AN ANALYSIS OF A CHARRING ABLATION THERMAL PROTECTION SYSTEM

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • DECEMBER 1965
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THERMAL PROTECTION SYSTEM

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SUMMARY

An analytical model is presented for predicting the transient one-dimensional thermal performance of a charring-ablator heat-protection system when exposed to a hyperthermal environment. The heat-protection system is considered to consist of an ablation material and backup structure. The ablating material is further considered to consist of three distinct regions or zones: char, reacting, and virgin material.

A FORTRAN IV digital computer program (STAB II) utilizing an implicit finite difference formulation has been written for the IBM 7094/40 computer system. The program considers one ablating material and a maximum of 12 backup materials with conduction or radiation and/or convection allowed between materials. Thermal properties of all materials are temperature dependent, with the properties of the charring material also being state dependent.

The governing differential equations and their implicit finite difference formulation are presented. The program input and output are described in detail. The FORTRAN program statements and nomenclature are presented. Also, the theoretical and experimental results are compared.

INTRODUCTION

The analysis and design of thermal protection systems for entry into an atmospheric environment have resulted in a voluminous amount of literature on the general subject of ablation. (See refs. 1 and 2 for a survey of information on ablation.) The ablation materials may generally be classified into three categories: subliming, melting and vaporizing, and charring. The charring ablator normally provides the most efficient thermal-protection shield for the major portion of a manned entry vehicle. This report describes a method for predicting the thermal response of a typical charring-ablation material. The response of a charring material to a hyperthermal environment is extremely complex, and the mathematical model presented to analyze the transient behavior of the material contains simplifying assumptions and approximations necessary to afford even a numerical solution.
The equations derived in this analysis have been programmed in FORTRAN IV for an IBM 7094/40 computer system. The numerical formulation of this digital program, designated STAB II, is such that an implicit solution is obtained. The thermal response of a typical charring material as predicted by STAB II is compared with arc tunnel results.

A sample problem is presented in appendix A. Program usage instructions, including definitions of the input terminology, are presented in appendix B. Appendixes C and D are the program FORTRAN IV statements and definitions of the program terminology. A general flow chart of the program is presented in appendix E.

SYMBOLS

A collision frequency
$c_p$ specific heat
$E$ activation energy
$F$ exterior view factor
$F_{env}$ view factor–emissivity product to cabin environment
$H_d$ heat of virgin material degradation
$H_T$ total enthalpy
$H_w$ wall enthalpy
$H_{300}$ enthalpy of air at 300° K
$h$ film coefficient between backup materials
$h_{env}$ film coefficient between last backup material and cabin environment
$k$ thermal conductivity
$\dot{m}_c$ mass loss rate of char material
$\dot{m}_g$ gas ablation rate
$NP$ number of nodes in ablation material
n order of reaction

$Q_{\text{in}}$ net heat rate into front surface

$\dot{q}_{\text{c blow}}$ hot wall convective heat flux with blowing

$\dot{q}_{\text{comb}}$ heat flux due to combustion

$\dot{q}_{\text{cw}}$ cold wall convective heat flux without blowing

$\dot{q}_{\text{rad}}$ radiation heat flux

R universal gas constant

S surface recession depth

$\dot{S}$ surface recession rate

T temperature of node at beginning of time step

$T_{\text{env}}$ cabin environment temperature

T' temperature of node at end of time step

$T_{\infty}$ radiation heat sink temperature

VL thickness of ablation material

X distance from surface to any point

$\Delta H_c$ heat of combustion per unit weight of char

$\Delta X$ thickness of a node

$\Delta \theta$ time step ($\theta' - \theta$)

$\epsilon$ emissivity of material

$\eta$ transpiration cooling efficiency

$\theta$ initial time

$\theta'$ final time

$\xi$ transform for the ablation material
The following general requirements were established before writing a digital computer program to analyze a charring ablation system:

(1) Stability of the equations for all applications.

(2) Machine running time short enough to make use of the program economically feasible (a minimum of turn around time per problem).

(3) A minimum of input per problem.

(4) A wide variety of boundary conditions for application to both trajectory data and ground or flight test data analysis.

STAB II has been formulated in FORTRAN IV to analyze the transient thermal performance of a charring ablator heat protection system. The program considers one ablating material and up to 12 different backup materials with or without air gaps. Pure conduction or radiation and/or convection between backup materials is allowed. The ablation material may be divided into a maximum of 50 nodes, and each backup material may be subdivided into a maximum of 10 nodes. The thermal properties of the materials are in tabular form and are temperature dependent. The ablation material is also dependent upon its state, that is, fully charred, partially charred, et cetera.

The following surface boundary condition options are provided:

(1) Cold-wall convective and radiative heat flux tables as a function of time. These components are specified separately, since mass transfer at the surface blocks part of the convective heating but, in general, has no effect on the radiant heating.
(2) Surface temperature as a function of time.

(3) Surface recession as a function of temperature or time. Surface recession as a function of temperature and pressure is also available.

Heat loss to the interior environment for the last node of the backup structure can be specified by two methods:

(1) Conduction into the node and radiation and/or convection loss to the interior environment.

(2) Conduction into the node and adiabatic wall.

The STAB II numerical formulation of the equations describing the response of the heat shield is such that an implicit solution has been obtained. It is well known that numerical solutions of partial differential equations are subject to several different types of errors. The first of these is the truncation error, due to the use of a finite subdivision. This error may be reduced by simply choosing a smaller subdivision, $\Delta X$. The exact values are approached more and more closely as $\Delta X$ decreases. The second kind of error is the numerical, or roundoff error. The way in which this numerical error grows or decays with time determines the stability of the difference equations.

To illustrate the differences in the explicit and implicit equation form, consider a nonablating homogeneous solid. The one-dimensional Fourier conduction equation, neglecting any heat generation terms, is

$$\frac{\partial}{\partial x} \left( k \frac{\partial T}{\partial x} \right) = \rho c_p \frac{\partial T}{\partial \theta}$$  \hspace{1cm} (1)

The finite difference form of equation (1) written in the conventional forward time step or explicit form for the $i$th node is

$$\frac{T_{i-1} - T_i}{\Delta X} + \frac{T_i - T_{i+1}}{2k_1} = \rho c_p \frac{\Delta X (T'_i - T_i)}{\Delta \theta}$$  \hspace{1cm} (2)

where the prime superscript denotes values at the end of the time step

$$\Delta \theta = \theta' - \theta$$

For explicit conduction solutions, the following stability criterion has been established:

$$\frac{\rho c_p}{k} \left( \frac{\Delta X}{\Delta \theta} \right)^2 \geq 2$$
which places an upper limit on the time step $\Delta \theta$ for a fixed truncation error. This criterion can require a prohibitive amount of machine time.

Liebmann (ref. 3) advocated a solution of the equation which does not require this stability criterion. The finite difference equations are written in a backward time step form which affords an implicit solution.

The implicit (backward time step) difference form of equation (1) for the $i$th node is:

$$
\left( \frac{T'_{i-1} - T'_{i}}{\Delta X} + \frac{\Delta X}{2k_{i-1}} \right) T'_{i-1} - \left( \frac{T'_{i-1} - T'_{i+1}}{\Delta X} + \frac{\Delta X}{2k_{i}} + \frac{\Delta X}{2k_{i+1}} \right) T'_{i} + \frac{\rho_{i} c_{p_{i}} \Delta X}{\Delta \theta} T_{i} + \left( \frac{1}{\Delta X} + \frac{\Delta X}{2k_{i}} + \frac{\Delta X}{2k_{i+1}} \right) T'_{i+1} = - \left( \frac{\rho_{i} c_{p_{i}} \Delta X}{\Delta \theta} \right) T_{i}
$$

Equation (3) uses the temperature differences at the end of the finite time interval instead of the beginning, as in the explicit method of equation (2). The only known temperature in equation (3) is $T'_{i}$, but there are corresponding equations for each point in the system, and all are solved simultaneously to yield the temperature at each node.

Collecting all unknown temperatures on the left side of the equation and the known temperature on the right side, equation (3) becomes

$$
\left( \frac{\Delta X}{2k_{i-1}} + \frac{\Delta X}{2k_{i}} \right) T'_{i-1} - \left( \frac{\Delta X}{2k_{i}} + \frac{\Delta X}{2k_{i+1}} \right) T'_{i+1} = - \left( \frac{\rho_{i} c_{p_{i}} \Delta X}{\Delta \theta} \right) T_{i}
$$

Equation (4) is of the form

$$
A T'_{i-1} + B T'_{i} + C T'_{i+1} = D
$$

STAB II generates such an equation for each node in the system.

Since radiation is an important mode of heat transfer in charring ablative systems, a problem is encountered in any equation containing a radiation term. The radiation heat flux, written in a backward difference form is:

$$
\dot{q}_{\text{rad}} = F \varepsilon \sigma \left( T'_{i}^{4} - T_{\infty}^{4} \right)
$$
This term cannot be used in an implicit solution since the unknown temperature $T_1'$ is to be the 4th power. The 4th power unknown can be eliminated by the following linearizations:

$$
\left( T_1' \right)^4 = \left( T_1 + \Delta T \right)^4 = T_1^4 \left( 1 + \frac{\Delta T}{T_1} \right)^4
$$

where

$$
\Delta T = T_1' - T_1
$$

let

$$
Z = \frac{\Delta T}{T_1}
$$

and rewrite equation (7) as

$$
\left( T_1' \right)^4 = \left( T_1 \right)^4 \left( 1 + Z \right)^4
$$

(8)

If $Z$ has an absolute value near zero, the following is true

$$
(1 + Z)^4 \approx 1 + 4Z
$$

(9)

Now substituting equation (9) into equation (8)

$$
\left( T_1' \right)^4 \approx \left( T_1 \right)^4 \left( 1 + 4Z \right) = \left( T_1 \right)^4 \left( 1 + 4 \frac{\Delta T}{T_1} \right)
$$

$$
\approx 4T_1^3 \frac{3T_1'}{T_1} - 3T_1^4
$$

(10)

Equation (10) is a linearized approximation of equation (7) in which the unknown temperature is only to the first power. The assumption in equation (10) is that $\Delta T/T_1$ has an absolute value near zero. Figure 1 is a plot of the error obtained when $(1 + 4Z)$ is substituted for $(1 + Z)^4$. For most ablation problems in which the surface temperature is high and the radiation losses are significant, the value of $\Delta T/T_1$ can easily be controlled to values of less than $\pm 0.1$.

Therefore, equation (6) can now be written

$$
\dot{q}_{\text{rad}} = F \alpha \sigma \left( \frac{4T_1^3}{T_1} \frac{3T_1'}{T_1} - 3T_1^4 - T_\infty^4 \right)
$$

(11)
Using the linearized approximation for the radiation terms, the resulting system of implicit difference equations constitute a tridiagonal matrix of the following form:

\[
\begin{align*}
B_1T_1 + C_1T_2 &= D_1 \\
A_2T_1 + B_2T_2 + C_2T_3 &= D_2 \\
A_3T_2 + B_3T_3 + C_3T_4 &= D_3 \\
&\vdots &\vdots \\
A_NT_{N-1} + B_NT_N &= D_N
\end{align*}
\]

Gauss' elimination method, discussed in reference 4, is applied to solve the system of equations. This method affords a fast and accurate solution for matrices containing a dominant diagonal. The solution of this matrix gives the temperature of each node in the system for the next future time step. The entire process is repeated for each time step throughout the run, giving a time history of the temperature at each node.

Using this method of solution, residual errors in the temperature computations at the beginning of the time step are distributed throughout the entire system of nodal equations and tend to cancel out rapidly. The principal advantage in using the implicit method is a set of equations that are mathematically stable in time and distance. Therefore, the magnitude of the time step is not limited by a convergence criterion. However, care must be taken in selecting the magnitude of the time step in order to minimize truncation errors when the second derivative of temperature with respect to time is large. A similar approach is used to minimize truncation errors in distance by choosing small node dimensions in locations where large second derivatives of temperature with respect to distance are expected.

In the case of a char-forming ablative heat shield where approximately 80 percent of the heat is reradiated, instability can arise in taking large time steps. The temperature of the surface node can start oscillating on successive time steps when a balance between the radiation source and the heat sink has been achieved. Therefore, in ablation problems in which the surface node loses a large percentage of heat by radiation, oscillations of the node can be damped out by taking small time steps during conditions of high heat flux and near radiation equilibrium temperatures.

ANALYSIS

Figure 2 is a schematic of the thermal protection system to be analyzed. A receding surface has been assumed with the formation of a residual char layer and reaction zone. The thermal protection system is composed of one charring material and a maximum of 12 different backup materials with or without air gaps.
The analysis is such that the entire system may be composed of noncharring materials. The thermal properties of all materials are temperature dependent; also, the charring material properties are state dependent (fully or partially charred).

The response of charring ablation heat shields to a hyperthermal environment is extremely complex, and simplifying assumptions and approximations are necessary to afford a numerical solution. The following assumptions and approximations are utilized in the equations developed in this report:

(1) The material decomposes from the virgin state to a porous char layer in the reaction zone.

(2) The reaction zone can be defined by an upper and lower temperature limit.

(3) The gas generated within the reaction zone is assumed to pass out of the structure with no pressure loss. No gas accumulation within a node is allowed.

(4) Local thermal equilibrium is maintained between the gas and porous char matrix.

(5) The gas undergoes no further chemical reaction within the residual material after having been formed.

Derivation of Equations

The equations are derived for a moving boundary coordinate system, where the front face is the moving surface (ref. 5). With this system, the ablating material is divided into a fixed number of nodes of thickness $\Delta X$ which depends on the instantaneous location of the front face. The surface recession is handled in a continuous manner, eliminating the need of throwing away or lumping off of nodes.

The physical model for the front surface, including all heating terms, is shown as follows:
The energy equation at the front char surface is

\[
\frac{d}{d\theta} \left( \frac{1}{2} \Delta X \rho_1 c_p T_1 \right) = \frac{1}{2} \Delta X \rho_1 c_p \frac{dT_1}{d\theta} + \frac{1}{2} \rho_1 c_p T_1 \frac{d(\Delta X)}{d\theta} = Q_{in} + \dot{m}_2 c_p T_2 + \rho_2 c_p S_2 T_2' - \dot{m}_1 c_p T_1' - \rho_1 c_p T_1' - k (\frac{\Delta T}{\Delta X})
\]

where

\[
Q_{in} = \dot{q}_e, \text{ blow} + \dot{q}_\text{rad} + \dot{q}_\text{comb} - \frac{F \sigma}{T_1} \left( T_1^4 - T_\infty^4 \right)
\]

and

\[
\frac{d(\Delta X)}{d\theta} = \frac{d}{d\theta} \left( \frac{VL - S}{NP - 1} \right) = - \frac{\dot{S}}{NP - 1}
\]

where \( \dot{S} \) is the linear surface recession rate and \( NP \) is the total number of nodes in the ablation material of thickness \( VL \).
Rewriting equation (12) in implicit finite difference form

\[ Q_{in} + \dot{m}_1 c_p T_1' - \dot{m}_2 c_p T_2' = \frac{\Delta X}{2k_1} + \frac{\Delta X}{2k_2} - \frac{T_1' - T_2'}{\Delta \theta} \]

\[ + \rho_2 c_p \left( \frac{NP - 1.5}{NP - 1.0} \right) T_2' = \rho_1 c_p \frac{\Delta X}{2} \left( \frac{T_1' - T_1}{\Delta \theta} \right) \]

\[ - \frac{1}{2} \rho_1 c_p T_1' \left( \frac{\dot{S}}{NP - 1} \right) \]  

(12a)

Then, rearranging and collecting terms yield

\[ - \left[ \dot{m}_1 c_p + \dot{s}_p c_p + \rho_1 c_p \frac{\Delta X}{2\Delta \theta} + \frac{1}{2k_1} + \frac{\Delta X}{2k_2} - \frac{1}{2} \rho_1 c_p \left( \frac{\dot{S}}{NP - 1} \right) \right] T_1' \]

\[ + \left[ \dot{m}_2 c_p + \frac{1}{2k_1} + \frac{\Delta X}{2k_2} + \rho_2 c_p \left( \frac{NP - 1.5}{NP - 1.0} \right) \right] T_2' \]

\[ = -\rho_1 c_p \frac{\Delta X}{2\Delta \theta} T_1' - Q_{in} \]  

(12b)
The physical model for interior points in the mature char zone, including all heating terms, is shown in the following sketch:

The energy equation for interior points in the char matrix is

\[
\frac{\partial}{\partial \theta} \left( \Delta X \rho_i c_p T_i \right) = \Delta X \rho_i c_p \frac{dT_i}{d\theta} - \rho_i c_p T_i \left( \frac{\dot{\dot{s}}}{NP - 1} \right)
\]

\[
= \dot{m}_{i+1} \rho_{i+1} c_p T_{i+1} + k_{i-1,i} \left( \frac{\Delta T}{\Delta X} \right) + \rho_i c_p T_i \left( \frac{\dot{\dot{s}}}{NP - 1} \right) T_{i+1}
\]

\[
- k_{i,i+1} \left( \frac{\Delta T}{\Delta X} \right) - \dot{m}_i c_p T_i - \rho_i c_p \dot{\dot{s}} \left( \frac{NP - 1 + \frac{1}{2}}{NP - 1} \right) T_i
\]

(13)
Putting equation (13) in an implicit finite difference form yields

\[
\left( \frac{1}{\Delta x} + \frac{\Delta x}{2k_{i-1}} \right) T_{i-1}^t - \left[ \hat{m}_i c_{p_i} + \rho_i c_{p_i} \frac{\dot{S}}{NP - 1} \left( \frac{NP - i + \frac{1}{2}}{NP - 1} \right) + \frac{1}{2k_{i-1}} \frac{\Delta x}{k_{i-1}} + \frac{\Delta x}{2k_i} \right] T_{i}^t + \frac{1}{2k_i} + \frac{\Delta x}{2k_{i+1}} \rho_i c_{p_i} \frac{\Delta x}{\Delta t} - \rho_i c_{p_i} \left( \frac{\dot{S}}{NP - 1} \right) T_{i}^t
\]

\[
+ \left[ \hat{m}_{i+1} c_{p_{i+1}} + \frac{1}{2k_{i+1}} + \frac{\Delta x}{2k_i} \right] + \rho_{i+1} c_{p_{i+1}} \frac{\Delta x}{\Delta t} - \rho_{i+1} c_{p_{i+1}} \left( \frac{\dot{S}}{NP - 1} \right) T_{i+1}^t
\]

\[
\left( \frac{1}{\Delta x} + \frac{\Delta x}{2k_{i-1}} \right) T_{i-1}^t - \hat{m}_{i} c_{p_{i}} T_{i}^t \left( \frac{\dot{S}}{NP - 1} \right) - \left( \hat{m}_i - \hat{m}_{i+1} \right) \frac{H_d}{k_{i+1}}
\]

In the mature char zone, no internal gaseous ablation products are assumed to form. The reaction zone is the source for the formation of the internal gaseous products. Therefore, in equations (12) and (15), \( \hat{m}_{i} = \hat{m}_{i+1} \)

The physical model for nodes in the reaction zone is identical to schematic shown for the interior nodes in the char except for considering the energy absorbed in formation of the gaseous ablation products. The heat balance equation for a node in the reaction zone is

\[
\frac{d}{d\theta} \left( \Delta x \rho_i c_{p_i} T_i \right) = \Delta x \rho_i c_{p_i} \frac{dT_i}{d\theta} - \rho_i c_{p_i} T_i \left( \frac{\dot{S}}{NP - 1} \right) - \left( \hat{m}_i - \hat{m}_{i+1} \right) H_d
\]

\[
= \hat{m}_{i+1} c_{p_{i+1}} T_{i+1} + k_{i-1,i} \left( \frac{\Delta T}{\Delta x} \right) + \rho_{i+1} c_{p_{i+1}} \frac{\dot{S}}{NP - 1} \left( \frac{NP - i - \frac{1}{2}}{NP - 1} \right) T_{i+1}^t
\]

\[
- k_{i,i+1} \left( \frac{\Delta T}{\Delta x} \right) - \hat{m}_i c_{p_i} T_i - \rho_i c_{p_i} \frac{\dot{S}}{NP - 1} \left( \frac{NP - i + \frac{1}{2}}{NP - 1} \right) T_i^t
\]

(14)
Rearranging,

\[
\left(\frac{\Delta X}{2k_{i-1}} + \frac{\Delta X}{2k_i} \right) T_{i-1}' - \left[ \frac{\dot{m}_i c_i p_i}{\Delta X} + \frac{\rho_i c_i p_i}{\Delta X} \left( \frac{\dot{S}}{NP - i + \frac{1}{2}} \right) + \frac{1}{\Delta X} + \frac{\Delta X}{2k_{i-1}} + \frac{\Delta X}{2k_i} \right] T_{i-1}' + \left[ \frac{\dot{m}_{i+1} c_{i+1}}{\Delta X} \right] T_{i+1}' \]

\[
+ \frac{\Delta X}{2k_i} + \frac{\Delta X}{2k_{i+1}} + \frac{\rho_{i+1} c_{i+1} p_{i+1}}{\Delta X} \left( \frac{\dot{S}}{NP - i + \frac{1}{2}} \right) T_{i+1}' \quad \text{(14a)}
\]

The physical model for the interface between the reaction zone and virgin material is illustrated as follows:

\[
\begin{align*}
\dot{m}_i c_i p_i & \rightarrow \Delta X \\
\dot{S}_{i-1,i} & \rightarrow k_{i-1,i} \left( \frac{\Delta T}{\Delta X} \right) \\
\dot{S}_{i,i+1} & \rightarrow k_{i,i+1} \left( \frac{\Delta T}{\Delta X} \right) \\
\dot{S}_{i-1,i} & = \dot{S} \left( \frac{NP - i + \frac{1}{2}}{NP - 1} \right) \\
\dot{S}_{i,i+1} & = \dot{S} \left( \frac{NP - i + \frac{1}{2}}{NP - 1} \right)
\end{align*}
\]
The heat balance equation for this node is

\[
\frac{d}{d\theta} \left( \Delta X \rho_1 c_{p_1} T_1 \right) = \Delta X \rho_1 c_{p_1} \frac{dT_1}{d\theta} - \rho_1 c_{p_1} T_1 \left( \frac{\dot{S}}{NP - 1} \right) - \dot{m}_i H_d
\]

\[
= k_{i-1,i} \left( \frac{\Delta T}{\Delta X} \right) + \rho_{i+1} c_{p_{i+1}} T_{i+1} \left( \frac{NP - 1 - \frac{1}{2}}{NP - 1} \right)
\]

\[
- k_{i,i+1} \left( \frac{\Delta T}{\Delta X} \right) - \dot{m}_i c_{p_1} T'_1 - \rho_1 c_{p_1} S \left( \frac{NP - i + \frac{1}{2}}{NP - 1} \right) T'_1
\]

Rearranging yields

\[
\left( \frac{1}{\Delta X} + \frac{\Delta X}{2k_{i-1}} \right) T'_{i-1} - \left[ \frac{\dot{m}_i c_{p_1}}{g_1} + \frac{1}{\Delta X} + \frac{1}{2k_{i-1}} + \frac{1}{2k_i} \right]
\]

\[
+ \rho_1 c_{p_1} \left( \frac{NP - i + \frac{1}{2}}{NP - 1} \right) + \rho_1 c_{p_1} \frac{\Delta X}{\Delta \theta} - \rho_1 c_{p_1} \left( \frac{\dot{S}}{NP - 1} \right) T_1
\]

\[
+ \left[ \frac{1}{\Delta X} + \frac{\Delta X}{2k_i} \right] + \rho_{i+1} c_{p_{i+1}} S \left( \frac{NP - i - \frac{1}{2}}{NP - 1} \right) T'_{i+1}
\]

\[
= -\rho_1 c_{p_1} \Delta \theta T_1 - \dot{m}_i H_d
\]

(15a)
The physical model for an interior node in the virgin material is

\[ \frac{d}{d\theta} (\Delta r_p c_p T) = \Delta X p_{i+1} \frac{dT_i}{d\theta} - \rho_i c_p T_i \left( \frac{S}{N_P - 1} \right) \]

\[ = k_{i-1,i} \left( \frac{AT}{\Delta X} \right) + \rho_{i+1} c_{p_{i+1}} \frac{S}{N_P - 1} T_{i+1} - k_{i,i+1} \left( \frac{AT}{\Delta X} \right) \]

\[ - \rho_i c_p T_i \left( \frac{N_P - i + \frac{1}{2}}{N_P - 1} \right) \]

(16)
Rearranging,

\[
\left( \frac{1}{\Delta X} + \frac{\Delta X}{2k_{i-1}} \right) T_{i-1}' - \left[ \frac{1}{\Delta X} + \frac{\Delta X}{2k_{i-1}} + \frac{\Delta X}{2k_i} + \frac{\Delta X}{2k_{i+1}} \right] T_{i-1}' + \rho_i c_p_i \frac{\Delta X}{\Delta \theta} \left( \frac{NP - i + \frac{1}{2}}{NP - 1} \right) T_{i-1}' + \rho_i c_p_i \frac{\Delta X}{\Delta \theta} - \rho_i c_p_i \left( \frac{\Delta \theta}{NP - 1} \right)
\]

\[
+ \left[ \frac{1}{\Delta X} + \frac{\Delta X}{2k_i} + \frac{\Delta X}{2k_{i+1}} \right] T_{i+1}' = -\rho_i c_p_i \frac{\Delta X}{\Delta \theta} T_{i+1}
\]

(16a)

The physical model for the last node in the ablation material and first node in the backup structure is

For this interface, \( T_{i,j}' = T_{i,j+1}' \).
The heat balance equation for this node is

\[ \frac{d}{d\theta} \left[ \left( \frac{\Delta X_j}{2} \rho_i, j \, c_{p_i, j} \rho_i, j \right) + \frac{\Delta X_{j+1}}{2} \, c_{p_{i+1, j+1}} \rho_{i+1, j+1} \right] T_1 \]

\[ = \left( \frac{\Delta X_j \rho_i, j \, c_{p_i, j} + \Delta X_{j+1} \, c_{p_{i+1, j+1}} \rho_{i+1, j+1}}{2} \right) \frac{dT_1}{d\theta} - \frac{1}{2} \left( \frac{1}{NP - 1} \right) c_{p_i, j} \rho_i, j^T_1 \]

\[ = k_{i-1, j} \left( \frac{\Delta T}{\Delta X} \right) - c_{p_i, j} \rho_i, j \left( \frac{1}{2} \frac{1}{NP - 1} \right) T_1' - k_{i, j+1} \left( \frac{\Delta T}{\Delta X} \right) \]

Rearranging yields

\[ \left( \frac{1}{\Delta X_j} + \frac{1}{2k_{i-1, j}} \right) T_1' - \left( \frac{1}{\Delta X_{j+1}} + \frac{1}{2k_{i, j+1}} \right) T_1' + \left( \frac{1}{\Delta X_j} + \frac{1}{2k_{i, j}} \right) \]

\[ + \left( \frac{1}{\Delta X_{j+1}} + \frac{1}{2k_{i+1, j+1}} \right) \]

\[ = - \left( \frac{\Delta X_j \rho_i, j \, c_{p_i, j} + \Delta X_{j+1} \, c_{p_{i+1, j+1}} \rho_{i+1, j+1}}{2\Delta \theta} \right) T_1 \]

\[ (17a) \]

The backup structure may contain up to a maximum of 12 different materials with or without air gaps between materials. Therefore, conduction or radiation and/or convection between materials is allowed. The heat balance equations for the various modes of heat transfer in the backup structure are presented in the following equations:
(1) Interior node material:

\[
\frac{(T'_{i-1,j} - T'_{i,j})}{\Delta X_j} + \frac{(T'_{i,j} - T'_{i+1,j})}{\Delta X_j} = \rho_{i,j}c_{p_{i,j}}\frac{\Delta X_j}{\Delta \theta} \bigg[ T'_{i,j} - T_{i,j} \bigg] \tag{18}
\]

Rearranging, equation (18) becomes

\[
\left( \frac{1}{2k_{i-1,j}} + \frac{1}{2k_{i,j}} \right) T'_{i-1,j} - \left( \frac{1}{2k_{i-1,j}} + \frac{1}{2k_{i,j}} \right) T'_{i,j} + \left( \frac{1}{2k_{i,j}} + \frac{1}{2k_{i+1,j}} \right) T'_{i+1,j} + \rho_{i,j}c_{p_{i,j}} \frac{\Delta X_j}{\Delta \theta} T_{i,j} \tag{18a}
\]

(2) First and last nodes of two interior materials with no gap:

\[
\frac{(T'_{i-1,j} - T'_{i,j})}{\Delta X_j} + \frac{(T'_{i,j+1} - T'_{i+1,j+1})}{\Delta X_{j+1}} = \frac{\rho_{i,j}c_{p_{i,j}} + \rho_{i,j+1}c_{p_{i,j+1}}}{2} \frac{\Delta X_{j+1}}{2 \Delta \theta} \bigg[ T'_{i,j} - T_{i,j} \bigg] \tag{19}
\]

For this case, \( T'_{i,j} = T'_{i,j+1} \)
Rearranging, equation (19) becomes

\[
\left( \frac{\Delta X_{i-1,j}^l}{2k_{i-1,j}^l} + \frac{\Delta X_{i,j}^l}{2k_{i,j}^l} \right) T_{i-1,j}^l = \left[ \frac{1}{2k_{i-1,j}^l} + \frac{1}{2k_{i,j}^l} \right] + \frac{\Delta X_{i,j}^l + \Delta X_{i,j+1}^l}{2 \Delta \theta} \\
+ \left( \frac{\Delta X_{i,j+1}^l}{2k_{i,j+1}^l} + \frac{\Delta X_{i+1,j}^l}{2k_{i+1,j}^l} \right) T_{i+1,j}^l
\]

\[
= \left( \frac{\rho_{i,j} c_{p_{i,j}^l}}{2} \cdot \frac{\Delta X_{i,j}^l}{2 \Delta \theta} \right) T_{i,j}^l
\]

(19a)

(3) First node of interior material with an air gap between materials:

\[
h_j \left( T_{i-1,j}^l - T_{i,j+1}^l \right) + \left( \frac{\sigma}{\varepsilon_j^l} + \frac{1}{\varepsilon_{j+1}^l} \right) \left( \frac{h_j}{\varepsilon_j^l} \right) \left( \frac{1}{\varepsilon_{j+1}^l} \right) \left( T_{i-1,j}^l - T_{i,j+1}^l \right)
\]

\[
= \left( \frac{T_{i,j+1}^l - T_{i+1,j}^l}{\Delta X_{i+1,j}^l + \Delta X_{i,j+1}^l} \right) = \frac{\rho_{i,j+1} c_{p_{i,j+1}^l}}{2 \Delta \theta} \left( T_{i,j+1}^l - T_{i,j+1}^l \right)
\]

(20)

Equation (20) may be linearized by using the approximation

\[
T_i^l \approx \frac{1}{4} \left( T_{i-1,j} + T_{i,j+1} + T_{i,j} + T_{i+1,j+1} \right)
\]

as discussed in the Program Description section.
Therefore, rearranging and linearizing, equation (20) becomes

\[
\begin{bmatrix}
    h_j + \left( \frac{4 \sigma T_{i-1,j}^2}{\frac{1}{\varepsilon_j} + \frac{1}{\varepsilon_{j+1}} - 1} \right) T_{i-1,j} - h_j + \left( \frac{4 \sigma T_{i,j+1}^2}{\frac{1}{\varepsilon_j} + \frac{1}{\varepsilon_{j+1}} - 1} \right) \\
    + \frac{1}{\Delta x_{i+1,j+1}} + \frac{1}{\Delta x_{i,j+1}} + \frac{\rho_{i,j+1} c_{i,j+1} \Delta x_{i,j+1}}{2 \Delta \theta} T_{i,j+1}^4 \\
    + \left( \frac{1}{\Delta x_{i+1,j+1}} + \frac{1}{\Delta x_{i,j+1}} \right) T_{i+1,j+1} = - \frac{\rho_{i,j+1} c_{i,j+1} \Delta x_{i,j+1}}{2 \Delta \theta} T_{i,j+1}^4 \\
    - \left( \frac{3 \sigma}{\frac{1}{\varepsilon_j} + \frac{1}{\varepsilon_{j+1}} - 1} \right) \left( T_{i,j+1}^4 - T_{i-1,j}^4 \right) 
\end{bmatrix}
\]

(20a)

(4) Last node of an interior material with an air gap between materials:

\[
\frac{T_{i-1,j} - T_{i,j}}{\Delta x_{i,j}} = \frac{T_{i,j} - T_{i,j+1}}{\Delta x_{i,j}} - h_j \left( T_{i,j} - T_{i,j+1} \right) 
\]

\[
- \left( \frac{1}{\varepsilon_j} + \frac{1}{\varepsilon_{j+1}} - 1 \right) \left( \frac{\rho_{i,j+1} c_{i,j+1} \Delta x_{i,j+1}}{2 \Delta \theta} \right) \left( T_{i,j} - T_{i,j} \right) 
\]

(21)
Rearranging and linearizing, equation (21) becomes

\[
\left(\frac{1}{\Delta x_j} + \frac{\Delta x_j}{2k_{i-1,j} + 2k_{i,j}}\right) T'_{i-1,j} - \left[ h_j + \frac{1}{\Delta x_j} + \frac{\Delta x_j}{2k_{i-1,j} + 2k_{i,j}} + \left(\frac{4\sigma T^3}{\varepsilon_j + \frac{1}{\varepsilon_{j+1}} - 1}\right) \right]
\]

\[+ \frac{\rho_i, j c_p j, j \Delta x_j}{2 \Delta \theta} T'_{i,j} + \left[ h_j + \left(\frac{4\sigma T^3}{\varepsilon_j + \frac{1}{\varepsilon_{j+1}} - 1}\right) \right] T'_{i,j+1}\]

\[= - \frac{\rho_i, j c_p j, j \Delta x_j}{2 \Delta \theta} T_{i,j} + \frac{3\sigma}{2} \left( T'_{i,j+1} - T'_{i,j} \right)\]

(21a)

(5) Final node in backup structure:

(a) Adiabatic surface

\[\frac{T'_{i-1,j} - T'_{i,j}}{\Delta x_j} = \frac{\rho_i, j c_p j, j \Delta x_j}{2 \Delta \theta} \left( T'_{i,j} - T_{i,j} \right)\]

(22)

Rearranging, equation (22) becomes

\[
\left(\frac{1}{\Delta x_j} + \frac{\Delta x_j}{2k_{i-1,j} + 2k_{i,j}}\right) T'_{i-1,j} - \left(\frac{1}{\Delta x_j} + \frac{\Delta x_j}{2k_{i-1,j} + 2k_{i,j}}\right)
\]

\[+ \frac{\rho_i, j c_p j, j \Delta x_j}{2 \Delta \theta} T'_{i,j} = - \frac{\rho_i, j c_p j, j \Delta x_j}{2 \Delta \theta} T_{i,j}\]

(22a)
(b) Radiation and/or convection loss to cabin environment

\[
\left( \frac{T_{i-1,j}^{'} - T_{i,j}^{'}}{\Delta X_j} + \frac{T_{i,j}^{'}}{2k_{i-1,j}} + \frac{T_{i,j}^{'}}{2k_{i,j}} \right) - h_{\text{env}} (T_{i,j}^{' - T_{\text{env}}} - T_{i,j}^{' - T_{\text{env}}})
\]

\[
- F_{\text{env}} \sigma (T_{i,j}^{' - T_{\text{env}}}^{'}) = \frac{\rho_{i,j} c_{p_{i,j}} \Delta X_j}{2 \Delta \theta} \left( T_{i,j}^{' - T_{i,j}} \right)
\]

Rearranging, equation (23) becomes

\[
\left( \frac{1}{\Delta X_j} + \frac{1}{2k_{i-1,j}} + \frac{1}{2k_{i,j}} \right) T_{i-1,j}^{' - T_{i,j}^{'}} = \left( \frac{h_{\text{env}} \Delta X_j}{2k_{i-1,j}} + \frac{h_{\text{env}} \Delta X_j}{2k_{i,j}} + F_{\text{env}} c_{\text{p}_{i,j}} \Delta T_{i,j}^{' - T_{i,j}} \right)
\]

\[
\frac{\rho_{i,j} c_{p_{i,j}} \Delta X_j}{2 \Delta \theta} T_{i,j}^{' - T_{i,j}} = - \frac{\rho_{i,j} c_{p_{i,j}} \Delta X_j}{2 \Delta \theta} T_{i,j}^{' - T_{i,j}}
\]

\[
- h_{\text{env}} T_{\text{env}} - F_{\text{env}} \sigma \left( 3T_{i,j}^{' - T_{\text{env}}}^{' - T_{\text{env}}} \right)
\]

Discussion of Assumptions

A brief discussion of several assumptions and approximations made in deriving the heat balance equations is now presented.

As shown in the Derivation of Equations section, transient heat conduction, thermal degradation, and the flow of the gaseous products from the reaction zone are the internal thermal transport phenomena of interest. Several methods are available in the treatment of the thermal decomposition process, and they differ primarily in whether the chemical decomposition occurs in a single plane at a fixed temperature or whether a spatially continuous decomposition in depth is assumed. This analysis assumes that the decomposition from the virgin to the char state occurs in a reaction zone that is defined by known temperature limits. These temperature limits are determined from thermogravimetric test data for the particular material being investigated. Figure 3 is a thermogravimetric curve for typical charring ablation material. From this curve, the rate of pyrolysis $\dot{m}_p$ is calculated by knowing the
temperature change of a particular node with time, that is,

\[
\dot{\rho}_i = \frac{\rho_i' - \rho_i}{\Delta \theta}
\]  

(24)

and

\[
\dot{m}_i = \sum_{j=1}^{NP} \dot{\rho}_i \Delta X_j
\]  

(25)

This method of computing the gas-generation rates and local instantaneous density may be subject to error since the thermogravimetric curve of a material is influenced by temperature rise rate (deg/sec), and the reaction zone may shift up and down the temperature scale. This error can be eliminated by the use of an Arrhenius expression of the form

\[
\frac{d\rho}{d\theta} = -A(\rho - \rho_c)^n e^{-\frac{E}{RT}}
\]  

(26)

The method now being used in STAB II (equation (25)) to calculate the pyrolysis rate is being investigated to determine its validity. The final formulation of the pyrolysis rate law must rest heavily on the experimental rate data for the material under investigation. The use of simple expressions such as equations (24) and (25) may be entirely adequate, depending upon activation energy for the decomposition process and order of reaction.

The aerodynamic heating input in the analysis consists of convective and radiative components treated separately. This distinction is necessary since the convective heating can be significantly reduced as a result of the injection of the ablation gases into the boundary layer, with generally no effect on radiant heating. Reduction in the convective heating rate can be approximated by the following expression (ref. 6):

\[
\dot{q}_{\text{block}} = \eta \dot{m}_i \left( H_T - H_w \right)
\]  

(27)

Therefore,

\[
\dot{q}_{c, \text{blow}} = \dot{q}_{cw} \left( \frac{H_T - H_w}{H_T - H_{300}} \right) - \dot{q}_{\text{block}}
\]  

(28)
However, equation (28) is unsatisfactory for high blowing rates, since $\dot{q}_{\text{block}}$ can become greater than $\dot{q}_{\text{cw}}$. An experimental curve of blocking effectiveness $\psi = \frac{\dot{q}_{\text{c, blow}}}{\dot{q}_{\text{cw}}}$ as a function of the mass transfer parameter $\frac{m_{\text{f}} H_{\text{f}}}{\dot{q}_{\text{cw}}}$ can be employed to determine the heating reduction at high blowing rates. Both methods have been employed in the STAB II analysis. Equation (28) is presently in use. However, no satisfactory method for accurately predicting the convective heat blockage has been determined.

Another source of heating is the combustion of the ablation products in the boundary layer. Reference 7 presents an analysis of the oxidation of a carbon surface and the resulting combustive heating. The heating due to combustion as derived in reference 7 is

$$\dot{q}_{\text{comb}} = m_c \Delta H_c$$  \hspace{1cm} (29)

where $\Delta H_c$ is the heat of combustion per unit weight of char.

The thermal properties of the ablation material are both temperature and state dependent (fully or partially charred). Figure 4 is an illustration of the variation of these properties with temperature and state. The thermal properties are assumed to vary as follows:

(1) Char zone \( (T_i \geq T_{\text{char}}) \)

$$k_c = f \text{(temp)}$$

$$c_p = f \text{(temp)}$$

$$\rho_c = \text{constant}$$

(2) Reaction zone \( (T_{\text{abl}} \leq T_i < T_{\text{char}}) \)

$$\rho = f \text{(temp)} = \rho_v + (\rho_v - \rho_c) \left( \frac{T_i - T_{\text{abl}}}{T_{\text{abl}} - T_{\text{char}}} \right)$$

$$k = f(\rho) = k_c + (k_v - k_c) \left( \frac{\rho_i - \rho_c}{\rho_v - \rho_c} \right)$$

$$c_p = f(\rho) = c_{\text{p,c}} + (c_{\text{p,v}} - c_{\text{p,c}}) \left( \frac{\rho_i - \rho_c}{\rho_v - \rho_c} \right)$$
(3) Virgin zone ($T_i < T_{abl}$)

\[ \rho_v = \text{constant} \]
\[ k_v = f(\text{temp}) \]
\[ c_v = f(\text{temp}) \]

The calculation of char removal, due to chemical, thermal, or mechanical mechanism or a combination of these mechanisms, has been examined by a multitude of investigators and numerous correlations exist, depending on the specific material involved.

To provide a maximum degree of flexibility for analyzing both ground and flight test data and synthesizing trajectories, the following provisions for char removal (surface movement) are provided:

1. Removal of char as a function of surface temperature.
2. Removal of char at a rate which is a function of time.

As the char is removed, the surface moves with respect to a coordinate fixed in the material. The distance between the initial surface location and the char surface is

\[ S = \int_0^\theta \dot{S} \, d\theta \]

**ANALYSIS VERIFICATION**

As discussed in the previous sections, approximations and assumptions were made in the analytical model to afford a quick and accurate solution in predicting the thermal response of a charring heat shield. These simplifying assumptions and approximations are expected to introduce only minor errors; however, the validity of the analyses and resultant accuracy can be judged only by a comparison with exact theoretical solutions and experimental data. Three examples have been selected, and a comparison of the STAB II results with the theoretical and test data is discussed in the following paragraphs.

An elementary transient heating example was chosen to demonstrate the accuracy and numerical stability of the STAB II program. A steel slab 6 inches thick was selected and assumed to be at uniform initial temperature of $460^\circ$ R ($0^\circ$ F). The thermal properties were considered constant.
front surface was subjected to a heating rate of 72 Btu/ft\(^2\)-sec, and an adiabatic back surface was assumed. Figure 5 shows a comparison of the STAB II calculated in-depth temperatures as a function of time with the exact solution taken from reference 8.

To demonstrate the STAB II solution with a moving boundary, a slab with constant properties, uniform initial temperature, front surface moving with a constant velocity, and constant surface temperature was chosen. The exact solution for a semi-infinite slab with these boundary and initial conditions is presented in reference 9. Figure 6 presents a comparison of the STAB II temperature response with the exact solutions. As can be seen from this figure, the two solutions are not in agreement for approximately the first 50 to 60 seconds of the transient. This disagreement is the result of the quasi-steady state assumption made in the exact solution analysis.

\[
\left[\left(\frac{\partial T}{\partial t}\right)_{\xi=0} = 0; \quad k\left(\frac{\partial T}{\partial x}\right)_{x=0} = \dot{S}_{\rho c, p} \Delta T\right]
\]

A calculation was made to estimate the induction time (time at which \(\frac{\partial T}{\partial \theta} = 0\) is a good assumption) and found to be approximately 60 seconds, which is in agreement with the STAB II results.

Finally, to verify the fully charring ablation model, an example of a typical charring material was chosen. (See the sample problem in appendix A.) The charring ablation material is initially 1.6 inches thick with an adiabatic back surface and a constant heat flux of 95 Btu/ft\(^2\)-sec applied to the front surface. The surface is assumed to recede at a constant velocity of \(3.05 \times 10^{-3}\) in./sec. Figure 7 presents a comparison of the in-depth temperatures with actual test results obtained in an arc tunnel. The results are in good agreement, with the largest deviations between calculated and measured values occurring for the thermocouple located at a depth of 1.0 inch. The disagreement could be attributed to several possible errors: thermal property values, incorrect location of thermocouples, et cetera. The effect of varying the thermal properties (thermal conductivity, specific heat, et cetera) is presently being investigated.

Tables I and II present the input and output data used for this example. Figures 8, 9, and 10 are the resulting plot routine output.

The comparisons between the computer results and the exact solutions and test results are considered satisfactory.
CONCLUDING REMARKS

An analysis and a computer program for predicting the transient thermal response of a charring ablation thermal protection system has been described. The numerical formulation of the equations is such that an implicit solution is obtained. This method of solution affords both a rapid and accurate solution for both ablating and nonablating type problems.

Provision is made in the program for a number of surface boundary conditions. These provisions allow efficient use of the program for analyzing both ground and flight test data and trajectory synthesis.

The computer program has been checked out with both exact solutions and actual ablation test data. The numerical results are in good agreement with the exact solutions and test data. However, the analysis depends upon using good property values, and some effort must be expended in obtaining the best possible thermal properties.

Manned Spacecraft Center
National Aeronautics and Space Administration
Houston, Texas, November 1, 1965
REFERENCES

1. Israel, Martin H.; and Nardo, S. V.: An Annotated Bibliography on Ablation and Related Topics. PIBAL rep. no. 686, Polytechnic Institute of Brooklyn, May 1964.


APPENDIX A

SAMPLE PROBLEM

The following sample problem is shown to indicate the form of the data input and the program output. A typical charring material subjected to a constant heating rate as experienced in an arc tunnel is presented. The following is a sketch of the model:

\[ \dot{q}_{cw} = 95 \text{ Btu/ft}^2\text{-sec} \]

\[ 1.5 \text{ in.} \]

\[ 0.1 \text{ in.} \]

The various material properties and dimensions are shown in the program output of Table II. The insulation is assumed to be ablation material for this problem. The problem coding sheet and subsequent data card listing are shown in Table I. The initial temperature of the structure was assumed uniform and equal to 530\(^\circ\) R (70\(^\circ\) F). Figures 8, 9, and 10 are the output data obtained from the plot routines.
IBM 7094/40 program F021, standard ablation program, designated STAB II, is designed to evaluate the transient thermal performance of a charring ablation heat protection system. The program considers one ablating material and up to 12 different materials in the supporting backup structure. A maximum of 50 nodes may be considered in the ablation material, and a maximum of 10 nodes per material is allowed for each backup structure material. Air gaps can be considered between successive materials in the backup, thus allowing for both radiative and/or convective heat transfer between materials. The heat loss to the cabin environment from the backup structure can be accomplished by both radiation and/or convection, or an adiabatic backface surface may be prescribed.

Unless otherwise specified, the input problem data are in "floating point" form (E12.8 format) and must end in columns 12, 24, 36, 48, 60, and 72. It is suggested that each floating point number have a sign, a two-digit exponent, and a decimal point. For example, the number 145.23 can be written as +1.4523+02, +145.23+00, or +1.4523+03.

### Input Nomenclature

The nomenclature used in the problem data input is as follows:

- **NCASE**: number of problems to be run successively
- **HEAD**: any 72 alphabetical and/or numerical characters
- **TITLE**: control card for reading in new input for successive problems
  1. blank card – new data will be read in
  2. Six asterisks in columns 1 to 6. Skip to next read statement
- **TLIM**: time limit of problem, sec
- **TINT**: starting time of problem, sec
- **NPTT**: number of points in time-step table (the minimum value of NPTT is 2)
- **NFLST**: output plot control
  - **1**: plot routine will be used
  - **0**: plot routine will be ignored
TTABLE  time in time-step table, sec
DELT  time step to be used for each calculation - starting at time TTABLE, sec
IPRC  variable print frequency in TTABLE table; that is, if DELT = 1.0 and IPRC = 10, the output will be printed at 10-second intervals
FCONV factor to correct convective heating rate for various body locations
FRAD factor to correct radiative heating for various body locations
TABL temperature at which ablation starts, °R
TCHAR temperature at which ablation stops, °R
TREC surface temperature, °R, or time at which char removal is to start, sec
RHOV density of virgin ablation material, lb/ft³
RHOC density of mature char material, lb/ft³
FBLOW blowing efficiency of ablation gases in reducing convective heating
EMV emissivity of virgin ablation material
EMC emissivity of charred ablation material
H300 enthalpy of air at 300° K, 129.06 Btu/lbm
V initial thickness of virgin ablation material, in.
HV heat of degradation of virgin material, Btu/lbm
VPT test to determine if the reaction zone and char zone thermal properties are irreversible with temperature
  =0 properties are irreversible and equal to the value at the maximum individual node temperature (this is the recommended value for VPT)
  =1 properties are reversible
FV view factor for external environment
TV sink temperature of external environment, °R
CHARK: thermal conductivity of material at TCHAR, Btu/ft-hr-°R
CHARC: specific heat of material at TCHAR, Btu/lbm-°R
ABLK: thermal conductivity of material at TABL, Btu/ft-hr-°R
ABLC: specific heat of material at TABL, Btu/lbm-°R
NP: number of node points in ablation material
NKC: number of points in char thermal conductivity - temperature table
NCPC: number of points in char specific heat - temperature table
NKV: number of points in virgin thermal conductivity - temperature table
NCPV: number of points in virgin specific heat - temperature table
NREC: number of points in surface recession - temperature or time table
TKC: temperature values in char thermal conductivity - temperature table, °R
XKC: thermal conductivity values in char thermal conductivity - temperature table, Btu/ft-hr-°R
TCPC: temperature values in char specific heat - temperature table, °R
CPC: specific heat values in char specific heat - temperature table, Btu/lbm-°R
TKV: temperature values in virgin thermal conductivity - temperature table, °R
XKV: thermal conductivity values in virgin thermal conductivity - temperature table, Btu/ft-hr-°R
TCPV: temperature values in virgin specific heat - temperature table, °R
CPV: specific heat values in virgin specific heat temperature table, Btu/lbm-°R
TS: temperature, °R, or time, sec, values in the surface recession table
SR  surface recession values in the surface recession - temperature or time table, in./sec
NTRAPT  number of time points in the trajectory input table
TIME  the array of (NTRAPT) trajectory time values, sec
QC/N  the corresponding array of cold wall convective heating rates, Btu/ft$^2$-sec
QRAD  the corresponding array of radiative heating rates, Btu/ft$^2$-sec
VEL  the corresponding array of flight velocity, ft/sec
NMB  number of materials in backup structure
NPBS  total number of node points in backup structure
BL  total thickness of backup structure, in.
XNPM  number of nodes in each individual material in backup structure
NKPB  number of points in each individual backup structure material thermal conductivity - temperature table
NCPB  number of points in each individual backup structure material specific heat - temperature table
XIDNT  any 72 alphanumeric characters used to describe each individual material in the backup structure
TXK  temperature values in backup material thermal conductivity - temperature table, °R
XK  thermal conductivity values in backup material thermal conductivity - temperature table, Btu/ft-hr-°R
TCP  temperature values in backup material specific heat - temperature tables, °R
CPX  specific heat values in backup material specific heat - temperature tables, Btu/lbm-°R
RH$\rho$/BX  density of individual materials in backup, lb/ft$^3$
XBM  thickness of individual materials in backup, in.
EMFB  emissivity of front surface of each material in backup
EMBB emissivity of back surface of each material in backup

H film coefficient between adjacent materials in backup, Btu/ft²-hr-°R

GAPX width of gap between adjacent materials in backup, in.

FTEST, BTEST tests to determine the mode of heat transfer between materials for the front and backface of each material respectively

=0 conduction only between materials

=+1 convective heat transfer only

=-1 radiation only or radiation and convection heat transfer

TENV temperature of interior cabin environment, °R

HENV film coefficient to interior cabin environment, Btu/ft²-hr-°R

FENV view factor and emissivity product for radiative heat transfer to cabin interior

QLØSS boundary condition between last node of the backup structure and cabin environment

=0 adiabatic surfaces

=+1 radiation and/or convective loss

TEST2 determines the proper heat shield initial temperature distribution

=0 constant, uniform initial temperature distribution

=-1 arbitrary initial temperature distribution

=+1 linear temperature distribution

TEMPI temperature to be used when constant temperature distribution option is used, °R

TXØ initial temperature at front surface of heat shield to be used in computing initial linear temperature gradient, °R

TEMDI arbitrary temperature distribution values, to be used only if TEST2 is negative, °R
The input data are given in the following order. Each number in the following listing refers to a separate record and must begin on a new data card. The input data have been grouped, where possible, into various sections dealing with a particular part of the input, that is, ablation material properties, trajectory data, backup structure, et cetera. This grouping permits the use of a minimum number of input cards for running successive problems. The title card as described in the input nomenclature controls the input for successive problems.

1. The first data card contains the value of NCASE. NCASE is an integer (I5 format) and must end in column 5. This card tells how many problems are to be run and is entered only once at the start of the data deck.

2. Columns 1 to 72 of the second data card contain any title or identification information desired; any alphanumeric character may be used. This card is printed at the top of the first page of the output. This card must be included in all successive problems to be run.

(a) Problem time section

3. TITLE card - if blank, cards 4 and 5 must be submitted. If six asterisks are punched in columns 1 to 6, skip to record number 6.

4. This record contains, in the following order, TLIM, TINT, NPTT, and NPL\$T. TLIM and TINT are entered as floating-point numbers and must end in columns 12 and 24. NPTT and NPL\$T are integers entered with an I5 format and must end in column 30 and 35.

5. Start entering the values of TTABLE, DELTT, IPRC. TTABLE and DELTT are floating-point numbers and must end in columns 12 and 24. IPRC is entered as integer with an I5 format and must end in column 30. Use as many cards as required to enter NPTT values.

(b) Heating rate factors section

6. TITLE card - if blank, card 7 must be submitted. If six asterisks are punched in columns 1 to 6, skip to record number 8.
7. Enter the FCINV and FRAD. These numbers are entered as floating-point numbers and must end in columns 12 and 24.

(c) Ablation material section

8. TITLE card – if blank, cards 9 to 18 must be submitted. If six asterisks are punched in columns 1 to 6, skip to record number 19.

9. HEADING card – any alphanumeric characters in columns 1 to 72. Records 9 to 18 contain input data for the ablation material.

10. Enter TABL, TCHAR, TREC, RHOF, RHOC, and FBLFW. These numbers are entered as floating-point numbers (6E12.8 format) and must end in columns 12, 24, 36, 48, 60, and 72.

11. Enter EMV, EMC, H300, VL, HV, and VPT. Use the same format as card 10.

12. Enter FV, TV, CHARK, CHARC, ABLK, and ABLC. Use the same format as card 10.

13. This card contains, in the following order, NP, NKC, NCPC, NKV, NCPV, and NREC. These numbers are fixed-point integers and must end in columns 5, 10, 15, 20, 25, and 30. An I5 format is used to read in these numbers.

14. Start entering the curve of TKC versus XKC, with the values of TKC ending in columns 12, 36, and 60. The corresponding values of XKC must end in columns 24, 48, and 72; for example, three TKC-XKC points are contained on one card. The numbers are entered as floating-point numbers. Use as many cards as required to enter NKC points on the curve.

15. Start entering the curve of TCPC versus CPC with the values of TCPC, ending in columns 12, 36, and 60. The corresponding values of CPC must end in columns 24, 48, and 72; for example, three TCPC-CPC points are contained on one card. The numbers are entered as floating-point numbers. Use as many cards as required to enter the NCPC points on the curve.

16. Start entering the curve of TKV versus XKV with the values of TKV ending in columns 12, 36, and 60. The corresponding values of XKV must end in columns 24, 48, and 72; for example, three TKV-XKV points are contained on one card. The numbers are entered as floating point. Use as many cards as required to enter the NKV points on the curve.

17. Start entering the curve of TCPV versus CPV with the values of TCPV, ending in columns 12, 36, and 60. The corresponding values of CPV must end in columns 24, 48, and 72; for example, three TCPV-CPV points are contained on one card. The numbers are entered as floating point. Use as many cards as required to enter the NCPV points on the curve.

18. Start entering the curve of TS versus SR with the values of TX, ending in columns 12, 36, and 60. The corresponding values of SR must end in columns
24, 48, and 72; for example, three TS-SR points are contained on one card. The numbers are entered as floating point. Use as many cards as required to enter NREC points on the curve.

(d) Trajectory data section

19. TITLE card - if blank, cards 20 to 22 must be submitted; if six asterisks are punched in columns 1 to 6, skip to record number 23.

20. HEADNG card - any alphanumeric characters in columns 1 to 72. Records 21 and 22 contain trajectory input data.

21. Enter NTRAPT. This number is an integer and must end in column 5. An I5 format is used to read in this number.

22. Start entering the trajectory data in the following order: TIME, QC0N, QRAD, VEL. These values are entered as floating-point numbers and must end in columns 12, 24, 36, and 48. There are four trajectory data points on one card. Use as many cards as required to enter NTRAPT points in the trajectory.

(e) Backup structure section

23. TITLE card - if blank, cards 24 to 31 must be submitted; if six asterisks are punched in columns 1 to 6, skip to record number 32.

24. Enter NMB, NPBS, and BL. These three values must end in columns 5, 10, and 24. NMB and NPBS are integers and are read in under an I5 format. BL is a floating-point number.

25. Enter the values of XNPM. XNPM is in floating-point form and must end in columns 12, 24, 36, 48, 60, and 72. Use as many cards as required to enter NMB points.

26. Enter the values of NKPB and NCPB. These numbers are integers and NKPB must end in columns 5, 15, 25, 35, and 45; and the corresponding values of NCPB must end in columns 10, 20, 30, 40, and 50. An I5 format is used to read these values. Five NKPB-NCPB values are contained on one card. Use as many cards as are required to enter NMB points.

27. XIDNT card - any alphanumeric characters in columns 1 to 72. This card contains a description of each backup material.

28. Start entering the curve of TXK versus XK with the values of TXK, ending in columns 12, 36, and 60. The corresponding values of XK must end in columns 24, 48, and 72; for example, three TXK-XK points are contained on one card. The numbers are entered as floating point. Use as many cards as required to enter NKPB points on the curve.
29. Start entering the curve of TCP versus CPX with the values of TCP, ending in columns 12, 36, and 60. The corresponding values of CPX must end in columns 24, 48, and 72; for example, three TCP-CPX points are contained on one card. The numbers are entered as floating point. Use as many cards as required to enter NCPB points on the curve. Repeat records 27, 28, and 29 until the properties for NMB materials have been entered. The maximum number for NMB is 12.

30. Start entering the following values in order: RHØBX, XB, EMFB, and EMBB. These values are entered as floating-point numbers (6E12.8 format) and must end in columns 12, 24, 36, 48, 60, and 72. Use as many cards as required to enter NMB points.

31. Start entering the following values in order: H, GAPX, FTEST, and BTEST. These values are entered as floating-point numbers (6E12.8 format) and must end in columns 12, 24, 36, 48, 60, and 72. Use as many cards as required to enter NMB points.

(f) Interior environment section

32. TITLE card — if blank, cards 33 and 34 must be submitted; if six asterisks are punched in columns 1 to 6, skip to record number 35.

33. HEADNG card — any alphanumeric characters in columns 1 to 72. Record 35 contains properties of environment.

34. Enter the following: TENV, HENV, FENV, and QLØSS. The values are entered as floating-point numbers and must end in columns 12, 24, 36, and 48.

(g) Initial temperature section

35. TITLE card — if blank, records 36 and 37 must be submitted; if six asterisks are punched in columns 1 to 6, skip to record number 39.

36. HEADNG card — any alphanumeric characters in columns 1 to 72. Records 37 and 38 contain initial temperature distribution input.

37. Enter TEST2, TEMPI, and TXØ. These values are entered as floating-point numbers and must end in columns 12, 24, and 36.

NOTE: If TEST2 is a negative number, record 38 must be submitted; otherwise, skip to record 39.

38. Enter the arbitrary temperature distribution values, TEMDI. These values are entered as floating points with a 6E12.8 format. Use as many cards as required to enter NP plus NPBS node points.

(h) Enthalpy - temperature section
39. TITLE card – if blank, records 40 and 41 must be submitted; if six asterisks are punched in columns 1 to 6, this is the last data card in the problem input.

40. Enter NHP. This value is an integer and must end in column 5. An I5 format is used to read in this number.

41. Start entering the curve of HX versus TW with the value of HX ending in columns 12, 36, and 60. The corresponding values of TW must end in columns 24, 48, and 72; for example, three HX-TW points are contained on one card. The numbers are entered as floating points. Use as many cards as required to enter NHP points on the curve. Record 41 consists of the last data cards required as input for a problem.

As many successive problems as desired may be run at one time by proper input preparation. STAB II has been designed to save all input information until it is changed by new input data. Therefore, the use of the TITLE control card is very important when running more than one problem and using the input data of previous problems. As shown, each input section starts with a TITLE control card for determining whether new input data are to be used. If any data are changed within a section, then all data cards required for that section must be submitted.

STAB II can also be used for solving one-dimensional transient heat-conduction problems of nonablating materials. The following input parameters must be adhered to:

1. TABL must be greater than the maximum temperature expected during the calculation. Also, TABL > TCHAR > TREC.

2. The ablation material must be considered to be the first material in the structure for calculation purposes.

3. The virgin and char properties must be inputed as described above but can have the same values; that is, XKV = XKC, CPC = CPV, RH0V = RH0C, et cetera.

The following dimensional statements and program limitations should not be violated when preparing the input described above for ablating and non-ablating structure:

1. All property tables can have a maximum of 20 points (i.e., a temperature and specific heat value constitute one point).

2. The surface recession table can have a maximum of 50 points (TS and SR constitute one point).

3. The trajectory table can have a maximum of 300 points (TIME, QC0N, QRAD, and VEL constitute one point).
4. The ablation material can be broken into a maximum of 50 nodes. The backup structure can consist of up to 12 different materials with a maximum of 10 nodes per material.

5. A minimum of three nodes per material (ablation or backup) must be specified.

6. A minimum of two materials must be specified (ablation material and one backup structure material).

7. Pure conduction only is allowed between the ablation material and the first material in the backup.

8. If any data input is changed in the Ablation Material Section on successive problems, the Ablation Material Section data cards plus the Initial Temperature Section data cards must be submitted.

Program Output Information

The computed results are available in two forms of output: tabular and plot outputs. The tabular output presents the computed results in block type form for each computation step as controlled by the print count control number. As discussed in the preparation of input data, both the computational time step and print control can be varied throughout the running of a problem. Therefore, excessive printed output is avoided, and there is a considerable savings in actual machine computation time. The plot outputs are printed and plotted only when the entire set of problems to be run are completed.

Tabular output. – The program prints a listing of the data input parameters for identification of the problem and ease in identifying any input mistakes. For stacked problems, the program prints only that input information that is changed from the previous problem. The following calculated problem output is printed:

1. Time, sec
2. Cold wall convective heating rate without blowing, Btu/ft\(^2\)-sec
3. Radiative heating rate, Btu/ft\(^2\)-sec
4. Velocity, ft/sec
5. Gas ablation rate, lbm/ft\(^2\)-hr
6. Char ablation rate, lbm/ft\(^2\)-hr
7. Total ablation rate, lbm/ft\(^2\)-hr
8. Surface recession depth from original surface, in.
9. Hot wall convective heating rate without blowing, Btu/ft$^2$-sec

10. Temperature distribution in ablation material, °R

11. Temperature distribution in backup structure, °R

The temperatures printed for the ablation material are for fixed distances from the original surface. These distances are calculated from the initial ablation material thickness and number of nodes in ablation material. For example

let

$$VL = 1.0 \text{ in.}$$

$$NP = 11$$

then

$$\Delta X = \frac{VL}{NP - 1} = 0.1$$

The temperatures will be printed for $X$ distances of 0, 0.1, 0.2, 0.3, et cetera, from the original surface until the surface has receded beyond these fixed distances at which time the node no longer exists and is dropped from the printout. This is illustrated in the following way: let surface recession = 0.26 inch. The first temperature printed then is the surface temperature of the material, located 0.26 inch from the original material surface. The following printed ablation material temperatures are for $X$ distances of 0.3, 0.4, 0.5, ..., 1.0 inch.

The format for the temperature distribution printout is E16.5 with six temperatures printed per line.

Plot output. – The plot output gives the following ablative material performance parameters as a function of time:

1. Surface depth, in.

2. Bondline temperature between ablator and backup structure, °R

3. Two selected isotherm depths

These values are also printed in tabular form for ease in checking and reploting of the results. The plotted curves contain all maximum and minimum values of the parameters.
APPENDIX C

PROGRAM IN FORTRAN STATEMENTS
SIBFTC MAIN

C STRUCTURES AND MECHANICS DIVISION
C THERMO-STRUCTURES BRANCH
C THERMAL PROTECTION SYSTEMS SECTION

THIS PROGRAM DETERMINES THE PERFORMANCE OF A CHARRING APPLATOR
ANALYSIS AND PROGRAM DEVELOPED BY DONALD M. CURRYS * E532

DIMENSION ESAVE1(3), ESAVE2(3), ESAVE3(3)
DIMENSION TITLE(12), HFAILE(12), XIDENT(12), TKC(20), XKC(20),
TCR(20), TCV(20), CPV(20), TIME(30), OCON(30),
RAD(30), VEL(30), XNP(12), NKP(12), NCP(12), TXX(20), XG(20),
CPX(20), RHOX(12), BMX(12), FMFB(12), EMBR(12), HXX(12),
GAPX(12), FTFST(12), RTEST(12), TFMW(12), TXX(20), XG(20),
TMX(12), TUL(200), TLUL(200), HP(50), TP(100), IR(50), TR(50),
IR(50), IT(50), IMF(50), TYY(200), A(200), P(200), C(200), T(200),
AYK(50), AB(10), RB(10), CR(10), DB(10), SR(10),
9RPL(10,12), 9RPL(10,12), H(12), S(50), NPM(12),
DIMENSION TIMFLP(30), PRS(30), CX(50), TXC(50), XV(50), XD(50),
DIMENSION TS(50), SR(50),
DIMENSION TAP(20), IT(20), I(120), IP(120),
DIMENSION ASA(3), ASAVE2(3), ASAVE3(3), BSAVE(3),
1KSAVE(3), CSAVE(3), CSAVE2(3), CSAVE3(3), HAXD(12),
LSAVE(3), DSAVE2(3), DSAVE3(3),
DIMENSION XRA(30), Y(30),

COMMON TXX, XG, TCX, TPX, CPX, CNX, HXX, S(50), NPM(12),
1FMPR, NKP, NCPX, TXX, TCX, CPX, CNX, GAPX, FTFST, RTEST, TFMW, TXC,
2TYX, TXZ, TUL, TUL, TUL, IR, IR, IR, IR, PP, PP, PP, PP, PP, PP, PP, PP, PP,
3RPL, 3RPL, TYY, TYY, XNP, XNP, XNP, XNP, XNP, XNP, XNP, XNP, XNP,
4TBP, 4TBP, 4TBP, 4TBP, 4TBP, 4TBP, 4TBP, 4TBP, 4TBP, 4TBP, 4TBP, 4TBP, 4TBP,
5NMP, NMP, NMP, NMP, NMP, NMP, NMP, NMP, NMP, NMP, NMP, NMP, NMP,
6TAB, TAB, TAB, TAB, TAB, TAB, TAB, TAB, TAB, TAB, TAB, TAB, TAB,
7COMMON TXX, XG, TCX, TPX, CPX, CNX, HXX, S(50), NPM(12),
8FMPR, NKP, NCPX, TXX, TCX, CPX, CNX, GAPX, FTFST, RTEST, TFMW, TXC,
9TYX, TXZ, TUL, TUL, TUL, IR, IR, IR, IR, PP, PP, PP, PP, PP, PP, PP, PP, PP,
10RPL, 3RPL, TYY, TYY, XNP, XNP, XNP, XNP, XNP, XNP, XNP, XNP, XNP,
11TBP, 4TBP, 4TBP, 4TBP, 4TBP, 4TBP, 4TBP, 4TBP, 4TBP, 4TBP, 4TBP, 4TBP, 4TBP,
12COMMON TXX, XG, TCX, TPX, CPX, CNX, HXX, S(50), NPM(12),
13FMPR, NKP, NCPX, TXX, TCX, CPX, CNX, GAPX, FTFST, RTEST, TFMW, TXC,
14TYX, TXZ, TUL, TUL, TUL, IR, IR, IR, IR, PP, PP, PP, PP, PP, PP, PP, PP, PP,
15RPL, 3RPL, TYY, TYY, XNP, XNP, XNP, XNP, XNP, XNP, XNP, XNP, XNP,
16TBP, 4TBP, 4TBP, 4TBP, 4TBP, 4TBP, 4TBP, 4TBP, 4TBP, 4TBP, 4TBP, 4TBP, 4TBP,
17COMON TXX, XG, TCX, TPX, CPX, CNX, HXX, S(50), NPM(12),
18FMPR, NKP, NCPX, TXX, TCX, CPX, CNX, GAPX, FTFST, RTEST, TFMW, TXC,
19TYX, TXZ, TUL, TUL, TUL, IR, IR, IR, IR, PP, PP, PP, PP, PP, PP, PP, PP, PP,
20RPL, 3RPL, TYY, TYY, XNP, XNP, XNP, XNP, XNP, XNP, XNP, XNP, XNP,
50 NK=1
I1=2
I2=2
I3=2
I4=2
I5=2
I6=2
I7=2
INT=1
XLOST=0.0
XMT=0.0
XMLT=0.0
FRR1=0.0
FRR2=0.0
FRR3=0.0
FRR4=0.0
ICT=0
ICONT=0
XMLC=0.0
NK=1
XLST=0.0
NR=2
FRRS=0.0
TPCT=0
IOTP=0
IOTP=1
NXA=1
NXA=1
NXC=1
NOD=1
SAVY3=-100.
SAVY=100.
SOF=0.0
SOF=0
C
GENERAL TITLE OF PROBLEM
100 READ(5,3000) (HEAD(K),K=1,12)
WRITE(6,3009) (HEAD(K),K=1,12)
LPOP=LPOP+1
WRITE(11) (HEAD(I),I=1,12)
WRITE(6,110)
110 FORMAT(/1X,11HINPUT DATA,/)  
FORMAT(5,33000) (TITLE(I),I=1,12)
T=TITLE(I),EQ.PREVIOUS 60 TO 150
READ(5,3011) LIM,TINT,NPTT,NPL,TMP,TMP
READ(5,3012) (TTL=1),DFLT(I),IPRC(I),I=1,NPTT)
T=TINT
NTS=DFLT(I)
N=DFLT(I)/3600.0
WRITE(6,120) LIM,TINT,NPTT
120 FORMAT(/1X,9HTIME LIMIT=,PE10.4,4X,9HINITIAL TIME=,PE10.4,4X,5
1HNPPTT=,I4)
WRITE(6,122)
122 FORMAT(/1X,aHTIME,1NX,9HSTEM,6X,15HPRINT CONTROL)
WRITE(6,124) (TTL=1),DFLT(I),IPRC(I),I=1,NPTT)
124 FORMAT(5X,PE10.4,6X,PE10.4,9X,14)
C
47
C LOCATION FACTORS FOR CONVECTIVE AND RADIATIVE HEATING

150 READ(5,3000) (TITLE(L),L=1,12)
TF(TITLE(1),EO,PRVIOUS) GO TO 200
READ(5,3002) FCONV,FRAD
WRITE(6,1155) FCONV,FRAD

155 FORMAT(1H0,6HFCONV=,1PE12.5,4X5HFRAD=,1PF12.5/)

C PROPERTIES OF ABLATION MATERIAL

200 READ(5,3000) (TITLE(L),L=1,12)
TF(TITLE(1),EO,PRVIOUS) GO TO 300
READ(5,3002) TABL,CHAR,T,PREC,PHOV,HRMC,FRLOW,FMV,EMC,H30N,VL,HV
1VPT,T,TV,CHARK,CHARC,ABLK,ABLC
READ(5,3003) NPK,NCPC,NKV,NCPC,NREC
READ(5,3002) (TKV(K),XKC(K),K=1,NKC)
READ(5,3002) (TCPC(M),CPC(M),M=1,NCPC)
READ(5,3002) (TKV(L),XKV(L),L=1,NKV)
READ(5,3002) (TCPV(N),CPV(N),N=1,NCPC)
READ(5,3002) (TSI(S),ST(S),S=1,1,1NFL)
WRITE(6,3008) (HEADN(K),K=1,12)
WRITE(6,210) TABL,CHAR,T,PREC,PHOV,HRMC,FRLOW,FMV,EMC,H30N,VL,HV
1VPT,T,TV,CHARK,CHARC,ABLK,ABLC
210 FORMAT(1H0,5HTABL=,1PF12.5,3X6HTCHAR=,1PF12.5,3X5HTREC=,1PE12.5,
13X5HRHC=,1PF12.5,21X1X,6HFRLow=,1PF12.5,4X,4
2HFMV=,1PF12.5,4X,4HTEC=,1PF12.5,5X,5H30N=,1PF12.5,5X,5HV=,1PF12.5,
35X4X,4HV=,1PF12.5,4X,4HTP=,1PF12.5,5X,5HV=,1PF12.5,5X,5HTV=,1PE,
112.5X2X6HTCHAR=,1PF12.5/1X,6HFRMC=,1PF12.5/1X,6HHRMC=,1PF12.5/1X,
2.5HFRLOW=,1PF12.5,1X,6HTMC=,1PF12.5/1X,6HTMC=,1PF12.5/1X,
VL=VL/12.0
VL=VL
WRITE(6,220) NPK,NCPC,NKCPC,NKV,NCPC,NREC
220 FORMAT(1X3HNP:,114,4X9HNKC=,114,4X5HNPC=,114,4X9HNKC=,114,4X9HN
15HNCPC=,4X9HNPC=,114,4X9HNREC=,114)
WRITE(6,221) TKV(L),XKV(L),TCPV(L),CPV(L),L=1,KLLL)
221 FORMAT(1X5HTCHAR MATERIAL/2NX,7HTHERMAL,38X,8HSPFCIFIC/3X,11H
1TEMPERATURE,4X,12CONDUCTIVITY,19X,11HTEMPERATURE,7X,4HHEAT)
KLLL=MIN0 (NKV,NCPV)
WRITE(6,222) (TKV(L),XKV(L),TCPV(L),CPV(L),L=1,KLLL)
222 FORMAT(1X1PF12.5,4X1PF12.5,18X,1PE12.5,3X1PF12.5)
IF(NKV-NCPV) 223PP27.225
223 KLLL=KLLL+1
WRITE(6,224) (TCPV(L),CPV(L),L=KLLL+NCPV)
224 FORMAT(1X4X1PF12.5,3X1PE12.5)
GO TO 227
225 KLLL=KLLL+1
WRITE(6,226) (TKV(L),XKV(L),L=KLLL+NK)
226 FORMAT(1X1PF12.5,4X,1PE12.5)
227 WRITE(6,228)
228 FORMAT(1X3X1HTCHAR MAT/2NX,7HTHERMAL,38X,8HSPFCIFIC/3X,11H
1TEMPERATURE,4X,12CONDUCTIVITY,19X,11HTEMPERATURE,7X,4HHEAT)
KLLL=MIN0 (NKCPC)
WRITE(6,222) (TKC(L),XKC(L),TCPC(L),CPC(L),L=1,KLLL)
228 FORMAT(1X3X1HTCHAR MAT/2NX,7HTHERMAL,38X,8HSPFCIFIC/3X,11H
1TEMPERATURE,4X,12CONDUCTIVITY,19X,11HTEMPERATURE,7X,4HHEAT)
KLLL=MIN0 (NKCPC)
WRITE(6,222) (TKC(L),XKC(L),TCPC(L),CPC(L),L=1,KLLL)
230 WRITE(6,224) (TCPC(L),CPC(L),L=KLLL+NCPV)
GO TO 235
232 KLLL=KLL+1
WRITE(6,296) (TKC(I),YKC(I),L=KLLL,NKC)
WRITE(6,296)
240 FORMAT(/28X,3H5SURFACE REFLECTION TABLE//25X,11HTMPERATURE,RA,11H
1SR = IN/SEC)
WRITE(6,295) (TS(I),SP(I),I=1,NRC)
WRITE(6,295)
245 FORMAT(24X,1PF12.5,7X,1PF12.5)

C PROPERTIES OF TRAJECTORY
300 HFAF(I,3,000) (TITLE(L),L=1,12)
IF(TITLE(1),FO,PRVOUS) GO TO 400
HFAF(I,3,000) (HEANA(L),L=1,12)
HFAF(I,3,004) NTRAPT
HFAF(I,3,010) (TMF(K),QCON(K),QRAD(K),VFL(K),K=1,NTRAPT)
WRITE(6,300) (HEAD(L),L=1,12)
WRITE(6,310) NTRAPT
310 FORMAT(/28X,N. OF TRAJECTORY POINTS =114)
WRITE(6,320)
320 FORMAT(/28X,TMPF,AX,12H CONVECTIVE,4X,11H RADIATIVE,7X,RHVELOG
11TY)
WRITE(6,330) (TMF(K),QCON(K),QRAD(K),VFL(K),K=1,NTRAPT)
340 FORMAT(/28X,HEAT) 5)

C PROPERTIES OF BACK-UP STRUCTURE
400 HFAF(I,3,000) (TITLE(L),L=1,12)
IF(TITLE(1),FO,PRVOUS) GO TO 400
WRITE(6,410)
410 FORMAT(/10X,11H PROPERTIES OF BACK-UP STRUCTURE/I)
HFAF(I,3,007) NMP,NPRC,BL
HFAF(I,3,012) (XNMP(K),K=1,NMR)
HFAF(I,4,113) (NKPR,I),NCPH(I),I=1,NMB)
415 FORMAT(1105)
NO 420 K=1,NMP
NMP(K)=XNMP(K)+0.0000000NMP
420 CONTINUE
WRITE(6,425) NMP,NPRC,BL
420 FORMAT(/4X,5HNMP, OF MATERIALS IN BACK-UP SHIELD=114/4X,4H TOTAL
1MMARS OF NODES IN BACK-UP SHIELD=114/4X,2HTHICKNESS OF BACK-UP
2SHIELD=1PE12.5//)
RL=RL/12.0
NO 440 I=1,NMR
LK=NKPB(I)
LCP=NCPB(I)
HFAF(I,3,000) ((XIONT(K,1)),K=1,12)
HFAF(I,3,002) ((TXK(J,1)),XK(J,1),J=1,LK)
HFAF(I,3,002) ((TCP(J,1),CPX(J,1)),J=1,LCP)
WRITE(6,432) (XIONT(K,1),K=1,12)
432 FORMAT(/12A5)
WRITE(6,433)
433 FORMAT(/20X,7HTHERMAL,3X,RHSPECIFIC/3X,11HTMPERATURE,4X,12HCOND
11CTIVITY,19X,11HTMPERATURE,7X,RHHEAT)
KLLL=MINU(LK,1,CP)
NO 436 N=1,KLLL
WRITE(6,422) (TXK(N,1),XK(N,1),TCP(N,1),CPX(N,1))
434 CONTINUE
IF(LK=LCP) 435,440,437
435 KLLL=KLL+1
436 CONTINUE
GO TO 440
437 N=KLLL+1
NO 438 N=KLLL+1
K
WRITE(6,296) (TXK(N),XK(N))
438 CONTINUE
440 CONTINUE
RFA(D(5,3,2,0) (RHORX(L),XRM(L),EMR(L),EMR(L),L=1,NMR)
RFA(D(5,3,1,2) (H(J),GAPX(J),TEST(J),BTEST(J),J=1,NMR)
WRITE(6,450)
450 FORMAT(///55X,10HFMTSqlVTTY/B'PAHMATEPIAL,5X,7Hr)
NO 440 +1,NMR
WRITE(6,455) LLJ,H=MCsITY/YRX,AMAT=ERIAL,5X,7HDENSTY,7X,9THICKW
1FSS,7X,5HFRENT,9X,4HHACK,7X,14HNOES/MATFRIAl/)
NO 460 LLJ=1,NMR
WRITE(6,455) LLJ,H=MCsITY/YRX,AMAT=ERIAL,5X,7HDENSTY,7X,9THICKW
1FSS,7X,5HFRENT,9X,4HHACK,7X,14HNOES/MATFRIAl/
455 FORMAT(11X.11P8X,1PFlO.u,4X@IPFIO.4e£4XIPEIO.L&,4XPF1Ol.4.6XIPFI
10.4/) A2L4L4f
460 CONTINUE
WRITE(6,465)
460 FORMAT(11X.11P8X,1PFlO.u,4X@IPFIO.4e£4XIPEIO.L&,4XPF1Ol.4.6XIPFI
10.4/) A2L4L4f
460 CONTINUE
WRITE(6,465)
460 FORMAT(11X.11P8X,1PFlO.u,4X@IPFIO.4e£4XIPEIO.L&,4XPF1Ol.4.6XIPFI
10.4/) A2L4L4f
C PROPERTIES OF ENVIRONMENT
500 RFAD(5,3,3,0,0) (TITLE(L),L=1,12)
1F(TITLE(1),FO,PREV)U) GO TO 600
RFAD(5,3,3,0,0) (HEADING(L),L=1,12)
RFAD(5,3,3,0,2) TENV,HFNV,FFNV,QL 05C
WRITE(6,300) (HFADN(L),L=1,12)
WRITE(6,500) TENV,HFNV,FFNV,QL 05C
520 FORMAT(///4X,12HTFRENTURE=,1PF12,5,4X,17HFLM COEFFICIENT=E,1PF12,5
1,4X,12HTFRENTURE FACTOR=1PE12,5,4X,7H0 LOST=,1PE12,5)
C INITIAL TEMPERATURE DISTRIBUTION
600 RFAD(5,3,3,0,0) (TITLE(L),L=1,12)
1F(TITLE(1),FO,PREV)U) GO TO 700
RFAD(5,3,3,0,0) (HEADING(L),L=1,12)
NPF=NP+NPS
TL=VL+BL
NXP=NP
2X=VL/(NP=1.0)
N=DX
RFAD(5,3,3,0,2) TEST?,TFMPI,DX0
1F(TEST2) 610,620,620
610 RFAD(5,3,3,0,2) (TEMDI(K),K=1,NPF)
NO 615 K=1,NPF
2X(K)=T(N)
TOL(K)=X(K)
2X2(K)=X(K)
615 CONTINUE
1=NP+1
24358
24280
24300
24210
24310
24330
24240
24250
24260
24270
24280
24290
24310
24330
24340
24350
24360
24370
24380
24390
24400
24410
24420
24430
24440
24450
24460
24470
24480
24490
24500
24510
24520
24530
24540
24550
24560
24570
24580
24590
24600
24610
24620
24630
24640
24650
24660
24670
24680
24690
24700
24710
24720
24730
24740
24750
24760
24770
24780
24790
24800
24810
24820
24830
24840
24850
NO 619 I=1,NMP
1 NE2NPM(I)
NO 617 J=1,LN
TX2T(J+1)=TFM(I(L))
I=L+1
617 CONTINUE
619 CONTINUE
GO TO 625
620 CALL TEMP
625 WRITE(6,3008) (HEADING(L),L=1,12)
TF(1,2) = 630,635,640
630 WRITE(6,632)
632 FORMAT(4X,52HTEMPERATURE DISTRIBUTION IN HEAT SHIELD IS ARBITRARY/1)
WRITE(6,633) (TFM(I,K),K=1,NPF)
633 FORMAT(1PRE12,5)
GO TO 645
635 WRITE(6,637) TEMP
637 FORMAT(4X,44HTEMPERATURE DISTRIBUTION IN HEAT SHIELD IS UNIFORM
1AND EQUAL TO ,1PE10.4/)
GO TO 645
640 WRITE(6,641)
641 FORMAT(4X,58HINEAR TEMPERATURE DISTRIBUTION ASSUMED IN HEAT SHIELD
10/)
WRITE(6,649) (TX1(L),TX2(L),L=1,NPF)
649 FORMAT(2X,1PF12.5,4X,1PF12.5)
WRITE(6,650)
650 FORMAT(//)
C
C FNTHALPY AS A FUNCTION OF TEMPERATURE
725 IF(TITLE(1).EQ.PREV) GO TO 725
READ(5,3001) (TITLE(L),L=1,12)
READ(5,3004) NHP
READ(5,3002) (HX(K),TW(K),K=1,NHP)
725 NO 728 I=1,NP
TF(I)=0
TP(I)=0
TP2(I)=0
TFM(I)=0
YMDG(I)=0.0
728 CONTINUE
WRITE(6,730)
730 FORMAT(1H1,12HOUTPUT DATA,//)
XC(I)=0.0
NO 740 I=2,NP
XC(I)=XC(I-1)+DX
740 CONTINUE
745 IF(IT-TIME(NK)) 765,770,760
750 NK=NK+1
TF(NK-NTHAPT) = 750,750,762
760 WRITE(6,763) NK
763 FORMAT(1H10,33H THE VALUE OF NK IS IN ERROR, NK=,1I4)
GO TO 905
A2850
A2860
A2870
A2880
A2890
A2900
A2910
A2920
A2930
A2940
A2950
A2960
A2970
A2980
A2990
A3000
A3010
A3020
A3030
A3040
A3050
A3060
A3070
A3080
A3090
A3100
A3110
A3120
A3130
A3140
A3150
A3160
A3170
A3180
A3190
A3200
A3210
A3220
A3230
A3240
A3250
A3260
A3270
A3280
A3290
A3300
A3310
A3320
A3330
A3340
A3350
A3360
A3370
A3380
A3390
A3400
A3410
765 1F(NK-2) 762,766,766
766 oCONX=QCONX(NK)+(QCON(NK)-QCON(NK-1))/(TIME(NK)-TIME(NK-1))
1*T-TIMF(NK-1))
766 oCONX=FCONV*QCONX
766 oRADX=QRAD(NK)+(QRAD(NK)-QRAD(NK-1))/(TIME(NK)-TIME(NK-1))
1*T-TIMF(NK-1))
766 oRADX=FRAD*QRADX
766 VFLO=VEL(NK)+(VEL(NK)-VEL(NK-1))/(TIME(NK)-TIME(NK-1))
1*T-TIMF(NK-1))
766 go TO 775
770 oCONX=FCONV*QCONX(NK)
770 oRADX=FRAD*QRAD(NK)
770 VFLO=VEL(NK)
770 C COMPUTE HFAT PLOCKAGE AT FRONT SURFACE
775 IF(I17=77A.778,776
776 IF(I17=NHP) 777,777,778
777 IF(TX(I17)-TW(I17)) 782,788,780
778 WRITE(6,779) TX(I17)
779 FORMAT(I10.5) THE RANGE OF THE ENTHALPY-TEMPERATURE CURVE FIT WAS
780 IF XCEED AT A TEMPERATURE OF 1E10.4)
780 go TO 906
780 117=117+1
780 go TO 775
782 IF(TX(I17)-TW(I17-1)) 784,788,786
784 117=117-1
784 go TO 775
786 HW=HX(I17-1)+(HX(I17)-HX(I17-1))/(TW(I17)-TW(I17-1))
1*T-TW(I17-1))
786 go TO 793
788 HW=HX(I17)
789 HTX=HTX+5(HTX**2)/50056.5
789 oPLOCK=(FRLOW*XMDG(I17)*(HTX-HW))/3600
789 C COMPUTE HFAT IN DUE TO SURFACE COMBUSTION
790 XMDO=XMDL
790 CALL OXIDAT(XMDO,001)
790 C COMPUTE O=HOT WALL
791 IF(TMP.EQ.0.0) 794,793
791 IF(T.GE.TMP) DMP=1.0
793 DMP=1.0
794 1F(Z=0.0) 790,792,793
790 AQW=0.0
790 go TO 1790
792 AQW=QCONX
792 go TO 1790
793 AQW=Z*QCONX
793 1F(ZZ=0.0) 1798,1790,1794
1798 oPLOCK=0.0
1798 C COMPUTE HFAT INTO FRONT SURFACE
1794 IF(IEM(I17)) 795,795,797
1795 IF(TX(I17)-TCHAR) 796,796,797
1796 FMX=EMV
GO TO 798
797 TMF(INT)=1
FMX=EMC
798 QN=GRADX+GH+G0XTD=GRLOCK-(4.833E-13)*FMX*FV*((TX2(INT)**4)-
1(TV**4)))
TF(DMP) A04,804,800
800 WRITE(6,801)
801 FORMAT(//)
WRITE(6,802) QCONV,GRADX,VELX,HTX,HW,7,GRLOCK,GH,G0XTD,QIN
802 FORMAT(1X,6H4CONX=,1PF12.5,2X,6HGRADX=,1PF12.5,2X,5HVFLX=,1PF12.5,
12X,4HHTX=,1PE12.5,2X,5HGW=,1PF12.5/1X,2H7=,1PF12.5,2X,7HGRLOCK=,1P
2F12.5,2X,4HGW=1PE12.5,2X,6H0XTD=1PE12.5,2X,4H0LT=,1PF12.5/)
804 QN=QIN=3600.
C
CHECK FOR FRONT SURFACE RECESSION (CHAR LAYER REMOVAL)
CALL RECESS(XMDC,XLOST,TRFC,DT,PHOC,TS,SR,TX2(1),NRF,ORS,ERS,50)
1,SDOT,DMP)
TF(QR5) A05,805,805
805 VLV=VLY=X10ST
X1ST=XLSTV+X10ST
NXV=VLY/(XNP-1.0)
XX(I)=0.0
NO 1740 I=2,NP
XX(I)=XX(I-1)+DXV
1740 CONTINUE
NX=DXV
1F(QR4) A06,806,806
806 GO TO 905
806 CALL COEFF(NPFTP,SDOT)
TF(DMP) A069,8069,8069
8061 WRITE(6,8062)
8062 FORMAT(1X,23H COEFFICIENTS FOR SWUFT/)
NO A066 I=1,NPFTP
WRITE(6,8064) A(I),R(I),C(I),D(I)1
8064 FORMAT(1H0,5HSH(I) =,1PF12.5,2X,SH(I) =,1PF12.5,2X,SHC(I) =,1PF12.5,2
1X,5HO(I) =,1PF12.5,2X,2HI=,13)
8066 CONTINUE
8069 I=ERR2) A07,807,807
807 I=ERR3) A10,810,810
808 WRITE(6,808) IKK
809 FORMAT(1H0,1AH THF VALUE OF IKK=,14)
GO TO 905
810 CALL SWUFT(A,R,C,D,TX,TPFTP,DMP)
827 NO 828 I=1,NP
TX1(I)=TX2(I)
TX2(I)=TY(I)
828 CONTINUE
CALL NONS(XLOST,XV,TX2,NP,XC,TX2C,XDV,XXV,XLSTV,DXV)
830 CALL ABLATE
XMDC=XMDC(INT)+XMDC
LT=NP+1
NO 1815 I=1,NMB
LT=NP(I)
TF(I,FQ.1) GO TO 1812
TF(GAPX(I-1),FQ.0) GO TO 1812
KKT=1
53
GO TO 1813

1812  KKT=2
1813  NO 1815  J=KKT,LLT
          TX2T(J,1)=TY(LT)
          LT=LT+1
1815  CONTINUE
          NO 1819  1=1,NMB
          IF(I,FQ,1) GO TO 1816
          IF(GAPX(I-1),FQ,0,1) GO TO 1817
          GO TO 1819
1816  TX2T(I+1)=TY(NP)
          GO TO 1819
1817  I=NP(I-1)
          TX2T(I+1)=TX2T(LX,1-1)
1819  CONTINUE
          I=NP+1
          NO 837  I=1,NMB
          1=-NPM(I)
          NO 831  J=1,LZ
          TX2(LM)=TX2T(J,1)
          M=L*+1
833  CONTINUE
          NO 5834  I=2,NPTT
          IF(I=TABLE(I)) 5835,5835,5834
5835  NT=DFLT(I-1)
          IPRTC=IPHC(I-1)
          NT=DELT(I-1)/3600,0
          GO TO 5836
5834  CONTINUE
          NT=DFLT(NPTT)
          IPRTC=IPHC(NPTT)
          NT=DELT(NPTT)/3600,0
5836  TCT=ICICT+1
5838  VLFM=SAVY3
       CALL TSOTHM(XV,TX2,10A0.,NP,SAVFIT)
       SAVFIT=SAVEIT+XLSTV
       IF(SAVY3,LT,SAVFIT)SAVY3=SAVFIT
       IF(VLFM,FQ,SAVY3)GO TO 839
       SAVY3=1
       SAVY1=XLSTI
       SAVY2=TX2(NP)
       CALL TSOTHM(XV,TX2,1460.,NP,SAVY4)
638  RLFM=SAVY4X
       CALL TSOTHM(XV,TX2,1460.,NP,WFKEFP)
       WFKEFP=WEKEEP+XLSTV
       IF(SAVY4X,LT,WEKEEP)SAVY4X=WFKEFP
       IF(VLFM,FQ,SAVY4X)GO TO 839
       SAVY4X=1
       SAVY1=XLSTI
       SAVY2=TX2(NP)
       CALL TSOTHM(XV,TX2,10A0.,NP,SAVY3X)
838  CONTINUE
       IF(IPRTC=ICT) 835,835,840
835  WRITE(6,837) T,CONVF,CONVX,F1X,MDG,MT,MDC,MTL,XLST,OH
837  FORMATT1H0,5TIME=;
       1 1PF12.5,2X,12HCONVFCTVE=1PF12.5,2X,11HORADIT
       11VE=1PF12.5,2X,9HVFLCITY=1PF12.5,1X,1AHGAS APATION RATE=1PF12
2.5,2X,1.9HCHAR ABLATION RATE=1PF12.5,2X,20HTOTAL ABLATION RATE=1P3F12.5/1X,16HRF
CESSION DPHTH=1PF12.5,2X,10HCHOT WALL=1PE12.5

840 T=T+DTS

841 IF(NPLOT.NE.1) GO TO 9842
CALL SAVE(ASAVE1,ASAVE2,ASAVE3,USFA,NX,XY,XYST,T,DMS,TL,IM,T,VALUES)
CALL ISOTHM(XV,TX2,1060.,NP,Y3)
CALL SAVE(CSAVE1,CSAVE2,CSAVE3,USFC,NX,Y,5,DT,SL,T,IM,T,VALUES)
CALL ISOTHM(XV,TX2,1460.,NP,Y4)
CALL SAVE(DSAVE1,DSAVE2,DSAVE3,USFD,NX,Y,4,DT,SL,T,IM,T,VALUES)
IF(ISFA,NF,0,0)GO TO 9842
IF(ISFB,NF,0,0)GO TO 9842
IF(ISFC,NF,0,0)GO TO 9842
IF(ISFD,NF,0,0)GO TO 9842
GO TO 9843

9842 XPLOT=T-DTS
YPLOT=VALUEA
IF(ISFA,NF,0,0)YPLOT1=USFA
YPLOT2=VALUEB
IF(ISFB,NF,0,0)YPLOT2=USFB
YPLOT3=VALUEC
IF(ISFC,NF,0,0)YPLOT3=USFC
YPLOT4=VALUED
IF(ISFD,NF,0,0)YPLOT4=USFD
WRITE (11)XPLOT1,YPLOT1,YPLOT2,YPLOT3,YPLOT4
9843 IF(I=CTP,NF,0) GO TO 9842
I=CTP=1
XPLOT=T
YPLOT1=XYST
YPLOT2=TX2(NP)
CALL ISOTHM(XV,TX2,1060.,NP,YPLOT3)
CALL ISOTHM(XV,TX2,1460.,NP,YPLOT4)
WRITE (11)XPLOT1,YPLOT1,YPLOT2,YPLOT3,YPLOT4
842 IF(I=CTP-I=CTP) 845,845,90N
845 WRITE(6,850) T
I=CTP=I=CTP+1
IF(I=CTP.EQ.2)I=CTP=0
IF(I=CTP.EQ.0)I=CTP=0
850 FORMAT(1H0,7HTEMPERATURE DISTRIBUTION IN HEAT SHIELD AT THE END OF)
IF THE TIME STEPS T=1PE12.5,1X,7HSFCONS/
WRITE(6,850)
860 FORMAT(4X,9HTEMPERATURE DISTRIBUTION IN THE ABLATING MATERIAL//)
KK=KKV+1
WRITE(6,862) (TX2(I),I=1,4K)
862 FORMAT(6X,1PF12.5,1PF16.5,
T)=NP+1
WRITE(6,864)
864 FORMAT(//4X,9HTEMPERATURE DISTRIBUTION IN THE PACK-UP STRUCTURE//
1)
WRITE(6,862) (TX2(I),I=1,I=NPF)
WRITE(6,865)
865 FORMAT(/)
I=CTP=0
900 CONTINUE
IF(T=TLIM) 750,750,90N
905 IF(NPLOT.NE.1) GO TO 909
XAVY3=SAYY3-SAYY1/12.
XAVY4X=SAVY4X=SAVY1X/12.
IF(SAVX.EQ.XPLOT)GO TO 9005
WRITE(11)SAVX,SAVY1,SAVY2,SAVY3,SAVY4
9005 IF(SAVEXX.EQ.XPLOT)GO TO 9006
SAV4I=SAVY4X*12.
9006 SAV3I=SAVY3*12.
WRITE(11)SAVXX,SAVY1X,SAVY2X,SAVY3X,SAVY4X
WRITE(6,929)SAV3I,SAV4I
929 FORMAT(1H0,23HMAXIMUM 10AN ISOOTHERM =E16.8,2X23HMAXIMUM 1460 T50TH
1FRM =F16.8)
WRITE (11)STOP,STOP,STOP,STOP,STOP
909 IF(LPLOT.NE.NRASE)GO TO 911
DATA FND/AH END/A
WRITE (11)FND,FND,FND,FND,FND,FND
QUIT=88A8,
WRITE(11)QUIT,QUIT,QUIT,QUIT,QUIT
FND FILE 11
RFWINN 11
911 IF(TEST2) 910,930,93n
910 DO 920 JJK=1,NPF
TX1(JJK)=TEMP1(JJK)
TX2(JJK)=TX1(JJK)
TIL1(K)=TX1(K)
TIL2(K)=TX1(K)
920 CONTINUE
IL=NP+1
DO 924 I=1,NMR
TIL=NPM(I)
DO 924 J=1,ILN
TX2(J+1)=TEMP1(IL)
IL=IL+1
924 CONTINUE
926 CONTINUE
GO TO 940
930 CALL TEMP
940 T=TINT
DTS=DELTT(1)
DT=DELT(1)/3600.0
VLV=V
GO TO 50
END
SIBFTC COEF

THIS SUBROUTINE DETERMINES THE COEFFICIENTS OF THE MATRIX

DIMENSION TITLE(12), HEADING(12), XIDNT(12), TKC(20), XKC(20),
1 CPC(20), TKV(20), TKPC(20), CPV(20), CPV(20), TIME(300), GCON(300),
2 RAD(300), VEL(300), XNPM(12), NKP(12), NCPB(12), TKX(20,12), XK(20,12),
3 CPC(20,12), CPX(20,12), RHOBX(12), XMB(12), EMFB(12), EMBB(12), HXX(12),
4 GAXP(12), FTEST(12), BTEST(12), TEMD(200), TXL(200), TX2(200),
5 TX2T(10,12), TUL1(200), TUL2(200), HX(50), TW(50), IR(50), IR(50),
6 IR(50), TUL(50), EM(50), TY(200), A(200), B(200), C(200), D(200),
7 R(50), RHO(50), CP(50), DBX(12), XKB(10,12), CPB(10,12), XMDG(50),
8 YK(50), Ap(10,12), Bb(10,12), Cb(10,12), Db(10,12), Sb(10,12),
9 RB1(10,12), RB2(10,12), H(12), S(50), NPM(12),
DIMENSION TITLE(12), XIDNT(12), TKC(20), XKC(20),
DIMENSION TTUL(50), RHOBX(50), XMB(50),
COMMON TKC, XK, TPC, TKV, TKPC, CPV, CPB, XNPM, RHOBX, XMB,
1 EMBF, NKP, NCPB, TKX, XK, CPX, NPM, GAXP, FTEST, BTEST, TEMDI, TXL,
2 TX2T, TX2T, TUL, TUL1, TUL2, IR, IR, IR, A, B, C, D, S, R, Ap, Bb, Cb, Db,
3 RB1, RB2, TY, ROY1, ROY2, XMDG, RHO, CP, YK, XKB, CPB, DBX, DT, XLOST,
4 TABL, TCHA, TREC, RHOC, FBLON, EMV, EMG, H300, NKc, NCPB, NKV, NCVP,
5 SNP, NMB, NBPS, NPF, TEST, TEMDI, TXO, TENV, HEVF, FENV, GLoss, TIM,
6 COMMON I1, I2, I3, I4, I5, I6, QIN, INT, DX, XMT, TL, BL, DMP, ERR1, ERR2,
7 ERR3, ERR4, HV, VPT, CHARK, CHARC, ABLK, ABLC, XMDC, H,
DIMENSION TTUL(50), RHOBX(50), XMB(50),
COMM...
GO TO 65
30 L=NPM(I-1)
   IF(FTEST(I)) 45*40,45
40 SB(I,I)=RHOBX(I)*CPB(I,I)*DXB(I)+RHOBX(I-1)*CPB(L,I-1)*DXB(I-1)/
   (2.0*DT)
   RB1(I,I)=(1.0)/((DXB(I-1)/(2.0*XKB(L,I-1)))+(DXB(I)/(2.0*XKB(L-1)
   I-1))))
   RB2(I,I)=(1.0)/((DXB(I)/(2.0*XKB(1,I)))+(DXB(I)/(2.0*XKB(2,I))))
   AB(I,I)=RB1(I,I)
   BB(I,I)=-(RB1(I,I)+RB2(I,I)+SB(I,I))
   CB(I,I)=RB2(I,I)
   DB(I,I)=-(SB(I,I)*TX2T(I,I))
   GO TO 66
45 IF(FTEST(I)) 50*40,55
50 G=(1.73E-09)/(1.0/EMBB(I-1)+1.0/EMFB(I)-1.0)
   GO TO 65
55 G=0.0
60 SB(I,I)=RHOBX(I)*CPB(I,I)*DXB(I)/(2.0*DT)
   RB1(I,I)=H(I-I)+4.0*G*(TX2T(I,I)**3)+RB2(I,I)+SB(I,I))
   CB(I,I)=RB2(I,I)
   DB(I,I)=-(SB(I,I)*TX2T(I,I))
   GO TO 200
65 L=NPM(I+1)
   DO 100 J=2,L
   SB(J,I)=RHOBX(I)*CPB(J,I)*DXB(I)/(2.0*DT)
   RB1(J,I)=H(I-I)+4.0*G*(TX2T(J,I)**3)+RB2(J,I)+SB(J,I))
   CB(J,I)=RB2(J,I)
   DB(J,I)=-(SB(J,I)*TX2T(J,I))
   100 CONTINUE
   IF(I-NMB) 110*250,250
110 LF=NPM(I)
   IF(BTEST(I)) 120*115,120
115 SB(LNF,I)=RHOBX(I)*CPB(LNF,I)*DXB(I)+RHOBX(I+1)*CPB(I+1)*DXB(I+1)/
   (2.0*DT)
   RB1(LNF,I)=(1.0)/((DXB(I)/(2.0*XKB(LNF-1,I)))+(DXB(I)/(2.0*XKB(LNF
   1,I))))
   RB2(LNF,I)=(1.0)/((DXB(I+1)/(2.0*XKB(1,I+1)))+(DXB(I)/(2.0*XKB(LNF
   1,I))))
   AB(LNF,I)=RB1(LNF,I)
   BB(LNF,I)=-(RB1(LNF,I)+RB2(LNF,I)+SB(LNF,I))
   CB(LNF,I)=RB2(LNF,I)
   DB(LNF,I)=-(SB(LNF,I)*TX2T(LNF,I))
   GO TO 200
120 IF(BTEST(I)) 125*115,127
125 G=(1.73E-09)/(1.0/EMBB(I+1)+1.0/EMFB(I)-1.0)
   GO TO 130
127 G=0.0
130 SB(LNF,I)=RHOBX(I)*CPB(LNF,I)*DXB(I)/(2.0*DT)
   RB1(LNF,I)=(1.0)/((DXB(I)/(2.0*XKB(LNF-1,I)))+(DXB(I)/(2.0*XKB(LNF
   1,I))))
   AB(LNF,I)=RB1(LNF,I)
   BB(LNF,I)=-(RB1(LNF,I)+RB2(LNF,I)+SB(LNF,I))
   CB(LNF,I)=RB2(LNF,I)
   DB(LNF,I)=-(SB(LNF,I)*TX2T(LNF,I)**3)
   GO TO 200
   CONTINUE
200
MN=NPM(NMB)
IF(QLOSS) 270,260,270
SB(MN,NMB)=(RHOBX(NMB)*CPB(MN,NMB)*DXB(NMB))/(2.0*DT)
RBI(MN,NMB)=((DXB(NMB)/(2.0*XKB(MN-1,NMB))))+(DXB(NMB)/(2.0*XK
1B(MN,NMB))))
AB(MN,NMB)=RB1(MN,NMB)
BB(MN,NMB)=-(RB1(MN,NMB)+SB(MN,NMB))
CB(MN,NMB)=0.0
DB(MN,NMB)=-(SB(MN,NMB)*TX2T(MN,NMB))
GO TO 280
260
SB(MN,NMB)=(RHOBX(NMB)*CPB(MN,NMB)*DXB(NMB))/(2.0*DT)
RBI(MN,NMB)=((DXB(NMB)/(2.0*XKB(MN-1,NMB))))+(DXB(NMB)/(2.0*X
1KB(MN,NMB))))
AB(MN,NMB)=RB1(MN,NMB)
BB(MN,NMB)=-(RB1(MN,NMB)+HENV+(1.73E-09)*FENV*4.0*(TX2T(MN,NMB)**
13)+SB(MN,NMB))
CB(MN,NMB)=0.0
DB(MN,NMB)=-(HENV*HENV+FENV*(1.73E-09)*((FENV**4)+3.0*(TX2T(MN,NM
1B)**4)))+SB(MN,NMB)*TX2T(MN,NMB))
270
L=NP+1
DO 300 I=1,NMB
K=NP(I)
IF(I.EQ.1) GO TO 282
IF(300)
IF(GAPX(I-1).EQ.0.) GO TO 282
KT=1
60 TO 285
280
L=L+1
300 CONTINUE
NPFT=L-1
RETURN
END
$sibfmc prp
C THIS SUBROUTINE DETERMINES THE PHYSICAL PROPERTIES OF THE
C HEAT SHIELD STRUCTURE
C $sibfmc prp
C
\begin{verbatim}
DIMENSION TTT(12),HFAANG(12),XIDNT(12,12),TWC(20),XWC(20),
1 CPC(20),TKV(20),XKV(20),TCPV(20),CPV(20),TME(30),QCON(30),
2 ROAD(30),VEL(30),XPMP(16),NKPR(12),NCRR(12),TCX(20,12),XK(20,12),
3, TCP(20,12),CPX(20,12),RNBX(12),XBM(12),FMR(12),FMP(12),HXX(12),
4,GAPX(12),FTFST(12),ATEST(12),TFMDI(201),TX1(200),TX2(200),
5,TXPT(10,12),TTL1(200),TUL(200),WC(50),TW(50),TR(50),TRM(50),
6,TPP(50),TUL(50),IFM(50),TY(201),AT(200),R(200),C(200),N(201),
7, TH(50),RHO(50),CP(50),ITP(12),XPR(12),CPR(12),XM(50),
AVK(50),An(10,12),AB(10,12),CR(10,12),DB(10,12),SR(10,12),
9,FL(10,12),RR(10,12),H(12,12),S(50,50),NPM(12),
DIMENSION TTI(10),RHOY1(50),RHOY2(50),DRH01(50),TCPC(90)
C
\end{verbatim}
C
\begin{verbatim}
COMMON TKC,XKC,TCPC,CPC,TKV,XKV,TCPV,CPV,YNPM,RHO,RX,RPM,EMBR,
1 FMR,NKPS,TCP,TXK,CPX,CPM,GAPX,FTFST,ATEST,TFMDI,TKI,
2 TPX,TVX,TUL,TT1,ILL,IR1,IP1,AP,B,C,D,S,R,AP,AB,CR,DD,SR,
3 R12,RT1,YNQH1,RYQH2,SYM6,RMO,CYX,XXR,CPB,DXR,DT,YLOST,
4 TABL,TCHAR,RFCS,RH01,RHC0,FRL0W,FMV,EMC,H300,NKC,NCPR,NCV,NCPV,
5 NAP,NKPR,NPF,TFST,TEMPI,TX0,TFNV,HENV,FFNV,BOOK,TLTo,INT
COMMON I1,I2,II,IV,IX,IN,TIT,DX,XTL,VL,BL,DMP,FRP1,FRP2,
1 FRP3,FRP4,HV,VP,CHY,CHAR,ALB,APL,AXM,CMC
C
KINT=TII
10 IF(I1(I))=12,12,100
11 TUL(I)=амиI(TXI(I),TX2(I))
12 IF(TUL(I),LC,TAPL) GO TO 20
13 IF(I1)=1
14 GO TO 100
20 IF(I1-1)=25,13,35
21 IF(I1-1)=25,13,35
22 IF(T12(I)-TKV(I))=35,55,30
23 WRITE(6,26) TV2(I)
26 FORMAT(1HO,R7H THE RANGE OF ONE OF THE ABRBATION PROPERTY CURVE FIT
1C WAS EXCEEDED AT A TOFPATTER OF 1PE12,5)
20 IF(I1)=10,5,50
30 IF(I1)=10,5,50
35 IF(T12(I)-TKV(I))=40,55,50
40 IF(I1)=10,5,50
50 IF(YK(I)=XKV(I))=40,55,50
60 IF(I1-1)=12,25,5,61
61 IF(I1-1)=25,5,61
62 IF(I2(I)-TCPV(I))=70,85,65
65 IF(I2)=12,10,61
70 IF(I2(I)-TCPV(I))=70,85,60
75 IF(I2)=12,10,61
C
\end{verbatim}

60
```
GO TO 60
A0 CP(I)=CPV(I2-1)+((CPV(I2)-CPV(I2-1))/TCPV(I2)-TCPV(I2-1)))
1*TX2(I)=TCPV(I2-1))
GO TO 90
A5 CP(I)=CPV(I2)
GO TO 170
100 TUL(I)=AMAX1(TUL(I),TX2(I))
1F(TUL(I)-TCHAR) 110,110,115
110 RHO(I)=RHOV+(RHOV-RHOC)*( (TUL(I)-TARL)/(TABL-TCHAR))
15(I)=CHARM+(ABLK-CHARM)*((RHO(I)-RHOC)/(RHOV-RHOC))
CP(I)=CHARC*(ABLC-CHARC)*URH.OCI)-RHOC)/(RHOV-RHOC))
GO TO 170
115 TF(VPT) 116,116,117
116 TUL(I)=TUL(I)
GO TO 120
117 TUL(I)=TX2(I)
120 TF(I3-1) 25,25,121
121 TF(I3-NKC) 122,122,25
122 TF(TTUL(I)-TKC(I3)) 124,135,123
123 I3=I3+1
GO TO 121
124 TF(TTUL(I)-TKC(I3-1)) 125,135,13n
125 I3=I3-1
GO TO 120
130 YK(I)=XKC(I3-1)+((XKC(I3)-XKC(I3-1))/(TKC(I3)-TKC(I3-1))
1*TTUL(I)-TKC(I3-1))
GO TO 140
135 YK(I)=XKC(I3)
140 TF(I4-1) 25,25,141
141 TF(I4-NCP) 142,142,25
142 TF(TTUL(I)-TCPC(I4)) 150,165,145
145 I4=I4+1
GO TO 141
150 TF(TTUL(I)-TCPC(I4-1)) 155,165,160
155 I4=I4-1
GO TO 140
160 CP(I)=CPC(I4-1)+((CPC(I4)-CPC(I4-1))/TCPC(I4)-TCPC(I4-1))
1*TTUL(I)-TCPC(I4-1))
GO TO 166,
165 CP(I)=CPC(I4)
166 RHO(I)=RHOC
170 CONTINUE
C
C DETERMINATION OF PROPER RACK-UP SHIELD MATERIAL PROPERTY
C
DO 300 I1=1,NMR
300 NXB(I)=XBM(I)/(XNPM(I)-1.0)*12.0)
LKP=NKPB(I)
LCP=NCBP(I)
NN=NPM(I)
DO 280 J=1,NN
280 IF(I5-I) 203,203,201
201 IF(I5=LKP) 202,202,203
202 IF(TX2(T(I1),I)=TXK(I5,I1)) 206,220,205
203 WRITE(6,204) I1,TX2(T(I1),I)
204 FORMAT(1HN0,3H THE RANGE OF ONE OF THE NUMBER,1P,71H BACKUP STRUC
```
ITIIRF PROPFRTY CURVE FITS WAS FXCFFED AT A TEMPRATURE OF ,1PF12.5

FPRZ=1.0
GO TO 355
205 T5=15+1
GO TO 201
206 IF(TXPT(J,I)-TXK(I5-1,I)) 210,220,215
210 T5=15+1
GO TO 200
215 XH(J,I)=XK(I5-1,I)+(XK(T5,I)-XK(I5-1,I))/(TXK(T5,I)-TXK(I5-1,I))
1)*(TXPT(J,I)-TXK(I5-1,I))
GO TO 230
220 XKB(J,I)=XK(I5,I)
230 IF(I6=1) 203,203,231
231 IF(I6=I-CPI) 232,232,233
232 IF(TXPT(J,I)-TCP(I6-1)) 234,245,233
233 T6=I6+1
GO TO 231
234 IF(TXPT(J,I)-TCP(I6-1,I)) 235,245,240
235 T6=I6-1
GO TO 230
240 CPB(J,I)=CPX(T6-1,I)+(CPX(I6,I)-CPX(T6-1,I))/(TCP(I6,I)-TCP(T6-1,1))
11))*(TXPT(J,I)-TCP(I6-1,I))
GO TO 230
245 CPB(J,I)=CPX(T6+1)
280 CONTINUE
T5=2
T6=2
300 CONTINUE
310 IF(DMP) 355,355,320
320 WRITE(6,330)
330 FORMAT(/1X,32H PROPFRTIFS OF ABLATION MATERIAl)
340 WRITE(6,335)
350 FORMAT(/5X,5HYK(I),9X,5HCP(I),9X,6HROH(I)1)
340 WRITE(6,340) (YP(I),CPI(I),RHO(I),I=1,IP)
340 FORMAT(2X,1PF12.5,2X,1PF12.5,1X,1PE12.5)
340 WRITE(6,345)
345 FORMAT(/1X,39H PROPFRTIFS OF BACK-UP STRUCTUPE)
350 WRITE(6,347)
350 FORMAT(/5X,8HYK(I),7X,8HCP(I),7X,7R'HROH(I)1)
350 WRITE(6,348) (YP(I),CP(I),RHO(I),I=1,IP)
350 FORMAT(3X,1PF12.5,3X,1PF12.5,3X,1PE12.5,3X,1PF12.5,3X,1PF12.5,3X,1PF12.5,3X,1PF12.5)
350 CONTINUE
350 CONTINUE
355 RETURN
FND
**SUBROUTINE ABL**

1. **SUBROUTINE DETERMINES THE MASS FLOW RATE FROM THE**
2. **ABLATING NODES**

**DIMENSION TITLE(12),HFADNG(12),XIDNT(12,12),TKC(20),XC(20)**

1. **TPC(20),TPX(20,12),RX(12),EMBR(12),HXX(12)**

4. **CAPX(12),FTEST(12),RTEST(12),TEDMI(200),TX1(200),TX2(200)**

5. **STX2(TX2(KI),TX1(KI),TX1(10,12),XP(12),XK(12,12),XMHD(50)**

6. **YP(50),XH(10,12),BR(10,12),CP(10,12),SR(10,12)**

9. **R1(10,12),R2(10,12),H(12),5(50),NP(12)**

10. **DIMENSION TTUL(50),RH0Y1(50),RHOY2(50),RCR0(50),TCP(20)**

**COMMON Tc,C,TCP,TPX,TPC,XK,TPV,TKC,TPN**, RX,CRM,FMBR,.

1. **IFMFE3,NKPBF1NCPPPTXK,TCP**

YMT=0

5. **K1=NP**

TF(DMP,H8,3)

3. **WRITE(6,*)**

5. **FORMAT(1X,20A1)**

8. **DO**

10. **IF(IR(I1,1))**

11. **IF(TX(KI),I,F,TABL) GO TO 9**

12. **TULI(KI)=AMAX1(TULI(KT),TULX(KI))**

13. **TP1(KI)=1**

14. **GO TO 20**

9. **IF(TX(KI)-TCHAR) 10,10,20**

10. **RHOY1(KT)=RHOV**

11. **GO TO 50**

20. **IF(TUL1(KI)-TCHAR) 40,30,30**

30. **RHOY1(KI)=RHOV**

40. **GO TO 50**

50. **RHOY1(KT)=RHOV**

60. **GO TO 70**

70. **IF(TUL2(KI)-TCHAR) 90,80,80**

80. **RHOY2(KI)=RHOV**

90. **GO TO 95**

**COMMON TKC,TPY,TPX,TPC,XK,TPV,TKC,TPN**, RX,CRM,FMBR,.

1. **IFMFE3,NKPBF1NCPPPTXK,TCP**

YMT=0

5. **K1=NP**

TF(DMP,H8,3)

3. **WRITE(6,*)**

5. **FORMAT(1X,20A1)**

8. **DO**

10. **IF(IR(I1,1))**

11. **IF(TX(KI),I,F,TABL) GO TO 9**

12. **TUL2(KI)=AMAX1(TUL2(KT),TX2(KI))**

13. **TP2(KI)=1**

14. **GO TO 20**

9. **IF(TX(KI)-TCHAR) 10,10,20**

10. **RHOY1(KT)=RHOV**

11. **GO TO 50**

20. **IF(TUL1(KI)-TCHAR) 40,30,30**

30. **RHOY1(KI)=RHOV**

40. **GO TO 50**

50. **RHOY1(KT)=RHOV**

60. **GO TO 70**

70. **IF(TUL2(KI)-TCHAR) 90,80,80**

80. **RHOY2(KI)=RHOV**

90. **GO TO 95**

**COMMON TKC,TPY,TPX,TPC,XK,TPV,TKC,TPN**, RX,CRM,FMBR,.

1. **IFMFE3,NKPBF1NCPPPTXK,TCP**

YMT=0

5. **K1=NP**

TF(DMP,H8,3)

3. **WRITE(6,*)**

5. **FORMAT(1X,20A1)**

8. **DO**

10. **IF(IR(I1,1))**

11. **IF(TX(KI),I,F,TABL) GO TO 9**

12. **TUL2(KI)=AMAX1(TUL2(KT),TX2(KI))**

13. **TP2(KI)=1**

14. **GO TO 20**

9. **IF(TX(KI)-TCHAR) 10,10,20**

10. **RHOY1(KT)=RHOV**

11. **GO TO 50**

20. **IF(TUL1(KI)-TCHAR) 40,30,30**

30. **RHOY1(KI)=RHOV**

40. **GO TO 50**

50. **RHOY1(KT)=RHOV**

60. **GO TO 70**

70. **IF(TUL2(KI)-TCHAR) 90,80,80**

80. **RHOY2(KI)=RHOV**

90. **GO TO 95**

**COMMON TKC,TPY,TPX,TPC,XK,TPV,TKC,TPN**, RX,CRM,FMBR,.

1. **IFMFE3,NKPBF1NCPPPTXK,TCP**

YMT=0

5. **K1=NP**

TF(DMP,H8,3)

3. **WRITE(6,*)**

5. **FORMAT(1X,20A1)**

8. **DO**

10. **IF(IR(I1,1))**

11. **IF(TX(KI),I,F,TABL) GO TO 9**

12. **TUL2(KI)=AMAX1(TUL2(KT),TX2(KI))**

13. **TP2(KI)=1**

14. **GO TO 20**

9. **IF(TX(KI)-TCHAR) 10,10,20**

10. **RHOY1(KT)=RHOV**

11. **GO TO 50**

20. **IF(TUL1(KI)-TCHAR) 40,30,30**

30. **RHOY1(KI)=RHOV**

40. **GO TO 50**

50. **RHOY1(KT)=RHOV**

60. **GO TO 70**

70. **IF(TUL2(KI)-TCHAR) 90,80,80**

80. **RHOY2(KI)=RHOV**

90. **GO TO 95**
95 nRHO(KI) = ((RHOY1(KI) - RHOY2(KI))/nT)*DY
TF(KI-NP) 97,96,96
96 nRHO(KI) = nRHO(KI)/2.0
GO TO 98
97 TF(KI-INT) 96,96,98
98 TF(DRHO(KI)) 110,120,120
110 nRHO(KI) = n,RHO(KI)
120 XMT=XMT+DRHO(KI)
XMDG(KI)=XMT
IF(DMP) 190,190,150
150 WRITE(6,160) XMDG(KI),DRHO(KI),RHOY2(KI),RHOY1(KI)
160 FORMAT(1X,5HxMDG=1PE12.5,2X,5HDRHO=1P12.5,6HRHOY2=1PE12.5,2
1X,6HRHOY1=1PE12.5)
190 KI=KI-1
200 CONTINUE
RETURN
FND
THIS SUBROUTINE CALCULATES THE HEATING RATE DUE TO COMBUSTION.
IT IS ASSUMED THAT OXYGEN AND CARBON REACT TO FORM CO ONLY.

SUBROUTINE OXDAT(XMD0,QOXID)
QOXID=XMD0*4000.0/3600.0
QOXID=0.0
RETURN
FND
SUBROUTINE SWUF

C THIS SUBROUTINE DETERMINES THE FORWARD TIME STEP TEMPERATURES
C BY SOLVING THE TRI-DIAGONAL MATRIX

SUBROUTINE SWUF(A,B,C,D,T,N,DMP)

DIMENSION A(200),B(200),C(200),D(200),T(200),CP(200),DP(200)

CP(1) = C(1)/B(1)
DP(1) = D(1)/B(1)
DO 100 I=2,N

CP(I) = C(I)/B(I) - A(I)*CP(I-1)
DP(I) = D(I)/B(I) - A(I)*DP(I-1)
100 CONTINUE

T(N) = DP(N)
NM1 = N-1
DO 200 J=1,NM1

T(I) = T(N-J) - CP(I)*T(I+1)
200 CONTINUE

WRITE(6,250)
250 FORMAT(300,300,250)

WRITE(6,260) (CP(I),DP(I),T(I),I=1,N)
260 FORMAT(2X,1PE12.5,2X,1PE12.5)

RETURN
FND
SUBROUTINE REC
C THIS SUBROUTINE DETERMINES THE FRONT FACF LOCATION AND CHAR MASS
C
C SUBROUTINE REC(xmdc,xlost,rfc,dt,roc,ts,tsr,tx2,nrec,nrs,frnk,
1*xt0,sdot,mp)
C
D DIMENSION TS(50),SR(50)
1 IF(TX2-TRFC) 10,20,20
10 XMDC=0.0
20 IF(NRS-1)25,25,21
21 IF(NRS-NRFC) 22,22,25
22 IF(TX2-TRSN) 32,40,30
25 WRITE(6,26) TX2
26 FORMAT(1H20,75H THE RANGEF OF THE SURFACE RECCESS TABLE WAS EXCEED
1FD AT A TEMPERATURE OF 1PE12.5)
1FD AT A TEMPERATURE OF 1PE12.5)
FPR5=1.0
20 GO TO 60
21 GO TO 60
22 GO TO 60
23 GO TO 20
24 NRS=NRS+1
25 GO TO 21
26 GO TO 21
27 GO TO 30
28 GO TO 34
29 GO TO 20
30 NRS=NRS+1
31 GO TO 21
32 IF(TX2-TRSN) 34,40,36
33 GO TO 60
34 GO TO 60
35 GO TO 30
36 SX=SR(NRS-1)+(SR(NRS)-SR(NRS-1))/(TS(NRS)-TS(NRS-1))
37 TX2=TS(NRS-1)
38 GO TO 50
39 SX=SR(NRS)
40 GO TO 30
41 XLOST=300.0*SYDT
42 XMDC=(XLOST*ROC)/DT
43 SDOT=SX*300.0
44 IF(DMP) 60,60,52
45 WRITE(6,54) SX,XLOST,XMDC
46 FORMAT(1H20,3H5X=,1PE12.5,1*6HXLOST=,1PE12.5,3X,5HXMDC=,1PE12.5)
47 GO TO 50
48 RETURN
FND
*IBFTC TEMP*

**C**
THIS SUBROUTINE DETERMINES THE INITIAL TEMPERATURE DISTRIBUTION

**C**
IN THE HEAT SHIELD STRUCTURE

**C**
SUBROUTINE TEMPD

**C**

**C**
**DIMENSION TITLE(12), HEADING(12), XIONT(12,12), TKC(20), XKC(20),
1 CPC(20), TKV(20), XKV(20), TCPV(20), CPV(20), TIME(30), QCON(30),
20 RAD(300), VEL(300), XNPM(12), NKPR(12), NCPR(12), TX(20,12), XK(20,12)
5, TCP(20,12), CPX(20,12), RHOBX(12), XBM(12), EMFS(12), EMBR(12), HXX(19)
4, 6APX(12), FTEST(12), ATEST(12), TEMDI(200), TX1(200), TX2(200)
5, TX2(10,12), TUL1(200), TUL2(200), XH(50), TW(50), IR(50), IR1(50)
6, TRP(50), TUL(50), TEM(50), TY(200), AT(200), R(200), C(200), D(200)
7, TR(50), RHO(50), CP(50), DX(12), XR(10,12), CPB(10,12), XMBG(50)
8, VY(50), A(10,12), RB(10,12), CR(10,12), DB(10,12), SR(10,12)
9, AR(10,12), TP(10,12), H(12), S(50), NPM(12)

**C**
**DIMENSION TITLE(12), HEADING(12), XIONT(12,12), TKC(20), XKC(20),
1 CPC(20), TKV(20), XKV(20), TCPV(20), CPV(20), TIME(30), QCON(30),
20 RAD(300), VEL(300), XNPM(12), NKPR(12), NCPR(12), TX(20,12), XK(20,12)
5, TCP(20,12), CPX(20,12), RHOBX(12), XBM(12), EMFS(12), EMBR(12), HXX(19)
4, 6APX(12), FTEST(12), ATEST(12), TEMDI(200), TX1(200), TX2(200)
5, TX2(10,12), TUL1(200), TUL2(200), XH(50), TW(50), IR(50), IR1(50)
6, TRP(50), TUL(50), TEM(50), TY(200), AT(200), R(200), C(200), D(200)
7, TR(50), RHO(50), CP(50), DX(12), XR(10,12), CPB(10,12), XMBG(50)
8, VY(50), A(10,12), RB(10,12), CR(10,12), DB(10,12), SR(10,12)
9, AR(10,12), TP(10,12), H(12), S(50), NPM(12)

**COMMON**
**TKC,XKC,TPC,CPC,TKV,XKV,TCPV,CPV,XNPM,RHOBX,RHOB,RHOC,EMFS,EMBR,
1 FTEST,NKPR,NCPB,TKX,XK,TCX,CPX,NPM,GAPX,FTEST,ATEST,TEMDI,TX1,
2 TX2,TX2T,TUL,TUL1,TUL2,IR,IR1,IR2,A,B,C,D,E,S,R,AR,RR,CR,DR,SB,
3 RRR,RR2,TY,RH0Y1,RH0Y2,XMGB,RHO,C,P,Y,XK,XPB,DXB,DT,VLST,
4 TABL,TRCH,TRFC,RH0V,FRLOW,FMV,EMC,H500,NNC,NCPC,NK,CNPC,
5 NNP,NPR,NP,FTEST,TEMP,TX0,TENV,HENV,FENV,GLOSS,TL,TIM,TINT
**COMMON**
**I1,12,13,14,15,16,IN,INT,DX,XMT,TL,VL,PL,MP,FMP,ERR2,FRF3,FRF4,HV,VPT,CHAR,CHAR,ABL,ARL,CMD,CMH
**COMMON**
**TI11,13,14,15,16,IN,INT,DX,XMT,TL,VL,PL,MP,FMP,ERR2,FRF3,FRF4,HV,VPT,CHAR,CHAR,ABL,ARL,CMD,CMH
**COMMON**
**TI11,13,14,15,16,IN,INT,DX,XMT,TL,VL,PL,MP,FMP,ERR2,FRF3,FRF4,HV,VPT,CHAR,CHAR,ABL,ARL,CMD,CMH
**COMMON**
**TI11,13,14,15,16,IN,INT,DX,XMT,TL,VL,PL,MP,FMP,ERR2,FRF3,FRF4,HV,VPT,CHAR,CHAR,ABL,ARL,CMD,CMH
**COMMON**
**TI11,13,14,15,16,IN,INT,DX,XMT,TL,VL,PL,MP,FMP,ERR2,FRF3,FRF4,HV,VPT,CHAR,CHAR,ABL,ARL,CMD,CMH

**C**
**X=X0,0**
**T(FTEST2) 300,100,200**
100 **NO 150 L=1,NNP**
**TX1(L)=TEMPI**
**TX2(L)=TEMPI**
**TUL1(L)=TX1(L)**
**TUL2(L)=TX1(L)**
**TFMDI(L)=TEMPI**
**150 CONTINUE**
**NO 160 I=1,NWR**
**J=NPM(I)**
**NO 155 M=1,SN**
**TX2(M,I)=TEMPI**
**155 CONTINUE**
**160 CONTINUE**
**GO TO 320**
200 **NO 220 L=1,NP**
**TFMDI(L)=TX0+(TENV-TX0)/TLL**
**TX1(L)=TEMDI(L)**
**TX2(L)=TEMDI(L)**
**TUL1(L)=TX1(L)**
**TUL2(L)=TX1(L)**
**X=X+DX**
**220 CONTINUE**
**L=NP+1**
**NO 270 I=1,NMR**
**KD=NP(I)**
**NO 250 J=1,KJ**
**TEMXI(L)=TX0+(TENV-TX0)/TLL**
**TX1(L)=TEMDI(L)**
**TX2(L)=TEMDI(L)**
TEST(J,I)=TMIN(I)  
X=X+D(i)  
L=L+1  
250 CONTINUE  
X=X+(GAPX(I)/12.0)  
270 CONTINUE  
GO TO 320  
C AN ARBITRARY TEMPERATURE DISTRIBUTION CAN BE READ IN FROM INPUT  
C DATA IF TEST? IS A NEGATIVE NUMBER  
300 WRITE(6,310)  
310 FORMAT(1HO.7th THE VALUE OF TEST? WAS NEGATIVE, SUBROUTINE TEMPD  
1SHOULD NOT HAVE BEEN CALLED.)  
ERR1=1.0  
320 RETURN  
FND
$IBFTC DO02
C THIS SUBROUTINE DETERMINES THE TEMPERATURE OF POINTS A FIXED
C DISTANCE FROM A REFERENCE PLANE FROM THE TEMPERATURES CALCULATED
C IN A VARYING THICKNESS
C
SUBROUTINE DO02(XLOST,XARRAY,TARRAY,NA,XNODE,TEMP,XXNODE,XXK,XXLSTV,
  1 X)
C
DIMENSION XARRAY(50),TARRAY(50),XXNODE(50),TEMP(50),XXNODEV(50)
C
  K=0
  NXT=0.0
  DO 100 I=1,NA
  IF(XXLSTV.LE.XNT) GO TO 100
  K=K+1
  100 NXT=XNT+NX
  150 XXK=NA-K
  XNOD(XXK)=XLLSTV
  TFM(XXK)=TARRAY(XXK)
  DO 200 I=1,XXK
  XNOD(XXK)=XXK+XX-XXLSTV
  CALL DISCT3(XNOD(XXK),XARRAY,TAARRAY,NA,TFM(XXK+1))
  XNODEV(XXK+1)=XXK+XX
  200 XXK=XXK+1.0
  HRETURN
  FNO

  10000
  10010
  10020
  10030
  10040
  10050
  10060
  10070
  10080
  10090
  10100
  10110
  10120
  10130
  10140
  10150
  10160
  10170
  10180
  10190
  10200
  10210
  10220
  10230
  10240
  10250
  10260
$IBFTC (UNTRP
SUBROUTINE UNTRP(X,XTBL,Y,YTPL,N,J)
DIMENSION XTL(50),YTPL(50)
I=J
1 IF(I,AT,N,OR,T,LT,2) I=2
10 IF(XTBL(I-1),E,X,AND,X,LT,XTBL(I)) GO TO 40
IF(X,AT,XTBL(I)) GO TO 30
20 I=I-1
1 IF(I,GE,2) GO TO 10
I=2
GO TO 40
30 I=I+1
1 IF(I,LE,N) GO TO 10
I=N
40 FRACT=(X-XTPL(I-1))/(XTPL(I)-XTPL(I-1))
Y=YTPL(I-1)+YTPL(I-1)*FRACT
RETURN
FEND
$16FTC 160T
SUBROUTINE I5ATHM(DEPTH,TFMP,ROND,N,ANS)
DIMENSION DEPTH(1),TFMP(1)
ANS=1.
K=N-1
10 I=1,K
IF(TMP(I)-ROND)2,1,3
1 ANS=DFPTH(I)
GO TO 100
2 I=I+1
IF(TEMP(I+1)-ROND)3,100,4
4 ANS=DFPTH(I+1)-(TFMP(I+1)-ROND)*(DEPTH(I+1)-DFPTH(I))/(TFMP(I+1)-1TFMP(I))
GO TO 100
3 I=I+1
IF(TEMP(I+1)-ROND)5,100,100
5 ANS=(TEMP(I)-ROND)*(DFPTH(I+1)-DFPTH(I))/(TFMP(I)-TEMP(I+1))*DEPTH
1(I)
GO TO 100
CONTINUE
IF(ROND,EG.,TFMP(N))ANS=DFPTH(N)
RETURN
END
SUBROUTINE I

DIMENSION SAVE2(1), SAVE2(2), SAVE2(3), USE, NX1, VALUE, DT, TFINAL, TIMF,

USE=0.0
<SAVE1(NX1)=VALUE
NX2=NX1-1
IF(NX2, 0.0) NY2=3
<SAVE2(NX2)=VALUE
NX3=NX2-1
IF(NX3, 0.0) NY3=3
<SAVE3(NX3)=VALUE
IF((TIME, LT, (2, *DT)), OR, (TIME, GF, (TFINAL-3, *DT))) GO TO 4
GO TO (1,?,3),NX1
1 IF(((ABS(SAVE2(1)-SAVE2(2)), I.E., 0.01), OR, (ABS(SAVE2(2)-SAVE2(3))
1, I.E., 0.01)) GO TO 5
2 IF(((ABS(SAVE3(1)-SAVE3(2)), I.E., 0.01), OR, (ABS(SAVE3(2)-SAVE3(3))
1, I.E., 0.01)) GO TO 6
3 IF(((SAVE1(1), LT, SAVE2(2)), AND, (SAVE2(2), GT, SAVE2(3))) OR, ((SAVE2(1), LT, SAVE2(3))) USE=SAVE2(2)
4 THING=SAVE2(2)
5 THING=SAVE2(2)
6 THING=SAVE2(2)
7 THING=SAVE2(2)
NX1=NX1+1
IF(NX1, 0.001) NX1=1
RETURN!
FND
L0000
L0010
L0020
L0030
L0040
L0050
L0060
L0070
L0080
L0090
L0100
L0110
L0120
L0130
L0140
L0150
L0160
L0170
L0180
L0190
L0200
L0210
L0220
L0230
L0240
L0250
L0260
L0270
L0280
L0290
L0300
L0310
L0320
L0330
L0340
73
**SHIFT DISCT3**

**SUBROUTINE DISCT3(XA,TAY, TAY, NY, ANS)**

**DIMENSION TABY(1), TARY(1)**

**CALL DISSFR(XA, TAY, 1, NY, 2, NN)**

**NNN=3**

**CALL LAGHAN(XA, TAY(NN), TABY(NN), NNN, ANS)**

**RETURN**

**END**
SUBROUTINE DISSER (XA, TAB, I, NX, ID, NPX)

DIMENSION TAB(2000)
C
DIMENSION TAB(2000)

NPT=ID+1
NPB=NPT/2
NP=NP=NPT-NPB
IF (NX-NPT) 10,5,10
NPX=1
RETURN

10 NLOW=I+NPB
NUPP=I+NX-(NP+1)
DO 15 II=NLOW,NUPP
NLOC=II
IF (TAB(II)-XA) 15,20,20
RETURN

15 CONTINUE
NPX=NUPP-NPB+1
RETURN

20 NL=NLOC-NPB
NU=NL+ID
DO 25 JJ=NL,NU
NDIS=JJ
IF (TAB(JJ)-TAB(JJ+1)) 25,30,25
NPX=NL
RETURN

25 CONTINUE
NPX=NU
RETURN

30 IF (TAB(NDIS)-XA) 40,35,35
NPX=NDIS-ID
RETURN

35 IF (TAB(NDIS)-XA) 40,35,35
NPX=NDIS+1
RETURN
END
SUBROUTINE LAGRAN (X, Y, N, ANS)

DIMENSION X(200), Y(200)

C

DIMENSION X(200), Y(200)

SUM=0.0
DO 3 I=1,N
  PROD=Y(I)
  DO 2 J=1,N
    A=X(I)-X(J)
    IF (A) 1,2,1
    1 B=(X(I)-X(J))/A
    PROD=PROD*B
  CONTINUE
3 SUM=SUM+PROD
ANS=SUM
RETURN
END
58FTC

RFIND 11
RFAD (11) (TITLE(I)*I=1,12)
RFAD (11) X(1),Y1(1),Y2(1),Y3(1),Y4(1)
Y1(I):Y1(I)*12.+Y1(I)
Y2(1):Y2(1)*12.+Y1(I)
Y3(I):Y3(I)*12.+Y1(I)
I=2
30 RFAD(11) X(I),Y1(I),Y2(I),Y3(I),Y4(I)
IF(X(I)=5001.)10,20,20
10 Y3(I):Y3(I)*12.+Y1(I)
I=1+1
G0 TO 30
20 NPIOT=I=1
YM1:Y1(1)
YM3:Y3(1)
YM4:Y4(1)
DO 40 K = 2, NPIOT
IF (Y1(K),GT,YM1) YM1 = Y1(K)
IF (Y2(K),GT,YM2) YM2 = Y2(K)
IF (Y3(K),GT,YM3) YM3 = Y3(K)
IF (Y4(K),GT,YM4) YM4 = Y4(K)
40 CONTINUE
1000 FORMAT(1H15.(1PA6))
CALL ACCEND(X,Y1,Y2,Y3,Y4,NPIOT)
XMAX=X(NPIOT)
CALL APLOT (X,Y1,XMAX,YM1,TITLE,NPIOT)
CALL CRPLOT (X,Y2,XMAX,YM2,TITLE)
CALL CPLOT (X,Y3,Y4,XMAX,YM3,YM4,TITLE,Y1)
WRITE(6,1000) (TITLE(I)*I=1,12)
WRITE(6,1001) (X(I),Y1(I),Y2(I),Y3(I),Y4(I)),I=1,NPIOT
1001 FORMAT(5E20.9)
WRITE(6,1002) YM1,YM2,YM3,YM4,NPIOT
1002 FORMAT(///6H XMAX=F10.4,YM1=F10.4,YM2=F10.4,YM3=F10.4,YM4=F10.4)
RFAD(11)(TITLE(I),I=1,12)
IF(X(1)=5001.)30,50,50
50 WRITE(6,1003) (TITLE(I)*I=1,12)
1003 FORMAT(///12A6)
RETURN
FIND
$IBFTC ACCEN

SUBROUTINE ACCEND(X,Y,A,R,C,N)

DIMENSION X(1),Y(1),A(1),R(1),C(1)

K=1

101 SMALL=X(K)

DO 100 I=K,N

SYM=Y(I)

IF(SMALL.EQ.SYM) INDEX=I

100 CONTINUE

X(INDEX)=X(K)

Y(K)=SMALL

SAVE=Y(K)

Y(INDEX)=SAVE

SAVEA=A(K)

A(INDEX)=SAVEA

SAVEB=B(K)

B(K)=B(INDEX)

SAVEC=C(K)

C(INDEX)=SAVEC

K=K+1

IF(K.EQ.N) RETURN

GO TO 101

FND
10 CONTINUE
20 VMAX = ALLO\(1)\)
11 FIX = 11
12 I = 14
13 I = (I + 1)
50 VMAX = ALLO\(1) \times 100
40 CONTINUE
60 VMAX = ALLO\(1) / 100
CALL PSTFP
CALL ARUN (123, 1023, 12, 924, 12, 12, 5)
CALL PLOT1 (1, 1), ZERO, VMAX, ZERO, XMAX, X, Y, NPL=, 1, 117/
AT LONG(1) = 0.0
AT LONG(1) = 0.1
NO 60 I = 1 + 6
CALL LARIX (ALONG(1), 1)
CALL LARY (ALONG(1), 1)
AT LONG(1 + 1) = ALONG(1) + .2 \times XMAX
60 AT LONG(1 + 1) = ALONG(1) + .2 \times VMAX
CALL PRINT(200, 975, 12, 0, 34, XTITLE)
CALL PRINT(200, 975, 12, 0, 34, YTITLE)
CALL PRINT(120, 1000, 12, 0, 72, TITLE)
CALL NMPFH
RETURN
END
$IBFIC PLOT
SUBROUTINE PLOT (X,Y,XLIM,YLIM,TITLE)
DIMENSION X(300),Y(300),XTITLE(10),ALONGY(7),XTITLE(10)
DIMENSION TITLE(12)
COMMON /ARC / ALLOW(7),ALONGX(7),NPLLOT,ZPO,SMAX,TLIX
DATA (XTITLE(I),I=1,10)/XH
DATA (XTITLE(I),I=1,10)/YH
XTITLE(1)=0.0
DO 10 I=1,7
10 CONTINUE
WRITE (6,1000) YLIM
1000 FORMAT(/// 37H PLOT WILL NOT BE DONE BFOUSE YLIM= F12.5 /////)
RETURN
20 YMAX=ALLOW(I)
CALL RSTFRM
CALL GRIUOGN(123,1023,24,924,11,5,5)
CALL PLOT (1,1,ZERO,YMAX,ZERO,YMAX,X,Y,NPLLOT,1,1H/)
DO 30 I=1,6
CALL LAPIFX (ALONGX(I),1)
CALL LAPIFY (ALONGY(I),1)
30 ALONGY(I+1)=ALONGY(I)+.2*YMAX
CALL PRINT (200,975,12,0,3X,XTITLE)
CALL PRINT (200,975,12,0,3X,XTITLE)
CALL PRINT (123,1100,12,0,72,TITLE)
CALL DMPHUF
RETURN
END
C *** FOUR (4) CHARACTERS ARE ALLOWED FOR CURVE(1)
CURVE(1)=ONE
SYMROI=WON
YMIN =AMAX1 (YLIM1,YLIM2 )
NCURVE =1
NO.1=I1,NPLOT
1 Y(Y(I))= Y(I)
NO.7=I1,4
T=I
IF(YBIG*100. ALLOW(I))6,6,7
7 CONTINUE
WRITE (6,1000) YLIM1,YLIM2
1000 FORMAT (//3'(" PLOT WILL NOT BE DONE BECAUSE YLIM1=F12.5,10H OR
1Y LIM2=F12.5,10H")
RETURN
6 YMAX = ALLOW (TI)/100,
VFCTR=VFAC(T)
CALL RSTFPM
CALL CRT0CN (123,1023,24,024,18,18,5,5)
J=1
70 NO. 10 I=J,NPLOT
T=I
INM=J-1
IF(Y(Y(I))=Y(I))120,110,10
10 CONTINUE
NPT=NPLMOT-J+1
LL=J+NPT/2
IVLOC= X(LL)*18. /VFCTR +123.,-48.
CALL PRINT(1,M Ot,IVLOC, R,0,4,CURVE)
CALL PLOT(i,i,7ERO,YMAX,MYAX0,X(J),YY(J),NPT ,7,SYMROI)
IF(NCURVE=1)90,85,50
85 NO. 86 I=J,NPLOT
86 YY(Y(I))=Y(Y(I))
CURVE(1)=TWO
SYMROI=TOO
NCURVE = 2
J=1
G0 TO 70
20 NPT=II-J
LL=J+NPT/2
IVLOC=X(LL)18. /VFCTR +123.,-48.
CALL PRINT(1,M Ot,IVLOC, R,0,4,CURVE)
CALL PLO11(1,1,ZERO,YMAX,ZERO,XX(J),YY(J),NPT,1,SYMPOL)

DO 50 JJ= 11, NPL0T
   JJ= JJ
   IF(YY(I(J))= Y(J)) CONT1NUE
   IF(NCURVE= 1) 90,A5,

40 JJ= JJ
   90 AI0NGY(I)=0,
   DO 100 I= 1, K
      CALL LARP1X(AI0NGX(I),1)
      CALL LARP1Y(AI0NGY(I),1)
   100 AI0NGY(I+1)=AI0NGY(I) + P*YMAX
      CALL P1NT(210,975,12,0,3A,XTITL
      CALL PRINT(147,200,0,12,3A,YT1TLE)
      CALL PRINT(129,1000,12,0,72,T1TLE)
      CALL NMPDF
      CALL PRINT
      END
<table>
<thead>
<tr>
<th>FORTRAN</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>&quot;A&quot; coefficient in matrix, single subscript</td>
</tr>
<tr>
<td>AB</td>
<td>&quot;A&quot; coefficient in matrix, double subscript</td>
</tr>
<tr>
<td>ABLC</td>
<td>specific heat of material at TABL</td>
</tr>
<tr>
<td>ABLK</td>
<td>thermal conductivity of material at TABL</td>
</tr>
<tr>
<td>B</td>
<td>&quot;B&quot; coefficient in matrix, single subscript</td>
</tr>
<tr>
<td>BB</td>
<td>&quot;B&quot; coefficient in matrix, double subscript</td>
</tr>
<tr>
<td>BL</td>
<td>Total thickness of backup structure</td>
</tr>
<tr>
<td>BLTEM</td>
<td>value of 1460 isotherm depth from previous time step</td>
</tr>
<tr>
<td>BTEST</td>
<td>test to determine mode of heat transfer out of back surface of backup materials</td>
</tr>
<tr>
<td>C</td>
<td>&quot;C&quot; coefficient in matrix, single subscript</td>
</tr>
<tr>
<td>CB</td>
<td>&quot;C&quot; coefficient in matrix, double subscript</td>
</tr>
<tr>
<td>CHARC</td>
<td>specific heat of material at TCHAR</td>
</tr>
<tr>
<td>CHARK</td>
<td>thermal conductivity of material at TCHAR</td>
</tr>
<tr>
<td>CP</td>
<td>specific heat of a node in ablation material</td>
</tr>
<tr>
<td>CPB</td>
<td>specific heat of backup material node</td>
</tr>
<tr>
<td>CPC</td>
<td>specific heat values in char specific heat table</td>
</tr>
<tr>
<td>CPV</td>
<td>specific heat values in virgin specific heat table</td>
</tr>
<tr>
<td>CFX</td>
<td>specific heat values in backup material specific heat tables</td>
</tr>
<tr>
<td>D</td>
<td>&quot;D&quot; coefficient in matrix, single subscript</td>
</tr>
<tr>
<td>DB</td>
<td>&quot;D&quot; coefficient in matrix, double subscript</td>
</tr>
<tr>
<td>DELTT</td>
<td>time step in the time step table</td>
</tr>
<tr>
<td>FORTRAN</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
</tr>
<tr>
<td>DMP</td>
<td>test used for dumping (DMP = 0 skip dump, DMP = 1.0 start dumping)</td>
</tr>
<tr>
<td>DRHO</td>
<td>local mass flow rate of ablation gas</td>
</tr>
<tr>
<td>DT</td>
<td>time step from the time step table in hours</td>
</tr>
<tr>
<td>DTS</td>
<td>time step from time step table in seconds</td>
</tr>
<tr>
<td>DX</td>
<td>thickness of a node in the ablation material</td>
</tr>
<tr>
<td>DXB</td>
<td>thickness of a node in a backup structure material</td>
</tr>
<tr>
<td>DXV</td>
<td>variable ablation node thickness ( \left( = \frac{V_{LV}}{N_{P} - 1} \right) )</td>
</tr>
<tr>
<td>DXX</td>
<td>fixed ablation material node thickness ( \left( = \frac{V_{LL}}{N_{P} - 1} \right) )</td>
</tr>
<tr>
<td>EMBB</td>
<td>emissivity of back surface of each material in backup</td>
</tr>
<tr>
<td>EMC</td>
<td>char material emissivity</td>
</tr>
<tr>
<td>EMFB</td>
<td>emissivity of front surface of each material in backup</td>
</tr>
<tr>
<td>EMV</td>
<td>virgin material emissivity</td>
</tr>
<tr>
<td>EMX</td>
<td>emissivity of front surface of ablation material</td>
</tr>
<tr>
<td>END</td>
<td>code word for plot routine</td>
</tr>
<tr>
<td>ERR1</td>
<td></td>
</tr>
<tr>
<td>ERR2</td>
<td></td>
</tr>
<tr>
<td>ERR3</td>
<td></td>
</tr>
<tr>
<td>ERR4</td>
<td></td>
</tr>
<tr>
<td>FBL%W</td>
<td>blowing efficiency in reducing convective heating</td>
</tr>
<tr>
<td>FC%NV</td>
<td>factor to correct convective heating rate for various body locations</td>
</tr>
<tr>
<td>FENV</td>
<td>emissivity - view factor product to cabin interior</td>
</tr>
<tr>
<td>FRAD</td>
<td>factor to correct radiative heating rate for various body locations</td>
</tr>
<tr>
<td>FTEST</td>
<td>test to determine mode of heat transfer into front surface of backup materials</td>
</tr>
<tr>
<td>FORTRAN</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
</tr>
<tr>
<td>FV</td>
<td>view factor for external environment</td>
</tr>
<tr>
<td>G</td>
<td>defined by FORTRAN statement</td>
</tr>
<tr>
<td>GAPX</td>
<td>gap width between backup materials</td>
</tr>
<tr>
<td>H</td>
<td>film coefficient between backup materials</td>
</tr>
<tr>
<td>H300</td>
<td>enthalpy of air at 300° K</td>
</tr>
<tr>
<td>HEAD</td>
<td>any 72 alphanumeric characters used to identify problems being run - printed at top of first page of output</td>
</tr>
<tr>
<td>HEADING</td>
<td>any 72 alphanumeric characters used to identify each input section</td>
</tr>
<tr>
<td>HENV</td>
<td>film coefficient to cabin environment</td>
</tr>
<tr>
<td>HTX</td>
<td>total enthalpy</td>
</tr>
<tr>
<td>HV</td>
<td>heat of degradation of virgin material</td>
</tr>
<tr>
<td>HW</td>
<td>wall enthalpy computed from enthalpy - temperature table</td>
</tr>
<tr>
<td>HX</td>
<td>enthalpy values in enthalpy table</td>
</tr>
<tr>
<td>IEM</td>
<td>test used to determine if front surface is virgin or char for using proper emissivity</td>
</tr>
<tr>
<td>IPRC</td>
<td>variable print frequency in time-step table</td>
</tr>
<tr>
<td>IFRCT</td>
<td>present print control number</td>
</tr>
<tr>
<td>IR</td>
<td>test to determine if node temperature is greater than TABL</td>
</tr>
<tr>
<td>IRL1</td>
<td>test used in determining node density at TX1 temperature</td>
</tr>
<tr>
<td>IR2</td>
<td>test used in determining node density at TX2 temperature</td>
</tr>
<tr>
<td>NCASE</td>
<td>number of problems to be run</td>
</tr>
<tr>
<td>NCPB</td>
<td>number of points in each backup material specific heat table</td>
</tr>
<tr>
<td>NCPC</td>
<td>number of points in char specific heat temperature table</td>
</tr>
<tr>
<td>NCPV</td>
<td>number of points in virgin specific heat temperature table</td>
</tr>
<tr>
<td>NKC</td>
<td>number of points in char thermal conductivity - temperature table</td>
</tr>
<tr>
<td>FORTRAN</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
</tr>
<tr>
<td>NKPB</td>
<td>number of points in each backup material thermal conductivity table</td>
</tr>
<tr>
<td>NKV</td>
<td>number of points in virgin thermal conductivity temperature table</td>
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APPENDIX E

GENERAL FLOW CHART

Start

Rewind 1
Read NCASE

Initialize program constants

Read and write input data and setup initial conditions

Transfer to subroutine TEMP determines initial temperature distribution

Calculate surface heating conditions

Transfer to subroutine RECESS calculates surface recession depth and char ablation rate

Transfer to subroutine CSHFF calculates tri-diagonal matrix coefficients

Transfer to subroutine SWUFT solves tri-diagonal matrix for temperature distribution

Continue
Continue

Transfer to subroutine DONO
calculates fixed location temperatures

Transfer to subroutine ABLATE
calculates gas ablation rate

Transfer to subroutine SAVE
determines maximum and minimum values for plot program

Setup temperature distribution for printing
Perform isotherm depth calculations

Transfer to subroutine ISOTHERM
calculates 1050° R and 1460° R isotherm depths

Write output tape

If time is less than TLIM, loop back to surface heating calculations

Check for time limit of problem

Check NCASE

Rewind 11

End File 11

Reinitialize program to initial input conditions

Go to initialization of program constants to start next problem
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Note: Write numbers 10, letters I, U, G, Z, C, symbols /,...
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<thead>
<tr>
<th>LOCATION</th>
<th>OPERATION</th>
<th>VARIABLE FIELD</th>
<th>FORTRAN STATEMENT</th>
<th>COMMENTS</th>
</tr>
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<td>+400.0</td>
<td>+00.00</td>
<td>+95.0</td>
<td>100 +0.0</td>
<td>400 +1.926 +04</td>
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<tr>
<td>2</td>
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**BACKUP MATERIAL**

+462.0  +00.00  +90.065  +00.0 +660.0  +00.0 +0.065  +00.0 +560.0  +00.0 +0.065 +00.0 +0.065 +00.0
+462.0  +00.00  +90.066  +00.0 +760.0  +00.0 +0.067  +00.0 +436.0  +00.0 +0.064 +00.0 +0.064 +00.0
+462.0  +00.00  +90.066  +00.0 +760.0  +00.0 +0.067  +00.0 +436.0  +00.0 +0.064 +00.0 +0.064 +00.0
+436.0  +00.00  +90.43  +00.0 +1.160.0  +00.0 +0.43  +00.0 +436.0  +00.0 +0.043 +00.0 +0.043 +00.0
+436.0  +00.00  +90.43  +00.0 +1.160.0  +00.0 +0.43  +00.0 +436.0  +00.0 +0.043 +00.0 +0.043 +00.0
+436.0  +00.00  +90.43  +00.0 +1.160.0  +00.0 +0.43  +00.0 +436.0  +00.0 +0.043 +00.0 +0.043 +00.0

**HEAT TRANSFER TO CABIN ENVIRONMENT**

+560.0  +00.00  +00.0  +00.0  +00.0  +00.0  +00.0

**INTERNAL TEMPERATURE IS CONSTANT**

+462.0  +00.00  +00.0  +00.0  +00.0  +00.0  +00.0
+462.0  +00.00  +00.0  +00.0  +00.0  +00.0  +00.0
+462.0  +00.00  +00.0  +00.0  +00.0  +00.0  +00.0
+462.0  +00.00  +00.0  +00.0  +00.0  +00.0  +00.0

**NOTE:** WRITE NUMBERS IN, LETTERS OF UGCZ, SYMBOLS /+.
**TABLE I.- SAMPLE PROBLEM INPUT - Concluded**

(a) Coding sheet

<table>
<thead>
<tr>
<th>STATEMENT</th>
<th>LOCATION</th>
<th>OPERATION</th>
<th>VARIABLE FIELD</th>
<th>FORTRAN STATEMENT</th>
<th>COMMENTS</th>
<th>SEQUENCE</th>
</tr>
</thead>
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<td>.+100</td>
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<td>.3100.0</td>
<td>100.0</td>
<td>2200.0</td>
</tr>
<tr>
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<td>209.00</td>
<td>.+100</td>
<td>.40</td>
<td>.3100.0</td>
<td>100.0</td>
<td>2200.0</td>
</tr>
<tr>
<td>42.00</td>
<td>209.00</td>
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<td>.40</td>
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<td>42.00</td>
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<td>2200.0</td>
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<td>42.00</td>
<td>209.00</td>
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<td>42.00</td>
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<td>.+100</td>
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<td>.3100.0</td>
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<td>209.00</td>
<td>.+100</td>
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<td>2200.0</td>
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<td>42.00</td>
<td>209.00</td>
<td>.+100</td>
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<td>.3100.0</td>
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<td>2200.0</td>
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<tr>
<td>42.00</td>
<td>209.00</td>
<td>.+100</td>
<td>.40</td>
<td>.3100.0</td>
<td>100.0</td>
<td>2200.0</td>
</tr>
</tbody>
</table>

**NOTE:** WRITE NUMBERS 10, LETTERS IGUCZC, SYMBOLS */*
### TABLE I: SAMPLE PROBLEM INPUT

(b) Fortran data card listing

<table>
<thead>
<tr>
<th>Typical Charring Ablator - Test Case - 4/6/65</th>
<th>Donald M. Curby</th>
</tr>
</thead>
<tbody>
<tr>
<td>+600.0 +Un +10.0 +Un 2 1</td>
<td></td>
</tr>
<tr>
<td>+1.0 +Un +11.0 +Un 100</td>
<td></td>
</tr>
<tr>
<td>+600.0 +Un +10.1 +Un 100</td>
<td></td>
</tr>
<tr>
<td>+1.0 +Un +11.0 +Un</td>
<td></td>
</tr>
<tr>
<td>Typical Charring Ablation Material Properties</td>
<td></td>
</tr>
<tr>
<td>+16b+u +Un +1404.0 +Un +0.0 +0.0 +36.0 +Un +20.0 +Un +0.0 +0.0 +0.0</td>
<td></td>
</tr>
<tr>
<td>+0.65 +Un +1.75 +Un +129.0 +Un +1.50 +Un +250.0 +Un +0.0 +0.0 +0.0</td>
<td></td>
</tr>
<tr>
<td>+1.0 +Un +11.0 +Un +11.12 +0.0 +0.43 +Un +0.070 +Un +0.43 +0.0</td>
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<tr>
<td>31 2 +2 a 2 2 +1060.0 +Un +11.12 +Un +1.0 +Un +0.12 +Un</td>
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<tr>
<td>+1060.0 +Un +1.0 +Un +1.0 +Un +0.43 +0.0</td>
<td></td>
</tr>
<tr>
<td>+360.0 +Un +1.069 +Un +160.0 +Un +0.065 +0.0 +560.0 +Un +0.0655 +0.0</td>
<td></td>
</tr>
<tr>
<td>+660.0 +Un +1.069 +Un +170.0 +Un +0.0672 +0.0 +860.0 +Un +0.0684 +0.0</td>
<td></td>
</tr>
<tr>
<td>+460.0 +Un +1.069 +Un +160.0 +Un +0.070 +0.0 +1160.0 +Un +0.070 +0.0</td>
<td></td>
</tr>
<tr>
<td>+360.0 +Un +110.0 +Un +0.43 +0.0</td>
<td></td>
</tr>
<tr>
<td>+9.0 +Un +45.0 +Un +10.0 +Un +2.925 +0.0</td>
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</tr>
<tr>
<td>-9.0 +Un +10.0 +Un +11.0 +Un +2.925 +0.0</td>
<td></td>
</tr>
<tr>
<td>NO TRAJECTORY = 0=95 RTU/Sec-SOFT</td>
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<tr>
<td>1 3 +v1.0 +Un</td>
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<tr>
<td>5.0 +Un</td>
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<tr>
<td>Backup Material 0.1 Inches Thick</td>
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</tr>
<tr>
<td>+360.0 +Un +110.0 +Un +460.0 +Un +0.065 +0.0 +560.0 +Un +0.0655 +0.0</td>
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<tr>
<td>+660.0 +Un +110.0 +Un +170.0 +Un +0.0672 +0.0 +860.0 +Un +0.0684 +0.0</td>
<td></td>
</tr>
<tr>
<td>+460.0 +Un +110.0 +Un +160.0 +Un +0.070 +0.0 +1160.0 +Un +0.070 +0.0</td>
<td></td>
</tr>
<tr>
<td>+360.0 +Un +110.0 +Un +0.43 +0.0</td>
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</tr>
<tr>
<td>-9.0 +Un +10.0 +Un +11.0 +Un +0.0 +0.0</td>
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<tr>
<td>Heat Transfer To Capin Environment – MENTV=0.0</td>
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<tr>
<td>+560.0 +Un +10.0 +Un +0.0 +0.0 +0.0 +0.0</td>
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<tr>
<td>Initial Temperature Is Constant</td>
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<td>+0.0 +Un +30.0 +Un +30.0 +Un</td>
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<tr>
<td>+2800.0 +Un +1678.0 +0.0 +2800.0 +Un +6186.0 +0.0 +2500.0 +0.0 +6991.0 +0.0</td>
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TABLE I - SAMPLE PROBLEM INPUT - Concluded

(b) Fortran data card listing

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TABLE II.- SAMPLE PROBLEM OUTPUT

TYPICAL CHARRING ABLATION - TEST CASE - 4/6/65 DONALD M. CURRY

INPUT DATA.

TIME LIMIT=6.00000E 02 INITIAL TIME=0. NPTT= 2

<table>
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<tr>
<th>TIME</th>
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<th>PRINT CONTROL</th>
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<tbody>
<tr>
<td>0.00000E 02</td>
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<tr>
<td>6.00000E 02</td>
<td>1.00000E-01</td>
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FCNV= 1.00000E 00 FRAD= 1.00000E 00

TYPICAL CHARRING ABLATION MATERIAL PROPERTIES

<table>
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<tr>
<th>TABL= 1.06000E 03</th>
<th>TCHAK= 1.46000E 03</th>
<th>TREC= 0.00000E 00</th>
<th>RHOM= 3.40000E 01</th>
<th>RHOCC= 2.00000E 01</th>
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<tbody>
<tr>
<td>FBDW= 0.00000E 00</td>
<td>EMD= 6.50000E-01</td>
<td>EMC= 7.50000E-01</td>
<td>H300= 1.29000E 02</td>
<td>V= 1.50000E 00</td>
</tr>
<tr>
<td>H= 2.50000E 02</td>
<td>VPT= 0.00000E 00</td>
<td>TV= 1.00000E 00</td>
<td>CHAK= 1.20000E 01</td>
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<tr>
<td>CHAC= 4.30000E-01</td>
<td>ABL= 7.00000E-02</td>
<td>ABLC= 4.30000E-01</td>
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N= 31 NKC= 2 NCPC= 2 NKV= 9 NCPV= 2 NREC= 2

VIRGIN MATERIAL

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<th>TEMPERATURE</th>
<th>SPECIFIC</th>
<th>HEAT</th>
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<td>6.50000E-02</td>
<td>3.60000E 02</td>
<td>4.30000E-01</td>
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<tr>
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<td>6.50000E-02</td>
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<td>6.60000E-02</td>
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<td>7.60000E 02</td>
<td>6.70000E-02</td>
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</tr>
<tr>
<td>1.16000E 03</td>
<td>7.10000E-02</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

CHAR MATERIAL

<table>
<thead>
<tr>
<th>TEMPERATURE</th>
<th>CONDUCTIVITY</th>
<th>TEMPERATURE</th>
<th>SPECIFIC</th>
<th>HEAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.46000E 04</td>
<td>1.20000E-01</td>
<td>1.46000E 04</td>
<td>4.30000E-01</td>
<td></td>
</tr>
<tr>
<td>1.00000E 04</td>
<td>1.20000E-01</td>
<td>1.00000E 04</td>
<td>4.30000E-01</td>
<td></td>
</tr>
</tbody>
</table>

SURFACE RECESSSION TABLE

<table>
<thead>
<tr>
<th>TIME</th>
<th>SK = 1/N/SEC</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00000E 02</td>
<td>9.00000E-04</td>
</tr>
</tbody>
</table>

NO TRAJECTORY = 0=95 BTU/SEC-SOFT

NO. OF TRAJECTORY POINTS = 2
TABLE II.- SAMPLE PROBLEM OUTPUT - Continued

<table>
<thead>
<tr>
<th>TIME</th>
<th>CONVECTIVE VELOCITY</th>
<th>RADIATIVE VELOCITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.</td>
<td>2.40000E 04</td>
<td>2.40000E 04</td>
</tr>
<tr>
<td>6.00000E 02</td>
<td>1.00000E 01</td>
<td>0.00000E 01</td>
</tr>
</tbody>
</table>

PROPERTIES OF BACKUP STRUCTURE

NO. OF MATERIALS IN BACK-UP SHIELD= 1
TOTAL NUMBER OF NODES IN BACK-UP SHIELD= 3
THICKNESS OF BACK-UP SHIELD= 1.00000E-01

BACKUP MATERIAL = 0.1 INCHES THICK

<table>
<thead>
<tr>
<th>TEMPERATURE</th>
<th>CONDUCTIVITY</th>
<th>TEMPERATURE</th>
<th>SPECIFIC HEAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.60000E 02</td>
<td>6.50000E-02</td>
<td>3.60000E 02</td>
<td>4.30000E-01</td>
</tr>
<tr>
<td>4.60000E 02</td>
<td>6.50000E-02</td>
<td>4.60000E 02</td>
<td>4.30000E-01</td>
</tr>
<tr>
<td>5.60000E 02</td>
<td>6.50000E-02</td>
<td>5.60000E 02</td>
<td>4.30000E-01</td>
</tr>
<tr>
<td>6.60000E 02</td>
<td>6.50000E-02</td>
<td>6.60000E 02</td>
<td>4.30000E-01</td>
</tr>
<tr>
<td>7.60000E 02</td>
<td>6.50000E-02</td>
<td>7.60000E 02</td>
<td>4.30000E-01</td>
</tr>
<tr>
<td>8.60000E 02</td>
<td>6.50000E-02</td>
<td>8.60000E 02</td>
<td>4.30000E-01</td>
</tr>
<tr>
<td>9.60000E 02</td>
<td>6.50000E-02</td>
<td>9.60000E 02</td>
<td>4.30000E-01</td>
</tr>
<tr>
<td>1.00000E 03</td>
<td>7.00000E-02</td>
<td>1.00000E 03</td>
<td>4.30000E-01</td>
</tr>
<tr>
<td>1.10000E 03</td>
<td>7.50000E-02</td>
<td>1.10000E 03</td>
<td>4.30000E-01</td>
</tr>
</tbody>
</table>

ADDITIONAL DATA FOR INDIVIDUAL MATERIALS IN BACKUP STRUCTURE

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>DENSITY</th>
<th>THICKNESS</th>
<th>EMISSIVITY</th>
<th>NODES/MATERIAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.40000E 01</td>
<td>1.00000E-01</td>
<td>9.00000E-01</td>
<td>9.00000E-01</td>
</tr>
</tbody>
</table>

HEAT TRANSFER TO CABIN ENVIRONMENT - HENV=0.0

TEMPERATURE= 5.60000E 02  FILM COEFFICIENT= 0.  VIEW FACTOR= 0.  Q LOST= 0.

INITIAL TEMPERATURE IS CONSTANT

TEMPERATURE DISTRIBUTION IN HEAT SHIELD IS UNIFORM AND EQUAL TO 5.30000E 02
### TABLE II.- SAMPLE PROBLEM OUTPUT - Concluded

#### OUTPUT DATA.

<table>
<thead>
<tr>
<th>TIME= 9.99000E 00</th>
<th>QCONVECTIVE= 9.50000E 01</th>
<th>QRADIATIVE= 0.</th>
<th>VELOCITY= 2.92500E 04</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAS ABLATION RATE= 0.</td>
<td>CHAR ABLATION RATE= 5.40000E 00</td>
<td>TOTAL ABLATION RATE= 5.40000E 00</td>
<td></td>
</tr>
<tr>
<td>RECESSION DEPTH= 9.00000E-03</td>
<td>QHOT WALL= 8.99282E 01</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**TEMPERATURE DISTRIBUTION IN HEAT SHIELD AT THE END OF THE TIME STEP, T= 1.00000E 01 SECONDS**

**TEMPERATURE DISTRIBUTION IN THE ABLATING MATERIAL**

<table>
<thead>
<tr>
<th>3.79022E 03</th>
<th>2.33046E 03</th>
<th>1.06300E 03</th>
<th>6.38075E 02</th>
<th>5.47300E 02</th>
<th>5.32634E 02</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.30000E 02</td>
<td>5.30000E 02</td>
<td>5.30000E 02</td>
<td>5.30000E 02</td>
<td>5.30000E 02</td>
<td>5.30000E 02</td>
</tr>
<tr>
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<td>5.30000E 02</td>
<td>5.30000E 02</td>
<td>5.30000E 02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.29999E 02</td>
<td>5.29999E 02</td>
<td>5.29999E 02</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**TEMPERATURE DISTRIBUTION IN THE BACK-UP STRUCTURE**

| 5.29999E 02 | 5.30000E 02 | 5.30000E 02 |

**TIME= 1.99000E 01 | QCONVECTIVE= 9.50000E 01 | QRADIATIVE= 0. | VELOCITY= 2.92500E 04 |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>GAS ABLATION RATE= 2.90700E 01</td>
<td>CHAR ABLATION RATE= 5.40000E 00</td>
<td>TOTAL ABLATION RATE= 3.44700E 01</td>
<td></td>
</tr>
<tr>
<td>RECESSION DEPTH= 1.90000E-02</td>
<td>QHOT WALL= 8.99173E 01</td>
<td></td>
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</tr>
</tbody>
</table>

**TEMPERATURE DISTRIBUTION IN HEAT SHIELD AT THE END OF THE TIME STEP, T= 2.00000E 01 SECONDS**

**TEMPERATURE DISTRIBUTION IN THE ABLATING MATERIAL**

<table>
<thead>
<tr>
<th>3.80935E 03</th>
<th>2.87678E 03</th>
<th>1.64575E 03</th>
<th>9.77202E 02</th>
<th>6.12640E 02</th>
<th>5.44204E 02</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.37857E 02</td>
<td>5.31489E 02</td>
<td>5.30254E 02</td>
<td>5.30028E 02</td>
<td>5.30000E 02</td>
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<td>5.29999E 02</td>
<td>5.29999E 02</td>
</tr>
</tbody>
</table>

**TEMPERATURE DISTRIBUTION IN THE BACK-UP STRUCTURE**

| 5.29999E 02 | 5.29999E 02 | 5.29999E 02 |

**TIME= 2.99000E 01 | QCONVECTIVE= 9.50000E 01 | QRADIATIVE= 0. | VELOCITY= 2.92500E 04 |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>GAS ABLATION RATE= 1.25330E 01</td>
<td>CHAR ABLATION RATE= 5.40000E 00</td>
<td>TOTAL ABLATION RATE= 1.79330E 01</td>
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</tr>
<tr>
<td>RECESSION DEPTH= 2.70000E-02</td>
<td>QHOT WALL= 8.98427E 01</td>
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<td></td>
</tr>
</tbody>
</table>
Figure 1. - Radiation temperature approximation error.
Figure 2. - Schematic diagram of charring ablavit thermal protection system.
Figure 3. - Thermogravimetric data for typical charring ablation material.
Figure 4. - Charring material property variation used as input to STAB II.
Figure 5. - Comparison of temperature histories for nonablating steel slab (pure conduction)
Figure 6. - Comparison of temperature histories for moving boundary model.
Figure 7. - Comparison of temperature histories for typical charring ablators.
Figure 8. - Plot program surface recession curve from typical charring ablator test case.
Figure 9. - Plot program bondline temperature curve from typical charring ablator test case.
Figure 10. -Plot program 1060°F and 1460°F isotherm curves from typical charring ablator test case.