - TH3 \cdot \cos(TH3)\right)$$

12. HØTSTR

$$ENC1 = XN(23.3) + XØ(24.3) + XC(35.7) + XA(15.26)$$

$$ENC2 = XN(49.83) + XØ(52.5) + XC(100.1) + XA(30.5)$$

$$AW = 0.001\left[\frac{2}{3}\,ENC1 - \frac{1}{6}\,ENC2\right]$$

$$BW = -\frac{10^{-6}}{9}\,[ENC1 - 0.5\,ENC2]$$

$$\mathrm{DELTAT} = \left\{ \mathrm{FC} \quad \mathrm{QCI} \left[1 - \frac{(\mathrm{AW} \cdot \mathrm{TW1} + \mathrm{BW} \quad \mathrm{TW1}^2)}{\mathrm{HG0RI}} \right] + \mathrm{FR} \cdot \mathrm{QRI} \right.$$

$$\left. - \ \mathrm{EMISS} \left(\frac{\mathrm{TW1}}{1200} \right)^4 \right\} \frac{1}{(\mathrm{WSTAR})\,(\mathrm{CP})}$$

$\mathrm{TW1} = \mathrm{TW} + 460$

WSTAR is current weight .

$\mathrm{TW} = \mathrm{TW} + \mathrm{DELTAT} \cdot \mathrm{DELTAU}$

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SPECIAL SUBROUTINES

CONTENTS

I GENERAL PURPOSE SUBROUTINES

A ARTLU

1 Purpose

The purpose of subroutine ARTLU is to perform a linear interpolation within $N \leq 10$ dependent variable tables Y1TBL, Y2TBL, , corresponding to a monotonically increasing independent variable table XTBL.

2. Calling Sequence

N	number of dependent variable tables ($N \leq 10$).
X	independent argument (X must not be larger than the last element of XTBL).
XTBL	table of independent variable (maximum of 1000 elements).
Y1	dependent argument.
Y1TBL	table of dependent variable, with elements corresponding to those in XTBL.
Y2	dependent argument.
Y2TBL	table of dependent variable, with elements corresponding to those in XTBL.

3 Method

Within the DO 11 loop the index I is increased until XTBL(I), the last value of XTBL smaller than the argument X has been found P is then defined as (X-XTBL(I)) /(XTBL(I+1)-XTBL(I)). The computed GØ TØ ensures that N values of the dependent variable will be computed between Statements N and 1 For each i, $1 \leq i \leq N$,

$$\mathrm{Yi} = \mathrm{YiTBL(I)} + \mathrm{P} * (\mathrm{YiTBL(I+1)} - \mathrm{YiTBL(I)}).$$

If X is smaller than the first element of XTBL, automatic linear extrapolation is performed from the first two elements of the tables. If X is larger than the last element of XTBL an unpredictable error will result, although a value of $I > 1000$ would produce an error message written according to FØRMAT Statement 30.

B. AR2TLU

1. Purpose

The purpose of Subroutine AR2TLU is to perform an interpolation within a two-dimensional table ZTBL the elements of which correspond to the entries in two one-dimensional monotonically increasing tables XTBL and YTBL.

2 Calling Sequence

NX	number of values in XTBL.
NY	number of values in YTBL.
X	independent argument.
XTBL	table of independent variable.
Y	independent argument
YTBL	table of independent variable
Z	dependent argument
ZTBL	table of dependent variable (with dimension (NX, NY))

3 Method

The DØ 5 loop searches XTBL for XTBL(I), the first element greater than or equal to X If there is no such XTBL(I), an error message is written, ICHK is set to 1, and a return to the calling routine is executed

Similarly, the DØ 15 loop searches YTBL for YTBL(J), the first element greater than or equal to Y If there is no such YTBL(J), an error message is written, ICHK is set to 1, and a return to the calling routine is executed

If there is no error return, Z is computed starting at Statement 20 according to the following formula:

$$Z = (1 - P1 - P2 + P3) * ZTBL\,(I-1,\ J-1) + (P1 - P3) * ZTBL(I,\ J-1) + (P2 - P3) * ZTBL\,(I-1,\ J) + P3 * ZTBL(I,\ J)$$

where,

$$P1 = (X - XTBL(I-1))/(XTBL(I) - XTBL(I-1))$$
$$P2 = (Y - YTBL(J-1))/(YTBL(J) - YTBL(J-1))$$
$$P3 = P1 * P2\ .$$

Return is then made to the calling routine

C. ARSIMP

1 Purpose

The purpose of Subroutine ARSIMP is to integrate by Simpson's Rule an array YARRAY of N points tabulated at an equally-spaced interval of the independent variable.

2 Method

The calling sequence is

```
CALL ARSIMP (N, DELTAX, YARRAY, ANSWER)
```

where,

N	number of points to be integrated (N must be odd)
DELTAX	interval of independent variable at which array points were tabulated
YARRAY	array of points to be integrated
ANSWER	result of integration

The Simpson's Rule algorithm is applied in a DØ loop

D. ADAMS4

1 Purpose

The purpose of Subroutine ADAMS4 is to integrate a set of N first order differential equations by a predictor-corrector method

2 Method

ADAMS4 is a slightly modified version of Subroutine ADM4RK The differences between the two routines are as follows:

a. The calling sequence for ADAMS4 is

```
CALL ADAMS4 (NZ, ZDEL, VALUE, DERN, UPBND,
DNBND, FACTØR, FREQ, HLIMIT, LZ, ZXINDE,
DELMIT, DEREQ, PAR, NPAR)
```

All but the last three arguments are defined identically as those in ADM4RK The arguments DEREQ, PAR, and NPAR were added to the list They have the following meanings

DEREQ	name of subroutine defining derivatives (The name can now be arbitrary but must appear in an external statement in the calling program)
PAR	array of parameters appearing in the derivative calculations (In ADM4RK, information is generally transmitted to DEREQ through CØMMØN)
NPAR	number of elements in the array PAR

b. Within ADAMS4 the calling sequence for DEREQ is

```
CALL DEREQ (NZ, VALUE, XINDEP, DERN, LZ,
PAR, NPAR)
```

The three elements added to the list NZ, PAR, and NPAR, have the same meaning here as in the ADAMS4 calling sequence.

c After the 3 CALL DEREQ statements within ADAMS4, the controlling parameter L is tested in an IF statement. If $L \geq 6$, immediate return is made to the calling program This allows L to be reset within DEREQ to indicate an error condition which the main program may act upon

The original writeup of ADM4RK has been included in this section of the manual.

E. ADM4RK[1]

1. Purpose

To allow integration of N differential equations by a predictor-corrector method which will alter the delta of integration so that the required accuracy is maintained.

---

[1] Sova, C., Avco Programmer's Handbook, No. F2-70, IBM 7094 (11 March 1965)

2. Usage

CALL ADM4RK (N, DEL, VALUE, DERN, UPBND, DNBND, FACTØR, FREQ, HLIMIT, L, XINDEP, DELMIT)

where,

N	The number of equations to be integrated.
DEL	The delta of integration.
VALUE	The array of N integrated values.
DERN	The array of N derivative values.
FREQ	The value which indicates the interval at which the user would like to return to the calling program
HLIMIT	The value which specifies the upper limit of integration When this value is reached, return is made to the calling program.
L:	The control parameter:
= 1	Indicates initial pass. Must be set by user who desires FREQ and HLIMIT testing.
= 2	Indicates that a FREQ interval has been reached.
= 3	Indicates that HLIMIT has been reached.
= 4	Indicates that HLIMIT and FREQ interval has been reached, simultaneously.
= -5	Indicates that return to the calling program is to be made after each successful integration step. This will be set to +5 during the initial pass. No tests are made for FREQ or HLIMIT.
= 6	Indicates that the integration interval is less than DELMIT.

XINDEP	The value of the independent variable.
UPBND	The upper bound on the absolute difference that is allowed between the extrapolated and interpolated values. If this bound is exceeded by this difference, the delta of integration is reduced and integration is retried.
DNBND	The lower bound on the absolute difference between the extrapolated and interpolated values. If this bound exceeds this difference, the delta of integration is increased and integration is carried on.
FACTOR	The percentage by which the delta of integration is increased or decreased in the above. This must be less than 1.
DELMIT	The value below which we do not wish to reduce the delta of integration. If this is not specified (i.e., = 0), it will be set to the initially specified delta of integration divided by 1000.0.

In addition, the user must supply a subroutine having the following specifications:

a. Calling sequence CALL DEREQ (A, B, C, I)

where,

A	The array of N integrated values
B	The value of the independent variable
C	The array of N derivative values
I	Corresponds to L in the explanation above.

b. Use

This routine should evaluate the N differential equations given the N integrated values at the value of the independent variable B

c. Restriction

The values of the integrated variables, if used in this routine should be picked up from the argument A and B above only and not from XINDEP and VALUE which were previously defined. Also nothing should be stored into A and B.

3. Sample of Use

Given: $\frac{d^2 y}{dx^2} = x$ where $y_o = 0$, $\frac{dy_o}{dx} = 0$

evaluate y from 0 to x = 100 and print the values of y at x = 0, 2, 4, 6, ... 100. Starting with an initial Δx of 0.005 and increase or decrease the Δx by 30 percent if the difference between the extrapolated and interpolated values do not fall between certain given bounds.

```
DEREQ (D, X, LT, L)

DIMENSION D(7), DT (8).

DT (1) = D (2)

DT (2) = x

RETURN

END

DIMENSION D (2), DT (2), UPBND (2), DNBND (2)

L = 1 or L = -5

DELTAX = 0.005

X = 0.0

D (1) = 0.0

D (2) = 0.0

UPBND (1) = 1.0E - 5

DNBND (1) = 1.0E - 6

UPBND (2) = 0.5E - 5

DNBND (2) = 0.5E - 6
```

```
1   CONTINUE
    CALL ADM4RK (2, DELTAX= D= DT= UPBND= 0.3, 2.0, 100.0,
    L, X, 1.0E-7)

    WRITE ØUTPUT TAPE 5, 2, X, D (1)

2   FØRMAT (1P2E20.5)

    GØ TØ (1, 1, 3, 3, 4, 5), L

3   STØP 77777

4   IF (X - 100.0) 1, 3, 3

5   CALL MESSAG (24H DEL X IS TØØ SMALL, 3)

    STØP 77776
    END
```

F. PØLRØT

1. Purpose

The purpose of Subroutine PØLRØT is to calculate the roots of a polynomial

2. Method

The calling sequence is

```
CALL PØLRØT (N, A, R, C)
```

N	degree of polynomial. Maximum of 20
A	coefficients of polynomial (Note that A(1) is the coefficient of X^n)
R	roots of polynomial R is dimensioned (2, N) where R(1, J) is the real, R(2, J) is the imaginary part of the J^{th} root
C	convergence factor. ($C = 10^{-5}$ is satisfactory in most cases)

Newton-Raphson iteration is used Therefore, if f(x) is the polynomial and if $f'(r) \longrightarrow 0$, the method will not converge. Moreover, the constant term of the polynomial cannot be 0.

(PØLRØT calls PØLRT1)

G. CØMDIV

1. Purpose

The purpose of Subroutine CØMDIV is to evaluate $E + iF = (A + iB)/(C + iD)$ when A, B, C, D are given

2. Method

The calling sequence is

```
CALL CØMDIV (A, B, C, D, E, F)
```

The routine calculates

```
G     = C * C + D * D
E     = (A * C + B * D)/G
F     = (B * C - A * D)/G
```

H. ATANQR

1 Purpose

The purpose of function ATANQR(W, H) is to calculate the arctangent of W/H where W and H are floating point numbers, and to return the result either in radians or degrees The convention to be observed is that

$$0 \leq \text{ATANQR}(W, H) < \begin{cases} 2\pi \\ 360 \text{ degrees} \end{cases}$$

2. Method

ATANQR is a multiple entry function with entry points ATANQ and ATANQD

If ATANQR (W, H) or ATANQ (W, H) is referenced, D is set to 1 , and X is defined as ATAN2(W, H), where ATAN2 is the FØRTRAN IV library function IF $X < 0$, it is reset to $X + 2\pi$ Then ATANQR is defined as X/D.

If ATANQD(W, H) is referenced, D is set to 0 017453293, and the remaining computations are carried out as before.

I ASINR

1 Purpose

The purpose of function ASINR(W) is to calculate the arc-sine of a floating point number W and to return the result either in radians or degrees. The convention to be observed is

$$0 \leq \text{ASINR (W)} \leq \begin{cases} \pi/2 \\ 90 \text{ degrees} \end{cases}$$

or,

$$\left.\begin{matrix} 3\pi/2 \\ 270 \text{ degrees} \end{matrix}\right\} \leq \text{ASINR(W)} \leq \begin{cases} 2\pi \\ 360 \text{ degrees} \end{cases} .$$

2. Method

ASINR is a multiple entry function with entry points ASIN and ASIND.

If ASINR(W) or ASIN(W) is referenced, D is set to 1., WS is defined as 1 - W * W, and ASINR is computed as

ASINR = ATANQR (W, SQRT(WS))/D

If ASIND(W) is referenced, D is set to 0 017453293, and the remaining computations are carried out as before

J. ACØSR

1. Purpose

The purpose of function ACØSR(W) is to calculate the arc-cosine of a floating point number W and to return the result either in radians or degrees The convention to be observed is

$$0 \leq \text{AC}\emptyset\text{SR(W)} \leq \begin{cases} \pi \\ 180 \text{ degrees} \end{cases} .$$

2 Method

ACØSR is a multiple entry function with entry points ACØS and ACØSD

If ACØSR(W) or ACØS(W) is referenced, D is set to 1 , WS is defined as 1 - W * W, and ACØSR is computed as

ACØSR = ATANQR (SQRT(WS), W)/D

If ACØSD(W) is referenced, D is set to 0 017453293, and the remaining computations are carried out as before

K. AICRT3[1]

1. Purpose

AICRT3 is a general-purpose subroutine for the displaying of output data in graphical form

2. Method

From the user's viewpoint, the version of AICRT3 to be used with FØRTRAN IV programs operates in the same manner as the FORTRAN II version Therefore, although no new writeup was issued for FORTRAN IV, the following original writeup still described the subroutine usage, if the reader makes allowances for the standard differences between the two systems 9(e.g., FORTRAN IV arrays being stored forward in core):

a. Log x Log

b. Log x Linear

c. Linear x Log

d. Linear x Linear.

Along with these types of graphs, AICRT3 has the ability of plotting multi-function graphs. If this feature of the code is used, one must obtain separately the upper and lower limits of the functions. One must then supply the upper and lower limits to the subroutine by use of the override feature, or first plot the curve which has both the maximum value of all functions being plotted and also the minimum value of all functions. If the override feature is used, the arguments supplied are unaltered. If the override feature is not used, the upper and lower limits are determined by the code and returned to the user via the arguments. Therefore, the programmer must not place a variable or constant for said arguments that are to be used again at their original values, since they will be changed by this subroutine. The override feature also will give the user the ability for a standard size grid for multiple case plotting.

---

[1] Hoffman, M , General Code for Display of Digital Data, Applied Mathematics, Atomic International, Naa, Inc., Canoga Park, California(8January 1963), published and distributed under bylaws of UAIDE

3. Use

The method one uses to obtain the above named plot is as follows:

a. On the EDPM Job Request, deck set up instructions; request subject deck first before data

b. In your program deck for each plot, use the following calling sequence:

```
CALL AICRT 3 (KX, KY, X, Y, NP, ND, NV, NS, NC, T, A, 0, NF,
NG, DCX, DCY, NX0, XL, XU, NY0, YL, YU) *
```

c. This routine should not be used to plot a point at a time.

4 Input Data Description

The inputs for this program are the arguments of the calling sequence in Section 5. They are as follows·

KX	0 for linear display in X 1 for log display in X
KY	0 for linear display in Y 1 for log display in Y
X	First location of storage for values of X
Y	First location of storage for values of Y
NP	Number of points in X and Y array to be plotted
ND	Interval at which points will be displayed, e.g., every point = 1, every 10th point = 10
NV	2 if one wishes to join points plotted with a straight line 1 if not

---

* The arguments for this calling sequence will be explained in the next section

NS	2 if the data is to be sorted as a function of X 1 if the data is not to be sorted (This is to enable the connecting of points by vectors.)
NC	Character representation of point to be plotted
T**	A nine word title to be displayed at the top of the graph
A**	A nine word abscissa title
Ø**	A nine word ordinate title
NF	1 if new frame is required 2 if overlay is required
NG	1 non-log labeling determined by code If any X meets the following condition, $\|X\| \geq 10^6$ or if all X are in the range $-10^5 < X < 10^5$ the labeling would automatically be E-label notation. -2 non-log labeling always E-label notation
DCX, DCY	Governs the coarseness of the X and Y linear meshes. (See Section V - Special Features.)
NXØ	2 override search for X-upper and X-lower. 1 let routine determine X-upper and X-lower (See section E - Special Features.)
XL	X-lower, if needed (NXØ = 2)
XU	X-upper, if needed (NXØ = 2)
NYØ	2 override search for Y-upper and Y-lower 1 let routine determine Y-upper and Y-lower
YL	Y-lower, if needed (NYØ = 2)
YU	Y-upper, if needed (NYØ = 2).

**Must be stored in FORTRAN order (backwards in core) or read into core using the A conversion

5. Special Features

It should be noted that 16.0 is the recommended value for DCX and DCY. If it is necessary to have more grid lines, all one has to do is decrease the value of DCX and DCY. If one wants fewer lines, increase the value of DCX and DCY. Another note of special interest is that the entire array of X and Y that are being plotted must be in core at the time of execution of this routine.

The feature of sorting the functions before plotting has one drawback; viz., after the functions have been sorted, the original order is totally destroyed. This feature should not be used unless the plotting of the data is the last function of the code or order of the data is of no importance.

If (XU/ XL -1) < 0.0001, or if XU = XL = 0, no graph will be drawn as the function is or is almost constant (similarily for YU and YL).

The titles used should be centered in the 48-character array to ensure centering of the titles on the graph. The abscissa and ordinate title can be as large as 54 characters.

If one uses the upper and lower limit search provided by AICRT3, care should be exercised in the definition of the variable or constant used for XL, XU, YL, or YU as they will be changed by the subroutine.

NG is used to permit a floating point notation labeling of linear plots. This is provided because the maximum fixed point number that can be used is 999999, and the smallest greater than zero 0.000001, similarly for negative values. To provide meaningful labeling of data outside this range, the floating point notation has been made available.

A very important factor is assigning X and Y arguments is to make sure you only have a singly subscripted array for each.

The limit of the number of cycles in log plotting is 10. Do not try to plot more than a 10 x 10 log x log plot.