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## ANALYTICAL STUDY TO EXTEND THE CAPABILITIES OF THE AEROJET-GENERAL ABLATION DIGITAL COMPUTER PROGRAM

Contract NAS 9-2832

A Report To

NASA MANNED SPACECRAFT CENTER

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A REPORT TO

NASA MANNED SPACECRAFT CENTER

HOUSTON, TEXAS

# ANALYTICAL STUDY TO EXTEND THE CAPABILITIES OF THE AEROJET-GENERAL ABLATION DIGITAL COMPUTER PROGRAM

Contract NAS 9-2832 LRO Contract

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Prepared By

AEROJET-GENERAL CORPORATION

Liquid Rocket Operations

Sacramento Plant

DK Carlson

D. K. Carlson

Program Manager

C. M. Beighley

C. M. Beighley, Manager

Advanced Technology Division

UNCLASSIFIED

## FOREWORD

This volume is the final report (9410:64-1R) on the "Analytical Study to Extend the Capabilities of the Aerojet-General Ablation Digital Computer Program." The work was conducted for the National Aeronautics and Space Administration's Manned Spacecraft Center under Contract NAS 9-2832, dated May 1964.

The work was conducted at the Aerojet-General Corporation Liquid Rocket Operations in Sacramento, California, by the Advanced Technology Division, and the Von Karman Center, Azusa, California, Computing Sciences Division. Primary contributors were D. K. Carlson, Program Manager; E. J. Harris, Programmer; D. G. Miller, Consultant, and F. H. Miller, Project Engineer.

## ABSTRACT

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A study was conducted under a contract to NASA (NAS 9-2832), to extend the capabilities of the Aerojet-General Ablation Computer Program (Number 8039). The 8039 computer program calculates temperature distribution, char depth and dimensional ablation of ablative chambers for large rocket engines. The program operates on a forward finite difference, one dimensional solution to the thermal diffussion equation.

The purpose of this study was to modify the computer program to permit performance of ablative heat transfer calculations in cylindrical coordinates with an increased number and variety of boundary conditions.

This report contains the modified computer program mathematical theory, definition of the mathematical model for programing, operational procedures and correlation of analyses with experimental data. The new computer program is written in Fortran IV and is acceptable to the IBM 7094 Digital Computer.

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1 Charring and Dimensional Ablation Model for Treating Cylindrical Coordinates

2 Backwall Temperature Transient for Full-Scale Engine Firing

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# I. INTRODUCTION

In many propulsion systems involving high energy combustion processes, regeneratively-cooled and radiation-cooled combustion chambers have proven inadequate. Chambers composed of a metal or plastic load bearing structure, thermally protected by an ablative liner, have proven satisfactory in these cases. In minimizing the design thickness of the ablative liner, correspondingly the weight penalty, accurate prediction of liner thickness required to maintain the temperature of the load bearing structure below a critical level is necessary. To facilitate analytical predetermination of dimensional ablation, char depth, and temperature distribution, Aerojet developed a digital computer program (AGC/Sacto Program 8039) to perform the computations.

Program 8039 utilizes the forward finite difference technique in a numerical solution for a one dimensional mathematical model. Provisions for boundary conditions in the computer program include convective and radiation heat transfer at the inner surface and radiation to two sinks at the backwall surface. The convective boundary condition must be a constant but arbitrary value throughout the computer solution. This constant boundary condition may be applied in a step-wise nonperiodic manner (on-off) for pulsed firing type duty cycles. This program was utilized in sizing the ablative liner for the Apollo AJ10-137 and Transtage AJ10-138 engines. Analytical data correlated well with measured results from engine static firings.

To advance the state-of-the-art in ablative heat transfer analyses, Aerojet solicited and was awarded a study contract by NASA, Ref 1, to extend the capabilities of the above computer program. Refinements to the program were to include:

1. Solution of the thermal diffusion equation in cylindrical coordinates.

2. Provision for various arbitrary, time varying and temperature varying convective thermal boundary conditions.

3. Inclusion of machine calculation of the internal heat transfer coefficient by Bartz' equation, Ref 2, and allowance for the variation of the coefficient as influenced by dimensional ablation.

## II. MATHEMATICAL THEORY

A mathematical description of the thermal diffusion, pyrolisis and boundary conditions involved in the revised computer program are discussed below:

### A. THERMAL DIFFUSION

The thermal diffusion equation expressed in cylindrical coordinates is as follows: (See Nomenclature)

$$\frac{\partial^2 T}{\partial R^2} + \frac{1}{R}\frac{\partial T}{\partial R} + \frac{1}{R^2}\frac{\partial^2 T}{\partial \beta^2} + \frac{\partial^2 T}{\partial Z^2} = \frac{1}{\alpha}\frac{\partial T}{\partial \theta}. \quad (1)$$

In essentially all cases involving rocket engines, axial symmetry exists and the longitudinal temperature gradient is small compared to the radial gradient. Therefore, the third and fourth terms can be ignored, and the relation for thermal diffusion through the ablative liner (Equation 1) reduces to:

$$\frac{\partial^2 T}{\partial R^2} + \frac{1}{R}\frac{\partial T}{\partial R} = \frac{1}{\alpha}\frac{\partial T}{\partial \theta}. \quad (2)$$

General boundary conditions consistent with this relationship are:

$-\left(k\frac{\partial T}{\partial R}\right)_{R_F}$ = net heat flux at inner surface, (3)

$-\left(k\frac{\partial T}{\partial R}\right)_{R_{LAST}}$ = net heat flux at outer surface, and (4)

$T\big|_{\theta=0} = f(R)$, initial temperature distribution (5)

These general boundary conditions must be defined by the net of the convective and radiative parameters with regard to the thermal environment.

## B. PYROLISIS

As heat propagates through the ablative liner, a plane within the virgin laminate can reach the temperature at which the resinous binder depolymerizes. Depolymerization of the resins may be idealized by an isothermal, endothermic process. Gases liberated in this process absorb heat from the previously charred liner as they pass through into the boundary layer. Mixing of this gas with the gas in the boundary layer reduces the recovery temperature, thereby reducing the heat flux into the liner. Latent heat is absorbed at the inner surface of the ablative liner when the surface temperature becomes high enough to initiate melting and vaporization of the matrix. The computer program does not evaluate the heat flux absorbed in any of these processes. However, it can be utilized to empirically determine "effective heat of char," $H_c$, and "effective heat of ablation," $H_a$, of ablative liner materials exposed to various thermochemical environments. These values are then used to analytically predetermine char depth, dimensional ablation and temperature distribution with regard to the chamber liner for selected mission duty cycles of engine operation.

Charring and dimensional ablation are treated as isothermal processes; therefore, the corresponding interfaces are discontinuities in the thermal diffusion equation. The difference in the heat flux gradient on each side of the char interface is absorbed as latent heat in propagating the interface through the liner, as follows:

$$k_c \frac{\partial T}{\partial R}\bigg|_c - k_L \frac{\partial T}{\partial R}\bigg|_L = - H_c \left( \rho_L - \rho_c \right) \frac{\partial \delta_c}{\partial \theta} . \qquad (6)$$

Similarly, the propagation of the dimensional ablating interface is a function of the difference in heat flux gradient across the interface. Since the interface for ablation occurs at the inner surface, the heat flux into the interface is dependent upon the particular boundary conditions that exist. The expression for ablation is then:

$$\text{(Boundary Condition)} + k_c \frac{\partial T}{\partial R}\bigg|_{\bar{R}} = H_a \rho_c \frac{\partial \delta_a}{\partial \theta} . \qquad (7)$$

## C. BOUNDARY CONDITIONS

In general, a variety of boundary conditions may exist at the inner and outer surface of a combustion chamber liner. These involve convection or radiation heat transfer at the surfaces, the magnitude being dependent upon the surface temperature. Arbitrary heat fluxes are also considered, such as solar heat input which in reality is thermal radiation but since the sun is at such high temperatures the influence of the surface temperature is negligible. Each or a combination of these modes of heat transfer may constitute the boundary conditions at either surface in the thermal analysis of the engine chamber and nozzle.

The most significant mode of heat transfer at the inner boundary of the chamber liner is convection heating by the combustion gases. Convective heat flux at this boundary is expressed as follows:

$$q/A_{conv} = h_{in} \left( T_R - T_F \right). \qquad (8)$$

To allow for different time variations in the arbitrary heat flux, it has been described in the form:

$$q/A_{ARB} = a' \sin\left(b' + k'\theta\right) + c' + d'\theta + f'\theta^2 + g' e^{h'\theta}, \qquad (9)$$

where a', b', c', d', f', g', h', and k' are arbitrary constants.

Allowances were made for thermal radiation interchange between the inner surface and two sinks (or sources) as follows:

$$q/A_{RAD} = \sigma \sum_{j=1}^{2} \epsilon_j F_j \left(T_{s,j}^{4} - T_F^{4}\right). \qquad (10)$$

When charring in the first node or dimensional ablation is occurring, $T_F$ is equal to $T_c$ or $T_a$, respectively.

Similarly, at the external surface the boundary conditions for convection, arbitrary heat flux, and radiation interchange between the external surface and five sinks (or sources) are respectively:

$$q/A_{CONV} = h_{ex}\left(T_{ex} - T_{LAST}\right), \qquad (11)$$

$$q/A_{ARB} = a'' \sin\left(b'' + k''\theta\right) + c'' + d''\theta + f''\theta^{2} + g''e^{h''\theta}, \qquad (12)$$

$$q/A_{RAD} = \sigma \sum_{k=1}^{5} \epsilon_K F_K \left(T_{s,K}^{4} - T_{LAST}^{4}\right). \qquad (13)$$

The best available approximation for the convective heat transfer coefficient in a rocket nozzle has been described by D. R. Bartz, Ref 2 as follows:

$$h_{in} = \frac{K}{D_t^{.2}} \left[ \left( \frac{\mu^{.2} C_P}{Pr^{.6}} \right)_o \left( \frac{P_c\, g}{c^*} \right)^{.8} \right] \left( \frac{D_t}{R_{cu}} \right)^{.1} \left( \frac{A^*}{A} \right)^{.9} \sigma_c. \qquad (14)$$

The bracketed terms in the expression account for the variation due to fluid transport properties and inertial effects. For convenience, the transport properties and fluid density are evaluated in terms of the stagnation and static temperature, respectively. Variation in these properties across the boundary layers are corrected for by the $\sigma_c$ factor. Bartz recommends corrections for viscosity and fluid density as follows:

$$\sigma_c \equiv \left(\frac{\mu_{am}}{\mu_o}\right)^{.2}\left(\frac{\rho_{am}}{\rho_\infty}\right)^{.8}, \qquad (15)$$

evaluated at a reference temperature which is the arithmetic mean of the local free stream and wall temperatures. This reference temperature does not account for the high temperatures recovered in the boundary layer when the free stream fluid velocity is very high. E.R.G. Eckert determined a reference temperature relation empirically for aerodynamic heating, Ref 3 as follows:

$$T' = 0.28\,T_\infty + 0.22\,T_R + 0.50\,T_F, \qquad (16)$$

which is very close to the reference temperature recommended by Rubesin and Johnson. Since the viscosity of gases increases and the density decreases with an increase in temperature, the application of Eckert's reference temperature would correspond to a reduced correction factor, .

In his paper, Bartz ignored the temperature effects upon specific heat and Prandtl number since their variation is small compared to the variation of viscosity. However, in Bartz equation, the exponent associated with viscosity is 0.2 and the effect is therefore of the same order as specific heat. Transport properties of the combustion gases vary exponentially with temperature in the following manner:

$$\frac{C_p'}{C_{p_o}} = \left(\frac{T'}{T_o}\right)^{\alpha}, \quad \frac{\mu'}{\mu_o} = \left(\frac{T'}{T_o}\right)^{\beta}, \quad \frac{Pr'}{Pr_o} = \left(\frac{T'}{T_o}\right)^{\gamma} \qquad (17)$$

where $\alpha$, $\beta$ and $\gamma$ are essentially constant dependent upon the gas composition. The temperature correction factor of the transport properties is then:

$$\sigma_1 = \left(\frac{T'}{T_o}\right)^{.2\beta}\left(\frac{T'}{T_o}\right)^{\alpha}\left(\frac{T'}{T_o}\right)^{-.6\gamma} \equiv \left(\frac{T'}{T_o}\right)^{\eta}. \qquad (18)$$

Fluid density varies inversely with the temperature; therefore, the density correction factor is:

$$\sigma_2 = \left(\frac{T_\infty}{T'}\right)^{.8}. \tag{19}$$

Combining these factors gives a compressibility correction factor of:

$$\sigma_c = \sigma_1 \sigma_2 = \left(\frac{T'}{T_0}\right)^{\eta}\left(\frac{T'}{T_\infty}\right)^{-.8}. \tag{20}$$

The computer program has been written to include the computation of the Bartz heat transfer coefficient and the compressibility correction based upon Eckert's reference temperatures.

### D. INFLUENCE OF PYROLISIS UPON BOUNDARY CONDITION

Due to hydrodynamic effects, the convective heat transfer in the ablative chamber is generally most severe at the nozzle throat. Consequently, charring and dimensional ablation are very severe. The increase in throat area due to dimensional ablation will be reflected in a reduction of chamber pressure. The mass flow rate from the propellant tank to the chamber can be expressed as follows:

$$\dot{\omega} = K_P \sqrt{P_T - P_c}, \tag{21}$$

where $K_p$ is a function of the propellant density and line geometry and considered a constant. Assuming isentropic flow of combustion gases through the nozzle, the mass flow is also (continuity) equal to:

$$\dot{\omega} = K_N P_c A^*. \tag{22}$$

Writing both of these equations in terms of conditions that exist before ablation (subscript 1) and after ablation (subscript 2), the simultaneous solution for the reduced chamber pressure can be expressed as follows:

$$P_{c2} = \frac{2P_T}{1 + \sqrt{1 + 4\left(\frac{A_1^*}{A_2^*}\right)^2\left(\frac{P_T}{P_{c2}}\right)\left(\frac{P_T}{P_c} - 1\right)}} . \qquad (23)$$

The computer program has been written to continuously evaluate the chamber pressure, in the above manner, as the throat area increases due to dimensional ablation. This reduced chamber pressure is introduced into Bartz' equation to make allowance for the corresponding reduction in the heat transfer coefficient.

## III. MATHEMATICAL MODEL

### A. MODEL DESCRIPTION

Solution of the thermal diffusion equation in cylindrical coordinates (Equation 2) accomplished in this study is engendered in the forward finite difference technique. The ablative liner is divided into cylindrical elements (Figure 1) of equal thickness, $\Delta R$, and unit length. At general locations, $n-1$, $n$, and $n+1$ within the liner interior, the temperatures of the respective elements at a time $\theta$ are $T_{n-1}$, $T_n$, and $T_{n+1}$, respectively. In accordance with the forward finite difference technique, the temperature of element $n$ at time $\theta+\Delta\theta$ can be described as follows:

$$T_{n,\theta+\Delta\theta} = \frac{\Delta\theta}{C_n}\left[\frac{T_{n-1,\theta}-T_{n,\theta}}{r_{n-1}} - \frac{T_{n,\theta}-T_{n+1,\theta}}{r_n}\right] + T_{n,\theta}, \quad (24)$$

when charring is not occurring within the element. In the above expression, $C_n$ is the thermal capacitance of the element, expressed as follows:

$$C_n = \rho_n C_{pn}\, \pi\left(R_{n+1}^2 - R_n^2\right). \quad (25)$$

To account for radial diffusion the thermal resistance from elements $n-1$ to $n$ and from $n$ to $n+1$ are best expressed by the respective logrithmic expressions:

$$r_{n-1} = \frac{1}{2\pi k_n} \ln\left(\frac{R_n}{R_{n-1}}\right), \qquad \text{and}$$

$$r_n = \frac{1}{2\pi k_n} \ln\left(\frac{R_{n+1}}{R_n}\right) \quad . \quad (26)$$

At either surface of the liner, Equation (24) must be modified to account for the boundary conditions. The respective expressions at the inner and outer surfaces are:

$$T_{F,\theta+\Delta\theta} = \frac{\Delta\theta}{C_F}\left[\frac{T_{R,\theta}-T_{F,\theta}}{r_{in}} - \frac{T_{F,\theta}-T_{F+1,\theta}}{r_F} + q_{ARB} + \sum_{j=1}^{2} q_{RAD,\theta}\right] + T_{F,\theta}, \quad (27)$$

and $$T_{LAST,\theta+\Delta\theta} = T_{LAST-1,\theta+\Delta\theta} + r_{LAST-1}\left[q_{ARB} + \sum_{k=1}^{3} q_{RAD} + \frac{T_{ex}-T_{LAST}}{r_{ex}}\right]_{\theta+\Delta\theta}. \quad (28)$$

The terms $r_{in}$ and $r_{ex}$ are the thermal resistances corresponding to the convective heating at the inner and outer liner surfaces.

When charring is occurring within an element, the thermal properties within the char are different than the virgin laminate. Therefore, the capacitance of a charring node is:

$$C_{n,\theta} = \pi \rho_c C_{pc}\left(\overline{R}_{c,\theta}^{\,2} - R_{n,\theta}^{2}\right) + \pi \rho_L C_{pL}\left(R_{n+1,\theta}^{2} - \overline{R}_{c,\theta}^{\,2}\right), \quad (29)$$

and the thermal resistance is:

$$r_{n,\theta} = \frac{1}{2\pi k_c} \ln\left(\frac{\overline{R}_c}{R_n}\right) + \frac{1}{2\pi k_L} \ln\left(\frac{R_{n+1}}{\overline{R}_c}\right). \quad (30)$$

Since charring is assumed to be an isothermal process, the temperature of the charring element, $T_c$, is held constant. The char depth, measured from the nozzle axis, $\overline{R}_c$, at a time $\theta + \Delta\theta$ is then:

$$\overline{R}_{c,\theta+\Delta\theta} = \sqrt{\frac{\Delta\theta}{\pi H_c(\rho_L - \rho_c)}\left[\frac{T_{n-1} - T_c}{r_{n-1}} - \frac{T_c - T_{n+1}}{r_n}\right]_\theta + \left(\overline{R}_{c,\theta}\right)^2}\,. \quad (31)$$

When charring occurs in the surface element, the boundary conditions are considered:

$$\overline{R}_{c,\theta+\Delta\theta} = \sqrt{\frac{\Delta\theta}{\pi H_c(\rho_L - \rho_c)}\left[\frac{T_R - T_c}{r_{in}} - \frac{T_c - T_{F+1}}{r_F} + q_{ABS} + q_{RAD}\right] + \left(\overline{R}_{c,\theta}\right)^2} \quad (32)$$

During dimensional ablation, the thickness of the surface element decreases; therefore, the capacitance of this element becomes (Figure 1):

$$C_{F,\theta+\Delta\theta} = \pi \rho_c C_{pc}\left(R_{F+1}^{2} - \overline{R}^{2}\right)_{\theta+\Delta\theta}, \quad (33)$$

and the thermal resistance of the element decreases as follows:

$$r_{F,\theta+\Delta\theta} = \frac{1}{2\pi k_c} \ln\left(\frac{R_{F+1}}{\overline{R}}\right). \quad (34)$$

Dimensional ablation also is isothermal so the surface element temperature, $T_a$, is assumed constant. The radius to the ablating surface at a time $\theta + \Delta\theta$ is:

$$\overline{R}_{\theta+\Delta\theta} = \sqrt{\frac{\Delta\theta}{\pi H_a \rho_c}\left[\frac{T_R - T_a}{r_{in}} - \frac{T_a - T_{F+1}}{r_F}\right] + \left(\overline{R}_\theta\right)^2}\,. \quad (35)$$

If, in the forward finite difference temperature statement (Equation 24) the computing time step criteria:

$$\Delta\theta_n \leqq \frac{C_n}{\frac{1}{r_{n-1}} + \frac{1}{r_n}} , \qquad (36)$$

is not satisfied, the temperature $T_n$ at time $\theta$ will have a negative influence on the temperature of that element at time $\theta+\Delta\theta$. The negative influence condition is not logical and results in calculated temperatures that tend to oscillate during the transient solution. It is operational procedure in the present computer program to continually satisfy the above stability criteria in computer autodetermination of the computing time step. The smallest of the $\Delta\theta$ for any element controls the computing time step.

## B. PROBLEM AREAS

The computer program was written in accordance with the forward finite difference solution modified to account for the effects associated with charring and dimensional ablation. Certain operational difficulties were encountered in early computer runs or were anticipated, but all were resolved. Since the corrections were made without sacrificing solution logic, the problems and solutions will only be described in a cursory manner.

The original analytical model considered the thermal capacitance of each element to be concentrated midway through the element. Early computer runs utilizing this model demonstrated oscillation of the inner surface temperature during transient heat-up when charring was occurring in the elements near the surface. When the analytical model was modified to consider the capacitance concentrated at the inner interface of the element, satisfactory results were obtained.

During ablation, the surface element is held constant at the ablation temperature; therefore, it is not necessary to subject the surface element to the stability criterial. However, as the inner surface, $\overline{R}$, approaches the interface of the next element, $R_{F+1}$, the thermal resistance to the next element approaches zero.

The computing time step will then approach zero; and under these circumstances the ablation boundary could only approach the interface. To obviate this, the approximation $\bar{R} = R_{F+1}$ is provided when $(T_{\alpha} - T_{F+1}) \leqq \Delta$ . The value of $\Delta$ is set at $1^{o}R$ in the program, but may be modified as required.

During a coast period following ablation, it is necessary to calculate the temperature transient of the surface element. Reduction of the element thickness by ablation, diminishes both the thermal capacitance of the surface element and the thermal resistance to the adjacent node. If considerable ablation has occurred in the element, the computing time step during coast will be very small resulting in excessive computer time per unit real time. To alleviate this result, provision for inputting a minimum $\Delta\theta$ was made in the program. A test in the program will analytically consolidate the surface element with the adjacent element when the calculated computing time step becomes less than the minimum An enthalpy balance is then automatically made to determine the effective temperature of the consolidated element. Dimensional ablation and char depths are not affected by this approximation.

Provisions are also made to input a maximum $\Delta\theta$ to ensure that the computing time step will be less than the period of a rapidly pulsed firing cycle.

## IV. OPERATIONAL PROCEDURES

### A. PROGRAM DESCRIPTION

This section outlines the general procedure followed by the program in solving all problems. Appendix A contains detailed flow charts of the entire program.

The program is written in Fortran IV and will operate on the IBM 7094 with no operator intervention. The system's input unit is designated as Fortran logical "5" the system's output unit is designated Fortran logical "6". No other tapes are used, on line messages will be printed.

The program is composed of a main program and 7 subprograms. A discussion of each of these components follows.

#### 1. Main Program: Deck A1

This deck controls the solution of all equations of the thermal model, the remaining subprograms are called by this deck as required.

a. Basic Input

The program begins by reading a title card and all basic input. If an error is detected in the basic input, an error message is printed, and the program will go on to the next case.

b. Model Geometry

From data read in as basic input, the model geometry is defined. Each node is assigned an ID number. Nodes are numbered from the interior to the exterior of the liner. A radius from the nozzle centerline to each node is determined. The interface between different materials is determined at this time. An index "ICHAR" is determined. ICHAR will always equal the ID number of the node where the char/laminate interface occurs.

c. Period Definition

The next card from the system's input file will determine the ensuing period. The program will accept, at this point, one of the following input cards (see Section IV, Input).

(1) "FIRE"
(2) "SOAK"
(3) "PULSE"
(4) "END DUTY"

If 1, 2, or 3 above; is present, the program will call Subroutine "Input" and the required period will be defined. If an "END DUTY" card is encountered, the program will proceed to the next case.

d. Time Step Calculation

A time step is next determined which will allow the finite difference equations to remain stable. Various tests are made on the magnitude of this value prior to proceeding with calculations.

e. Interior Surface Calculations

Each iteration will begin by determining conditions at the liner interior surface. Figure II-1 outlines the procedure followed.

The net heat flux at node "F" is determined as:

$$QNET = \left(Q_{INI} - \left(\frac{T_{F,\theta} - T_{F+1,\theta}}{r_{F+1}}\right)\right)\Delta\theta$$

If this value is $\leqq 0.0$, the surface node, if ablating at time $\theta$, will cease ablating. In which event, a new value of $\Delta\theta$ must be determined.

If $Q_{NET}$ is $> 0.0$, and node "F" was ablating at time $\theta$, the program will proceed to Statement 2300.

If neither of the above is true, the temperature of node "F" is calculated as:

$$T_{F,\theta+\Delta\theta} = \frac{Q_{NET}}{C_{F,\theta}} + T_{F,\theta}$$

If the char boundary lies at node "F" (ICHAR=F) the program will proceed to Statement 2050.

If the surface node has reached the ablation temperature ($T_{F,\theta+\Delta\theta} \geqq T_a$), execution will continue at Statement 2200.

If none of the above conditions is satisfied, the program will branch to Statement 3000.

(1) Statement 2050 (Char-Calculations)

If the surface has not reached $T_{C,F}$ (char-temperature for the surface material) the program will proceed to Statement 3000. If the surface node was previously charring ($T_{F,\theta} = T_C$) subroutine "CHAR" is called and execution continues at Statement 3000. If neither of the above conditions are satisfied, $\Delta\theta$ will be modified such that $T_{F,\theta+\Delta\theta} = T_{C,F}$. Execution then continues at Statement 3000.

When subroutine "CHAR" is called, a new value is determined for $\bar{R}_{c,\theta+\Delta\theta}$(char-depth). If this value should exceed $R_{F+1}$, $\Delta\theta$ will be reduced such that $\bar{R}_{c,\theta+\Delta\theta} = R_{F+1}$. Subroutine "CHAR" will set:

$$T_{F,\theta+\Delta\theta} = T_{c,F}$$

(2) Statement 2200 (Ablation Commencing)

$\Delta\theta$ will be reduced such that $T_{F,\theta+\Delta\theta} = T_{a}$ and execution continue at Station 3000.

(3) Statement 2300 (Ablation in Progress)

The interior liner radius is determined for time $\theta+\Delta\theta$ as $(\bar{R}_{\theta+\Delta\theta})$. If this value is $< R_{F+1}$, the program will contiue at Statement 2800. If ablation has proceded past the boundary of node "F", $\Delta\theta$ will be reduced such that $\bar{R}_{\theta+\Delta\theta} = R_{F+1}$. The index "F" is increased by one. New values are computed for the surface resistor and capacitor. The program proceeds to Statement 3010.

(4) Statement 2800

A new balue for $r_{F-F+1}$ and $C_{F,\theta+\Delta\theta}$ are calculated. The program continue at Statement 3000.

f. Calculations At Liner Interior

After determining the surface temperature ($T_{F,\theta+\Delta\theta}$) and performing any required dimensional ablation or char-depth calculations, the program will proceed to Statements 3000 or 3010. The temperature of all interior nodes will now be determined. If the char/laminate interface is located beyond "F", it will also be considered at this time. Prior to solving for the temperature of each node "INDEX" is set to correspond to the appropriate material number (1, 2--- 8). This subscript is used to determine the material properties at each node. The temperature of the zero capacitance node located at the liner exterior is calculated at Statement 3350.

g. Advance Real Time

At this point in the program, the temperature of all nodes of the model have been determined. Char-depth and dimensional ablation propagation have been accordingly determined. Real time is advanced by $\Delta\theta$ seconds and new values are calculated for any resistors and capacitors which may have changed during this time interval.

h. Test for Ablation

At Statement 4010, a test is made which will allow dimensional ablation to proceed from node "F" to node "F+1". (See Section III-Part B, Problem Areas.)

i. Heat Flux

Boundary conditions are considered beginning at Statement 4020. A value is determined for the net heat flux into the liner at its interior and exterior. Resistors are computed at this time which link the liner to its environment.

This procedure outlined above is repeated until such time as the period being investigated is terminated. The next period is defined, and execution resumes.

2. Subroutine Input: Deck A2

This subprogram defines fire and soak period. Various logical flags are set to be used by the main program in defining boundary conditions. Any errors detected by "INPUT" will cause the main program to skip to the next problem after writing an error message. Subroutine "INPUT" returns control to the main program when encountering an "END FIRE" or "END SOAK" card.

3. Subroutine Capace: Deck S1

This subroutine calculates the thermal capacitance for all nodes of the liner. The equation solved is:

$$C_{i,\theta} = \sum \rho_i C_{P_i} V_i$$

The appropriate thermal properties are chosen depending upon the composition of the node. All values determined are stored in the array "CAP".

4. Subroutine Restan: Deck S2

This subroutine calculates all concuction resistors of the nodal system. The general equation solved is:

$$r_{i,\theta} = \sum \frac{\ln \frac{R_{i+1}}{R_i}}{2\pi k_i}$$

The appropriate values for R and k are chosen depending upon the nodal configuration. If the node consists of two materials there will be two terms. These values are stored in array "RES".

5. Subroutine Char: Deck S3

This routine determines the propagation of the char/laminate interface during the time interval $\Delta\theta$.

The heat required to raise the temperature of the charring node to $T_{c,j}$ is considered by modifying the value of QNET. If the temperature of node ICHAR at time $\theta$ was less than $T_{c,j}$, the value of QNET is reduced.

If during the interval $\Delta\theta$, sufficient energy is available to propagate the interface beyond $R_{ICHAR+1}$, the temperature of the charring node will be increased, or, if ICHAR = FIRST, will be reduced; in either event $\overline{R}_c$ will be set equal to $R_{ICHAR+1}$.

6. Subroutine Print: Deck S4

This routine is called by the main program to produce both on and off line output. Normally an online message will be printed at the start of each period.

7. Subroutine Block Data: Deck S5

Defines Hollerith constants used by Subroutine Print.

8. Function Intplt: Deck S6

Performs straight line interpolations in tables defined by the main program.

## B. INPUT

Required input for all problems must include the following:

1. Basic Input
    - a. Title card
    - b. A description of the model
    - c. Material properties
    - d. Starting temperature profile
2. Duty Cycle Definition
    - a. Fire period definitions
    - b. Soak period definitions
    - c. Input blocks

Sample input sheets are included with this report and should be used in the preparation of all input. The following discussion describes their use.

3. Basic Input

Basic input is described with two input sheets. Sheet 1 must be completed for all problem. Sheet 2 will normally be omitted.

a. Basic Input Sheet 1

(1) Card 1

(a) A "T" must be punched in Column 1.

(b) The remaining Columns 2-80 may contain any title information and will head the output.

(2) Card 2

(a) The liner may be composed of as many as eight materials. This value (an integer) must be entered in Column 18.

(b) The liner may be divided into a maximum of 500 nodes. The number of nodes selected will normally be a compromise between desired accuracy and estimated machine time. Enter this value in Columns 36-38 right justified.

(c) If the nozzle station being investigated is at the throat, enter a "T" in Column 68, otherwise leave blank.

(3) Card 3

(a) Enter the inside nozzle radius (inches) at the station of interest.

(b) The initial char depth (measured from the liner's interior surface) will normally be zero. If the problem is a "restart" the initial char depth should be entered. For some cases, the innermost material(s) may not char, in which case the initial char depth should be the distance to the first "char-able" material. Enter this value (inches) as required or leave blank.

(c) If the temperature profile through the liner is uniform at start time, enter this value in degrees Rankine. If the profile is not uniform, leave this value blank; in which case, Basic Input Sheet 2 must be completed.

(4) Card 4

(a) Enter the ablation temperature of the interior surface material (°R). If this is a nonablating material, enter any temperature greater than the recovery temperature.

(b) Enter the heat of ablation for the interior surface material, (BTU/LB of char). If the surface is nonablating this value may be omitted.

The liner may be composed of 1 to 8 materials. These materials are numbered 1, 2, 3 through 8 from the interior to the exterior of the nozzle. The remaining basic input defines the geometry and thermal properties of these materials. The appropriate columns of Basic Input Sheet 1 must be completed for as many materials as input on Card 2.

(5) Card 5

(a) Enter the thickness (inches) of each material.

(6) Card 6

(a) Enter the specific heat (laminate value) for each material (BTU/LB-°R).

(7) Card 7

(a) Enter the specific heat (char value for each material (BTU/LB-°R).

(8) Card 8

(a) Enter the thermal conductivity (laminate value) for each material (BTU/IN-SEC-°R).

(9) Card 9

(a) Enter the thermal conductivity (char value) for each material (BTU/IN-SEC-°R).

(10) Card 10

(a) Enter the density (laminate value) for each material. ($LB/IN^3$).

(11) Card 11

(a) *Enter the density (char value) for each material (LB/IN$^3$).

(12) Card 12

(a) **Enter the char temperature of each material (°R).

(13) Card 13

(a) Enter the effective heat of char for each material (BTU/LB).

Basic Input Sheet 2.

If the starting temperature profile is uniform, omit Sheet 2., if not uniform, input a temperature for each node indicated on Card 2. The liner temperature on Card 3 must be blank.

### 4. Duty Cycle Definition

A duty cycle is described by a series of fire and soak periods. Each fire and/or soak period is described by the use of various input blocks. Input data may be related to successive fire periods or successive soak periods. An input block used to specify some conditions in a fire period will continue in effect, for all future fire periods only, until modified.

An input block used to specify some conditions in a soak period will continue in effect for all future soak periods only, until modified.

#### a. Fire Period Description

Each fire period of the duty is described by the use of two cards plus the necessary input blocks.

The first card of each fire period description (see enclosed input form) must contain the following data.

---

* This value must be less than the laminate density.

**Successive materials must have char temperatures greater than or equal to the material preceding it.

(1) The word "FIRE" in Columns 1-4.

(2) The duration of the fire period (seconds).

The following items may be omitted and will be ignored if not input.

(3) Print interval (seconds). If omitted the program will print at the beginning and end of the period only.

(4) $\Delta\theta_{min}$ (seconds). If the machine computed $\Delta\theta$ is less than this value, the problem will be terminated. (See Section IV "stability")

(5) $\Delta\theta_{max}$ (seconds). If the machine computed $\Delta\theta$ is greater than this value, calculations will be performed using $\Delta\theta_{max}$

The final card of each fire period description must (contain the word "END FIRE" in Columns 1-7.

Input blocks are to be included between these cards, as necessary to describe the fire period. If no changes are necessary between this fire period and the previous fire period description, only the "FIRE" and "END FIRE" cards need be input.

b. Soak Period Description

Each soak period of the duty cycle is described by the use of two cards plus the necessary input blocks.

The first card of each soak period description (see enclosed input form) must contain the following data.

(1) The word "SOAK" in Columns 1-4.

(2) The duration of the soak period (seconds).

The following items may be omitted and will be ignored if not input.

(3) Print interval (seconds). If omitted the program will print at the beginning and end of the period only.

(4) $\Delta\theta_{min}$ (seconds). If the machine computed $\Delta\theta$ is less than this value, the problem will be terminated.

(5) $\Delta\theta_{max}$ (seconds). If the machine computed $\Delta\theta$ is greater than this value, calculations will be performed using $\Delta\theta_{max}$.

(6) *T-EXT. If the exterior temperature reaches this input value (°R). The soak period will end.

If T-EXT is negative, the soak period will end when the exterior temperature peaks, ie, $T_{\theta+\Delta\theta} < T_{\theta}$.

(7) *Steady State. If the temperature profile is changing at a rate (°R/sec) less than this input value, the soak period will end.

(8) RESET. The temperature profile will be set to this input value (°R) at the end of the soak period before continuing with the duty cycle.

The final card of each soak period description must contain the workd "END SOAK" in Column 1-7.

Input blocks are to be included between these cards as necessary to describe the soak period. If no changes are necessary between this soak period and the previous soak period description, only the "SOAK" and "END SOAK" cards need be input.

* If the soak period is terminate as described, the elapsed time in the duty cycle is advanced to correspond with the end of the period as specified by the duration.

## C. Input Blocks

Each input block begins with a caption, and ends with a blank card. Data within each block must be ordered as shown or the respective input sheets. Unless otherwise noted, any elements of an input block may be omitted.

The following input blocks may be used in describing fire <u>and</u> soak periods.

| | |
|---|---|
| Input Block 1 | Arbitrary Heat Flux |
| Input Block 3 | Radiation |
| Input Block 4 | Exterior Convection |

The following input blocks may be used in describing fire periods <u>only</u>.

| | |
|---|---|
| Input Block 2 | Interior Convection |
| Input Block 5 | Bartz Equation |

(1) <u>Input Block 1 Arbitrary Heat Flux. (See enclosed input sheets)</u>

To use this option the following must be included.

(a) Caption card with the word "ARB-Q" In Columns 1-5.

(b) Coefficient cards 1, 2 or both.

(c) A blank card following the last coefficient card.

The arbitrary heat flux equation is:

$$\text{Q-arb } (\text{BTU/IN}^2\text{-SEC}) = a \sin(b+K\theta)+c+d\theta+f\theta^2+ge^{h\theta} \; ;$$

where e is the base of the natural log and $\theta$ is time referenced from the start of the duty cycle.

To use an arbitrary heat flux at the interior, complete coefficient Card 1. To use an arbitrary heat flux at the exterior complete coefficient Card 2. Omitted coefficient are set equal to zero.

(2) Input Block Interior Convection

This option allows convection at the interior of the liner to be described by a constant or in tabular form. If Input Block 5, BARTZ Equation, has been previously used, it will no longer be in effect.

To use this option, the following must be included:

(a) Caption card with the work "INTERIOR" in Columns 1-8,

(b) Card 1 or Card 2

(c) A blank card following the last input item of this block.

Card 1 Recovery Temperature: Specify the required constant recovery temperature on this card. A "1" must be punched in Column 1. This card may be omitted if previously input. (°R)

Card 2 Convection Coefficient: Specify the required constant recovery temperature on this card. A "2" must be punched in Column 1. This card may be omitted if the previous convection coefficient is to remain in effect. (BTU/IN$^2$-SEC-°R)

To enter a time dependent convection coefficient include the "2" card with the value left blank. Follow this card with a table of h vs. $\theta$. The final card of the table must have a "1" in Column 1. $\theta$ is referenced from the start of the duty cycle (time = 0).

### (3) Input Block 3 Radiation

The model accepts up to five radiation terms at the liner exterior and two radiation terms at the interior. Exterior radiation may be to time dependent sink temperatures.

To use this option, the following must be input:

(a) Caption card with the word "RADIAT" in Columns 1-7.

(b) Term cards 1, 2-7 and/or tables.

(c) A blank card following the last input item of this block.

To include interior radiation, Cards 1 and/or 2 must be input. Each card must contain the following:

(a) Emissivity

(b) Shape Factor

(c) Sink temperature

If a radiation term has previously been defined, it will remain in effect until altered by the input of subsequent card describing the same radiation term.

To include exterior radiation one or more of the exterior radiation cards must be input. These cards are Numbers 3-7. Each card input must contain the following:

(a) Emissivity

(b) Shape Factor

(c) Sink temperature if constant

To incorporate a time dependent sink temperature, the following must be input.

(a) Card 8 (8 puncl in Column 1)

(b) A table of sink temperature versus time.

Time is referred from the start of the duty cycle. A sink temperature is considered to be time dependent if the radiation term card contains a sink temperature of zero, (blank).

The sink tables may contain up to 50 entries. The final entry must have a "1" in Column 1. This table must follow immediately behind the "8" card.

A radiation term, once input, will remain in effect until altered by the presence of a like radiation term card.

### (4) Input Block 4 Exterior Convection

This option allows the liner to receive or lose heat by convection at the exterior surface. The convection coefficient may be constant, time dependent or temperature dependent. The ambient temperature at the exterior is constant.

To use this option, the following must be included.

(a) Caption card with the word "EXTERIOR" in Columns 1-8.

(b) Cards 1, 2, 3, or 4 as required.

(c) A blank card following the final input item for this block.

Card 1 Ambient Temperature: This value is constant (°R) and may be omitted if previously input. The input value remains in effect until altered.

Card 2. Constant Convection Coefficient: If the convection coefficient (BTU/IN$^2$-SEC-°R) is to remain constant during the period, input its constant value, a "2" must be input in Column 1.

Card 3. Time dependent Convection Coefficient. If the convection coefficient (BTU/IN$^2$-SEC-°R) is to be time dependent include the "3" card, followed by a table of h versus $\theta$ .

Card 4. Temperature dependent Convection Coefficient. If the convection coefficient (BTU/IN$^2$-SEC-°R) is to be a function of the exterior surface temperature, include the "4" card, followed by a table of h versus T.

If Card 3 or 4 has been input, the appropriate table must be input. This table may contain up to 50 values. The final entry of the table must contain a "1" in Column 1.

A convection coefficient once specified will remain in effect until altered.

### (5) Input Block 5 BARTZ EQUATION

If this option is specified, the program will compute the interior convection coefficient and gas recovery temperature, using the following relationships. If Input Block 2 has been previously used, it will no longer be in effect.

$$h = \frac{K}{D_{t,\theta}^{.2}} \left( \frac{\mu^{.2} C_p}{P_r^{.6}} \right)_o \left( \frac{P_{c,\theta}\ g}{C^*} \right)^{.8} \left( \frac{D_{t,\theta}}{R_{cu}} \right)^{.1} \left( \frac{A^*_\theta}{A_\theta} \right)^{.9} \sigma_c$$

$$\sigma_c = \left( \frac{.5 + .11 P_r^{1/3} (\gamma - 1) M^2}{1 + \frac{\gamma - 1}{2} M^2} + .5 \frac{T_{F,\theta}}{T_o} \right)^{\eta}$$

$$((.5 + .11 P_r^{1/3} (\gamma - 1) M^2 + .5 \left(1 + \frac{\gamma - 1}{2} M^2\right) \frac{T_{F,\theta}}{T_o} )^{-.8}$$

$P_c$ may be constant or calculated as:

$$P_{c,\theta} = \frac{2P_T}{1+\left[1+4\left(\frac{D_{t,\theta}}{D_t}\right)^4\left(\frac{P_T}{P_{c,1}}\right)\left(\frac{P_T}{P_{c,1}}-1\right)\right]^{1/2}},$$

$T_{R,}$ is calculated as:

$$T_{R,\theta} = T_{\infty,\theta} = \left(1 + P_r^{1/3}\,\frac{\gamma-1}{2}\,M_\theta^2\right)$$

M and $T_\infty$ may be constant or tabular functions of $A/A_t$. $(A/A_t)_\theta$ is determined by the program, where $D_t$ may be constant or a tabular function of time.

C* is determined as:

$$C^* = \frac{P_{c,\theta}\,\pi\,D_{t,\theta}^2\,g}{4\,\dot{\omega}}$$

To use this option, the following must be input.

(a) Caption card with the word "BARTZ" in Columns 1-5.

(b) Two cards containing various parameters.

(c) A blank card following the last input item of this block.

Parameters. The caption card must always be followed by two cards which contain the following parameters:

1st card $k, \mu, C_{Pgas}, P_r, P_c, D_t, \gamma$

2nd card $R_{cw}, K, Y, P_t, \mu, T_o$

To use this option at the throat, include a third card containing the following information:

(a) $T_\infty$

(b) Mach number

The station of interest must have been specified as the throat on the second card of Basic Input Sheet 1.

No other cards will be accepted as input.

If the station under investigation is not the throat complete the remaining input list as required.

Card 1. Throat Diameter: If the throat diameter is constant, enter this value (inches), a "1" must be punched in Column 1. If the throat is dimensionally ablating, includ the "1" card with the value portion left blank; a table of Throat Diameter versus $\theta$ must be input following the "1" card. $\theta$ is referenced from the start of the duty cycle. Fifty entries may be made in the table, the final entry of the table must contain a "1" in Column 1.

The value(s), specified for the throat diameter, will remain in effect, until modified or until Input Block 2 is used.

Card 2. Mach Number and free stream temperature. If the Mach number and/or $T_\infty$ are constant enter their value(s) as indicated on Input Block 5, Sheet 2. If either or both are variable, include CARD "2", but leave the appropriate entries, blank. If required, complete the table of $A/A_t$ versus and/or $T_\infty$. Only the variable parameter(s) need be included in the table. This table may contain 50 entries the final entry must contain a "1" in Column 1.

The value(s) of $T_\infty$ and will remain in effect until modified, or until Input Block 2 is specified.

The final card of each input case must contain the word "END DUTY" in Columns 1-6.

One further option is available which allows the engine to be pulsed with a minimum of input. A pulse is defined to be a FIRE PERIOD followed by a SOAK PERIOD. The pulse option may be used when identical

FIRE/SOAK combinations are to be repeated. To use this option include a caption card with the word "PULSE" in Columns 1-5 immediately before the "FIRE" card of the pulse. The pulse card must contain the number of pulses to be executed in Columns 8-15, written with a decimal point. The FIRE period and soak period following the pulse card, will be repeated the number of times so specified. To avoid large quantities of output, the program will print only at intervals as specified on the "FIRE" card.

### C. OUTPUT

Output for all problems will begin with a listing of the basic input. In addition, the program will list the radial increment to be used in dividing the model into nodes. The ID number of nodes located at the interface between materials is printed, as the final line of the first output page.

The remaining printout will be under the control of various input options. A printout will always occur at the beginning and end of the duty cycle. Unless the "PULSE" option is specified, a printout will always occur at the start and finish of each fire and soak period. The following information is contained in all printouts.

1. Period Number
2. Remaining time in the period
3. Elapsed time since the duty cycle began
4. Char depth measured from the center line of the nozzle
5. Nozzle radius at the interior
6. Elapsed time since the start of this period
7. Char depth measured from the original interior surface
8. Dimensional ablation measured from the original interior surface

9. Convection coefficient at the interior

10. Convection coefficient at the exterior

11. Gas recovery temperature

12. Ambient temperature at the exterior

13. Convective heat flux at the interior

14. Convective heat flux at the exterior (+ if into the liner).

15. Radiation heat flux at the interior (+ if into the liner).

16. Radiation heat flux at the exterior (+ if into the liner).

17. Arbitrary heat flux at the exterior (+ if into the liner).

18. Arbitrary heat flux at the exterior (+ if into the liner).

19. ID number of node having minimum time step.

20. $\Delta\theta$ computed at this time point.

21. Temperature Profile (°R): Nodes are listed from interior to exterior of liner. Only those nodes remaining are output.

At the conclusion of the duty cycle, the temperature profile when the maximum exterior temperature was reached, will be output.

## V. CORRELATION AND DISCUSSION

### A. CORRELATION OF TEST DATA

Correlation of monitored data, from full-scale and subscale engine tests, with computed results was to have been accomplished utilizing the completed ablation computer program. During the period when correlation calculations were made, no complete sets of sull-scale test data were sufficiently reduced and consolidated to serve as a proper basis for correlation. Nevertheless, one set of full-scale data was made available and utilized for a correlation run. Tests of ablative chamber Part No. 091850-1, S/N A-9 were conducted in the altitude facility at AEDC, Tullahoma. The test duty cycle employed was as follows.

| Fire (sec) | Coast (sec) |
|---|---|
| 16 | 2700 |
| 17 | 1800 |
| 7 | 1800 |
| 7 | 1800 |
| 51 | Cooled to ambient temperature |
| 135 | Cooled to ambient temperature |
| 317 | Cooled to ambient temperature |

Tests J37A-05-05A and -05B correspond to the 135-second and 317-second firing cycles, respectively. The entire duty cycle was used in the computer analysis, but only data from the above tests were available for comparison. Ablation parameters and thermal properties of the chamber used in the analysis were the same as had been used in analyses performed on Computer Program 8025.

Monitored temperature data and analytical results are shown in Figure 2. These results, compared at an area of 2.6:1 in the diverging section, show the computed peak backwall temperature to exceed the monitored peak by 130°F. Computed char depth was 0.93 in. compared to a measured average of 0.69 in.

No dimensional ablation was indicated by the computer results or measured in the test.

Correlation of subscale data was accomplished repeating the test duty cycle shown in Figure 2 of the Aerojet proposal (Ref. 3). The test duty cycle was as shown below:

| Fire (sec) | Coast (sec) |
|---|---|
| 5 | 1800 |
| 10 | 1800 |
| 11.5 | 3600 |
| 413.5 | Cool to ambient temperature |
| 5 (Repeated 20 times) | 30 (Repeated 19 times, cool to ambient on the final coast.) |

A comparison of monitored subscale and computer program calculated backwall temperature transients is shown in Figure 3. The peak backwall temperature as calculated is nearly 450°F higher than the monitored peak. Calculated char depth was 1.80 in. compared to a 1.05 in. average measured depth. Dimensional ablation was calculated to be 0.45 in.; whereas, a negligible amount was indicated in the test results.

Ablation parameters of the liner material have not been well defined, and values used with the modified computer program have not been determined by correlation with test data. Since the logic of the present program is different in many respects than that of Computer Program 8025, it is not to be expected that ablation parameters which correlated with test data on the 8025 program will be consistent with those for the new program. Also, the calculated ablation depth of 0.45 in. reduces the liner thickness by that amount, and it follows that the backwall temperatures would be much higher. In order to show the significance of the ablation parameters, the computer analysis for the subscale test duty cycle was repeated with the recovery temperature reduced arbitrarily by 25% to ensure that ablation would not occur. A reduction would realistically be expected as cooler gases liberated by charring mix with the boundary layer. The heat of char was increased from 374 BTU/LB to 1000 BTU/LB, also arbitrarily. Calculated results for this computer solution are also shown in Figure 3. Calculated peak backwall temperature was again higher than that monitored during the test, but in this case less than 120°F higher. Char depth agreed closely; a calculated depth of 0.98 in. compared to the measured depth of 1.05 in. These results are not meant to establish the correlation, but rather to indicate that while the computer program mathematically satisfies the necessary heat balances, the associated thermal properties must be accurately known to achieve a good correlation.

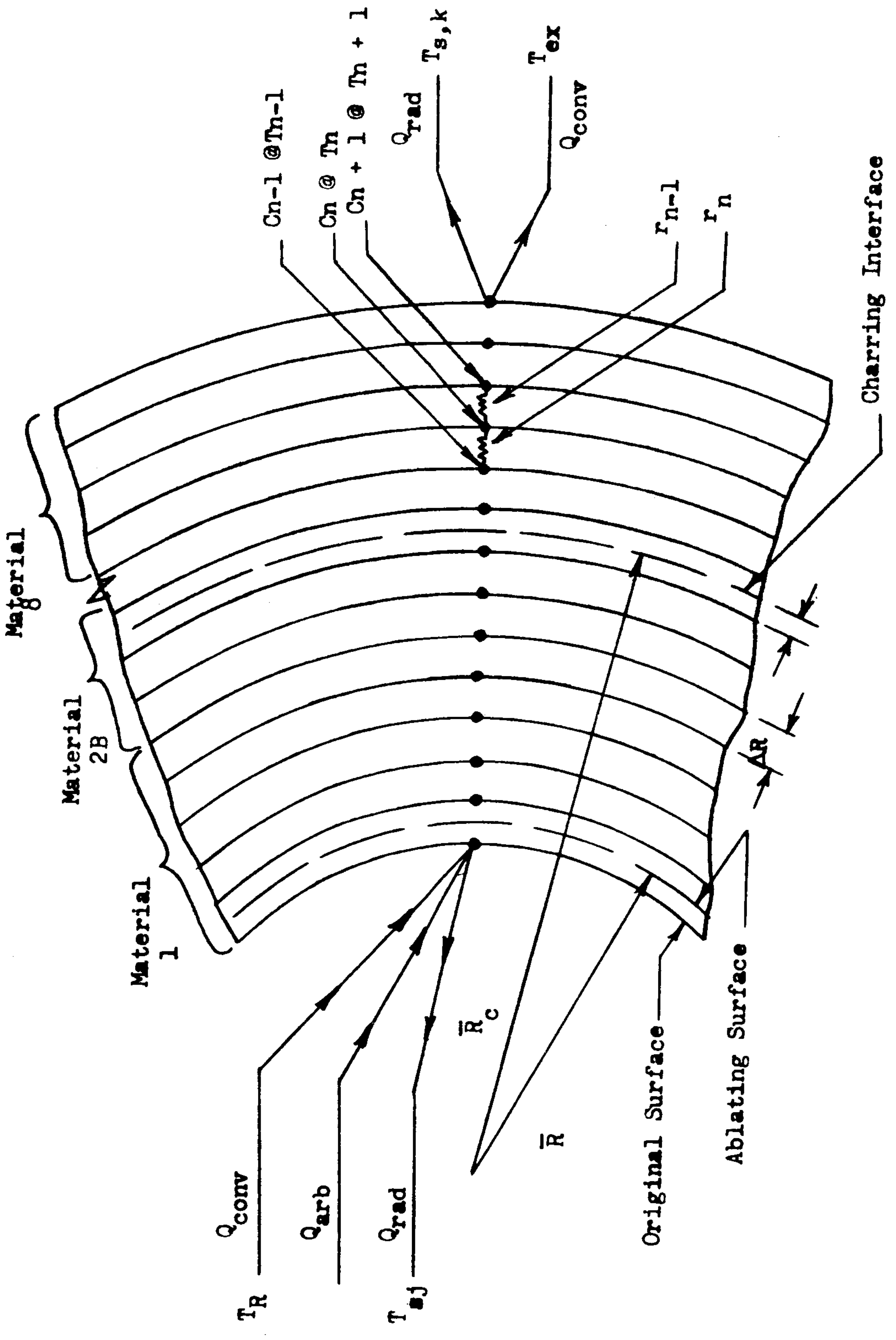
## B. LIMITATIONS OF THE PROGRAM AS ANALYTICAL TOOL

The correlation results listed above serve to point out some of the limitations of the program. As is true of any computer program, the computational results are only as good as the input used to obtain them. In a process as complicated as that of ablation, it is mandatory that valid definition of the heat transfer problem be given and that the thermal and ablation properties of the materials concerned be accurately known. If this computer input is not sufficiently well known then the computational results may be misleading.

Best results are obtained when ablation parameters are established empirically from experimental or test data. Use of data from limited testing can be correlated with computer analysis to establish "effective values" which are compatible to the logic of the computer program. The computer program does not account for mixing of the gases liberated by charring with the flowing gases in the boundary layer which would reduce the recovery temperature. This is only one example of complex effects that cannot be accounted for, and serves to point out the necessity of compatible "effective" parameters for use in the program.

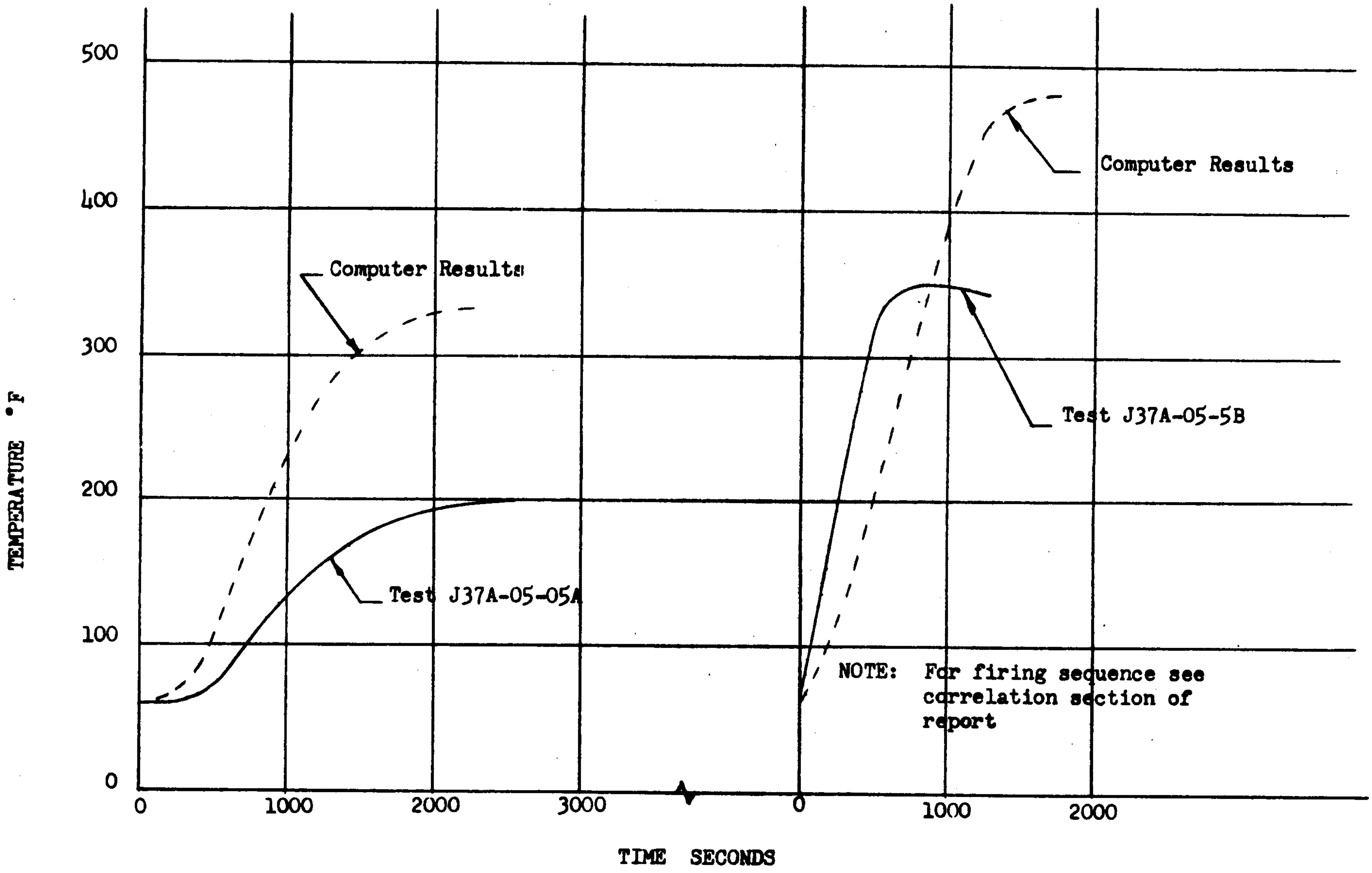
## VI. CONCLUSIONS

Examination of heat balances "in" and "out" of model elements, using results from computer runs indicate that the computer program complies to the analytical model. However, there was a variance in the results measured in engine tests and computed by the ablation program. This does not mean the computer program is not satisfactory, but only that the "effective" ablation parameters ($H_c$, $H_a$, $T_c$, $T_a$) were not properly selected to be compatible with the program logic. A test program, limited in scope, made in conjunction with computer program analyses will make it possible to evaluate compatible "effective" ablation parameters. Further study of the effects of gases liberated in charring upon the recovery temperature should also be made. The logic of these effects might then be incorporated in the computer program to further extend the capabilities of the program much in an evolutionary manner.



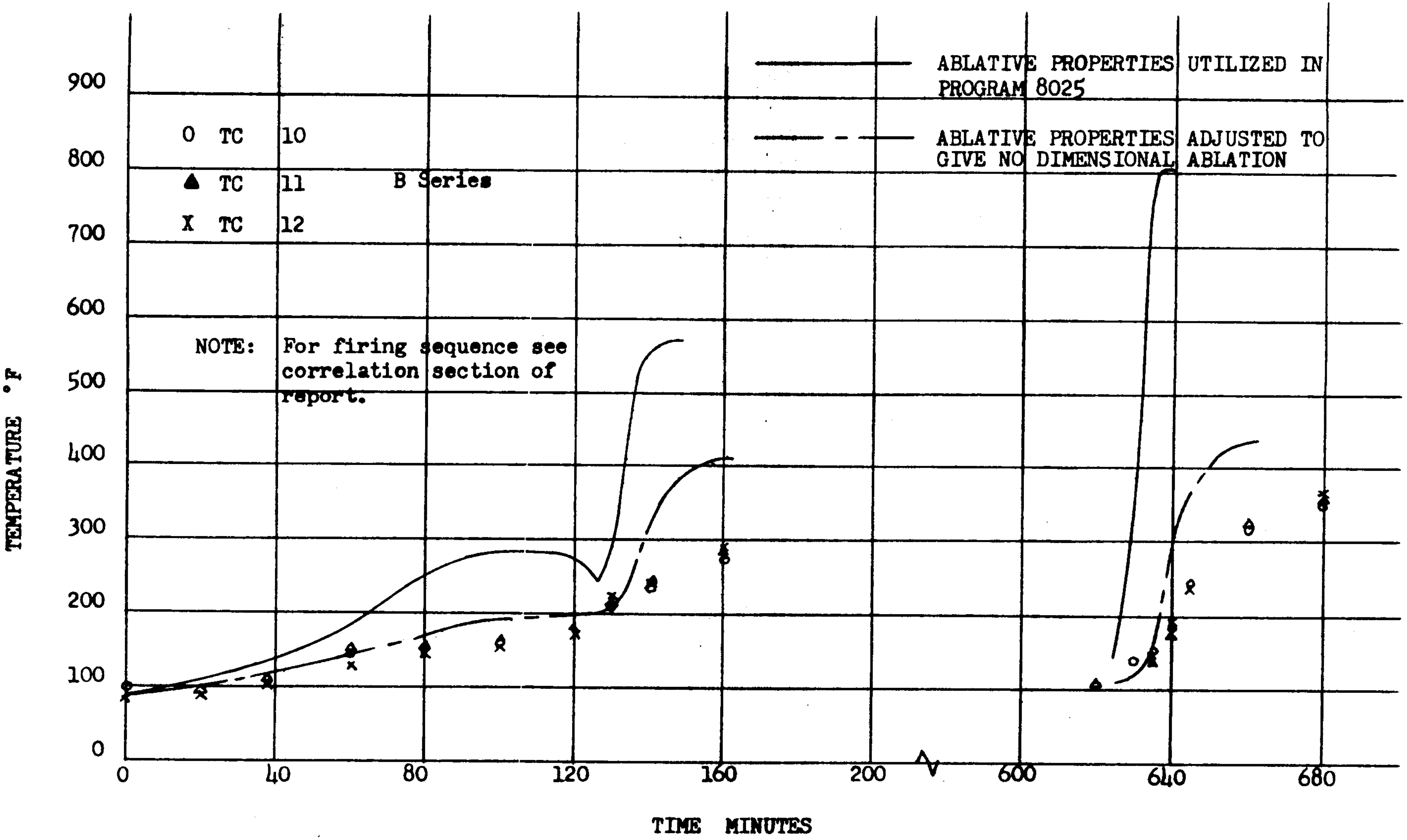
CHARRING AND DIMENSIONAL ABLATION
MODEL FOR TREATING CYLINDRICAL COORDINATES

Figure 1



BACKWALL TEMPERATURE TRANSIENT FOR FULL SCALE ENGINE FIRING
(ABLATIVE CHAMBER PART NO. 091850-1, S/N A-9)

Figure 2



BACKWALL TEMPERATURE TRANSIENT FOR SUBSCALE ENGINE FIRING

Figure 3

## VII. REFERENCES

1. "Analytical Study to Extend Capabilities of Aerojet-General Ablation Digital Computer Program," NASA Contract NAS 9-2832, May 1964.

2. Bartz, D. R., "A Simple Equation for Rapid Estimation of Rocket Nozzle Convestive Heat Transfer Coefficients," Jet Propulsion, January 1957, pp 49-51.

3. Eckert, E. R. G., "Engineering Relations for Heat Transfer and Friction in High-Velocity Laminar and Turbulent Boundary-Layer Flow Over Surfaces with Constant Pressure and Temperature," Transactions of the ASME, August 1956, pp 1273-83.

4. "Analytical Study to Extend the Capabilities of the Aerojet-General Ablation Digital Computer Program" AGC Proposal LR 63960, September 1963.

## VIII. NOMENCLATURE

| Engineering Symbol | Description | Units | Fortran Symbol |
|---|---|---|---|
| $A$ | Area | $(in)^2$ | |
| $A^*$ | Throat Area | $(in)^2$ | |
| $C$ | Thermal Capacitance | BTU/$^{o}$F | CAP |
| $C_p$ | Specific Heat | BTU/lb$^{o}$F | CP |
| $C^*$ | Characteristic Exhaust Velocity | in/sec | CSTAR |
| $D$ | Diameter | in | DIAM |
| $F$ | Configuration Factor | | |
| $g$ | Acceleration of Gravity | in/$(sec)^2$ | 386.4 |
| $h$ | Heat Transfer Coefficient | BTU/in$^2$sec$^{o}$F | H |
| $H_a$ | Effective Heat of Ablation | BTU/lb | QA |
| $H_c$ | Effective Heat of Char | BTU/lb | QC |
| $K$ | Coefficient of Bartz Equation | | C(9) |
| $k$ | Thermal Conductivity | BTU/in sec$^{o}$F | K |
| $M$ | Mach Number | | MACH |
| $P$ | Pressure | lb/in$^2$ | PC |
| $P_r$ | Prandtl Number | | C(4) |
| QINI | Summation of Modes of Heat Transfer, Interior | BTU | |
| $Q$ | Heat | BTU | |
| $q$ | Heat Flux | BTU/in$^2$sec | |
| $R$ | Radius | in | R |

Nomenclature (Cont'd)

| Engineering Symbol | Description | Units | Fortran Symbol |
|---|---|---|---|
| $\bar{R}$ | Distance from Centerline to Internal Surface | in | RBAR |
| $\bar{R}_c$ | Distance from Centerline to Char Interface | in | RBARC |
| $r$ | Thermal Resistance | sec/BTU | RES |
| $T$ | Temperature | °R | T |
| $T'$ | Eckert Temperature | °R | |
| $V$ | Volume | $in^3$ | |
| $\dot{\omega}$ | Weight Flow | lb/sec | C(12) |
| $z$ | Axial Distance Along the Nozzle | in | |
| $\alpha$ | Thermal Diffusivity | $in^2 sec^{-1}$ | |
| $\beta$ | Cylindrical Coordinate | Radians | |
| $\gamma$ | Ratio of Specific Heats | | C(10) |
| $\delta$ | Incremental Distance | in | DR |
| $\epsilon$ | Thermal Emissivity | | EPSILN |
| $\eta$ | Exponent for Bartz Compressibility Term | | C(7) |
| $\theta$ | Time | sec | THETA |
| $\mu$ | Viscosity | $lb\ sec/in^2$ | C(2) |
| $\rho$ | Density | $lb/in^3$ | RHO |
| $\sigma$ | Stefan-Boltzmann Constant | $3.31 \times 10^{-15}$ $BTU/in^2 sec\ R^4$ | SIGMA |
| $\sigma_c$ | Compressibility Correction Factor | | SIG |

Nomenclature (Cont'd)

## SUBSCRIPTS

| Engineering Symbol | Description | Units | Fortran Symbol |
|---|---|---|---|
| $a$ | Ablation | | A |
| $am$ | Arithmetic Mean | | |
| $c$ | Char Node | | C |
| $ave$ | Average | | |
| $ARB$ | Arbitrary Value | | ARB |
| $cu$ | Curvature | | |
| $ex$ | External | | |
| $F$ | First Node | | (FIRST) |
| $in$ | Internal | | |
| $ICHAR$ | Charring Node | | (ICHAR) |
| $i$ | Node Designation | | (I) |
| $j$ | Internal Body J | | |
| $k$ | External Body K | | |
| $o$ | Stagnation Conditions | | |
| $LAST$ | Last Node in the Composite | | LAST |
| $L$ | Laminate | | L |
| $R$ | Gas Recovery Conditions | | R |
| $s$ | Sink | | |
| $t$ | Throat Conditions | | TH |
| $\infty$ | Free Stream Conditions | | FREE |
| $\Delta\theta$ | Time Constant | Sec | DT |
| $T_{i,\theta}$ | Temperature | °R | TP |

## IX. APPENDIX

The appendixes of this report include:

A. PROGRAM LISTING

B. SAMPLE PROBLEMS

## IX-A PROGRAM LISTING

```
HARRIS          4F        C0800914EH                          A1          11-06-64   TIME 10.500V12D03 5011 PAGE  1
        EXTERNAL FORMULA NUMBER    -    SOURCE STATEMENT    -  INTERNAL FORMULA NUMBER(S)

C
C
C               **** AEROJET-GENERAL CORPORATION ****
C
C            CHARRING AND DIMENSIONAL ABLATION PROGRAM
C.....................................................................
C
      INTEGER TYPE,TYPEX,FIRST,HI,BLANK
      REAL KL, KC, MACH, INTPLT
      LOGICAL BARTZ, INHCON, TIDSNK,EXHCON,TDPEXH,PCCON,THROAT,THDCON
      LOGICAL CONMAC,CONTFR,FIRE,SOAK,ABLATE,PULSE,ERROR
      COMMON /CONSNT/ PI, PI2
      COMMON  /DIRECT/ TYPEX(4),CONTRL(7),NTALPH,BLANK
      COMMON /FLUX/ CONVIN,CONVEX,RADFLI,RADFLX,QARB(2)
      COMMON /GEOMRY/ LAST(10),MATERS,  DR,DR2, RO,  X(10), R(500),LASTN
      COMMON /LOAD/ ARBCOE(2,2,8),TR,H,EPSILN(2,7), VIEW(2,7),TSINK(2,7)
     1,TAM(2), HX(2),TFREE, MACH,THDIAM ,C(13),CC(10)
      COMMON /LOGIC/ BARTZ,INHCON,TIDSNK(2,7),EXHCON(2),TDPEXH(2), PCCON
     1,THROAT, THDCON,CONMAC,CONTFR
      COMMON /PCINTR/RBAR,RBARN,RBARC,RBARCN,ICHAR,ICHARN, FIRST
      COMMON /PROPTY/ TC(10),TA, QC(10),QA,RHOL(10), RHOC(10),RHOCPL(10)
     1,RHOCPC(10), RES(500), CAP(500), KC(10),KL(10),CPL(10),CPC(10)
      COMMON /TABLES/  XTABLE(51,12,2),YTABLE(51,12,2)
      COMMON /TEMPS/ T(500), TP(500)
      COMMON /TIMES/ DTX(500), LSTABL,THETA, DT, PEREND, START
      DIMENSION TMAX(500),ID(14),RADFL(2),STOPX(6),STOP(2,6),DP(2)
C
C.....................................................................
C                                                   FIRST INSTRUCTIONS
C                                                   LOAD BASIC INPUT
   10 READ(5,9100) N, ID                                                            ,1     ,2     ,3     ,4
 9100 FORMAT(1A1,13A6,1A1)
   20 WRITE(6,9110) ID                                                              ,5     ,6     ,7
 9110 FORMAT(1H1,/35X37H**** AEROJET-GENERAL CORPORATION ****/35X,37H---
     1------------------------------------ // 33X,41HCHARRING AND DIMENSIO
     2NAL ABLATION PROGRAM//14X,14A6    //42X25H--- LINER DESCRIPTION --
     3-//)
C
C     DEFINITION OF INPUT QUANTITIES
```

```
C      MATERS=   NUMBER OF MATERIALS                          - NO UNITS
C      LASTN =   NUMBER OF NODES, ALSO ID. NO. OF LAST NODE- NO UNITS
C      THROAT=   LOGICAL VARIABLE, TRUE IF THROAT             - ENTER T
C      RO    =   RADIUS FROM CENTER-LINE TO INTERIOR          - INCHES
C      RBARC =   INITIAL CHAR-DEPTH FROM INTERIOR OF LINER - INCHES
C      T(1)  =   LINER TEMP. IF UNIFORM,OMIT IF NOT UNIFORM- DEG-R.
C      TA    =   ABLATION TEMPERATURE OF MATERIAL 1           - DEG-R.
C      QA    =   HEAT OF ABLATION FOR MATERIAL 1              - BTU/LB.
C
       READ(5,9120) MATERS, LASTN,N                                                   ,8    ,9    ,10   ,11   ,12
 9120  FORMAT(17X,I1,17X,I3,29X,1A1)
       THROAT = .FALSE.                                                               ,13
       IF(N .NE. BLANK) THROAT =.TRUE.                                                ,14   ,15   ,16
       READ(5,9125) RO, RBARC, T(1), TA,QA                                            ,17   ,18   ,19
 9125  FORMAT(17X, F8.0,17X,F8.0,22X,F8.0/17X,F8.0,29X,E12.8)
C
C      MATERIAL PROPERTIES
C      X     =   THICKNESS                                    - INCHES
C      CPL   =   SPECIFIC HEAT-LAMINATE                       - BTU/LB
C      CPC   =   SPECIFIC HEAT-CHAR                           - BTU/LB
C      KL    =   THERMAL CONDUCTIVITY-LAMINATE                - BTU/IN-S-R
C      KC    =   THERMAL CONDUCTIVITY-CHAR                    - BTU/IN-S-R
C      RHOL  =   DENSITY-LAMINATE                             - LB/CUBIC-IN
C      RHOC  =   DENSITY-CHAR                                 - LB/CUBIC-IN
C      TC    =   CHAR TEMPERTURE                              - DEG-RANKIN
C      QC    =   EFFECTIVE HEAT OF CHARRING                   - BTU/LB-CHAR
C
       READ(5,9130)(X(I)     ,I=1,MATERS)                                             ,20   ,21   ,22   ,23   ,24
       READ(5,9130)(CPL(I)   ,I=1,MATERS)                                             ,25   ,26   ,27   ,28   ,29
       READ(5,9130)(CPC(I)   ,I=1,MATERS)                                             ,30   ,31   ,32   ,33   ,34
       READ(5,9131)(KL(I)    ,I=1,MATERS)                                             ,35   ,36   ,37   ,38   ,39
       READ(5,9131)(KC(I)    ,I=1,MATERS)                                             ,40   ,41   ,42   ,43   ,44
       READ(5,9130)(RHOL(I)  ,I=1,MATERS)                                             ,45   ,46   ,47   ,48   ,49
       READ(5,9130)(RHOC(I)  ,I=1,MATERS)                                             ,50   ,51   ,52   ,53   ,54
       READ(5,9130)(TC(I)    ,I=1,MATERS)                                             ,55   ,56   ,57   ,58   ,59
       READ(5,9131)(QC(I)    ,I=1,MATERS)                                             ,60   ,61   ,62   ,63   ,64
 9130  FORMAT(8X, 8F9.0)
 9131  FORMAT(8X, 8E9.5)
C                                   IF START TEMP. IS NOT UNIFORM,
C                                   READ START TEMPS. FOR ALL NODES
```

```
      EXTERNAL FORMULA NUMBER   -   SOURCE STATEMENT    -  INTERNAL FORMULA NUMBER(S)
      IF(T(1) .NE. 0.0)  GO  TO  40                              ,65   ,66   ,67
      READ(5,9135) (T(I),I=1,LASTN)                              ,68   ,69   ,70   ,71   ,72
 9135 FORMAT(10F8.0)
      GO TO 50                                                   ,73
   40 DO 45 I=2,LASTN                                            ,74
   45 T(I)= T(1)                                                 ,75   ,76
   50 DO  55 I=1,LASTN                                           ,77
   55 TP(I)=T(I)
C......................................CHECK FOR ERRORS IN BASIC INPUT  ,78   ,79
      DO 56 I=1,LASTN                                            ,80
   56 IF( T(I) .GT. 6000.0  .OR. T(I) .LT. 0.0) GO TO  8030      ,81   ,82   ,83   ,84
      DO 57 I=1,MATERS                                           ,85
      IF( X(I) .LE. 0.0) GO TO 8030                              ,86   ,87   ,88
      IF( CPL(I) .LE. 0.0  .OR.CPL(I) .GT.  10.0 ) GO TO 8030    ,89   ,90   ,91
      IF( KL(I)  .LE. 0.0  .OR. KL(I) .GT. 1.0E-03) GO TO 8030   ,92   ,93   ,94
   57 IF( RHOL(I).LE. 0.0  .OR. RHOL(I).GT. 5.0) GO TO 8030
C.......................................................INITIALIZE  ,95   ,96   ,97   ,98
      NFIRE = 0                                                  ,99
      NSOAK = 0                                                  ,100
      ABLATE=.FALSE.                                             ,101
      DO 58 I=1,2                                                ,102
      EXHCON(I) = .TRUE.                                         ,103
      DO 58 J=1,7                                                ,104
      VIEW(I,J)=0.0                                              ,105
      EPSILN(I,J)=0.0                                            ,106
      TSINK(I,J)=0.0                                             ,107
   58 TIDSNK(I,J)=.FALSE.                                        ,108  ,109  ,110
      ERROR = .FALSE.                                            ,111
      PULSE = .FALSE.                                            ,112
      HX(1)=0.0                                                  ,113
      HX(2)=0.0                                                  ,114
      H = 0.0                                                    ,115
      TR=0.0                                                     ,116
      TAM(1) = 0.0                                               ,117
      TAM(2) = 0.0                                               ,118
      NPASS =0                                                   ,119
      LSTABL =1                                                  ,120
      DTX(1)=0.0                                                 ,121
      FIRST=1                                                    ,122
      RBAR=RO                                                    ,123
```

```
      RBARN=RO                                                              ,124
      ICHAR=1                                                               ,125
      THETA=0.0                                                             ,126
      TMAX(LASTN) = 0.0                                                     ,127
      DO 60 I=1,2                                                           ,128
      DO 60 J = 1,2                                                         ,129
      DO 60 K = 1,8                                                         ,130
   60 ARBCOE(I,J,K) = 0.0                                                   ,131  ,132  ,133  ,134
      DO 65 I=1,2                                                           ,135
      DO 65 J=1,12                                                          ,136
      DO 65 K=1,51                                                          ,137
      YTABLE(K,J,I)=0.0                                                     ,138
   65 XTABLE(K,J,I) = -1.0
C     ------------------------------------ESTABLISH NODAL CONFIGURATION
C
C                                          TX= TOTAL LINER THICKNESS.
C                                          DR= RADIAL INCREMENT.
C                                          LAST(I) = LAST NODE OF
C                                                 MATERIAL (I)
C                                          R(I) = THE RADIUS MEASURED
C                                                TO NODE (I)                ,139  ,140  ,141  ,142
  300 TX=0.0                                                                ,143
      DO 310 I=1,MATERS                                                     ,144
  310 TX=X(I) +TX                                                           ,145  ,146
      DR= TX/FLOAT(LASTN-2)                                                 ,147
      DR2=DR/2.0                                                            ,148
      IF(MATERS .EQ.1) GO TO 360                                            ,149  ,150  ,151
      LAST(1)=(X(1)-DR2)/DR  +1.5                                           ,152
      DO   350 I=2,MATERS                                                   ,153
      IF(I .EQ. MATERS) GO TO 330                                           ,154  ,155  ,156
      LAST(I)= X(I)/DR  + .5                                                ,157
      LAST(I)=LAST(I) +LAST(I-1)                                            ,158
      GO TC 350                                                             ,159
  330 LAST(I)=LASTN                                                         ,160
  350 CONTINUE                                                              ,161  ,162
      GO TO 365                                                             ,163
  360 LAST(1)=LASTN                                                         ,164
  365 R(1) = RO                                                             ,165
      R(2)=RO +DR2                                                          ,166
      M = LASTN -1                                                          ,167
```

```
      DO 370 I = 3,M                                                        ,168
  370 R(I)=R(I-1) +DR                                                       ,169  ,170
      R(LASTN) = R(M) +DR2                                                  ,171
      N = LAST(1)-2                                                         ,172
      ENDLIN = R(N)                                                         ,173
      DO 380 I = 1, MATERS                                                  ,174
  380 ID(I) = LAST(I) +1                                                    ,175  ,176
      ID(MATERS) = LASTN
C     ------------------------------------------------PROBLEM CONSTANTS     ,177
      PI = 3.14159265                                                       ,178
      PI2 = 2.0 * PI                                                        ,179
      SIGMA = 3.31E-15
C------------------------------------------------------ PROPERTY CONSTANTS  ,180
      DO 400 I=1,MATERS                                                     ,181
      RHOCPL(I)=RHOL(I)*CPL(I)                                              ,182
  400 RHOCPC(I)=RHOC(I)*CPC(I)                                              ,183  ,184
      CAB = QA*PI*RHOC(1)                                                   ,185
      DIAMEX= 2.0 * R(LASTN)
C                                    *******OUTPUT LINER DESCRIPTION..      ,186
      IF(THROAT) WRITE(6,9140)                                              ,187  ,188  ,189  ,190
 9140 FORMAT(5X,  29HSTATION OF INTEREST IS THROAT)
      WRITE(6,9150) MATERS,LASTN,RO,R(LASTN),TX,DR,QA,TA                    ,191  ,192  ,193
 9150 FORMAT(5X,  20HLINER IS COMPOSED OF, I3,12H MATERIAL(S)/ 5X,   17H
     1NUMBER CF NODES =, I4/  5X,   32HRADIUS FROM NOZZLE CENTER-LINE =,
     2F8.4, 8H INCHES./ 5X,  26HRADIUS TO LINER EXTERIOR =, F8.4, 8H INC
     3HES./5X, 23HTOTAL LINER THICKNESS =, F8.4, 8H INCHES./ 5X,18HRADIA
     4L INCREMENT =, F8.5, 8H INCHES./5X, 18HHEAT OF ABLATION =,1PE12.4,
     5  8H BTU/LB./5X, 22HABLATION TEMPERATURE =,0PF8.2, 7H DEG.-R//)
      WRITE(6,9160)                                                         ,194  ,195
 9160 FORMAT(    43X, 23HMATERIAL SPECIFICATIONS//38X, 12H MATERIAL 1 ,
     112H MATERIAL 2 ,12H MATERIAL 3 , 12H MATERIAL 4 ,12H MATERIAL 5 ,
     212H MATERIAL 6 ,12H MATERIAL 7 ,12H MATERIAL 8 //)
      WRITE(6,9170) (X(I),I=1,MATERS)                                       ,196  ,197  ,198  ,199  ,200
 9170 FORMAT(6X, 9HTHICKNESS,9X, 7HINCHES. 6X,   8F12.4)
      WRITE(6,9180) (CPL(I),I=1,MATERS)                                     ,201  ,202  ,203  ,204  ,205
 9180 FORMAT(6X,  25HSP-HEAT LAMINATE  B/LB-R.,  6X,  1P8E12.4)
      WRITE(6,9190)(CPC(I),I=1,MATERS)                                      ,206  ,207  ,208  ,209  ,210
 9190 FORMAT(6X,  12HSP-HEAT CHAR, 6X, 7HB/LB-R.,6X,1P8E12.4)
      WRITE(6,9200)(KL(I),I=1,MATERS)                                       ,211  ,212  ,213  ,214  ,215
 9200 FORMAT( 6X,   13HCOND LAMINATE, 5X, 11HB/IN-SEC-R.2X, 1P8E12.4)
```

```
      WRITE(6,9210) (KC(I),I=1,MATERS)                                                 ,216  ,217  ,218  ,219  ,220
 9210 FORMAT( 6X,   9HCOND CHAR, 9X,11HB/IN-SEC-R., 2X, 1P8E12.4)
      WRITE(6,9220) (RHOL(I),I=1,MATERS)                                               ,221  ,222  ,223  ,224  ,225
 9220 FORMAT( 6X, 16HDENSITY LAMINATE,2X,  9HLB/CU-IN.,4X, 1P6E12.4)
      WRITE(6,9230) (RHOC(I),I=1,MATERS)                                               ,226  ,227  ,228  ,229  ,230
 9230 FORMAT( 6X,  12HDENSITY CHAR, 6X, 9HLB/CU-IN., 4X, 1P6E12.4)
      WRITE(6,9240) (TC(I),I=1,MATERS)                                                 ,231  ,232  ,233  ,234  ,235
 9240 FORMAT( 6X,  16HCHAR TEMPERATURE,2X, 6HDEG-R. ,7X,  6F12.3)
      WRITE(6,9250) (QC(I),I=1,MATERS)                                                 ,236  ,237  ,238  ,239  ,240
 9250 FORMAT( 6X,  17HEFF. HEAT OF CHAR,14H B/LB CHARRED ,  1P6E12.4)
      WRITE(6,9260) (ID(I),I = 1,MATERS)                                               ,241  ,242  ,243  ,244  ,245
 9260 FORMAT(6X, 14HINTERFACE NODE,4X, 6HNUMBER, 7X, 6I12)
C
C------------------------------------------------ TEST FOR INITIAL CHAR
  450 IF(RBARC .EQ. 0.0) GO TO 455                                                     ,246  ,247  ,248
      IF(RBARC .GT. 0.0) GO TO 453
C                                                  IF INITIAL CHAR DEPTH
C                                                  IS NEGATIVE, THIS IS
C                                                  TAKEN TO MEAN THAT THE
C                                                  ABS(RBARC) IS THE FIRST
C                                                  CHAR-ABLE MATERIAL                  ,249  ,250  ,251
      N = ABS(RBARC) +.5                                                               ,252
      IF(N .GT. MATERS) GO TO 8030                                                     ,253  ,254  ,255
      IF(N .NE. 1) GO TO 452                                                           ,256  ,257  ,258
      RBARC = 0.0                                                                      ,259
      GO TO 455                                                                        ,260
  452 ICHAR = LAST(N-1) +1                                                             ,261
      RBARC = R(ICHAR)                                                                 ,262
      GO TO 456                                                                        ,263
  453 IF(RBARC .LT. DR2) GO TO 455                                                     ,264  ,265  ,266
      ICHAR= 2 + IFIX(     (RBARC-DR2)/ DR      )                                      ,267
  455 RBARC=RO +RBARC                                                                  ,268
  456 RBARCN=RBARC                                                                     ,269
      ICHARN=ICHAR                                                                     ,270
      GO TO 6400
C
C
C------------------------------------------- SELECT STABLE TIME INCREMENT            ,271
  990 NPASS = 1
C                                                 COMPUTE CAPACITANCE FOR
```

```
C                                                 ALL NODES OF THE MODEL
C                                                 CAP = CAPACITANCE                  ,272
      CALL  CAPACE                                                                   ,273
      CALL  RESTAN
C                                                 COMPUTE RESISTANCE  FOR
C                                                 ALL NODES OF THE MODEL
C                                                 RES = RESISTANCE                   ,274
 1000 DO 1010 I = FIRST,LASTN                                                        ,275
 1010 TP(I) = T(I)                                                                   ,276  ,277
      CIN = CAP(FIRST)                                                               ,278
      RIN = RES(FIRST)                                                               ,279
      GO TO 1050                                                                     ,280
 1025 ABLATE = .FALSE.
C                                                 COMPUTE A TIME CONSTANT
C                                                 FOR EACH NODE OF MODEL             ,281
 1050 N = LASTN-1                                                                    ,282
      L=FIRST+1                                                                      ,283
      DO 1200 I=L,N                                                                  ,284
 1200 DTX(I)=CAP(I)/(1.0/RES(I) + 1.0/RES(I-1))                                      ,285  ,286
      DT = DTX(L)                                                                    ,287
      LSTABL = L
C                                                 SELECT MINIMUM TIME
C                                                 CONSTANT                           ,288
      DO 1220 I=L,N                                                                  ,289
      IF(DTX(I) .GE. DT  ) GO TO 1220                                                ,290  ,291  ,292
      DT=DTX(I)                                                                      ,293
      LSTABL=I                                                                       ,294
 1220 CONTINUE                                                                       ,295  ,296
      IF(ABLATE)  GO TO 1270
C                                                 IF LINER IS NOT ABLATIG
C                                                 COMPUTE TIME CONSTANT
C                                                 FOR INTERIOR SURFACE               ,297  ,298  ,299
      DTX(FIRST) =CAP(FIRST)/(1.0/CONRI+1.0/RADRI+1.0/RES(FIRST))                    ,300
      IF(DTX(FIRST).LT. DT) GO TO 1260                                               ,301  ,302  ,303
      GO TO 1270                                                                     ,304
 1260 LSTABL =FIRST                                                                  ,305
      DT=DTX(FIRST)                                                                  ,306
 1270 DT= DT * .999
C                                                 TEST FOR COMPUTED TIME
C                                                 CONSTANT LESS THAN
```

```
C                                                ALLOWABLE VALUE (SEC.)              ,307
      IF( ABLATE) GO TO 1280                                                         ,308  ,309  ,310
      IF(DT .GT. STOP(INDEX,2)) GO TO 1280                                           ,311  ,312  ,313
      IF(RBAR .EQ. R(FIRST)) GO TO 8020
C                                                IF A PARTIALLY ABLATED
C                                                NODE IS ON THE LINER
C                                                SURFACE, CONSOLIDATE
C                                                NODES FIRST AND FIRST+1
C                                                                                    ,314  ,315  ,316
      N=FIRST +1                                                                     ,317
      WRITE(6,1275) FIRST, N                                                         ,318  ,319  ,320
 1275 FORMAT( 1H1,  11X    11H----- NODES,I4, 4H AND,I4,64H ARE BEING CO
     1NSOLIDATED DUE TO MINIMUM STABILITY RESTRAINT -----)
      CALL PRINT(2,INDEX,NFIRE,NSOAK)
C                                                ENTHALPY BALANCE TO
C                                                DETERMINE AVERAGE TEMP.             ,321
      TAVE = (CAP(FIRST)*T(FIRST)+CAP(FIRST+1)*T(FIRST+1))/(CAP(FIRST)
     1 +CAP(FIRST+1))                                                                ,322
      ABLATE=.FALSE.                                                                 ,323
      FIRST = FIRST +1                                                               ,324
      T(FIRST) = TAVE                                                                ,325
      TP(FIRST) = TAVE                                                               ,326
      R(FIRST) = RBAR                                                                ,327
      GO TO 990
C
C                                                TEST FOR COMPUTED TIME
C                                                CONSTANT GREATER THAN
C                                                ALLOWABLE.                          ,328
 1280 IF(STOP(INDEX,3).LT. DT) DT = STOP(INDEX,3)
C                                                ADJUST TIME CONSTANT TO
C                                                AGREE WITH PERIOD END/
C                                                OR PRINT INTERVAL                   ,329  ,330  ,331
      IF((THETA+DT).GT. PEREND) DT=PEREND -THETA                                     ,332  ,333  ,334
      IF((THETA +DT) .GT. PRTIME) DT = PRTIME- THETA
C     -----------------------------------------------------------------
C
C                                                   --------SURFACE NODE             ,335  ,336  ,337
 2000 CONTINUE
C                                                QOUT = CONDUCTIVE HEAT
C                                                FLUX FROM INTERIOR SUR-
```

```
C                                                FACE NODE TO THE LINER
C                                                INTERIOR    -BTU/SEC.
C
C                                             QINI = NET HEAT FLUX TO
C                                             LINER SURFACE                         ,338
      QOUT = (TP(FIRST)-TP(FIRST+1))/RES(FIRST)                                     ,339
      QNET= (QINI-QOUT )*DT                                                         ,340
      IF(QNET .LT. 0.0 .AND. ABLATE) GO TO 1025                                     ,341  ,342  ,343
      IF(ABLATE) GO TO 2300
C                                                    SURFACE TEMPERTURE.             ,344  ,345  ,346
      T(FIRST)=QNET/CAP(FIRST)+TP(FIRST)                                            ,347
      IF(ICHAR .EQ. FIRST) GO TO 2050                                               ,348  ,349  ,350
      IF(T(FIRST) .GE. TA) GO TO 2200                                               ,351  ,352  ,353
      GO TO 3000                                                                    ,354
 2050 IF(T(FIRST) .GE. TC(1)) GO TO 2060                                            ,355  ,356  ,357
      GO TO 3000                                                                    ,358
 2060 IF(TP(FIRST) .EQ. TC(1)) GO TO 2070                                           ,359  ,360  ,361
      T(FIRST) = TC(1)                                                              ,362
      DT =((TC(1)-TP(FIRST))*CAP(FIRST))/(QINI-QOUT)                                ,363
      ICHARN = ICHAR                                                                ,364
      GO TO 3000                                                                    ,365
 2070 CALL CHAR(QNET)                                                               ,366
      GO TO 3000
C------------------------------------- DIMENSIONAL ABLATION CALCULATIONS             ,367
 2200 ABLATE =.TRUE.                                                                ,368
      T(FIRST)=TA                                                                   ,369
      DT = ((TA-TP(FIRST))*CAP(FIRST))/(QINI-QOUT)                                  ,370
      GO TO 3000                                                                    ,371
 2300 RBARN = SQRT(QNET/CAB+RBAR**2)                                                ,372
      IF(RBARN .LT. R(FIRST+1)) GO TO 2800
C                                                ABLATION HAS PROCEEDED
C                                                ACROSS THE BOUNDRY OF
C                                                THE SURFACE NODE. ADJUS
C                                                TIME CONSTANT SUCH THAT
C                                                ABLATION IS AT NODE
C                                                BOUNDRY
C                                                                                   ,373  ,374  ,375
      DT = CAB/(QINI-QOUT)*(R(FIRST+1)**2-RBAR**2)                                  ,376
      FIRST = FIRST +1                                                              ,377
      RIN = RES(FIRST)                                                              ,378
```

```
      CIN = CAP(FIRST)                                                             ,379
      RBAR = R(FIRST)                                                              ,380
      RBARN= RBAR                                                                  ,381
      ABLATE = .FALSE.                                                             ,382
      LOW = FIRST -1                                                               ,383
      GO TO 3010
C
C                                                COMPUTE NEW RESISTOR
C                                                AND CAPACITOR VALUES
C                                                FOR SURFACE NODE                  ,384
 2800 RIN = ALOG(R(FIRST+1)/RBARN)/(PI2*KC(1))                                     ,385
      CIN = RHOCPC(1) *PI*(R(FIRST+1)**2-RBARN**2)
C
C--------------------------------------------------------------------------
C                                            TEMPERTURE DISTRIBUTION----
C                                            AND CHAR DEPTH PROPOGATION-
C                                            FOR NODES OTHER THAN FIRST
C
C                                                SET INDEXX TO MATERIAL
C                                                NUMBER AND PICK-UP
C                                                PROPERTIES                        ,386
 3000 LOW=FIRST +1                                                                 ,387
 3010 INDEXX = 0                                                                   ,388
 3100 INDEXX = INDEXX +1                                                           ,389
      HI = LAST(INDEXX)                                                            ,390
      IF(INDEXX .EQ. 1) GO TO 3200                                                 ,391  ,392  ,393
      LOW = LAST(INDEXX-1) +1                                                      ,394
 3200 DO 3300  I=LOW, HI                                                           ,395
      IF(I .EQ. LASTN) GO TO 3350
C                                                CONDUCTIVE HEAT FLUX
C                                                FROM NODE(I-1), MUST
C                                                EQUAL  QIN  AT NODE(I)
C                                                BTU/SEC.                          ,396  ,397  ,398
      QIN=QOUT                                                                     ,399
      QOUT= (TP(I)-TP(I+1))/RES(I)                                                 ,400
 3280 QNET=(QIN-QOUT)*DT
C                                                GET TEMPERTURE AT NODE            ,401
      T(I)= QNET/CAP(I) + TP(I)
C                                                TEST FOR CHAR INTERFACE
C                                                AT NODE
```

```
C                                                                                ,402
 3300 IF(I .FQ. ICHAR .AND. T(I) .GE. TC(INDEXX))CALL CHAR(QNET)                 ,403   ,404   ,405   ,406
      GO TO 3100
C-----------------------------------------------------------------------
C
C............................................TEMPERATURE AT EXTERIOR
C                                                                                ,407
 3350 T(LASTN)= T(LASTN-1)-QOUTEX*RES(LASTN-1)                                   ,408
 4000 THETA =THETA +DT                                                           ,409
      RES(FIRST) = R1N                                                           ,410
      CAP(FIRST) = C1N                                                           ,411
      DO 4005 I = 1, MATERS                                                      ,412
 4005 IF(ICHAR .LE. LAST(I)) GO TO 4006                                          ,413   ,414   ,415   ,416
 4006 CAP(ICHAR) = RHOCPL(I)*PI*(R(ICHAR+1)**2-RBARCN**2)
     1  + RHOCPC(I)*PI*(RBARCN**2-R(ICHAR)**2)                                   ,417
      RES(ICHAR) =ALOG(R(ICHAR+1)/RBARCN)/(PI2*KL(I)) + ALOG(RBARCN/
     1 R(ICHAR))/(PI2*KC(I))                                                     ,418
      ICHAR = ICHARN                                                             ,419
      RBAR=RBARN                                                                 ,420
      RBARC=RBARCN                                                               ,421
      IF(ABLATE) GO TO 4010                                                      ,422   ,423   ,424
      GO TC 4020                                                                 ,425
 4010 IF((T(FIRST) -T(FIRST +1)).GT. 1.0) GO TO 4020                             ,426   ,427   ,428
      FIRST = FIRST +1                                                           ,429
      RBAR = R(FIRST)                                                            ,430
      T(FIRST) = TA
C
C**********************************************************************
C                            TEMPERATURE CALCULATIONS ARE COMPLETED
C                            DETERMINE HEAT FLUX AT INTERIOR AND
C                            EXTERIOR OF LINER.
C                                                                                ,431
 4020 IF(SOAK) GO TO 4100
C                   **************CONVECTIVE HEAT FLUX AT INTERIOR               ,432   ,433   ,434
      IF(BARTZ) GO TO 4040                                                       ,435   ,436   ,437
      IF(INHCCN) GO TO 4080
C                                         CONVECTION COEFF. IS
C                                         TIME DEPENDENT                         ,438   ,439   ,440
      H = INTPLT(1,1,1,THETA)                                                    ,441
      GO TO 4C80
```

```
C                                              DETERMINE H FROM BARTZ             ,442
 4040 IF(THRCAT) GO TO 4045                                                       ,443   ,444   ,445
      IF(.NOT. THDCON) THDIAM = INTPLT(1,4,9,THETA)                               ,446   ,447   ,448
      GO TC 4C50                                                                  ,449
 4045 THDIAM = 2.0*RBAR                                                           ,450
 4050 RATIC2=(2.0*RBAR/THDIAM)**2                                                 ,451
      IF(PCCON)  GO  TO 4055                                                      ,452   ,453   ,454
      PC=  2.0*C(11)/(1.0+(1.0+CC(3)*(THDIAM/C(6))**4)**.5)                       ,455
      GO TO 4060                                                                  ,456
 4055 PC=C(5)                                                                     ,457
 4060 CSTAR = PC*CC(2)*THDIAM**2*386.4                                            ,458
      IF(CONMAC) GO TO 4070                                                       ,459   ,460   ,461
      MACH = INTPLT(1,5,10,RATIO2)                                                ,462
 4070 IF(CONTFR) GO TO 4075                                                       ,463   ,464   ,465
      TFREF = INTPLT(1,5,11,RATIO2)                                               ,466
 4075 XM2=MACH**2                                                                 ,467
      TR = TFREF*(1.0+CC(1)*XM2)                                                  ,468
      SIG = ((.50+CC(6)*XM2)/(1.0+CC(7)**XM2) +.5*T(FIRST)/C(13))**C(7)*
     1( (.5+ CC(6)*XM2)+ .5*(1.0+CC(7)*XM2)*T(FIRST)/C(13))**(-.80)               ,469
      H=(C(9)/THDIAM**.2*CC(5)*(PC*386.4/CSTAR)**.8 *(THDIAM/C(8))**.1)*
     1(1.0/RATIO2)**.9*SIG                                                        ,470
 4080 CONRI= 1.0/(H*PI2*RBAR)                                                     ,471
      CONVIN= (TR-T(FIRST))/CONRI                                                 ,472
      GO TC 4120                                                                  ,473
 4100 CONRI=C.0                                                                   ,474
      CONVIN=0.0
C                       **************CONVECTIVE HEAT FLUX AT EXTERIOR            ,475
 4120 IF(EXHCCN(INDEX)) GO TO 4150                                                ,476   ,477   ,478
      ARG= T(LASTN)                                                               ,479
      IF(TDPFXH(INDEX)) ARG=THETA                                                 ,480   ,481   ,482
      HX(INDFX) = INTPLT(INDEX,3,8,ARG)                                           ,483
 4150 CONVEX=PI*DIAMEX*HX(INDEX)*(T(LASTN)-TAM(INDEX))
C                       ***************************ARBITRARY HEAT FLUX            ,484
      DO 4200 I = 1,2                                                             ,485
      ZZ = PI2*RBAR                                                               ,486
      IF(I .EQ. 2) ZZ = PI2*R(LASTN)                                              ,487   ,488   ,489
 4200 QARB(I) = ZZ*(ARBCOE(INDEX,I,1)*SIN(ARBCOE(INDEX,I,2)+ARBCOE(INDEX
     1 ,I,3)*THETA) + ARBCOE(INDEX,I,4)+ARBCOE(INDEX,I,5)*THETA +ARBCOE
     2 (INDEX,I,6)*THETA**2 +ARBCOE(INDEX,I,7)*EXP(ARBCOE(INDEX,I,8)*
     3 THETA))
```

```
      EXTERNAL FORMULA NUMBER  -   SOURCE STATEMENT    -   INTERNAL FORMULA NUMBER(S)

C                      ***************RADIATION HEAT FLUX AT INTERIOR        ,490  ,491
      RADRI = 0.0                                                             ,492
      DO 425C I = 1,2                                                         ,493
      RADFL(I) = 0.0                                                          ,494
      ZZ = SIGMA*EPSILN(INDEX,I)*VIEW(INDEX,I)*PI2*RBAR                       ,495
      RADFL(I) =ZZ* (T(FIRST)**4 -TSINK(INDEX,I)**4)                          ,496
 4250 RADRI = RADRI + 1.0/(ZZ*(T(FIRST)**2+TSINK(INDEX,I)**2)
     1*(T(FIRST) +TSINK(INDEX,I)))                                            ,497  ,498
      RADFLI = RADFL(1) + RADFL(2)
C                      ***************RADIATION HEAT FLUX AT EXTERIOR        ,499
 4400 RADFLX=0.0                                                              ,500
      DO 4450 I=3,7                                                           ,501
      IF(TIDSNK(INDEX,I)) TSINK(INDEX,I) = INTPLT(INDEX,2,I,THETA)            ,502  ,503  ,504
      TSINKK= TSINK(INDEX,I)**4                                               ,505
 4450 RADFLX = RACFLX + PI2*R(LASTN)*SIGMA*EPSILN(INDEX,I)*VIEW(INDEX,
     1 I)*(T(LASTN)**4-TSINKK)                                                ,506  ,507
      QOUTEX =CCNVEX+RADFLX-QARB(2)                                           ,508
      QINI = CONVIN-RADFLI+QARB(1)
C     **************SAVE TEMP. PROFILE WHEN MAX. EXTERIOR TEMP. REACHED       ,509
      IF(T(LASTN) .LT. TMAX(LASTN)) GO TO 4480                                ,510  ,511  ,512
      DO 4460 I=FIRST,LASTN                                                   ,513
 4460 TMAX(I)=T(I)                                                            ,514  ,515
      MAXFIR=FIRST                                                            ,516
      THEMAX=THETA                                                            ,517
 4480 IF(NPASS .NE. 0) GO TO 5100                                             ,518  ,519  ,520
      GC TO 7520
C                         ................ TEST FOR END OF PERIOD            ,521
 5100 IF(RBAR .GE. ENDLIN) GO TO 8040                                         ,522  ,523  ,524
      IF(ABS(THETA-PEREND) .LE. 1.0E-10) GO TO 5150                           ,525  ,526  ,527
      IF(FIRE) GO TO 5140                                                     ,528  ,529  ,530
      IF(STOP(2,4) .LE. 0.0) GO TO 5110
C                                           HAS T(LASTN) EXCEEDED
C                                           MAXIMUM VALUE                     ,531  ,532  ,533
      IF(T(LASTN) .LT. STOP(2,4)) GO TO 5120                                  ,534  ,535  ,536
      WRITE(6, 5105)                                                          ,537  ,538
 5105 FORMAT(1H125X,58H***** EXTERIOR TEMPERATURE HAS REACHED MAXIMUM VA
     1LUE *****)
      GO TC 5130                                                              ,539
 5110 IF(STCP(2,4) .EQ. 0.0) GO TO 5120
C                                           HAS EXTERIOR TEMP.
```

```
C                                       REACHED A PEAK                          ,540  ,541  ,542
      IF(T(LASTN) .GE. TP(LASTN)) GO TO 5120                                    ,543  ,544  ,545
      WRITE(6,5115)                                                             ,546  ,547
 5115 FORMAT(1H1,  26X,  56H***** EXTERIOR TEMPERTURE HAS REACHED A PEAK
     1 VALUE *****)
      GO TO 5130                                                                ,548
 5120 IF(STOP(INDEX,5) .EQ. 0.0) GO TO 5140
C                                       HAS LINER SOAKED TO
C                                       STEADY STATE CONDITIONS                 ,549  ,550  ,551
      DO 5125 I=FIRST,LASTN                                                     ,552
 5125 IF((ABS(TP(I)-T(I))/DT) .GT. STOP(INDEX,5)) GO TO 5140                    ,553  ,554  ,555  ,556
      WRITE(6,5126)                                                             ,557  ,558
 5126 FORMAT(1H1, 26X, 55H***** LINER HAS SOAKED TO STEADY STATE CONDITI
     1ONS *****)
 5130 CALL PRINT(2,INDEX,NFIRE,NSOAK)                                           ,559
      GO TO 5150
C                                       TEST TO PRINT                           ,560
 5140 IF(ABS(THETA-PRTIME) .GT. 1.0E-10) GO TO 1000                             ,561  ,562  ,563
      PRTIME=THETA + DP(INDEX)                                                  ,564
      CALL PRINT(2,INDEX,NFIRE,NSOAK)                                           ,565
      GO TO 1000                                                                ,566
 5150 THETA = PEREND                                                            ,567
 5300 IF(PULSE) GO TO 5320                                                      ,568  ,569  ,570
 5310 CALL PRINT(3,INDEX,NFIRE,NSOAK)                                           ,571
      IF( STOP(INDEX,6) .EQ. 0.0) GO TO 6400
C                                       RESET LINER TEMP.
C                                       BEFORE CONTINUING                       ,572  ,573  ,574
      DO 5210 I=FIRST,LASTN                                                     ,575
 5210 T(I) = STOP(INDEX,6)                                                      ,576  ,577
      WRITE(6, 5215) STOP(INDEX,6)                                              ,578  ,579  ,580
 5215 FORMAT(1H126X,35H***** ALL NODES HAVE BEEN RESET TO. F8.2,19H DEG-
     1 RANKINE *****)
      GO TO 6400                                                                ,581
 5320 NPKNT = NPKNT +1                                                          ,582
      IF(NPKNT .LT. NPULSE) GO TO 5325                                          ,583  ,584  ,585
      PULSE = . FALSE.                                                          ,586
      GO TO 5310                                                                ,587
 5325 IF(FIRE) GO TO 5360                                                       ,588  ,589  ,590
      FIRE = .TRUE.                                                             ,591
      SOAK = . FALSE.                                                           ,592
```

```
      INDEX = 1                                                              ,593
      NFIRE = NFIRE +1                                                       ,594
       IF(STOP(2,6) .EQ. 0.0) GO TO 5370                                     ,595   ,596   ,597
      DO 5365 I = FIRST,LASTN                                                ,598
 5365 T(I) = STOP(2,6)                                                       ,599   ,600
      GO TO 5370                                                             ,601
 5360 FIRE = .FALSE.                                                         ,602
      NSOAK = NSOAK +1                                                       ,603
      SOAK = .TRUE.                                                          ,604
      INDEX = 2                                                              ,605
 5370 PEREND = THETA + STOP(INDEX,1)                                         ,606
      START = THETA                                                          ,607
      GO TC 1000
C
C     ----------------------------------------------------------------
C*********************************************************************
C                                      *******PERIOD DEFINITION*******      ,608
 6400 READ(5,7001) TYPE,STOPX(1), DPX,(STOPX(I),I=2,6)                       ,609   ,610   ,611   ,612   ,613   ,
                                                                             ,615
 7001 FORMAT( 1A6, 1X, 7F8.0)
C
C                                         BRANCH DEPENDENT ON TYPE.
C                                      1. FIRE   GO TO STATEMENT 7100
C                                      2. SOAK   GO TO STATEMENT 7200
C                                      3. PERIODIC     STATEMENT 7300
C                                      4. END DUTY CYCLE         7900
      DO  7010 I=1,4                                                         ,616
 7010 IF(TYPE .EQ.TYPEX(I))  GO TO(7100,7200, 7300, 7900), I                 ,617   ,618   ,619   ,620
      WRITE(6,7015)TYPE                                                      ,621   ,622   ,623
 7015 FORMAT(//5X, 1A6,30H IS NOT A DEFINED CONTROL WORD )
      GO TO 8000
C
C.........................................DEFINITION OF FIRE PERIOD         ,624
 7100 FIRE =.TRUE.                                                           ,625
      SOAK = .FALSE.                                                         ,626
      NFIRE=NFIRE +1                                                         ,627
      INDEX = 1                                                              ,628
      IF(STOPX(3) .LE. 0.0)STOPX(3)=1.0E+30                                  ,629   ,630   ,631
      IF(DPX .LE. 0.0) DPX = 1.0E+30                                         ,632   ,633   ,634
      DP(INDEX)=DPX                                                          ,635
```

```
      DO 7105 I = 1,6                                                     ,636
 7105 STCP(INCEX,I) = STCPX(I)                                            ,637  ,638
      IF(STOP(1,1) .GT. 0.0) GO TO 7250                                   ,639  ,640  ,641
      WRITE(6,7106) NFIRE                                                 ,642  ,643  ,644
 7106 FORMAT(// 5X,   30H*** TERMINATION OF FIRE PERIOD, I4,16H IS NOT DE
     1FINED   )
      GO TO 8000
C.....................................................DEFINITION OF SOAK PERIOD   ,645
 7200 FIRE =.FALSE.                                                       ,646
      SCAK = .TRUE.                                                       ,647
      NSOAK=NSOAK +1                                                      ,648
      INDEX=2                                                             ,649
      IF(STOPX(3) .LE. 0.0) STOPX(3)=1.0E+30                              ,650  ,651  ,652
      IF(DPX .LE. 0.0) DPX = 1.0E+30                                      ,653  ,654  ,655
      DP(INDEX) =DPX                                                      ,656
      DO 7205 I = 1,6                                                     ,657
 7205 STOP(INDEX,I) = STOPX(I)                                            ,658  ,659
      IF(STCP(2,1) .GT. 0.0) GO TO 7250                                   ,660  ,661  ,662
      WRITE(6,7206) NSOAK                                                 ,663  ,664  ,665
 7206 FORMAT(//5X,   30H*** TERMINATION OF SOAK PERIOD, I4,16H IS NOT DE
     1FINED   )
      GO TO 8000                                                          ,666
 7250 CALL INPUT(ERROR,INDEX)                                             ,667
      IF(ERROR)GO TO 8000                                                 ,668  ,669  ,670
      GO TO 7500
C................................................PERIODIC FIRE AND SOAK FOLLOWS   ,671
 7300 PULSE = .TRUE.                                                      ,672
      NPULSE=STCPX(1) +.5                                                 ,673
      NPKNT = 0                                                           ,674
      WRITE(6,7310) NPULSE                                                ,675  ,676  ,677
 7310 FORMAT(1H1, 28X,   32H********** ENGINE WILL BE PULSED, I5,
     1 17H TIMES **********    )
      NPULSE = 2*NPULSE                                                   ,678
      GO TO 6400                                                          ,679
 7500 IF(.NOT. PULSE) GO TO 7510                                          ,680  ,681  ,682
      IF(INDEX .EQ. 1) GO TO 6400                                         ,683  ,684  ,685
      NSOAK = NSOAK -1                                                    ,686
      SOAK = .FALSE.                                                      ,687
      FIRE = .TRUE.                                                       ,688
      INDEX = 1                                                           ,689
```

```
      DP(2) = DP(1)                                                     ,690
 7510 IF(NPASS .EQ. 0) GO TO 4020                                       ,691  ,692  ,693
 7520 CONTINUE
C-------------------------------------A FIRE OR SOAK PERIORD IS BEGINNIN  ,694
      START = THETA                                                     ,695
      PRTIME = THETA + DP(INDEX)                                        ,696
      PEREND = THETA + STOP(INDEX,1)                                    ,697
      CALL PRINT (1, INDEX, NFIRE, NSOAK)                               ,698
      IF(NPASS .EQ. 0) GO TO 990                                        ,699  ,700  ,701
      GO TO 1000
C
C******************************************************END OF DUTY CYCLE  ,702
 7900 WRITE(6,7910) THEMAX                                              ,703  ,704  ,705
 7910 FORMAT(1H1 39X 30H**** DUTY CYCLE HAS ENDED **** // 19X, 38HMAXIMU
     1M EXTERIOR TEMPERTURE OCCURED AT,F8.2,24H SECONDS INTO DUTY CYCLE/
     2//  38X,31H----- TEMPERATURE PROFILE -----//)
      LO=MAXFIR                                                         ,706
 7920 NHI=LO+9                                                          ,707
      IF(NHI .GE. LASTN) NHI = LASTN                                    ,708  ,709  ,710
      WRITE(6,7930)(I,I=LO,NHI)                                         ,711  ,712  ,713  ,714  ,715
 7930 FORMAT(8X,10I10)
      WRITE(6,7940)(TMAX(I),I=LO,NHI)                                   ,716  ,717  ,718  ,719  ,720
 7940 FORMAT(8X,10F10.3//)
      IF(NHI .EQ.LASTN)GO TO 10                                         ,721  ,722  ,723
      LO=NHI+1                                                          ,724
      GO TO 7920                                                        ,725
 8000 WRITE(6, 8010)                                                    ,726  ,727
 8010 FORMAT(//5X,                    32H********** SKIPPING TO NEXT CASE)
      DO 8015 I = 1,100                                                 ,728
      READ(5,9100) NT, ID                                               ,729  ,730  ,731  ,732
 8015 IF(NT .EQ. NTALPH) GO TO 20                                       ,733  ,734  ,735  ,736
      RETURN                                                            ,737
 8020 WRITE(6,8021) DT, STOP(INDEX,2)                                   ,738  ,739  ,740
 8021 FORMAT(1H120X, 67HUNABLE TO CONTINUE WITH THIS CASE DUE TO RESTRAI
     1NT ON TIME CONSTANT/  29X14HCOMPUTED VALUE, 1PE12.4, 5X, 11HINPUT
     2VALUE, 1PE12.4)
 8025 CALL PRINT(2,INDEX,NFIRE,NSOAK)                                   ,741
      GO TO 8000                                                        ,742
 8030 WRITE(6,8035)                                                     ,743  ,744
 8035 FORMAT(//5X,  48H***** AN ERROR HAS BEEN DETECTED IN BASIC INPUT )
```

```
     EXTERNAL FORMULA NUMBER   -   SOURCE STATEMENT   -   INTERNAL FORMULA NUMBER(S)

      GO TO 8000                                                    ,745
8040 WRITE(6,8045)                                                 ,746  ,747
8045 FORMAT(1H1,28X,52H***** MATERIAL 1 IS APPROACHING TOTAL ABLATION *
    1****)
     GO TO 8025                                                    ,748
     END                                                           ,749
```

```
      SUBROUTINE INPUT( ERROR, INDEX)
C-----------------------------------------------------------------------
C     THIS PROGRAM LOADS ALL INPUT REQUIRED  TO DESCRIBE A FIRE OR SOAK.
C-----------------------------------------------------------------------
C
      COMMON /DIRECT/  TYPEX(4),CONTRL(7),NTALPH,BLANK
      INTEGER CONTRL
      REAL MACH
      LOGICAL ERROR,BARTZ,INHCON,TIDSNK,EXHCON, TDPEXH,PCCON,THROAT,
     1THDCON,CONMAC,CONTFR
      COMMON /LOAD/ ARBCOE(2,2,8),TR,H,EPSILN(2,7), VIEW(2,7),TSINK(2,7)
     1,TAM(2), HX(2),TFREE, MACH,THDIAM ,C(13),CC(10)
      COMMON /LOGIC/ BARTZ,INHCON,TIDSNK(2,7),EXHCON(2),TDPEXH(2), PCCON
     1,THROAT, THDCON,CONMAC,CONTFR
      COMMON /TABLES/  XTABLE(51,12,2),YTABLE(51,12,2)
      DIMENSION Z(12)
C                                            DETERMINE INPUT BLOCK
   50 READ(5,100) NCODE                                                        ,1      ,2      ,3
  100 FORMAT(1A6)
      DO 200 I=1,7                                                             ,4
  200 IF(NCODE .EQ. CONTRL(I)) GO TO(1000, 2000, 3000, 4000, 5000, 6000,
     16000),I                                                                  ,5      ,6      ,7      ,8
      ERROR =.TRUE.                                                            ,9
      WRITE(6,250) NCODE                                                       ,10     ,11     ,12
  250 FORMAT(// 5X, 1A6, 28H IS NOT A LEGAL CONTROL WORD)
      RETURN
C
C...................................INPUT BLOCK 1 ARBITRARY HEAT FLUX          ,13
 1000 READ(5,1050)NCARD,(Z(I),I=1,8)                                           ,14     ,15     ,16     ,17     ,18     ,1

 1050 FORMAT( I1,7X,8E9.5)
      IF(NCARD .LE. 0) GO TO 50                                                ,20     ,21     ,22
      IF(NCARD .GT. 2) GO TO 8000                                              ,23     ,24     ,25
      DO 1100 I=1,8                                                            ,26
 1100 ARBCOE(INDEX,NCARD,I)= Z(I)                                              ,27     ,28
      GO TO 1000
C-----------------------------------------------------------------------
C
C..................................INPUT BLOCK 2 INTERIOR CONVECTION.         ,29
```

```
      EXTERNAL FORMULA NUMBER   -   SOURCE STATEMENT    -  INTERNAL FORMULA NUMBER(S)

 2000 IF(INDEX .EQ. 2) GO TO 8000                                          ,30   ,31   ,32
 2010 READ(5,2050) NCARD, X1                                               ,33   ,34   ,35   ,36
 2050 FORMAT( I1,19X,E12.8)
      IF(NCARD .LE. 0) GO TO 50                                            ,37   ,38   ,39
      IF(NCARD .GT. 2) GO TO 8000                                          ,40   ,41   ,42
      BARTZ =.FALSE.                                                       ,43
      IF(NCARD .EQ. 2) GO TO 2100                                          ,44   ,45   ,46
      TR=X1                                                                ,47
      GO TO 2010                                                           ,48
 2100 IF( X1 .EQ. 0.0) GO TO 2200                                          ,49   ,50   ,51
      INHCON= .TRUE.                                                       ,52
      H=X1                                                                 ,53
      GO TO 2010                                                           ,54
 2200 INHCON =.FALSE.
C                                      READ TIME DEPENDENT INT
C                                      CONVECTION COEFFICIENT              ,55
      DO 2250 I=1,50                                                       ,56
      READ(5,2225) N,  XTABLE(I,1,1),  YTABLE(I,1,1)                       ,57   ,58   ,59   ,60
 2225 FORMAT(I1,11X,F8.0,E12.8)
 2250 IF( N .NE. 0) GO TO 2275                                             ,61   ,62   ,63   ,64
 2275 XTABLE(I+1,1,1)=-1.0                                                 ,65
      GO TO 2010
C--------------------------------------------------------------
C
C.........................................INPUT BLOCK 3 RADIATION          ,66
 3000 READ(5,3010) NCARD, (Z(J),J=1,3)                                     ,67   ,68   ,69   ,70   ,71   ,7

 3010 FORMAT(I1,17X,F8.0,8X,F8.0,8X,F8.0)
      IF(NCARD .LE. 0) GO TO 50                                            ,73   ,74   ,75
      IF(NCARD .GT. 8) GO TO 8000                                          ,76   ,77   ,78
      IF(NCARD .EQ. 8) GO TO 3200
C                                      LOAD RADIATION CONSTANT             ,79   ,80   ,81
      EPSILN(INDEX,NCARD)=Z(1)                                             ,82
      VIEW  (INDEX,NCARD)=Z(2)                                             ,83
      IF(Z(3) .EQ. 0.0) GO TO 3100                                         ,84   ,85   ,86
      TIDSNK(INDEX,NCARD)=.FALSE.                                          ,87
      TSINK(INDEX,NCARD)= Z(3)                                             ,88
      GO TO 3000                                                           ,89
 3100 TIDSNK(INDEX,NCARD)=.TRUE.                                           ,90
      GO TO 3000
```

```
C                                          LOAD TIME DEPENDENT
C                                          SINK TEMPERATURES                   ,91
 3200 DO 3275 I=1,50                                                           ,92
      READ(5,3210)N, XTABLE(I,2,INDEX),(Z(J),J=3,7)                            ,93    ,94    ,95    ,96    ,97    ,9
                                                                               ,99
 3210 FORMAT(I1,11X,6F8.0)
      DO 3250 J=3,7                                                            ,100
 3250 IF(TIDSNK(INDEX,J))YTABLE(I,J,INDEX) = Z(J)                              ,101   ,102   ,103   ,104
 3275 IF(N .NE. 0) GO TO 3300                                                  ,105   ,106   ,107   ,108
 3300 XTABLE(I+1,2,INDEX)=-1.0                                                 ,109
      GO TO 3000
C
C.....................................INPUT BLOCK 4 EXTERIOR CONVECTION         ,110
 4000 READ(5,4010) NCARD, X1,X2                                                ,111   ,112   ,113   ,114
 4010 FORMAT(I1,19X,F8.0,8X,E8.4)
      IF(NCARD  .LE. 0) GO TO 50                                               ,115   ,116   ,117
      IF(NCARD  .GT. 4) GO TO 8000                                             ,118   ,119   ,120
      IF(NCARD  .NE. 1) GO TO 4100                                             ,121   ,122   ,123
      TAM(INDEX)=X1                                                            ,124
      GO TO 4000                                                               ,125
 4100 IF(NCARD .GT. 2) GO TO 4200                                              ,126   ,127   ,128
      EXHCON(INDEX)=.TRUE.                                                     ,129
      HX(INDEX)=X2                                                             ,130
      GO TO 4000                                                               ,131
 4200 EXHCON(INDEX)=.FALSE.                                                    ,132
      TDPEXH(INDEX)=.TRUE.                                                     ,133
      IF(NCARD .EQ. 4)TDPEXH=.FALSE.
C                                          LOAD VARIABLE EXTERIOR
C                                          CONVECTION COEFF.                   ,134   ,135   ,136
      DO 4250 I=1,100                                                          ,137
      READ(5,4220) N,  XTABLE(I,3 ,INDEX), YTABLE(I,8  ,INDEX)                 ,138   ,139   ,140   ,141
 4220 FORMAT(I1,13X,F8.0,8X,E8.4)
 4250 IF( N  .NE. 0) GO TO  4260                                               ,142   ,143   ,144   ,145
 4260 XTABLE(I+1,3,INDEX)=-1.0                                                 ,146
      GO TO 4000
C.........................................INPUT BLOCK 5 BARTZ EQUATION         ,147
 5000 IF(INDEX .EQ. 2) GO TO  8000                                             ,148   ,149   ,150
      BARTZ= .TRUE.                                                            ,151
      READ(5,5010) C                                                           ,152   ,153   ,154
 5010 FORMAT( 6E12.8, F8.0/6E12.8)
```

```
      CC(1) = C(4)**.333*((C(10)-1.0)/2.0)                                  ,155
      CC(2)=3.14159/(4.0*C(12))                                             ,156
      CC(3)= 4.0*C(11)/C(6)*(C(11)/C(6)-1.0)                                ,157
      CC(5) = (C(2)*386.4)**.2*C(3)/C(4)**.6                                ,158
      CC(6)=.11 * C(4)**.333*(C(10)-1.0)                                    ,159
      CC(7)=(C(10)-1.0)/2.0                                                 ,160
      PCCON=.FALSE.                                                         ,161
      IF( C(11) .LT. 0.0)PCCON= .TRUE.                                      ,162  ,163  ,164
      IF( .NOT. THROAT) GO TO 5100                                          ,165  ,166  ,167
      READ(5,5010) TFREE, MACH                                              ,168  ,169  ,170
      CONTFR = .TRUF.                                                       ,171
      CONMAC = .TRUE.                                                       ,172
 5100 READ(5, 5120) NCARD, X1,X2                                            ,173  ,174  ,175  ,176
 5120 FORMAT(I1, 19X,F8.0,24X,F8.0)
      IF(NCARD .LE.  0) GO TO 50                                            ,177  ,178  ,179
      IF(NCARD .GT.  2) GO TO 8000                                          ,180  ,181  ,182
      IF(NCARD .EQ.  2) GO TO 5300                                          ,183  ,184  ,185
      IF(X1 .FQ. 0.0) GO TO 5150                                            ,186  ,187  ,188
      THDCON=.TRUE.                                                         ,189
      THDIAM=X1                                                             ,190
      GO TC 5100                                                            ,191
 5150 THDCON= .FALSE.
C                                      LOAD VARIABLE THROAT                 ,192
      DO 5200 I=1,50                                                        ,193
      READ(5,5210) N,  XTABLE(I,4,1),YTABLE(I,9,1)                          ,194  ,195  ,196  ,197
 5210 FORMAT(I1,19X,2F8.0)
 5200 IF(N .NE. 0) GO TO 5250                                               ,198  ,199  ,200  ,201
 5250 XTABLE(I+1,4,1)=-1.0                                                  ,202
      GO TO 5100                                                            ,203
 5300 IF( X1 .EQ. 0.0) GO TO 5320                                           ,204  ,205  ,206
      CONMAC=.TRUF.                                                         ,207
      MACH =X1                                                              ,208
      GO TO  5330                                                           ,209
 5320 CONMAC=.FALSE.                                                        ,210
 5330 IF(X2  .EQ.  0.0) GO  TO  5350                                        ,211  ,212  ,213
      CCNTFR=.TRUF.                                                         ,214
      TFREF=X2                                                              ,215
      GO TC 5400                                                            ,216
 5350 CONTFR=.FALSE.                                                        ,217
 5400 IF(CONMAC .AND. CONTFR) GO TO 5100                                    ,218  ,219  ,220
```

```
        EXTERNAL FORMULA NUMBER   -   SOURCE STATEMENT    -   INTERNAL FORMULA NUMBER(S)

      DO 5550 I=1,50                                                         ,221
      READ(5,5510) N, XTABLE(I,5,1), X1,X2                                   ,222   ,223   ,224   ,225
 5510 FORMAT(I1,19X,3F8.0)
      IF( .NOT. CONMAC) YTABLE(I,10,1)=X1                                    ,226   ,227   ,228
      IF( .NOT. CONTER) YTABLE(I,11,1)=X2                                    ,229   ,230   ,231
 5550 IF(N .NE.0) GO TO 5560                                                 ,232   ,233   ,234   ,235
 5560 XTABLE(I+1,5,1)=-1.0                                                   ,236
      GO TO 5100
C                                                                            ,237
 6000 RETURN                                                                 ,238
 8000 WRITE(6,8010) TYPEX(INDEX)                                             ,239   ,240   ,241
 8010 FORMAT(// 5X,   27HINPUT ERROR ENCOUNTERED IN ,1A5,11HDESCRIPTION)
      ERROR=.TRUE.                                                           ,242
      GO TO 6000                                                             ,243
      END                                                                    ,244
```

```
      SUBROUTINE CAPACE
C     ---------------------------------------------------------------
C     THIS ROUTINE COMPUTES THE CAPACITANCE FOR ALL NODES OF THE LINER
C     VALUES GENERATED ARE STORED IN ARRAY-CAP- WITH SUBSCRIPTS EQUAL TO
C     THE ASSIGNED NODE NUMBERS
C     ---------------------------------------------------------------
      INTEGER FIRST
      REAL KL,KC
      COMMON /CONSNT/ PI, PI2
      COMMON /GEOMRY/ LAST(10),MATERS,  DR,DR2, RO,  X(10), R(500),LASTN
      COMMON /PCINTR/RBAR,RBARN,RBARC,RBARCN,ICHAR,ICHARN, FIRST
      COMMON /PROPTY/ TC(10),TA, QC(10),QA,RHOL(10), RHOC(10),RHOCPL(10)
     1,RHOCPC(10), RES(500), CAP(500), KC(10),KL(10),CPL(10),CPC(10)
C     --------------------------------------------SURFACE NODE)....
      IF(ICHAR .GT. FIRST) GO TO 400
C                                                     NO ABLATION        ,1    ,2    ,3
      CAP(FIRST)=RHOCPC(1)*PI*(RBARC**2-R(FIRST)**2) +RHOCPL(1)*PI*
     1  (R(FIRST+1)**2-RBARC**2)                                         ,4
      GO TO 500
C                                                   WITH ABLATION        ,5
  400 CAP(FIRST)=PI*RHOCPC(1)* (R(FIRST+1)**2 -RBAR**2)                  ,6
  500 N = FIRST +1                                                       ,7
      M = LASTN-1                                                        ,8
      DO 700 I=N,M
C                                        -----SELECT PROPERTIES          ,9
      DO 520 J=1,MATERS                                                  ,10
  520 IF(I .LE.LAST(J)) GO TO 530                                        ,11   ,12   ,13   ,14
  530 IF(I .LT. ICHAR) GO  TO 580                                        ,15   ,16   ,17
      IF(I .EQ. ICHAR) GO  TO 600
C                                                   LAMINATE NODE        ,18   ,19   ,20
      CAP(I) = PI*RHOCPL(J)* (R(I+1)**2-R(I)**2)                         ,21
      GO TO 700
C                                                    CHARRED NODE        ,22
  580 CAP(I) = PI*RHOCPC(J)*(R(I+1)**2-R(I)**2)                          ,23
      GO TO 700
C                                                   CHARRING NODE        ,24
  600 CAP(I)= PI*RHOCPL(J)*(R(I+1)**2 -     RBARC**2)
     1 +RHOCPC(J) *PI*(RBARC**2 -R(I)**2)                                ,25
  700 CONTINUE                                                           ,26   ,27
```

```
      SUBROUTINE RESTAN
C     ------------------------------------------------------------------
C     THIS ROUTINE COMPUTES THE VALUE OF ALL RESISTORS, EXCEPTING THOSE
C     LOCATED ON THE INTERIOR OR EXTERIOR SURFACES. VALUES GENERATED ARE
C     STORED IN ARRAY -RES-. THE RESISTOR CONNECTED BETWEEN NODES N AND
C     N+1, IS ASSIGNED SUBSCRIPT N
C     ------------------------------------------------------------------
      INTEGER FIRST,FIRSTN
      REAL KL,KC
      COMMON /CONSNT/ PI, PI2
      COMMON /GEOMRY/ LAST(10),MATERS,  DR,DR2, RO,  X(10), R(500),LASTN
      COMMON /POINTR/RBAR,RBARN,RBARC,RBARCN,ICHAR,ICHARN, FIRST,FIRSTN,
     1DC,DCN
      COMMON /PROPTY/ TC(10),TA, QC(10),QA,RHOL(10), RHOC(10),RHOCPL(10)
     1,RHOCPC(10), RES(500), CAP(500), KC(10),KL(10),CPL(10),CPC(10)
C
C                                                         SURFACE NODE
      I = FIRST                                                               ,1
      IF(ICHAR .EQ. FIRST) GO TO 150
C                                                         ABLATION            ,2    ,3    ,4
      RES(I) = ALOG( R(I+1)/RBAR)/(PI2*KC(1))                                 ,5
      GO  TO  200
C                                                      NO ABLATION....        ,6
  150 RES(I)=  ALOG( RBARC/R(I))/(PI2 *KC(1)) + ALOG( R(I+1)/RBARC)/(PI2
     1*KL(1))                                                                 ,7
  200 INDEX= FIRST  +1                                                        ,8
  300 M=LASTN-1                                                               ,9
      DO 600 I=INDEX,M
C                                  -------------SELECT PROPERTIES             ,10
      DO 350 J=1,MATERS                                                       ,11
  350 IF(I .LE. LAST(J)) GO TO 380                                            ,12   ,13   ,14   ,15
  380 IF(I .LT. ICHAR) GO  TO  550                                            ,16   ,17   ,18
      IF(I  .GT.  ICHAR) GO  TO  500
C                                                      CHARRING NODE..        ,19   ,20   ,21
      RES(I) = ALOG(RBARC/R(I))/(PI2*KC(J))+ALOG(R(I+1)/RBARC)/(PI2*
     1 KL(J))                                                                 ,22
      GO TO 600
C                                                      LAMINATE NODE..        ,23
  500 RES(I) = ALOG(R(I+1)/R(I))/(PI2*KL(J))                                  ,24
```

```
      GO TO 600
C                                                   CHARRED NODE...          ,25
  550 RES(I)= ALOG( R(I+1)/R(I))/(PI2*KC(J))                                 ,26
  600 CONTINUE                                                               ,27   ,28
      RETURN                                                                 ,29
      END                                                                    ,30
```

```
      SUBROUTINE CHAR(QNET)
C     ----------------------------------------------------------------
C     THIS SUBROUTINE CALCULATES THE PROPOGATION OF THE CHAR/LAMINATE
C     INNERFACE DURING THE TIME INTERVAL -DT.
C     ----------------------------------------------------------------
      INTEGER FIRST
      REAL KL,KC
      COMMON /CONSNT/ PI, PI2
      COMMON /GEOMRY/ LAST(10),MATERS,  DR,DR2, RO,  X(10), R(500),LASTN
      COMMON /POINTR/RBAR,RBARN,RBARC,RBARCN,ICHAR,ICHARN, FIRST
      COMMON /PROPTY/ TC(10),TA, QC(10),QA,RHOL(10), RHOC(10),RHOCPL(10)
     1,RHOCPC(10), RES(500), CAP(500), KC(10),KL(10),CPL(10),CPC(10)
      COMMON /TEMPS/ T(500), TP(500)
      COMMON /TIMES/ DTX(500), LSTABL,THETA, DT, PEREND, START
C
C                                                 IF CHAR NODE IS LAST
C                                                 NODE, NO FURTHER CHARR-
C                                                 CAN OCCUR.
      IF(ICHAR.EQ. LASTN) RETURN
C                                                 SELECT CHAR PROPERTIES              ,1    ,2    ,3
      DO 100 J=1,MATERS                                                               ,4
  100 IF(ICHAR  .LE. LAST(J)) GO TO 150                                               ,5    ,6    ,7    ,8
  150 IF(TP(ICHAR) .EQ. TC(J)) GO TO 160
C                                                 SUBTRACT FROM QNET,
C                                                 ENERGY REQUIRED
C                                                 TO RAISE NODE TO TC(J).             ,9    ,10   ,11
      QNET = QNET-((TC(J)-TP(ICHAR))*CAP(ICHAR))                                      ,12
  160 T(ICHAR) = TC(J)
C                                                 DETERMINE PROPAGATION
C                                                 OF CHAR/LAMINATE INTER-
C                                                 FACE DURING INTERVAL DT
C                                                                                     ,13
      RBARCN = SQRT((QNET/QC(J))/(PI*(RHOL(J)-RHOC(J)))+RBARC**2)
C
C                                                 TEST FOR INTERFACE AT
C                                                 NODE BOUNDRY                        ,14
      IF(RBARCN .LT. (R(ICHAR+1)))RETURN                                              ,15   ,16   ,17
      IF(ICHAR .EQ. FIRST)  GO TO 400
C                                                 NODE IS FULLY CHARRED
```

```
C                                             ALLOW NODE TO RISE
C                                             ABOVE TC(I).
C                                                                             ,18    ,19    ,20
      QNET = QNET-(PI*(R(ICHAR+1)**2-RBARC**2)*(RHOL(J)-RHOC(J))*QC(J))       ,21
  300 T(ICHAR)=TC(J)+QNET/(RHOCPC(J)*PI*(R(ICHAR+1)**2-R(ICHAR)**2))          ,22
  310 ICHARN=ICHAR +1                                                         ,23
      RBARCN = R(ICHARN)                                                      ,24
      RETURN
C                                             CHAR NODE IS THE FIRST
C                                             NODE. MODIFY DT SUCH
C                                             THAT CHAR BOUNDRY IS AT
C                                             BOUNDRY OF NEXT NODE.
C                                                                             ,25
  400 DT= (PI*(R(ICHAR +1)**2 -RBARC**2)*(RHOL(1)-RHOC(1))*QC(1))/(QNET/
     1DT)                                                                     ,26
      GO TO 310                                                               ,27
      END                                                                     ,28
```

```
       SUBROUTINE PRINT(NFLAG, INDEX, NFIRE, NSOAK)
C-----------------------------------------------------------------------
C      THIS IS THE MAIN OUTPUT ROUTINE.  ONLINE MESSAGES ARE PRINTED AT
C      THE START OF EACH PERIOD UNLESS THE -PULSE- OPTION IS IN EFFECT.
C-----------------------------------------------------------------------
       INTEGER TYPEX,FIRST
       COMMON /CONSNT/ PI, PI2
       COMMON  /DIRECT/ TYPEX(4),CONTRL(7),NTALPH,BLANK
       COMMON /FLUX/ CONVIN,CONVEX,RADFLI,RADFLX,QARB(2)
       COMMON /GEOMRY/ LAST(10),MATERS,  DR,DR2, RO,  X(10), R(500),LASTN
       COMMON /LOAD/ ARBCDE(2,2,8),TR,H,EPSILN(2,7), VIEW(2,7),TSINK(2,7)
      1,TAM(2), HX(2),TFREE, MACH,THDIAM ,C(13),CC(10)
       COMMON /POINTR/RBAR,RBARN,RBARC,RBARCN,ICHAR,ICHARN, FIRST
       COMMON /TEMPS/ T(500), TP(500)
       COMMON /TIMES/ DTX(500), LSTABL,THETA, DT, PEREND, START
       DIMENSION DESCP(3, 2)
       DATA (DESCP(1,I), I= 1,2)/  6HIS BEG, 6HINNING/
       DATA (DESCP(2,I), I= 1,2) /6HIN PRO, 5HGRESS/
       DATA (DESCP(3,I), I= 1,2) /6HHAS EN, 3HDED/
       K = NFIRE                                                                     ,1
       IF(INDEX .EQ. 2) K = NSOAK                                                    ,2    ,3    ,4
       X1= PEREND -THETA                                                             ,5
       IF(NFLAG .EQ. 1) PRINT 999, TYPEX(INDEX),K,(DESCP(NFLAG,I),I=1,2)             ,6    ,7    ,8    ,9    ,10   ,1
                                                                                     ,12   ,13
       IF(NFLAG .NE. 3) GO TO 40                                                     ,14   ,15   ,16
       WRITE(6,690) TYPEX(INDEX), K, (DESCP(NFLAG,I) , I = 1,2)                      ,17   ,18   ,19   ,20   ,21   ,2

   690 FORMAT(1H2,28X11H.......... 1A5,6HPERIODI5,1X,2A6,11H ..........//
      1/)
       GO TO 50                                                                      ,23
   999 FORMAT(     8X,10H****      ,1A5,6HPERIOD,I5,1X, 2A6)
    40 WRITE(6,700) TYPEX(INDEX), K,(DESCP(NFLAG,I),I=1,2) , X1
      1,TYPEX(INDEX)                                                                 ,24   ,25   ,26   ,27   ,28   ,2
                                                                                     ,30
   700 FORMAT(1H2   8X,10H......... ,1A5,6HPERIOD,I5,1X, 2A6,4H ---,  F8.
      12, 9H SEC. OF ,1A5,17HFOLLOWS ......... ///)
    50 CONTINUE                                                                      ,31
       X1=THETA-START                                                                ,32
       WRITE(6,900) THETA, X1                                                        ,33   ,34   ,35
```

```
      EXTERNAL FORMULA NUMBER   -   SOURCE STATEMENT    -   INTERNAL FORMULA NUMBER(S)

900 FORMAT(     5X, 26HELAPSED TIME IN DUTY CYCLE,  12X,  F9.2, 5H SEC.
   17X,   26HELAPSED TIME THIS PERIOD  , F9.2,  4H SEC)
    X1=RBARC-RO                                                      ,36
    WRITE(6,901) RBARC,X1                                            ,37    ,38    ,39
901 FORMAT(  5X, 35HCHAR-DEPTH WITH RESPECT TO      C/L,F12.4, 7H INCH
   1ES, 5X, 16HTOTAL CHAR-DEPTH,12X, F7.4,  4H IN.)
    X1=RBAR-RO                                                       ,40
    WRITE(6,902) RBAR,X1                                             ,41    ,42    ,43
902 FORMAT( 5X,   35HABLATION DEPTH WITH RESPECT TO  C/L, F12.4,  8H I
   1NCHES., 4X, 26HTOTAL DIMENSIONAL ABLATION,  F9.4, 4H IN.)
    WRITE(6,903)                                                     ,44    ,45
903 FORMAT (///60X,      31H-- INTERIOR --    -- EXTERIOR --//)
    X1 = H                                                           ,46
    IF(INDEX .EQ. 2) X1 = 0.0                                        ,47    ,48    ,49
    WRITE(6,904) X1, HX(INDEX)                                       ,50    ,51    ,52
904 FORMAT( 5X, 43HCONVECTION COEFFICIENT    BTU/SQ-IN-SEC-R. , 12X,
   11PE14.5,3X, 1PE14.5)
    X1 = TR                                                          ,53
    IF(INDEX .EQ. 2) X1 = 0.0                                        ,54    ,55    ,56
    WRITE(6,905) X1,TAM(INDEX)                                       ,57    ,58    ,59
905 FORMAT( 5X, 34HRECOVERY/AMBIENT TEMP.    DEG. R.  21X, F14.3, 3X,
   1F14.3)
    X1= CONVIN/( PI2* RBAR)                                          ,60
    X2=-CONVEX/( PI2* R(LASTN))                                      ,61
906 FORMAT(/5X, 40HHEAT FLUX (CONVECTION)    BTU/SQ-IN-SEC., 15X, 1PE1
   14.5 ,3X, 1PE14.5)
    WRITE(6,906) X1,X2                                               ,62    ,63    ,64
    X1=-RADFLI/(PI2*RBAR)                                            ,65
    X2=-RADFLX/(PI2*R(LASTN))                                        ,66
    WRITE(6,907)  X1,X2                                              ,67    ,68    ,69
907 FORMAT( 5X, 40HHEAT FLUX (RADIATION)     BTU/SQ-IN-SEC., 15X, 1PE1
   14.5,  3X,  1PE14.5)
    X1 = QARB(1)/(PI2 *RBAR)                                         ,70
    X2 = QARB(2)/(PI2 *R(LASTN))                                     ,71
    WRITE(6,908) X1,X2                                               ,72    ,73    ,74
908 FORMAT( 5X, 40HHEAT FLUX (ARBITRARY)     BTU/SQ-IN-SEC., 15X, 1PE1
   14.5,  3X,  1PF14.5)
    WRITE(6, 915) LSTABL, DTX(LSTABL)                                ,75    ,76    ,77
915 FORMAT( /5X, 14HSTABILITY NODE, I4, 1PE20.8)
    WRITE(6, 909)                                                    ,78    ,79
```

```
   HARRIS        4F        C0800914EH                      S4          11-06-64   TIME 10.518V12D03 5011 PAGE  42
        EXTERNAL FORMULA NUMBER    -    SOURCE STATEMENT     -    INTERNAL FORMULA NUMBER(S)

909 FORMAT(//  34X, 41H********** TEMPERATURE PROFILE **********///)
    LINE=0                                                                          ,80
    LC = FIRST                                                                      ,81
580 NHI = LC + 9                                                                    ,82
    IF(NHI .GE. LASTN)NHI = LASTN                                                   ,83   ,84   ,85
    WRITE( 6,920)(I,I = LO, NHI)                                                    ,86   ,87   ,88   ,89   ,90
920 FORMAT(8X, 10I10)
    WRITE(6,921)(T(I),I = LO,NHI)                                                   ,91   ,92   ,93   ,94   ,95
921 FORMAT(8X, 10F10.3//)
    IF( NHI .EQ. LASTN) RETURN                                                      ,96   ,97   ,98
    LINE=LINE +1                                                                    ,99
    IF(LINE .NE. 5) GO TO 590                                                       ,100  ,101  ,102
    LINE=0                                                                          ,103
    WRITE(6,930)                                                                    ,104  ,105
930 FORMAT(1H1 34X,  41H***** TEMPERATURE PROFILE CONTINUED ***** ///)
590 LO = NHI +1                                                                     ,106
    GO TO 580                                                                       ,107
    END                                                                             ,108
```

```
 BLOCK DATA
 COMMON  /DIRECT/ TYPEX(4),CONTRL(7),NTALPH,BLANK
 INTEGER TYPEX,NTALPH,BLANK,CONTRL
 DATA NTALPH/1HT/
 DATA BLANK/1H /
 DATA(TYPEX(I),I=1,4)/4HFIRE,4HSOAK,5HPULSE,  6HENDDUT  /
 DATA (CONTRL(I),I=1,7) / 5HARB-Q,6HINTERI,  6HRADIAT, 6HEXTERI,
15HBARTZ, 6HENDFIR, 6HENDSOA/
 END
```

```
      EXTERNAL FORMULA NUMBER   -   SOURCE STATEMENT   -   INTERNAL FORMULA NUMBER(S)

       REAL FUNCTION INTPLT(INDEX,NOX,NOY, ARG)
C-----------------------------------------------------------------------
C      THIS ROUTINE PERFORMS STRAIGHT LINE INTERPLOATIONS BETWEEN POINTS
C      FALLING ON THE CURVE Y= F(X).  NO ERRORS ARE INDICATED IF THE
C      ARGUMENT FALLS OUTSIDE OF THE CURVE.
C-----------------------------------------------------------------------
       COMMON /TABLES/ X(51,12,2),Y(51,12,2)
       DO  40 I=1,51                                                        ,1
       IF(ARG .LE. X(I,NOX,INDEX))GO TO 45                                  ,2     ,3     ,4
    40 IF(X(I,NOX,INDEX).LT. 0.0) GO TO 42                                  ,5     ,6     ,7     ,8
    42 INTPLT=Y(I-1,NOY,INDEX)                                              ,9
       RETURN                                                               ,10
    45 INTPLT= Y(I,NOY,INDEX)-(X(I,NOX,INDEX)-ARG)/(X(I,NOX,INDEX)-X(I-1,
      1NOX,INDEX))*(Y(I,NOY,INDEX)-Y(I-1,NOY,INDEX))                        ,11
       RETURN                                                               ,12
       END                                                                  ,13
```

## IX-B - SAMPLE PROBLEMS

This section is included to demonstrate the use of the various options available with the program. For each problem the following is included:

1. A brief description
2. Sample input sheets
3. Sample output

The times given in the parentheses are approximate running times.

### SAMPLE PROBLEM NO.1. ($\approx$1 MIN)

The liner is composed of "3" materials. The duty cycle consists of 1, 50 second fire period. Basic Input Sheet -- 1, and Input Blocks 1, 2, and 3 have been used.

During the 50 second fire period, the liner interior will lose heat in an amount equal to:

$$Q/A = -.285\, e^{-.05\theta}$$

This information has been input using Input Block 1, Arbitrary Heat Flux. The gas recovery temperature has been specified as 4585.0°R. The interior convection coefficient is to vary as a function of time, (note that the "2" card has been included in Block 2, with the value portion left blank).

The liner radiates from its interior and exterior. Both sinks have been set constant at 620.0°R.

Printouts have been requested at intervals of 10.0 seconds.

Keypunch all printed and handwritten data enclosed in ☐; if the line is preceded by *, omit all others.

## AEROJET-GENERAL CORPORATION CHARRING AND DIMENSIONAL ABLATION PROGRAM

BASIC INPUT ---- Sheet 1

1) This sheet must be completed for all cases.
2) Sheet 2 must be completed if the temperature frofile at start time is not uniform.

PAGE 1 OF 3

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

TITLE CARD-79 CHARACTERS

* T SAMPLE PROBLEM NO. 1 ARB-Q, TABULAR H, RADIATION

* Number of Materials ≤ 8 [3] Number of Nodes. ≤ 500 [25] Enter(T) if nozzle station is throat. [ ]

* Inside radius from ¢ IN [2.1] Initial Char Depth IN. From Internal Surface [.] Liner temperature if uniform °R [620.0]

* Ablation Temperature °R [3760.0] Heat of ablation BTU/lb of CHAR [+9.42 +02]

MATERIAL SPECIFICATIONS

| | MATERIAL 1 | MATERIAL 2 | MATERIAL 3 | MATERIAL 4 | MATERIAL 5 | MATERIAL 6 | MATERIAL 7 | MATERIAL 8 |
|---|---|---|---|---|---|---|---|---|
| * Thickness Inches | .27 | .03 | .075 | . | . | . | . | . |
| * C$_p$-Laminate BTU/LB-°R | .26 | .45 | .30 | . | . | . | . | . |
| * C$_p$-Char BTU/LB-°R | .30 | .45 | .30 | . | . | . | . | . |
| * K-Laminate B/IN-SEC-R | 1.5 −06 | 3.31 −06 | 4.24 −06 | . − | . − | . − | . − | . − |
| * K-Char B/IN-SEC-R | 5.3 −06 | 3.31 −06 | 4.24 −06 | . − | . − | . − | . − | . − |
| * ρ-Laminate LB/IN$^3$ | .065 | .036 | .074 | . | . | . | . | . |
| * ρ-Char LB/IN$^3$ | .045 | .036 | .074 | . | . | . | . | . |
| * T-Char °R | 1460.0 | 1460.0 | 1460.0 | . | . | . | . | . |
| * Q-Char BTU/LB | 2.145+03 | 2.145+03 | 2.145+03 | . + | . + | . + | . + | . + |

Keypunch all printed
and handwritten data
enclosed in ☐; if
the line is preceded
by *, omit all others.

## FIRE PERIOD DESCRIPTION

PAGE 2 OF 3

| | Duration(sec.) | Print(sec.) | Δθ min. | Δθ max. | |
|---|---|---|---|---|---|
| * FIRE | 50.0 | 10.0 | .01 | 1.0 | The word "FIRE" must be input in Columns 1 - 4. A duration must be input. |

$q/A = a \sin(b + kt) + c + dt + ft^2 + ge^{ht}$

* ARB-Q ---- Input Block 1 Arbitrary Heat Flux ----

| | a | b | k | c | d | f | g | h |
|---|---|---|---|---|---|---|---|---|
| * 1 at interior | | | | | | | -.285 +00 | -.05 |
| 2 at exterior | | | | | | | | |

* -blank card-

* INTERIOR ----- Input Block 2 Interior Convection -----

| | | |
|---|---|---|
| * 1 Recovery Temp. °R | 4585.0 | |
| * 2 Convection Coefficient | . - | BTU/in$^2$-sec °R |

Input convection coefficient value only if constant.

| | Time | h BTU/in$^2$-sec °R | |
|---|---|---|---|
| * The final entry | 0.0 | 1.78 -04 | If the interior convection |
| * of this table | 16.5 | 1.36 -04 | coefficient is time dependent |
| * must have a "1" | 33.3 | 1.37 -04 | complete this table. Card 2 |
| * in Column 1. | 41.8 | 1.39 -04 | above must be input with value |
| * 1 Add more cards | 50.0 | 1.42 -04 | left blank |
| as required up | | . - | |
| to 50. | | . - | |

* -blank card-

| | |
|---|---|
| ENDFIRE | Include this card at the end of a fire period description. |
| ENDDUTY | Include this card after the final period of the duty cycle. |

Keypunch all printed
and handwritten data
enclosed in ☐ ; if
the line is preceded
by *, omit all others.

# AEROJET-GENERAL CORPORATION CHARRING AND DIMENSIONAL ABLATION PROGRAM

## INPUT BLOCK 3 - RADIATION

Include this block as required to describe a fire and/or soak period.

PAGE 3 OF 3

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

* RADIATE

| | | Emissivity | Shape Factor | Sink Temp °R |
|---|---|---|---|---|
| * 1 | Interior Term 1 | .80 | .009 | 620.0 |
| 2 | Interior Term 2 | . | . | . |
| * 3 | Exterior Term 1 | .70 | 1.0 | 620.0 |
| 4 | Exterior Term 2 | . | . | . |
| 5 | Exterior Term 3 | . | . | . |
| 6 | Exterior Term 4 | . | . | . |
| 7 | Exterior Term 5 | . | . | . |

If any sink temperature is intended to be 0 °R enter .001.

* —blank card—

8 Include this card if any exterior sink temperatures are to be time dependent

If all exterior radiation is to constant sink temperatures, omit these cards.

| | Time (sec.) | Sink 1 °R | Sink 2 °R | Sink 3 °R | Sink 4 °R | Sink 5 °R |
|---|---|---|---|---|---|---|
| The final entry | | . | . | . | . | . |
| of this table | | . | . | . | . | . |
| must have a "1" | | . | . | . | . | . |
| in Column 1. | | . | . | . | . | . |
| Add more cards | | . | . | . | . | . |
| as required up | | . | . | . | . | . |
| to 50. | | . | . | . | . | . |
| | | . | . | . | . | . |
| | | . | . | . | . | . |
| | | . | . | . | . | . |

Enter tabular values for all time varying exterior sink temperatures.

* ENDFIRE Include this card if this is the final input block for a fire period.

ENDSOAK Include this card if this is the final input block for a soak period.

* ENDDUTY If this is the final fire or soak period of the duty cycle, include this card.

```
                                    **** AEROJET-GENERAL CORPORATION ****
                                    -------------------------------------

                                 CHARRING AND DIMENSIONAL ABLATION PROGRAM

                           SAMPLE PROBLEM NO. 1 ARB-G, TABULAR H, RADIATION

                                          --- LINER DESCRIPTION ---

LINER IS COMPOSED OF  3 MATERIAL(S)
NUMBER OF NODES =  25
RADIUS FROM NOZZLE CENTER-LINE =  2.1000 INCHES.
RADIUS TO LINER EXTERIOR =  2.4750 INCHES.
TOTAL LINER THICKNESS =  0.3750 INCHES.
RADIAL INCREMENT = 0.01630 INCHES.
HEAT OF ABLATION =  9.4200E 02 BTU/LB.
ABLATION TEMPERATURE = 3760.00 DEG.-R

                                          MATERIAL SPECIFICATIONS

                                      MATERIAL 1  MATERIAL 2  MATERIAL 3  MATERIAL 4  MATERIAL 5  MATERIAL 6  MATER

 THICKNESS          INCHES.              0.2700      0.0300      0.0750
 SP-HEAT LAMINATE   B/LB-R.          2.6000E-01  4.5000E-01  3.0000E-01
 SP-HEAT CHAR       B/LB-R.          3.0000E-01  4.5000E-01  3.0000E-01
 COND LAMINATE      B/IN-SEC-R.      1.5000E-06  3.3100E-06  4.2400E-06
 COND CHAR          B/IN-SEC-R.      5.3000E-06  3.3100E-06  4.2400E-06
 DENSITY LAMINATE   LB/CU-IN.        6.5000E-02  3.6000E-02  7.4000E-02
 DENSITY CHAR       LB/CU-IN.        4.5000E-02  3.6000E-02  7.4000E-02
 CHAR TEMPERATURE   DEG-R.             1460.000    1460.000    1460.000
 EFF. HEAT OF CHAR  B/LB CHARRED     2.1450E 03  2.1450E 03  2.1450E 03
 INTERFACE NODE     NUMBER                   18          20          25
```

```
......... FIRE PERIOD    1 IS BEGINNING ---   50.00 SEC. OF FIRE FOLLOWS .........

ELAPSED TIME IN DUTY CYCLE                   0.    SEC.      ELAPSED TIME THIS PERIOD       0.    SEC
CHAR-DEPTH WITH RESPECT TO      C/L     2.1000 INCHES      TOTAL CHAR-DEPTH              0.       IN.
ABLATION DEPTH WITH RESPECT TO  C/L     2.1000 INCHES.     TOTAL DIMENSIONAL ABLATION    0.       IN.


                                                          -- INTERIOR --   -- EXTERIOR --

CONVECTION COEFFICIENT     BTU/SQ-IN-SEC-R.                  1.78000E-04      0.
RECOVERY/AMBIENT TEMP.     DEG. R.                             4585.000              0.

HEAT FLUX (CONVECTION)     BTU/SQ-IN-SEC.                    7.05770E-01     -0.
HEAT FLUX (RADIATION)      BTU/SQ-IN-SEC.                  -0.               -0.
HEAT FLUX (ARBITRARY)      BTU/SQ-IN-SEC.                  -2.85000E-01       0.

STABILITY NODE    1       0.

                       ********** TEMPERATURE PROFILE **********

          1         2         3         4         5         6         7         8         9        10
    620.000   620.000   620.000   620.000   620.000   620.000   620.000   620.000   620.000   620.000

         11        12        13        14        15        16        17        18        19        20
    620.000   620.000   620.000   620.000   620.000   620.000   620.000   620.000   620.000   620.000

         21        22        23        24        25
    620.000   620.000   620.000   620.000   620.000
```

```
......... FIRE PERIOD    1 IN PROGRESS  ---   40.00 SEC. OF FIRE FOLLOWS .........

FLAPSED TIME IN DUTY CYCLE                 10.00 SEC.      ELAPSED TIME THIS PERIOD      10.00 SEC
CHAR-DEPTH WITH RESPECT TO       C/L       2.1306 INCHES   TOTAL CHAR-DEPTH              0.0306 IN.
ABLATION DEPTH WITH RESPECT TO   C/L       2.1000 INCHES.  TOTAL DIMENSIONAL ABLATION    0.     IN.


                                                        -- INTERIOR --   -- EXTERIOR --

CONVECTION COEFFICIENT     BTU/SQ-IN-SEC-R.                 1.52545E-04      0.
RECOVERY/AMBIENT TEMP.     DEG. R.                            4585.000             0.

HEAT FLUX (CONVECTION)     BTU/SQ-IN-SEC.                   3.53171E-01     -0.
HEAT FLUX (RADIATION)      BTU/SQ-IN-SEC.                  -6.29068E-04     -0.
HEAT FLUX (ARBITRARY)      BTU/SQ-IN-SEC.                  -1.72861E-01      0.

STABILITY NODE    1        1.37053224E-01

                        ********** TEMPERATURE PROFILE **********

          1         2         3         4         5         6         7         8         9        10
   2269.815  1996.300  1460.000  1131.054   859.096   720.176   658.064   633.168   624.148   621.190

         11        12        13        14        15        16        17        18        19        20
    620.312   620.075   620.016   620.003   620.001   620.000   620.000   620.000   620.000   620.000

         21        22        23        24        25
    620.000   620.000   620.000   620.000   620.000
```

```
......... FIRE PERIOD    1 IN PROGRESS  ---   30.00 SEC. OF FIRE FOLLOWS .........

ELAPSED TIME IN DUTY CYCLE                 20.00 SEC.      ELAPSED TIME THIS PERIOD      20.00 SEC
CHAR-DEPTH WITH RESPECT TO      C/L       2.1540 INCHES    TOTAL CHAR-DEPTH             0.0540 IN.
ABLATION DEPTH WITH RESPECT TO  C/L       2.1000 INCHES.   TOTAL DIMENSIONAL ABLATION   0.      IN.


                                                          -- INTERIOR --   -- EXTERIOR --

CONVECTION COEFFICIENT    BTU/SQ-IN-SEC-R.                 1.36208E-04      0.
RECOVERY/AMBIENT TEMP.    DEG. R.                             4585.000            0.

HEAT FLUX (CONVECTION)    BTU/SQ-IN-SEC.                   2.66094E-01     -0.
HEAT FLUX (RADIATION)     BTU/SQ-IN-SEC.                  -1.13914E-03     -0.
HEAT FLUX (ARBITRARY)     BTU/SQ-IN-SEC.                  -1.04846E-01      0.

STABILITY NODE   1      1.39903457E-01

                    ********** TEMPERATURE PROFILE **********

          1         2         3         4         5         6         7         8         9        10
   2631.417  2389.275  1919.771  1460.000  1296.452  1025.524   848.587   741.219   680.644   648.694

         11        12        13        14        15        16        17        18        19        20
    632.858   625.460   622.198   620.839   620.304   620.104   620.034   620.009   620.004   620.001

         21        22        23        24        25
    620.000   620.000   620.000   620.000   620.000
```

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```
......... FIRE PERIOD    1 IN PROGRESS  ---   20.00 SEC. OF FIRE FOLLOWS .........

FLAPSED TIME IN DUTY CYCLE                    30.00 SEC.      ELAPSED TIME THIS PERIOD      30.00 SEC
CHAR-DEPTH WITH RESPECT TO        C/L         2.1734 INCHES   TOTAL CHAR-DEPTH              0.0734 IN.
ABLATION DEPTH WITH RESPECT TO    C/L         2.1000 INCHES.  TOTAL DIMENSIONAL ABLATION    0.      IN.


                                                              -- INTERIOR --    -- EXTERIOR --

CONVECTION COEFFICIENT     BTU/SQ-IN-SEC-R.                     1.36804E-04      0.
RECOVERY/AMBIENT TEMP.     DEG. R.                                4585.000             0.

HEAT FLUX (CONVECTION)     BTU/SQ-IN-SEC.                       2.16970E-01     -0.
HEAT FLUX (RADIATION)      BTU/SQ-IN-SEC.                      -1.92430E-03     -1.94127E-08
HEAT FLUX (ARBITRARY)      BTU/SQ-IN-SEC.                      -6.35921E-02      0.

STABILITY NODE   1      1.39755920E-01

                         ********** TEMPERATURE PROFILE **********

         1         2         3         4         5         6         7         8         9        10
  2999.002  2769.386  2323.257  1892.895  1529.800  1366.425  1103.331   922.950   802.427   725.544

        11        12        13        14        15        16        17        18        19        20
   678.722   651.442   636.206   628.041   623.838   621.758   620.759   620.276   620.147   620.069

        21        22        23        24        25
   620.036   620.019   620.011   620.009   620.009
```

```
......... FIRE PERIOD    1 IN PROGRESS ---   10.00 SEC. CF FIRE FOLLOWS .........

ELAPSED TIME IN DUTY CYCLE                 40.00 SEC.      ELAPSED TIME THIS PERIOD      40.00 SEC
CHAR-DEPTH WITH RESPECT TO      C/L        2.1897 INCHES   TOTAL CHAR-DEPTH              0.0897 IN.
ABLATION DEPTH WITH RESPECT TO  C/L        2.1000 INCHES.  TOTAL DIMENSIONAL ABLATION    0.     IN.


                                                      -- INTERIOR --    -- EXTERIOR --

CONVECTION COEFFICIENT     BTU/SQ-IN-SEC-R.             1.38576E-04       0.
RECOVERY/AMBIENT TEMP.     DEG. R.                        4585.000              0.

HEAT FLUX (CONVECTION)     BTU/SQ-IN-SEC.               1.81509E-01      -0.
HEAT FLUX (RADIATION)      BTU/SQ-IN-SEC.              -2.73873E-03      -3.14091E-07
HEAT FLUX (ARBITRARY)      BTU/SQ-IN-SEC.              -3.85706E-02       0.

STABILITY NODE    1       1.39406554E-01

                    ********** TEMPERATURE PROFILE **********

         1         2         3         4         5         6         7         8         9        10
  3275.192  3062.475  2650.228  2258.598  1907.608  1627.955  1438.917  1146.684   966.993   843.079

        11        12        13        14        15        16        17        18        19        20
   759.187   704.314   669.611   648.353   635.717   628.406   624.246   621.836   621.107   620.613

        21        22        23        24        25
   620.376   620.238   620.166   620.143   620.142
```

```
          .......... FIRE PERIOD    1 HAS ENDED    ..........

ELAPSED TIME IN DUTY CYCLE                 50.00 SEC.     ELAPSED TIME THIS PERIOD       50.00 SEC
CHAR-DEPTH WITH RESPECT TO      C/L        2.2060 INCHES  TOTAL CHAR-DEPTH               0.1060 IN.
ABLATION DEPTH WITH RESPECT TO  C/L        2.1000 INCHES. TOTAL DIMENSIONAL ABLATION     0.     IN.


                                                      -- INTERIOR --    -- EXTERIOR --

CONVECTION COEFFICIENT    BTU/SQ-IN-SEC-R.              1.42000E-04        0.
RECOVERY/AMBIENT TEMP.    DEG. R.                         4585.000             0.

HEAT FLUX (CONVECTION)    BTU/SQ-IN-SEC.                1.56341E-01       -0.
HEAT FLUX (RADIATION)     BTU/SQ-IN-SEC.               -3.50784E-03       -1.82731E-06
HEAT FLUX (ARBITRARY)     BTU/SQ-IN-SEC.               -2.33942E-02        0.

STABILITY NODE    1       1.38776571E-01

                   ********** TEMPERATURE PROFILE **********

       1         2         3         4         5         6         7         8         9        10
3484.006  3267.290  2904.136  2531.367  2169.635  1833.589  1566.920  1402.962  1159.382   990.768

      11        12        13        14        15        16        17        18        19        20
 868.673   782.690   723.897   684.768   659.341   643.129   632.870   626.236   624.076   622.507

      21        22        23        24        25
 621.700   621.196   620.921   620.829   620.826
```

```
                         **** DUTY CYCLE HAS ENDED ****

         MAXIMUM EXTERIOR TEMPERTURE OCCURED AT   50.00 SECONDS INTO DUTY CYCLE

                         ----- TEMPERATURE PROFILE -----

         1         2         3         4         5         6         7         8         9        10
  3484.006  3287.290  2904.136  2531.367  2169.635  1833.589  1566.920  1402.962  1159.382   990.768

        11        12        13        14        15        16        17        18        19        20
   868.673   782.690   723.897   684.768   659.341   643.129   632.870   626.236   624.076   622.507

        21        22        23        24        25
   621.700   621.196   620.921   620.829   620.826
```

## SAMPLE PROBLEM NO. 2. ($\approx$1 MIN)

This problem is included to demonstrate the use of the restart option. Note that Problem 1 ended with a char depth of .1060 inches measured from the liner's interior surface. At the end of the fire period, the char/laminate boundary was still moving through the liner interior. To contiune with the duty cycle, the char depthat the end of the duty cycle is entered on Card 3 of Basic Input Sheet 1. Basic Input Sheet 2 contains a listing of the node temperatures at the completion of the 50 second fire period; the liner temperature on Card 3 Basic Input Sheet 1 has been left blank. The duty cycle for this problem consists of 1 soak period. T-ext °R has been set negative; the duty cycle will end when the exterior temperature peaks or after 1000 seconds of soak (whichever occurs first). Input Block 3 has again been used.

Printouts have been requested at intervals of 100.0 seconds.

Output for this problem indicates that the exterior temperature reached a peak value of 369.50 seconds into the soak period. At this point the soak period was terminated and the elapsed time advanced to 1000.0 seconds to agree with the duration of the period. The final printout will always indicate the time when the maximum exterior temperature was reached, in this case 369.33 seconds.

Keypunch all printed
and handwritten data
enclosed in ☐ ; if
the line is preceded
by *, omit all others.

## AEROJET-GENERAL CORPORATION CHARRING AND DIMENSIONAL ABLATION PROGRAM

BASIC INPUT ---- Sheet 1

1) This sheet must be completed for all cases.
2) Sheet 2 must be completed if the temperature frofile at start time is not uniform.

PAGE 1 OF 4

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

TITLE CARD-79 CHARACTERS

* T SAMPLE PROBLEM NO. 2 RESTART

* Number of Materials ≤ 8 3 Number of Nodes ≤ 500 25 Enter (T) if nozzle station is throat.

* Inside radius from ¢ IN 2.1 Initial Char Depth IN. From Internal Surface .1060 Liner temperature if uniform °R .

* Ablation Temperature °R 3760.0 Heat of ablation BTU/lb of CHAR +9.42 +02

MATERIAL SPECIFICATIONS

| | MATERIAL 1 | MATERIAL 2 | MATERIAL 3 | MATERIAL 4 | MATERIAL 5 | MATERIAL 6 | MATERIAL 7 | MATERIAL 8 |
|---|---|---|---|---|---|---|---|---|
| * Thickness Inches | .27 | .03 | .075 | . | . | . | . | . |
| * $C_p$-Laminate BTU/LB-°R | .26 | .45 | .30 | . | . | . | . | . |
| * $C_p$-Char BTU/LB-°R | .30 | .45 | .30 | . | . | . | . | . |
| * K-Laminate B/IN-SEC-R | 1.5 -06 | 3.31 -06 | 4.24 -06 | . - | . - | . - | . - | . - |
| * K-Char B/IN-SEC-R | 5.3 -06 | 3.31 -06 | 4.24 -06 | . - | . - | . - | . - | . - |
| * ρ-Laminate LB/IN³ | .065 | .036 | .074 | . | . | . | . | . |
| * ρ-Char LB/IN³ | .045 | .036 | .074 | . | . | . | . | . |
| * T-Char °R | 1460.0 | 1460.0 | 1460.0 | . | . | . | . | . |
| * Q-Char BTU/LB | 2.145+03 | 2.145+03 | 2.145+03 | . + | . + | . + | . + | . + |

Keypunch all printed
and handwritten data
enclosed in ☐; if
the line is preceded
by *, omit all others.

## AEROJET-GENERAL CORPORATION CHARRING AND DIMENSIONAL ABLATION PROGRAM

### BASIC INPUT ---- Sheet 2

Complete this sheet if the liner temperature profile
is not uniform at start time.

PAGE 2 OF 4

ENTER NODE TEMPERATURES IN °R (MUST AGREE WITH CARD 2-SHEET 1)

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | NODE 1 | NODE 2 | NODE 3 | NODE 4 | NODE 5 | NODE 6 | NODE 7 | NODE 8 | NODE 9 | NODE 10 |
| * | 3484.006 | 3287.290 | 2904.136 | 2531.367 | 2169.635 | 1833.589 | 1566.920 | 1402.962 | 1159.382 | 990.768 |
| | NODE 11 | NODE 12 | NODE 13 | NODE 14 | NODE 15 | NODE 16 | NODE 17 | NODE 18 | NODE 19 | NODE 20 |
| * | 868.673 | 782.690 | 723.897 | 684.768 | 659.341 | 643.129 | 632.870 | 626.236 | 624.076 | 622.507 |
| | NODE 21 | NODE 22 | NODE 23 | NODE 24 | NODE 25 | NODE 26 | NODE 27 | NODE 28 | NODE 29 | NODE 30 |
| * | 621.700 | 621.196 | 620.921 | 620.829 | 620.826 | . | . | . | . | . |

Keypunch all printed
and handwritten data
enclosed in ☐ ; if
the line is preceded
by *, omit all others.

AEROJET-GENERAL CORPORATION CHARRING AND DIMENSIONAL ABLATION PROGRAM

## SOAK PERIOD DESCRIPTION

PAGE 3 OF 4

| | | Duration (sec.) | Print (sec.) | Δθ min. | Δθ max. | T-EXT °R | Steady State °R/sec. | Reset °R | |
|---|---|---|---|---|---|---|---|---|---|
| * | SOAK | 1900.0 | 100.0 | .01 | 5.0 | -1.0 | | | the word "SOAK" must be input in Columns 1 - 4. |

(T-EXT °R) The SOAK period will end if the exterior temperature reaches this value.

(STEADY STATE) The SOAK period will end if all the nodal temperatures are changing at a rate less than this input value.

If (T-EXT °R) is negative, the SOAK period will end when the exterior temperature peaks.

(RESET) The temperature profile will be set to this input value at the end of the soak period.

ARB-Q ---- Input Block 1, Arbitrary heat flux----

| | a | b | k | c | d | f | g | h |
|---|---|---|---|---|---|---|---|---|
| 1 At interior | | | | | | | | |
| 2 At exterior | | | | | | | | |

ENDSOAK Include this card at the end of a soak period description.

ENDDUTY Include this card after the final period of the duty cycle.

Keypunch all printed
and handwritten data
enclosed in ☐ ; if
the line is preceded
by *, omit all others.

## AEROJET-GENERAL CORPORATION CHARRING AND DIMENSIONAL ABLATION PROGRAM

## INPUT BLOCK 3 - RADIATION

Include this block as required to describe a fire and/or soak period.

PAGE 4 OF 4

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

* RADIATE

| | | | Emissivity | Shape Factor | Sink Temp °R | |
|---|---|---|---|---|---|---|
| | | | | | | If any sink |
| * | 1 | Interior Term 1 | .80 | .01 | 629.0 | temperature is |
| | 2 | Interior Term 2 | . | . | . | intended to be |
| * | 3 | Exterior Term 1 | .70 | 1.0 | 629.9 | 0 °R enter .001. |
| | 4 | Exterior Term 2 | . | . | . | |
| | 5 | Exterior Term 3 | . | . | . | |
| | 6 | Exterior Term 4 | . | . | . | |
| | 7 | Exterior Term 5 | . | . | . | |

* — blank card —

8 Include this card if any exterior sink temperatures are to be time dependent

| | Time (sec.) | Sink 1 °R | Sink 2 °R | Sink 3 °R | Sink 4 °R | Sink 5 °R | |
|---|---|---|---|---|---|---|---|
| | | | | | | | If all exterior |
| | | | | | | | radiation is to |
| | | | | | | | constant sink |
| The final entry | | . | . | . | . | . | temperatures, |
| of this table | | . | . | . | . | . | omit these cards. |
| must have a "1" | | . | . | . | . | . | |
| in Column 1. | | . | . | . | . | . | Enter tabular |
| Add more cards | | . | . | . | . | . | values for all |
| as required up | | . | . | . | . | . | time varying |
| to 50. | | . | . | . | . | . | exterior sink |
| | | . | . | . | . | . | temperatures. |
| | | . | . | . | . | . | |

| | | |
|---|---|---|
| | ENDFIRE | Include this card if this is the final input block for a fire period. |
| * | ENDSOAK | Include this card if this is the final input block for a soak period. |
| * | ENDDUTY | If this is the final fire or soak period of the duty cycle, include this card. |

```
                              **** AEROJET-GENERAL CORPORATION ****
                              -------------------------------------

                             CHARRING AND DIMENSIONAL ABLATION PROGRAM

                          SAMPLE PROBLEM NO. 2            RESTART

                                     --- LINER DESCRIPTION ---

LINER IS COMPOSED OF  3 MATERIAL(S)
NUMBER OF NODES =  25
RADIUS FROM NOZZLE CENTER-LINE =  2.1000 INCHES.
RADIUS TO LINER EXTERIOR =  2.4750 INCHES.
TOTAL LINER THICKNESS =  0.3750 INCHES.
RADIAL INCREMENT = 0.01630 INCHES.
HEAT OF ABLATION =  9.4200E 02 BTU/LB.
ABLATION TEMPERATURE = 3760.00 DEG.-R

                                       MATERIAL SPECIFICATIONS

                                    MATERIAL 1  MATERIAL 2  MATERIAL 3  MATERIAL 4  MATERIAL 5  MATERIAL 6  MATER

 THICKNESS         INCHES.              0.2700      0.0300      0.0750
 SP-HEAT LAMINATE  B/LB-R.          2.6000E-01  4.5000E-01  3.0000E-01
 SP-HEAT CHAR      B/LB-R.          3.0000E-01  4.5000E-01  3.0000E-01
 COND LAMINATE     B/IN-SEC-R.      1.5000E-06  3.3100E-06  4.2400E-06
 COND CHAR         B/IN-SEC-R.      5.3000E-06  3.3100E-06  4.2400E-06
 DENSITY LAMINATE  LB/CU-IN.        6.5000E-02  3.6000E-02  7.4000E-02
 DENSITY CHAR      LB/CU-IN.        4.5000E-02  3.6000E-02  7.4000E-02
 CHAR TEMPERATURE  DEG-R.             1460.000    1460.000    1460.000
 EFF. HEAT OF CHAR B/LB CHARRED     2.1450E 03  2.1450E 03  2.1450E 03
 INTERFACE NODE    NUMBER                   18          20          25
```

```
......... SOAK PERIOD    1 IS BEGINNING --- 1000.00 SEC. OF SOAK FOLLOWS .........

ELAPSED TIME IN DUTY CYCLE                    0.   SEC.      ELAPSED TIME THIS PERIOD       0.   SEC
CHAR-DEPTH WITH RESPECT TO       C/L     2.2060 INCHES     TOTAL CHAR-DEPTH             0.1060 IN.
ABLATION DEPTH WITH RESPECT TO   C/L     2.1000 INCHES.    TOTAL DIMENSIONAL ABLATION   0.      IN.


                                                         -- INTERIOR --    -- EXTERIOR --

CONVECTION COEFFICIENT     BTU/SQ-IN-SEC-R.                0.                 0.
RECOVERY/AMBIENT TEMP.     DEG. R.                                 0.                 0.

HEAT FLUX (CONVECTION)     BTU/SQ-IN-SEC.                  0.                -0.
HEAT FLUX (RADIATION)      BTU/SQ-IN-SEC.                 -3.89760E-03       -1.82812E-06
HEAT FLUX (ARBITRARY)      BTU/SQ-IN-SEC.                  0.                 0.

STABILITY NODE    1       0.

                          ********** TEMPERATURE PROFILE **********

          1          2          3          4          5          6          7          8          9         10
   3484.006   3287.290   2904.136   2531.367   2169.635   1833.589   1566.920   1402.962   1159.382    990.768

         11         12         13         14         15         16         17         18         19         20
    868.673    782.690    723.897    684.768    659.341    643.129    632.870    626.236    624.076    622.507

         21         22         23         24         25
    621.700    621.196    620.921    620.829    620.826
```

```
......... SOAK PERIOD    1 IN PROGRESS ---   900.00 SEC. OF SOAK FOLLOWS .........

ELAPSED TIME IN DUTY CYCLE                 100.00 SEC.      ELAPSED TIME THIS PERIOD       100.00 SEC
CHAR-DEPTH WITH RESPECT TO        C/L      2.2213 INCHES    TOTAL CHAR-DEPTH               0.1213 IN.
ABLATION DEPTH WITH RESPECT TO    C/L      2.1000 INCHES.   TOTAL DIMENSIONAL ABLATION     0.     IN.


                                                      -- INTERIOR --     -- EXTERIOR --
CONVECTION COEFFICIENT     BTU/SQ-IN-SEC-R.            0.                 0.
RECOVERY/AMBIENT TEMP.     DEG. R.                            0.                 0.

HEAT FLUX (CONVECTION)     BTU/SQ-IN-SEC.              0.                -0.
HEAT FLUX (RADIATION)      BTU/SQ-IN-SEC.             -6.93704E-05       -3.66371E-04
HEAT FLUX (ARBITRARY)      BTU/SQ-IN-SEC.              0.                 0.

STABILITY NODE   1      1.69252262E-01

                   ********** TEMPERATURE PROFILE **********

        1         2         3         4         5         6         7         8         9        10
 1289.798  1289.492  1287.239  1283.373  1277.935  1270.976  1262.556  1252.744  1239.987  1195.149

       11        12        13        14        15        16        17        18        19        20
 1146.215  1094.601  1041.711   988.879   937.321   888.106   842.141   800.173   783.154   768.220

       21        22        23        24        25
  758.829   751.728   746.922   744.391   743.687
```

```
......... SOAK PERIOD    1 IN PROGRESS  ---  800.00 SEC. OF SOAK FOLLOWS .........

ELAPSED TIME IN DUTY CYCLE                200.00 SEC.      ELAPSED TIME THIS PERIOD      200.00 SEC
CHAR-DEPTH WITH RESPECT TO      C/L       2.2213 INCHES    TOTAL CHAR-DEPTH              0.1213 IN.
ABLATION DEPTH WITH RESPECT TO  C/L       2.1000 INCHES.   TOTAL DIMENSIONAL ABLATION    0.     IN.


                                                        -- INTERIOR --    -- EXTERIOR --

CONVECTION COEFFICIENT    BTU/SQ-IN-SEC-R.              0.                0.
RECOVERY/AMBIENT TEMP.    DEG. R.                             0.                0.

HEAT FLUX (CONVECTION)    BTU/SQ-IN-SEC.                0.                -0.
HEAT FLUX (RADIATION)     BTU/SQ-IN-SEC.                -3.90167E-05      -8.59205E-04
HEAT FLUX (ARBITRARY)     BTU/SQ-IN-SEC.                0.                0.

STABILITY NODE    1      1.69259238E-01

                  ********** TEMPERATURE PROFILE **********

        1         2         3         4         5         6         7         8         9        10
 1128.391  1128.270  1127.311  1125.643  1123.281  1120.242  1116.544  1112.211  1106.541  1086.449

       11        12        13        14        15        16        17        18        19        20
 1064.205  1040.286  1015.193   989.439   963.530   937.960   913.192   889.649   879.676   870.459

       21        22        23        24        25
  864.104   858.615   854.001   850.260   848.606
```

```
......... SOAK PERIOD    1 IN PROGRESS  ---  700.00 SEC. OF SOAK FOLLOWS .........

ELAPSED TIME IN DUTY CYCLE                  300.00 SEC.      ELAPSED TIME THIS PERIOD       300.00 SEC
CHAR-DEPTH WITH RESPECT TO       C/L        2.2213 INCHES    TOTAL CHAR-DEPTH               0.1213 IN.
ABLATION DEPTH WITH RESPECT TO   C/L        2.1000 INCHES.   TOTAL DIMENSIONAL ABLATION     0.     IN.


                                                         -- INTERIOR --    -- EXTERIOR --

CONVECTION COEFFICIENT    BTU/SQ-IN-SEC-R.                0.                0.
RECOVERY/AMBIENT TEMP.    DEG. R.                             0.                0.

HEAT FLUX (CONVECTION)    BTU/SQ-IN-SEC.                  0.               -0.
HEAT FLUX (RADIATION)     BTU/SQ-IN-SEC.                 -2.83297E-05      -1.05585E-03
HEAT FLUX (ARBITRARY)     BTU/SQ-IN-SEC.                  0.                0.

STABILITY NODE    1      1.69262081E-01

                    ********** TEMPERATURE PROFILE **********

        1         2         3         4         5         6         7         8         9        10
 1050.455  1050.403  1049.916  1049.051  1047.816  1046.217  1044.263  1041.964  1038.945  1028.189

       11        12        13        14        15        16        17        18        19        20
 1016.184  1003.128   989.231   974.708   959.775   944.640   929.502   914.542   907.912   901.459

       21        22        23        24        25
  896.622   891.998   887.593   883.411   881.378
```

```
***** EXTERIOR TEMPERTURE HAS REACHED A PEAK VALUE *****

......... SOAK PERIOD    1 IN PROGRESS  ---  630.50 SEC. OF SOAK FOLLOWS .........

ELAPSED TIME IN DUTY CYCLE                369.50 SEC.      ELAPSED TIME THIS PERIOD     369.50 SEC
CHAR-DEPTH WITH RESPECT TO      C/L       2.2213 INCHES    TOTAL CHAR-DEPTH             0.1213 IN.
ABLATION DEPTH WITH RESPECT TO  C/L       2.1000 INCHES.   TOTAL DIMENSIONAL ABLATION   0.     IN.

                                                        -- INTERIOR --    -- EXTERIOR --

CONVECTION COEFFICIENT    BTU/SQ-IN-SEC-R.                   0.                0.
RECOVERY/AMBIENT TEMP.    DEG. R.                                   0.                0.

HEAT FLUX (CONVECTION)    BTU/SQ-IN-SEC.                     0.               -0.
HEAT FLUX (RADIATION)     BTU/SQ-IN-SEC.                  -2.44479E-05      -1.08244E-03
HEAT FLUX (ARBITRARY)     BTU/SQ-IN-SEC.                     0.                0.

STABILITY NODE   1      1.69263192E-01

                   ********** TEMPERATURE PROFILE **********

        1         2         3         4         5         6         7         8         9        10
 1017.301  1017.271  1016.936  1016.333  1015.463  1014.333  1012.947  1011.311  1009.155  1001.448

       11        12        13        14        15        16        17        18        19        20
  992.790   983.295   973.081   962.269   950.983   939.341   927.458   915.441   909.980   904.522

       21        22        23        24        25
  900.267   896.029   891.813   887.623   885.538
```

```
          .......... SOAK PERIOD    1 HAS ENDED    ..........

ELAPSED TIME IN DUTY CYCLE              1000.00 SEC.      ELAPSED TIME THIS PERIOD    1000.00 SEC
CHAR-DEPTH WITH RESPECT TO      C/L      2.2213 INCHES     TOTAL CHAR-DEPTH              0.1213 IN.
ABLATION DEPTH WITH RESPECT TO  C/L      2.1000 INCHES.    TOTAL DIMENSIONAL ABLATION   0.      IN.


                                                       -- INTERIOR --    -- EXTERIOR --

CONVECTION COEFFICIENT     BTU/SQ-IN-SEC-R.              0.               0.
RECOVERY/AMBIENT TEMP.     DEG. R.                           0.               0.

HEAT FLUX (CONVECTION)     BTU/SQ-IN-SEC.                0.              -0.
HEAT FLUX (RADIATION)      BTU/SQ-IN-SEC.               -2.44479E-05     -1.08244E-03
HEAT FLUX (ARBITRARY)      BTU/SQ-IN-SEC.                0.               0.

STABILITY NODE   1      1.69263192E-01

                  ********** TEMPERATURE PROFILE **********


         1         2         3         4         5         6         7         8         9        10
  1017.301  1017.271  1016.936  1016.333  1015.463  1014.333  1012.947  1011.311  1009.155  1001.448

        11        12        13        14        15        16        17        18        19        20
   992.790   983.295   973.081   962.269   950.983   939.341   927.458   915.441   909.980   904.522

        21        22        23        24        25
   900.267   896.029   891.813   887.623   885.538
```

```
                                   **** DUTY CYCLE HAS ENDED ****

                  MAXIMUM EXTERIOR TEMPERTURE OCCURED AT  369.33 SECONDS INTO DUTY CYCLE

                                   ----- TEMPERATURE PROFILE -----

         1          2          3          4          5          6          7          8          9         10
  1017.370   1017.339   1017.004   1016.400   1015.530   1014.399   1013.012   1011.374   1009.217   1001.504

        11         12         13         14         15         16         17         18         19         20
   992.841    983.339    973.118    962.300    951.007    939.359    927.470    915.448    909.985    904.524

        21         22         23         24         25
   900.269    896.029    891.813    887.623    885.538
```

## SAMPLE PROBLEM NO. 3. ($\approx$3 MIN)

The duty cycle for this problem is as follows:

1. FIRE 90 seconds
2. SOAK until $T_{exterior} = 540°R$
3. FIRE 400 seconds
4. SOAK to steady state

The following items should be noted on the input forms for this problem:

1. T-ext has been input as 540°R for the first soak period; however, a duration of 1000 seconds has also been input. The soak period will end when the exterior temperature reaches 540°R, or if 1000 seconds elapses.

2. At the conclusion of the first soak period, the liner temperature is to be reset to 530°R. This value has been included in the "RESET" field of the soak card. .

3. The minimum value of $\Delta\theta$ to be used during the first soak period may be no less than .01 seconds.

4. The final soak period is to end when the liner reaches steady state conditions (in this case $\frac{dT}{d\theta} = .005\frac{°R.}{sec}$) The steady state field on the "SOAK" card contains this value. The minimum allowable $\Delta\theta$ is .05 seconds for this final soak.

5. Radiation losses during the final soak period of 2 exterior terms and 1 interior term. Exterior term "2" radiates to a time dependent sink temperature. (Note that time is referenced to the start of the duty cycle).

Output for Sample Problem 3 indicates that Nodes 2 and 3 were consolidated at the beginning of the second soak period. This procedure is expained in Section III Program Techniques.

Keypunch all printed
and handwritten data
enclosed in ☐ ; if
the line is preceded
by *, omit all others.

AEROJET-GENERAL CORPORATION CHARRING AND DIMENSIONAL ABLATION PROGRAM

BASIC INPUT ---- Sheet 1

1) This sheet must be completed for all cases.
2) Sheet 2 must be completed if the temperature frofile at start time is not uniform.

PAGE 1 OF 8

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

TITLE CARD-79 CHARACTERS

* T SAMPLE PROBLEM NO. 3

* Number of Materials ≤ 8 1 Number of Nodes. ≤ 500 20 Enter(T) if nozzle station is throat. T

* Inside radius from ¢ IN • Initial Char Depth IN. From Internal Surface • Liner temperature if uniform °R •

* Ablation Temperature °R 4660•0 Heat of ablation BTU/lb of CHAR +2•6 +04

MATERIAL SPECIFICATIONS

| | MATERIAL 1 | MATERIAL 2 | MATERIAL 3 | MATERIAL 4 | MATERIAL 5 | MATERIAL 6 | MATERIAL 7 | MATERIAL 8 |
|---|---|---|---|---|---|---|---|---|
| * Thickness Inches | 1•5 | • | • | • | • | • | • | • |
| * $C_p$-Laminate BTU/LB-°R | 0•03 | • | • | • | • | • | • | • |
| * $C_p$-Char BTU/LB-°R | 0•03 | • | • | • | • | • | • | • |
| * K-Laminate B/IN-SEC-R | 2•0 -06 | • - | • - | • - | • - | • - | • - | • - |
| * K-Char B/IN-SEC-R | 6•0 -06 | • - | • - | • - | • - | • - | • - | • - |
| * $\rho$-Laminate LB/IN$^3$ | •052 | • | • | • | • | • | • | • |
| * $\rho$-Char LB/IN$^3$ | •035 | • | • | • | • | • | • | • |
| * T-Char °R | 1460•0 | • | • | • | • | • | • | • |
| * Q-Char BTU/LB | 3•7 +03 | • + | • + | • + | • + | • + | • + | • + |

Keypunch all printed
and handwritten data
enclosed in ☐; if
the line is preceded
by *, omit all others.

## AEROJET-GENERAL CORPORATION CHARRING AND DIMENSIONAL ABLATION PROGRAM

## FIRE PERIOD DESCRIPTION

PAGE 2 OF 8

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

Duration(sec.) Print(sec.) Δθ min. Δθ max.

| | Duration(sec.) | Print(sec.) | Δθ min. | Δθ max. |
|---|---|---|---|---|
| * FIRE | 90.0 | | .01 | 5.0 |

The word "FIRE" must be input in Columns 1 - 4. A duration must be input.

$q/A = a \sin(b + kt) + c + dt + ft^2 + ge^{ht}$

ARB-Q ---- Input Block 1 Arbitrary Heat Flux ----

| | a | b | k | c | d | f | g | h |
|---|---|---|---|---|---|---|---|---|
| 1 at interior | | | | | | | | |
| 2 at exterior | | | | | | | | |

* INTERIOR ---- Input Block 2 Interior Convection ----

* 1 Recovery Temp. °R 5100.0

* 2 Convection Coefficient 1.02 -03 BTU/in$^2$-sec °R

Input convection coefficient value only if constant.

* blank card

| | Time | h BTU/in$^2$-sec °R |
|---|---|---|
| The final entry | | . - |
| of this table | | . - |
| must have a "1" | | . - |
| in Column 1. | | . - |
| Add more cards | | . - |
| as required up | | . - |
| to 50. | | . - |

If the interior convection coefficient is time dependent complete this table. Card 2 above must be input with value left blank

| | |
|---|---|
| ENDFIRE | Include this card at the end of a fire period description. |
| ENDDUTY | Include this card after the final period of the duty cycle. |

Keypunch all printed
and handwritten data
enclosed in ☐ ; if
the line is preceded
by *, omit all others.

## AEROJET-GENERAL CORPORATION CHARRING AND DIMENSIONAL ABLATION PROGRAM

## INPUT BLOCK 3 - RADIATION

Include this block as required to describe a fire
and/or soak period.

PAGE 3 OF 8

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

* RADIATE

|  |  | Emissivity | Shape Factor | Sink Temp °R |
|---|---|---|---|---|
| * | 1 Interior Term 1 | .9 | .1 | 530.0 |
|  | 2 Interior Term 2 | [illegible] | . | . |
| * | 3 Exterior Term 1 | .9 | 1.0 | 530.0 |
|  | 4 Exterior Term 2 | . | . | . |
|  | 5 Exterior Term 3 | . | . | . |
|  | 6 Exterior Term 4 | . | . | . |
|  | 7 Exterior Term 5 | . | . | . |

If any sink temperature is intended to be 0 °R enter .001.

* —blank card—

8 Include this card if any exterior sink temperatures are to be time dependent

If all exterior radiation is to constant sink temperatures, omit these cards.

The final entry of this table must have a "1" in Column 1. Add more cards as required up to 50.

| Time (sec.) | Sink 1 °R | Sink 2 °R | Sink 3 °R | Sink 4 °R | Sink 5 °R |
|---|---|---|---|---|---|
|  | . | . | . | . | . |
|  | . | . | . | . | . |
|  | . | . | . | . | . |
|  | . | . | . | . | . |
|  | . | . | . | . | . |
|  | . | . | . | . | . |
|  | . | . | . | . | . |
|  | . | . | . | . | . |
|  | . | . | . | . | . |

Enter tabular values for all time varying exterior sink temperatures.

* ENDFIRE Include this card if this is the final input block for a fire period.

ENDSOAK Include this card if this is the final input block for a soak period.

ENDDUTY If this is the final fire or soak period of the duty cycle, include this card.

Keypunch all printed
and handwritten data
enclosed in ☐ ; if
the line is preceded
by *, omit all others.

# AEROJET-GENERAL CORPORATION CHARRING AND DIMENSIONAL ABLATION PROGRAM

## SOAK PERIOD DESCRIPTION

PAGE 4 OF 8

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

| | Duration (sec.) | Print (sec.) | Δθ min. | Δθ max. | T-EXT °R | Steady State °R/sec. | Reset °R |
|---|---|---|---|---|---|---|---|
| * SOAK | 1000.0 | | .01 | 5.0 | 549.0 | | 530.0 |

the word "SOAK" must be input in Columns 1 - 4.

(T-EXT °R) The SOAK period will end if the exterior temperature reaches this value.

(STEADY STATE) The SOAK period will end if all the nodal temperatures are changing at a rate less than this input value.

If (T-EXT °R) is negative, the SOAK period will end when the exterior temperature peaks.

(RESET) The temperature profile will be set to this input value at the end of the soak period.

ARB-Q

----Input Block 1 Arbitrary heat flux----

| | | a | b | k | c | d | f | g | h |
|---|---|---|---|---|---|---|---|---|---|
| 1 | At interior | – | – | – | – | – | – | – | – |
| 2 | At exterior | – | – | – | – | – | – | – | – |

ENDSOAK Include this card at the end of a soak period description.

ENDDUTY Include this card after the final period of the duty cycle.

Keypunch all printed
and handwritten data
enclosed in ☐ ; if
the line is preceded
by *, omit all others.

# AEROJET-GENERAL CORPORATION CHARRING AND DIMENSIONAL ABLATION PROGRAM

## INPUT BLOCK 3 - RADIATION

Include this block as required to describe a fire and/or soak period.

PAGE ~~*~~ 5 OF 8

*RADIATE

| | | Emissivity | Shape Factor | Sink Temp °R |
|---|---|---|---|---|
| * | 1 Interior Term 1 | .9 | .1 | 530.9 |
| | 2 Interior Term 2 | . | . | . |
| * | 3 Exterior Term 1 | .9 | 1.0 | 530.9 |
| | 4 Exterior Term 2 | . | . | . |
| | 5 Exterior Term 3 | . | . | . |
| | 6 Exterior Term 4 | . | . | . |
| | 7 Exterior Term 5 | . | . | . |

If any sink temperature is intended to be 0 °R enter .001.

* —blank card—

8 Include this card if any exterior sink temperatures are to be time dependent

| | Time (sec.) | Sink 1 °R | Sink 2 °R | Sink 3 °R | Sink 4 °R | Sink 5 °R |
|---|---|---|---|---|---|---|
| The final entry | | . | . | . | . | . |
| of this table | | . | . | . | . | . |
| must have a "1" | | . | . | . | . | . |
| in Column 1. | | . | . | . | . | . |
| Add more cards | | . | . | . | . | . |
| as required up | | . | . | . | . | . |
| to 50. | | . | . | . | . | . |
| | | . | . | . | . | . |
| | | . | . | . | . | . |

If all exterior radiation is to constant sink temperatures, omit these cards.

Enter tabular values for all time varying exterior sink temperatures.

| | | |
|---|---|---|
| | ENDFIRE | Include this card if this is the final input block for a fire period. |
| * | ENDSOAK | Include this card if this is the final input block for a soak period. |
| | ENDDUTY | If this is the final fire or soak period of the duty cycle, include this card. |

Keypunch all printed
and handwritten data
enclosed in ☐; if
the line is preceded
by *, omit all others.

AEROJET-GENERAL CORPORATION CHARRING AND DIMENSIONAL ABLATION PROGRAM

## FIRE PERIOD DESCRIPTION

PAGE 6 OF 8

| | Duration(sec.) | Print(sec.) | Δθ min. | Δθ max. | |
|---|---|---|---|---|---|
| *FIRE | 400.0 | | .01 | 5.0 | The word "FIRE" must be input in Columns 1 - 4. A duration must be input. |

$$q/A = a \sin(b + kt) + c + dt + ft^2 + ge^{ht}$$

ARB-Q ---- Input Block 1 Arbitrary Heat Flux ----

| | a | b | k | c | d | f | g | h |
|---|---|---|---|---|---|---|---|---|
| 1 at interior | | | | | | | | |
| 2 at exterior | | | | | | | | |

INTERIOR ---- Input Block 2 Interior Convection ----

1 Recovery Temp. °R .

2 Convection Coefficient . - BTU/$in^2$-sec °R Input convection coefficient value only if constant.

| Time | h BTU/$in^2$-sec °R | |
|---|---|---|
| The final entry | . - | If the interior convection |
| of this table | . - | coefficient is time dependent |
| must have a "1" | . - | complete this table. Card 2 |
| in Column 1. | . - | above must be input with value |
| Add more cards | . - | left blank |
| as required up | . - | |
| to 50. | . - | |

*ENDFIRE Include this card at the end of a fire period description.

ENDDUTY Include this card after the final period of the duty cycle.

Keypunch all printed
and handwritten data
enclosed in ☐ ; if
the line is preceded
by *, omit all others.

AEROJET-GENERAL CORPORATION CHARRING AND DIMENSIONAL ABLATION PROGRAM

## SOAK PERIOD DESCRIPTION

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1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

| | Duration (sec.) | Print (sec.) | Δθ min. | Δθ max. | T-EXT °R | Steady State °R/sec. | Reset °R |
|---|---|---|---|---|---|---|---|
| * SOAK | 3999.9 | | .95 | 19.9 | | .005 | |

the word "SOAK" must be input in Columns 1 - 4.

(T-EXT °R) The SOAK period will end if the exterior temperature reaches this value.

(STEADY STATE) The SOAK period will end if all the nodal temperatures are changing at a rate less than this input value.

If (T-EXT °R) is negative, the SOAK period will end when the exterior temperature peaks.

(RESET) The temperature profile will be set to this input value at the end of the soak period.

ARB-Q

---- Input Block 1, Arbitrary heat flux----

| | a | b | k | c | d | f | g | h |
|---|---|---|---|---|---|---|---|---|
| 1 At interior | - | - | - | - | - | - | - | - |
| 2 At exterior | - | - | - | - | - | - | - | - |

| | |
|---|---|
| ENDSOAK | Include this card at the end of a soak period description. |
| ENDDUTY | Include this card after the final period of the duty cycle. |

Keypunch all printed
and handwritten data
enclosed in ☐ ; if
the line is preceded
by *, omit all others.

## AEROJET-GENERAL CORPORATION CHARRING AND DIMENSIONAL ABLATION PROGRAM

### INPUT BLOCK 3 - RADIATION

Include this block as required to describe a fire and/or soak period.

PAGE 8 OF 8

| | | Emissivity | Shape Factor | Sink Temp °R | |
|---|---|---|---|---|---|
| * | RADIATE | | | | |
| * | 1 Interior Term 1 | .9 | 1.0 | 530.0 | If any sink |
| | 2 Interior Term 2 | . | . | . | temperature is |
| | 3 Exterior Term 1 | . | . | . | intended to be |
| * | 4 Exterior Term 2 | .9 | 1.0 | . | 0 °R enter .001. |
| | 5 Exterior Term 3 | . | . | . | |
| | 6 Exterior Term 4 | . | . | . | |
| | 7 Exterior Term 5 | . | . | . | |

* 8 Include this card if any exterior sink temperatures are to be time dependent

| | | Time (sec.) | Sink 1 °R | Sink 2 °R | Sink 3 °R | Sink 4 °R | Sink 5 °R | |
|---|---|---|---|---|---|---|---|---|
| * | The final entry | 1490.0 | . | 300.0 | . | . | . | If all exterior radiation is to |
| * | of this table | 1500.0 | . | 530.0 | . | . | . | constant sink temperatures, |
| * | 1 must have a "1" | 4490.0 | . | 530.0 | . | . | . | omit these cards. |
| | in Column 1. | | . | . | . | . | . | |
| | Add more cards | | . | . | . | . | . | Enter tabular |
| | as required up | | . | . | . | . | . | values for all |
| | to 50. | | . | . | . | . | . | time varying |
| * | —blank card— | | . | . | . | . | . | exterior sink |
| | | | . | . | . | . | . | temperatures. |

| | | |
|---|---|---|
| | ENDFIRE | Include this card if this is the final input block for a fire period. |
| * | ENDSOAK | Include this card if this is the final input block for a soak period. |
| * | ENDDUTY | If this is the final fire or soak period of the duty cycle, include this card. |

```
                         **** AEROJET-GENERAL CORPORATION ****
                         -------------------------------------

                       CHARRING AND DIMENSIONAL ABLATION PROGRAM

                              SAMPLE PROBLEM NO. 3

                              --- LINER DESCRIPTION ---

STATION OF INTEREST IS THROAT
LINER IS COMPOSED OF  1 MATERIAL(S)
NUMBER OF NODES =  20
RADIUS FROM NOZZLE CENTER-LINE =  4.1400 INCHES.
RADIUS TO LINER EXTERIOR =  5.6400 INCHES.
TOTAL LINER THICKNESS =  1.5000 INCHES.
RADIAL INCREMENT = 0.08333 INCHES.
HEAT OF ABLATION =  2.6000E 04 BTU/LB.
ABLATION TEMPERATURE = 4660.00 DEG.-R

                               MATERIAL SPECIFICATIONS

                           MATERIAL 1  MATERIAL 2  MATERIAL 3  MATERIAL 4  MATERIAL 5  MATERIAL 6  MATER

 THICKNESS          INCHES.         1.5000
 SP-HEAT LAMINATE  B/LB-R.       3.0000E-02
 SP-HEAT CHAR      B/LB-R.       3.0000E-02
 COND LAMINATE     B/IN-SEC-R.   2.0000E-06
 COND CHAR         B/IN-SEC-R.   6.0000E-06
 DENSITY LAMINATE  LB/CU-IN.     5.2000E-02
 DENSITY CHAR      LB/CU-IN.     3.5000E-02
 CHAR TEMPERATURE  DEG-R.          1460.000
 EFF. HEAT OF CHAR B/LB CHARRED  3.7000E 03
 INTERFACE NODE    NUMBER                20
```

```
......... FIRE PERIOD    1 IS BEGINNING ---   90.00 SEC. OF FIRE FOLLOWS .........

ELAPSED TIME IN DUTY CYCLE                  0.    SEC.      ELAPSED TIME THIS PERIOD        0.    SEC
CHAR DEPTH WITH RESPECT TO       C/L     4.1400 INCHES     TOTAL CHAR-DEPTH              0.       IN.
ABLATION DEPTH WITH RESPECT TO   C/L     4.1400 INCHES.    TOTAL DIMENSIONAL ABLATION    0.       IN.


                                                         -- INTERIOR --    -- EXTERIOR --

CONVECTION COEFFICIENT    BTU/SQ-IN-SEC-R.               1.02000E-03       0.
RECOVERY/AMBIENT TEMP.    DEG. R.                          5100.000            0.

HEAT FLUX (CONVECTION)    BTU/SQ-IN-SEC.                 4.66140E 00      -0.
HEAT FLUX (RADIATION)     BTU/SQ-IN-SEC.                -0.               -0.
HEAT FLUX (ARBITRARY)     BTU/SQ-IN-SEC.                 0.                0.

STABILITY NODE    1       0.

                        ********** TEMPERATURE PROFILE **********

         1         2         3         4         5         6         7         8         9        10
   530.000   530.000   530.000   530.000   530.000   530.000   530.000   530.000   530.000   530.000

        11        12        13        14        15        16        17        18        19        20
   530.000   530.000   530.000   530.000   530.000   530.000   530.000   530.000   530.000   530.000
```

```
                    .......... FIRE PERIOD    1 HAS ENDED     ..........

ELAPSED TIME IN DUTY CYCLE                90.00 SEC.     ELAPSED TIME THIS PERIOD       90.00 SEC
CHAR-DEPTH WITH RESPECT TO      C/L      4.4037 INCHES   TOTAL CHAR-DEPTH              0.2637 IN.
ABLATION DEPTH WITH RESPECT TO  C/L      4.1550 INCHES.  TOTAL DIMENSIONAL ABLATION    0.0150 IN.


                                                     -- INTERIOR --   -- EXTERIOR --

CONVECTION COEFFICIENT    BTU/SQ-IN-SEC-R.             1.02000E-03      0.
RECOVERY/AMBIENT TEMP.    DEG. R.                        5100.000            0.

HEAT FLUX (CONVECTION)    BTU/SQ-IN-SEC.               4.48800E-01     -0.
HEAT FLUX (RADIATION)     BTU/SQ-IN-SEC.              -1.40456E-01     -1.09527E-05
HEAT FLUX (ARBITRARY)     BTU/SQ-IN-SEC.               0.               0.

STABILITY NODE    2      2.98190230E-01

                     ********** TEMPERATURE PROFILE **********

        1         2         3         4         5         6         7         8         9        10
 4660.000  4207.782  2819.464  1460.000  1357.660  1190.964  1044.810   920.849   819.169   738.480

       11        12        13        14        15        16        17        18        19        20
  676.488   630.336   597.022   573.701   557.895   547.577   541.200   537.669   536.296   536.069
```

```
......... SOAK PERIOD    1 IS BEGINNING --- 1000.00 SEC. OF SOAK FOLLOWS .........

ELAPSED TIME IN DUTY CYCLE                     90.00 SEC.      ELAPSED TIME THIS PERIOD        0.   SEC
CHAR DEPTH WITH RESPECT TO         C/L       4.4037 INCHES     TOTAL CHAR-DEPTH             0.2637 IN.
ABLATION DEPTH WITH RESPECT TO     C/L       4.1550 INCHES.    TOTAL DIMENSIONAL ABLATION   0.0150 IN.


                                                              -- INTERIOR --    -- EXTERIOR --

CONVECTION COEFFICIENT     BTU/SQ-IN-SEC-R.                      0.                 0.
RECOVERY/AMBIENT TEMP.     DEG. R.                                   0.                 0.

HEAT FLUX (CONVECTION)     BTU/SQ-IN-SEC.                        4.48800E-01       -0.
HEAT FLUX (RADIATION)      BTU/SQ-IN-SEC.                       -1.40456E-01       -1.09527E-05
HEAT FLUX (ARBITRARY)      BTU/SQ-IN-SEC.                        0.                 0.

STABILITY NODE    2       2.98190230E-01

                         ********** TEMPERATURE PROFILE **********

          1         2         3         4         5         6         7         8         9        10
   4660.000  4207.782  2819.464  1460.000  1357.660  1190.964  1044.810   920.849   819.169   738.480

         11        12        13        14        15        16        17        18        19        20
    676.488   630.336   597.022   573.701   557.895   547.577   541.200   537.669   536.296   536.069
```

```
                 ***** EXTERIOR TEMPERATURE HAS REACHED MAXIMUM VALUE *****

     ......... SOAK PERIOD    1 IN PROGRESS  ---  989.50 SEC. OF SOAK FOLLOWS .........

ELAPSED TIME IN DUTY CYCLE                 100.50 SEC.     ELAPSED TIME THIS PERIOD       10.50 SEC
CHAR-DEPTH WITH RESPECT TO        C/L      4.4084 INCHES   TOTAL CHAR-DEPTH               0.2684 IN.
ABLATION DEPTH WITH RESPECT TO    C/L      4.1550 INCHES.  TOTAL DIMENSIONAL ABLATION     0.0150 IN.


                                                      -- INTERIOR --    -- EXTERIOR --

CONVECTION COEFFICIENT     BTU/SQ-IN-SEC-R.             0.                 0.
RECOVERY/AMBIENT TEMP.     DEG. R.                             0.                 0.

HEAT FLUX (CONVECTION)     BTU/SQ-IN-SEC.               0.                -0.
HEAT FLUX (RADIATION)      BTU/SQ-IN-SEC.              -1.61070E-03       -1.82644E-05
HEAT FLUX (ARBITRARY)      BTU/SQ-IN-SEC.               0.                 0.

STABILITY NODE    1       1.23372620E-01

                      ********** TEMPERATURE PROFILE **********

          1         2         3         4         5         6         7         8         9        10
   1530.415  1533.753  1507.542  1459.202  1375.389  1220.123  1079.529   957.280   854.551   770.853

         11        12        13        14        15        16        17        18        19        20
    704.643   653.753   615.740   588.160   568.764   555.627   547.212   542.381   540.388   540.008
```

```
                    .......... SOAK PERIOD    1 HAS ENDED    ..........

 ELAPSED TIME IN DUTY CYCLE                   1090.00 SEC.      ELAPSED TIME THIS PERIOD    1000.00 SEC
 CHAR-DEPTH WITH RESPECT TO       C/L            4.4084 INCHES   TOTAL CHAR-DEPTH               0.2684 IN.
 ABLATION DEPTH WITH RESPECT TO   C/L            4.1550 INCHES.  TOTAL DIMENSIONAL ABLATION     0.0150 IN.


                                                             -- INTERIOR --    -- EXTERIOR --

 CONVECTION COEFFICIENT      BTU/SQ-IN-SEC-R.                  0.                 0.
 RECOVERY/AMBIENT TEMP.      DEG. R.                                 0.                 0.

 HEAT FLUX (CONVECTION)      BTU/SQ-IN-SEC.                    0.                -0.
 HEAT FLUX (RADIATION)       BTU/SQ-IN-SEC.                   -1.61070E-03       -1.82644E-05
 HEAT FLUX (ARBITRARY)       BTU/SQ-IN-SEC.                    0.                 0.

 STABILITY NODE    1        1.23372620E-01

                     ********** TEMPERATURE PROFILE **********

          1         2         3         4         5         6         7         8         9        10
   1539.615  1533.753  1507.542  1459.202  1375.389  1220.123  1079.529   957.280   854.551   770.853

         11        12        13        14        15        16        17        18        19        20
    706.643   653.753   615.740   588.160   568.764   555.627   547.212   542.381   540.388   540.008
```

```
                    ***** ALL NODES HAVE BEEN RESET TO.  530.00 DEG- RANKINE *****

     ......... FIRE PERIOD    2 IS BEGINNING ---  400.00 SEC. OF FIRE FOLLOWS .........

ELAPSED TIME IN DUTY CYCLE                  1090.00 SEC.     ELAPSED TIME THIS PERIOD       0.   SEC
CHAR-DEPTH WITH RESPECT TO       C/L         4.4084 INCHES   TOTAL CHAR-DEPTH             0.2684 IN.
ABLATION DEPTH WITH RESPECT TO   C/L         4.1550 INCHES.  TOTAL DIMENSIONAL ABLATION   0.0150 IN.

                                                         -- INTERIOR --   -- EXTERIOR --

CONVECTION COEFFICIENT    BTU/SQ-IN-SEC-R.                1.02000E-03       0.
RECOVERY/AMBIENT TEMP.    DEG. R.                           5100.000             0.

HEAT FLUX (CONVECTION)    BTU/SQ-IN-SEC.                  0.               -0.
HEAT FLUX (RADIATION)     BTU/SQ-IN-SEC.                 -1.61070E-03      -1.82644E-05
HEAT FLUX (ARBITRARY)     BTU/SQ-IN-SEC.                  0.                0.

STABILITY NODE    1       1.23372620E-01

                        ********** TEMPERATURE PROFILE **********

         1         2         3         4         5         6         7         8         9        10
   530.000   530.000   530.000   530.000   530.000   530.000   530.000   530.000   530.000   530.000

        11        12        13        14        15        16        17        18        19        20
   530.000   530.000   530.000   530.000   530.000   530.000   530.000   530.000   530.000   530.000
```

```
          .......... FIRE PERIOD    2 HAS ENDED    ..........

ELAPSED TIME IN DUTY CYCLE             1490.00 SEC.      ELAPSED TIME THIS PERIOD     400.00 SEC
CHAR-DEPTH WITH RESPECT TO      C/L     4.7327 INCHES    TOTAL CHAR-DEPTH             0.5927 IN.
ABLATION DEPTH WITH RESPECT TO  C/L     4.2629 INCHES.   TOTAL DIMENSIONAL ABLATION   0.1229 IN.


                                                 -- INTERIOR --   -- EXTERIOR --

CONVECTION COEFFICIENT    BTU/SQ-IN-SEC-R.          1.02000E-03      0.
RECOVERY/AMBIENT TEMP.    DEG. R.                    5100.000            0.

HEAT FLUX (CONVECTION)    BTU/SQ-IN-SEC.            4.48800E-01     -0.
HEAT FLUX (RADIATION)     BTU/SQ-IN-SEC.           -1.40456E-01     -9.21056E-04
HEAT FLUX (ARBITRARY)     BTU/SQ-IN-SEC.            0.               0.

STABILITY NODE    3      3.05437860E-02

             ********** TEMPERATURE PROFILE **********

         2         3         4         5         6         7         8         9        10        11
  4660.000  4642.868  3978.788  3329.514  2693.969  2071.124  1460.000  1409.339  1327.782  1250.804

        12        13        14        15        16        17        18        19        20
  1178.684  1111.586  1049.555   992.508   940.244   892.448   848.712   808.541   789.282
```

```
 .......... SOAK PERIOD    2 IS BEGINNING --- 3000.00 SEC. OF SOAK FOLLOWS .........

ELAPSED TIME IN DUTY CYCLE                  1490.00 SEC.      ELAPSED TIME THIS PERIOD        0.   SEC
CHAR-DEPTH WITH RESPECT TO      C/L          4.7327 INCHES    TOTAL CHAR-DEPTH              0.5927 IN.
ABLATION DEPTH WITH RESPECT TO  C/L          4.2629 INCHES.   TOTAL DIMENSIONAL ABLATION    0.1229 IN.


                                                           -- INTERIOR --    -- EXTERIOR --

CONVECTION COEFFICIENT     BTU/SQ-IN-SEC-R.                  0.                0.
RECOVERY/AMBIENT TEMP.     DEG. R.                                 0.                0.

HEAT FLUX (CONVECTION)     BTU/SQ-IN-SEC.                    4.48800E-01      -0.
HEAT FLUX (RADIATION)      BTU/SQ-IN-SEC.                   -1.40456E-01      -9.21056E-04
HEAT FLUX (ARBITRARY)      BTU/SQ-IN-SEC.                    0.                0.

STABILITY NODE    3       3.05437860E-02

                     ********** TEMPERATURE PROFILE **********

         2         3         4         5         6         7         8         9        10        11
  4660.000  4642.868  3978.788  3329.514  2693.969  2071.124  1460.000  1409.339  1327.782  1250.804

        12        13        14        15        16        17        18        19        20
  1178.684  1111.586  1049.555   992.508   940.244   892.448   848.712   808.541   789.282
```

```
----- NODES   2 AND   3 ARE BEING CONSOLIDATED DUE TO MINIMUM STABILITY RESTRAINT -----

......... SOAK PERIOD    2 IN PROGRESS  --- 2999.97 SEC. OF SOAK FOLLOWS .........

ELAPSED TIME IN DUTY CYCLE                1490.03 SEC.      ELAPSED TIME THIS PERIOD         0.03 SEC
CHAR-DEPTH WITH RESPECT TO      C/L        4.7327 INCHES    TOTAL CHAR-DEPTH               0.5927 IN.
ABLATION DEPTH WITH RESPECT TO  C/L        4.2629 INCHES.   TOTAL DIMENSIONAL ABLATION     0.1229 IN.

                                                      -- INTERIOR --    -- EXTERIOR --

CONVECTION COEFFICIENT     BTU/SQ-IN-SEC-R.           0.                0.
RECOVERY/AMBIENT TEMP.     DEG. R.                          0.                0.

HEAT FLUX (CONVECTION)     BTU/SQ-IN-SEC.             0.               -0.
HEAT FLUX (RADIATION)      BTU/SQ-IN-SEC.            -1.40456E 00      -2.05296E-03
HEAT FLUX (ARBITRARY)      BTU/SQ-IN-SEC.             0.                0.

STABILITY NODE    2      6.96575236E-04

                    ********** TEMPERATURE PROFILE **********

         2         3         4         5         6         7         8         9        10        11
  4660.000  4642.938  3978.843  3329.555  2693.996  2071.138  1460.000  1409.354  1327.800  1250.824

        12        13        14        15        16        17        18        19        20
  1178.705  1111.608  1049.577   992.530   940.264   892.467   848.728   808.555   789.295
```

```
                    ***** LINER HAS SOAKED TO STEADY STATE CONDITIONS *****

    ......... SOAK PERIOD    2 IN PROGRESS  ---  638.48 SEC. OF SOAK FOLLOWS .........

ELAPSED TIME IN DUTY CYCLE                3851.52 SEC.      ELAPSED TIME THIS PERIOD     2361.52 SEC
CHAR-DEPTH WITH RESPECT TO      C/L        4.7361 INCHES    TOTAL CHAR-DEPTH              0.5961 IN.
ABLATION DEPTH WITH RESPECT TO  C/L        4.2629 INCHES.   TOTAL DIMENSIONAL ABLATION    0.1229 IN.


                                                       -- INTERIOR --    -- EXTERIOR --

CONVECTION COEFFICIENT     BTU/SQ-IN-SEC-R.             0.                0.
RECOVERY/AMBIENT TEMP.     DEG. R.                           0.                0.

HEAT FLUX (CONVECTION)     BTU/SQ-IN-SEC.               0.               -0.
HEAT FLUX (RADIATION)      BTU/SQ-IN-SEC.              -3.84185E-06      -4.61639E-06
HEAT FLUX (ARBITRARY)      BTU/SQ-IN-SEC.               0.                0.

STABILITY NODE    7       6.13160878E-01

                        ********** TEMPERATURE PROFILE **********

          3         4         5         6         7         8         9        10        11        12
    532.152   532.201   532.241   532.276   532.303   532.325   532.348   532.362   532.349   532.310

         13        14        15        16        17        18        19        20
    532.245   532.155   532.041   531.907   531.752   531.580   531.393   531.296
```

```
                    .......... SOAK PERIOD    2 HAS ENDED    ..........

ELAPSED TIME IN DUTY CYCLE                4490.00 SEC.      ELAPSED TIME THIS PERIOD     3000.00 SEC
CHAR-DEPTH WITH RESPECT TO       C/L       4.7361 INCHES    TOTAL CHAR-DEPTH               0.5961 IN.
ABLATION DEPTH WITH RESPECT TO   C/L       4.2629 INCHES.   TOTAL DIMENSIONAL ABLATION     0.1229 IN.


                                                     -- INTERIOR --    -- EXTERIOR --

CONVECTION COEFFICIENT     BTU/SQ-IN-SEC-R.           0.                0.
RECOVERY/AMBIENT TEMP.     DEG. R.                           0.                0.

HEAT FLUX (CONVECTION)     BTU/SQ-IN-SEC.             0.               -0.
HEAT FLUX (RADIATION)      BTU/SQ-IN-SEC.            -3.84185E-06      -4.61639E-06
HEAT FLUX (ARBITRARY)      BTU/SQ-IN-SEC.             0.                0.

STABILITY NODE    7      6.13160878E-01

                         ********** TEMPERATURE PROFILE **********

          3         4         5         6         7         8         9        10        11        12
    532.152   532.201   532.241   532.276   532.303   532.325   532.348   532.362   532.349   532.310

         13        14        15        16        17        18        19        20
    532.245   532.155   532.041   531.907   531.752   531.580   531.393   531.296
```

```
                         **** DUTY CYCLE HAS ENDED ****

     MAXIMUM EXTERIOR TEMPERTURE OCCURED AT 1490.03 SECONDS INTO DUTY CYCLE

                         ----- TEMPERATURE PROFILE -----

       2         3         4         5         6         7         8         9        10        11
4660.000  4642.938  3978.843  3329.555  2693.996  2071.138  1460.000  1409.354  1327.800  1250.824

      12        13        14        15        16        17        18        19        20
1178.705  1111.608  1049.577   992.530   940.264   892.467   848.728   808.555   789.295
```

## SAMPLE PROBLEM NO. 4 ($\approx$3 MIN)

In this problem the interior convection coefficient is to be determined by the Bartz equation. Input Block 2, has been omitted from the fire period description, and input Block 5 "Bartz Equation" used in its place. Because the station of interest is the throat, only the first "BARTZ SHEET" is required. The Mach number and free stream temperatures have been input as constants. The program will determine the interior convection coefficient and the gas recovery temperature.

Keypunch all printed
and handwritten data
enclosed in ☐; if
the line is preceded
by *, omit all others.

## AEROJET-GENERAL CORPORATION CHARRING AND DIMENSIONAL ABLATION PROGRAM

BASIC INPUT ---- Sheet 1

1) This sheet must be completed for all cases.
2) Sheet 2 must be completed if the temperature frofile at start time is not uniform.

PAGE 1 OF 6

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

TITLE CARD-79 CHARACTERS

* T SAMPLE PROBLEM NO. 4 BARTZ EQUATION AT THROAT

* Number of Materials ≤ 8 [1] Number of Nodes. ≤ 500 [50] Enter(T) if nozzle station is throat. [T]

* Inside radius from ¢ IN. [4.4] Initial Char Depth IN. From Internal Surface [.] Liner temperature if uniform °R [530.0]

* Ablation Temperature °R [5000.0] Heat of ablation BTU/lb of CHAR [+1.5 +03]

MATERIAL SPECIFICATIONS

| | MATERIAL 1 | MATERIAL 2 | MATERIAL 3 | MATERIAL 4 | MATERIAL 5 | MATERIAL 6 | MATERIAL 7 | MATERIAL 8 |
|---|---|---|---|---|---|---|---|---|
| * Thickness Inches | 1.5 | . | . | . | . | . | . | . |
| * $C_p$-Laminate BTU/LB-°R | .29 | . | . | . | . | . | . | . |
| * $C_p$-Char BTU/LB-°R | .29 | . | . | . | . | . | . | . |
| * K-Laminate B/IN-SEC-R | 1.075 -05 | . - | . - | . - | . - | . - | . - | . - |
| * K-Char B/IN-SEC-R | 6.97 -06 | . - | . - | . - | . - | . - | . - | . - |
| * ρ-Laminate LB/IN$^3$ | .052 | . | . | . | . | . | . | . |
| * ρ-Char LB/IN$^3$ | .043 | . | . | . | . | . | . | . |
| * T-Char °R | 1260.0 | . | . | . | . | . | . | . |
| * Q-Char BTU/LB | 3.74 +02 | . + | . + | . + | . + | . + | . + | . + |

Keypunch all printed
and handwritten data
enclosed in ☐; if
the line is preceded
by *, omit all others.

## AEROJET-GENERAL CORPORATION CHARRING AND DIMENSIONAL ABLATION PROGRAM

## FIRE PERIOD DESCRIPTION

PAGE 2 OF 6

| Duration(sec.) | Print(sec.) | $\Delta\theta$ min. | $\Delta\theta$ max. | |
|---|---|---|---|---|
| *FIRE 90.0 | 10.0 | .01 | 5.0 | The word "FIRE" must be input in Columns 1 - 4. A duration must be input. |

$q/A = a \sin(b + kt) + c + dt + ft^2 + ge^{ht}$

ARB-Q ---- Input Block 1 Arbitrary Heat Flux ----

| | a | b | k | c | d | f | g | h |
|---|---|---|---|---|---|---|---|---|
| 1 at interior | | | | | | | | |
| 2 at exterior | | | | | | | | |

INTERIOR ---- Input Block 2 Interior Convection ----

1 Recovery Temp. °R .

2 Convection Coefficient . - BTU/in$^2$-sec °R Input convection coefficient value only if constant.

| | Time | h BTU/in$^2$-sec °R |
|---|---|---|
| The final entry | | . - |
| of this table | | . - |
| must have a "1" | | . - |
| in Column 1. | | . - |
| Add more cards | | . - |
| as required up | | . - |
| to 50. | | . - |

If the interior convection coefficient is time dependent complete this table. Card 2 above must be input with value left blank

ENDFIRE Include this card at the end of a fire period description.

ENDDUTY Include this card after the final period of the duty cycle.

Keypunch all printed
and handwritten data
enclosed in ☐; if
the line is preceded
by *, omit all others.

## AEROJET-GENERAL CORPORATION CHARRING AND DIMENSIONAL ABLATION PROGRAM

### INPUT BLOCK 5 - BARTZ EQUATION -- Sheet 1 of 2

Include this block as required to describe fire periods.

PAGE 3 OF 6

* BARTZ

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | k (gas) BTU/sec-IN-°R | μ #sec/in² | $C_p$ BTU/LB°R | Pr | Pc PSIA | Dt in | r |
| * | 6.9 -06 | .88 -08 | .874 - | .4242 - | 1.0 +02 | 8.28 | .348 |
| | $r_c$* IN/SEC | K | γ | $P_t$ PSIA | ṁ LB/sec | To °R | If station |
| * | 8.28 - | .30 - | 1.3 - | 1.5 +02 | 2.96 +01 | 5528. | is throat |
| | T∞ | MACH NO | Include this card only | | | | omit remaining |
| * | 4620.0 | 1.0 | if station is throat. | | | | ing cards. |
| * | blank card | | | | | | |

1 THROAT DIAMETER Enter value if constant (in) ☐.

| Time Sec. | THROAT DIAMETER in |
|---|---|
| | . |
| | . |
| | . |
| | . |
| | . |
| | . |
| | . |
| | . |
| | . |
| | . |
| | . |
| | . |

The final entry of this table must have a "1" in Column 1.
Add more cards as required up to 50.

If throat diameter is constant omit this table.
If variable, include throat diameter card and leave value blank.

| | |
|---|---|
| ENDFIRE | Include this card at the end of a fire period description |
| ENDDUTY | Include this card after the final period of the duty cycle. |

Keypunch all printed
and handwritten data
enclosed in ☐ ; if
the line is preceded
by *, omit all others.

## AEROJET-GENERAL CORPORATION CHARRING AND DIMENSIONAL ABLATION PROGRAM

### INPUT BLOCK 3 - RADIATION

Include this block as required to describe a fire and/or soak period.

PAGE 4 OF 6

* RADIATE

| | | Emissivity | Shape Factor | Sink Temp °R | |
|---|---|---|---|---|---|
| * | 1 Interior Term 1 | .9 | .1 | 539.0 | If any sink |
| | 2 Interior Term 2 | . | . | . | temperature is |
| * | 3 Exterior Term 1 | .9 | 1.0 | 539.0 | intended to be |
| | 4 Exterior Term 2 | . | . | . | 0 °R enter .001. |
| | 5 Exterior Term 3 | . | . | . | |
| | 6 Exterior Term 4 | . | . | . | |
| | 7 Exterior Term 5 | . | . | . | |

* —blank card—

8 Include this card if any exterior sink temperatures are to be time dependent

| | Time (sec.) | Sink 1 °R | Sink 2 °R | Sink 3 °R | Sink 4 °R | Sink 5 °R | |
|---|---|---|---|---|---|---|---|
| The final entry | | . | . | . | . | . | If all exterior |
| of this table | | . | . | . | . | . | radiation is to |
| must have a "1" | | . | . | . | . | . | constant sink |
| in Column 1. | | . | . | . | . | . | temperatures, |
| Add more cards | | . | . | . | . | . | omit these cards. |
| as required up | | . | . | . | . | . | Enter tabular |
| to 50. | | . | . | . | . | . | values for all |
| | | . | . | . | . | . | time varying |
| | | . | . | . | . | . | exterior sink temperatures. |

* ENDFIRE Include this card if this is the final input block for a fire period.

ENDSOAK Include this card if this is the final input block for a soak period.

ENDDUTY If this is the final fire or soak period of the duty cycle, include this card.

Keypunch all printed
and handwritten data
enclosed in ☐ ; if
the line is preceded
by *, omit all others.

## SOAK PERIOD DESCRIPTION

PAGE 5 OF 6

| | Duration (sec.) | Print (sec.) | Δθ min. | Δθ max. | T-EXT °R | Steady State °R/sec. | Reset °R |
|---|---|---|---|---|---|---|---|
| * SOAK | 1000.0 | | .01 | 100.0 | | | |

the word "SOAK" must be input in Columns 1 - 4.

(T-EXT °R) The SOAK period will end if the exterior temperature reaches this value.

(STEADY STATE) The SOAK period will end if all the nodal temperatures are changing at a rate less than this input value.

If (T-EXT °R) is negative, the SOAK period will end when the exterior temperature peaks.

(RESET) The temperature profile will be set to this input value at the end of the soak period.

ARB-Q ---- Input Block 1 Arbitrary heat flux----

| | a | b | k | c | d | f | g | h |
|---|---|---|---|---|---|---|---|---|
| 1 At interior | — | — | — | — | — | — | — | — |
| 2 At exterior | — | — | — | — | — | — | — | — |

| | |
|---|---|
| ENDSOAK | Include this card at the end of a soak period description. |
| ENDDUTY | Include this card after the final period of the duty cycle. |

Keypunch all printed
and handwritten data
enclosed in ☐ ; if
the line is preceded
by *, omit all others.

## AEROJET-GENERAL CORPORATION CHARRING AND DIMENSIONAL ABLATION PROGRAM

### INPUT BLOCK 3 - RADIATION

Include this block as required to describe a fire
and/or soak period.

PAGE 6 OF 6

*RADIATE

| | | Emissivity | Shape Factor | Sink Temp °R | |
|---|---|---|---|---|---|
| * | 1 Interior Term 1 | .9 | .1 | 539.0 | If any sink |
| | 2 Interior Term 2 | . | . | . | temperature is |
| * | 3 Exterior Term 1 | .9 | 1.0 | 539.9 | intended to be |
| | 4 Exterior Term 2 | . | . | . | 0 °R enter .001. |
| | 5 Exterior Term 3 | . | . | . | |
| | 6 Exterior Term 4 | . | . | . | |
| | 7 Exterior Term 5 | . | . | . | |

* —blank card—

8 Include this card if any exterior sink temperatures are to be time dependent

| | Time (sec.) | Sink 1 °R | Sink 2 °R | Sink 3 °R | Sink 4 °R | Sink 5 °R | |
|---|---|---|---|---|---|---|---|
| The final entry | | . | . | . | . | . | If all exterior radiation is to |
| of this table | | . | . | . | . | . | constant sink temperatures, |
| must have a "1" | | . | . | . | . | . | omit these cards. |
| in Column 1. | | . | . | . | . | . | |
| Add more cards | | . | . | . | . | . | Enter tabular |
| as required up | | . | . | . | . | . | values for all |
| to 50. | | . | . | . | . | . | time varying |
| | | . | . | . | . | . | exterior sink |
| | | . | . | . | . | . | temperatures. |

ENDFIRE Include this card if this is the final input block for a fire period.

*ENDSOAK Include this card if this is the final input block for a soak period.

*ENDDUTY If this is the final fire or soak period of the duty cycle, include this card.

```
                               **** AEROJET-GENERAL CORPORATION ****
                               -------------------------------------

                            CHARRING AND DIMENSIONAL ABLATION PROGRAM

                      SAMPLE PROBLEM NO. 4  BARTZ EQUATION AT THROAT

                                      --- LINER DESCRIPTION ---

STATION OF INTEREST IS THROAT
LINER IS COMPOSED OF  1 MATERIAL(S)
NUMBER OF NODES =  50
RADIUS FROM NOZZLE CENTER-LINE =  4.1400 INCHES.
RADIUS TO LINER EXTERIOR =  5.6400 INCHES.
TOTAL LINER THICKNESS =  1.5000 INCHES.
RADIAL INCREMENT = 0.03125 INCHES.
HEAT OF ABLATION =  1.5000E 03 BTU/LB.
ABLATION TEMPERATURE = 5000.00 DEG.-R

                                         MATERIAL SPECIFICATIONS

                                     MATERIAL 1  MATERIAL 2  MATERIAL 3  MATERIAL 4  MATERIAL 5  MATERIAL 6  MATER

THICKNESS         INCHES.              1.5000
SP-HEAT LAMINATE  B/LB-R.          2.9000E-01
SP-HEAT CHAR      B/LB-R.          2.9000E-01
COND LAMINATE     B/IN-SEC-R.      1.0750E-05
COND CHAR         B/IN-SEC-R.      6.9700E-06
DENSITY LAMINATE  LB/CU-IN.        5.2000E-02
DENSITY CHAR      LB/CU-IN.        4.3000E-02
CHAR TEMPERATURE  DEG-R.             1260.000
EFF. HEAT OF CHAR B/LB CHARRED     3.7400E 02
INTERFACE NODE    NUMBER                   50
```

```
......... FIRE PERIOD    1 IS BEGINNING ---   90.00 SEC. OF FIRE FOLLOWS .........

ELAPSED TIME IN DUTY CYCLE                     0.   SEC.     ELAPSED TIME THIS PERIOD       0.    SEC
CHAR-DEPTH WITH RESPECT TO       C/L      4.1400 INCHES      TOTAL CHAR-DEPTH            0.       IN.
ABLATION DEPTH WITH RESPECT TO   C/L      4.1400 INCHES.     TOTAL DIMENSIONAL ABLATION  0.       IN.


                                                           -- INTERIOR --    -- EXTERIOR --

CONVECTION COEFFICIENT     BTU/SQ-IN-SEC-R.                  1.30856E-02       0.
RECOVERY/AMBIENT TEMP.     DEG. R.                              5140.852             0.

HEAT FLUX (CONVECTION)     BTU/SQ-IN-SEC.                    6.03357E 01      -0.
HEAT FLUX (RADIATION)      BTU/SQ-IN-SEC.                  -0.                -0.
HEAT FLUX (ARBITRARY)      BTU/SQ-IN-SEC.                   0.                 0.

STABILITY NODE   1      0.

                      ********** TEMPERATURE PROFILE **********

          1          2          3          4          5          6          7          8          9         10
    530.000    530.000    530.000    530.000    530.000    530.000    530.000    530.000    530.000    530.000

         11         12         13         14         15         16         17         18         19         20
    530.000    530.000    530.000    530.000    530.000    530.000    530.000    530.000    530.000    530.000

         21         22         23         24         25         26         27         28         29         30
    530.000    530.000    530.000    530.000    530.000    530.000    530.000    530.000    530.000    530.000

         31         32         33         34         35         36         37         38         39         40
    530.000    530.000    530.000    530.000    530.000    530.000    530.000    530.000    530.000    530.000

         41         42         43         44         45         46         47         48         49         50
    530.000    530.000    530.000    530.000    530.000    530.000    530.000    530.000    530.000    530.000
```

```
......... FIRE PERIOD    1 IN PROGRESS  ---   80.00 SEC. OF FIRE FOLLOWS .........

ELAPSED TIME IN DUTY CYCLE                    10.00 SEC.      ELAPSED TIME THIS PERIOD       10.00 SEC
CHAR-DEPTH WITH RESPECT TO       C/L        4.3119 INCHES     TOTAL CHAR-DEPTH               0.1719 IN.
ABLATION DEPTH WITH RESPECT TO   C/L        4.2137 INCHES.    TOTAL DIMENSIONAL ABLATION     0.0737 IN.


                                                           -- INTERIOR --    -- EXTERIOR --

CONVECTION COEFFICIENT     BTU/SQ-IN-SEC-R.                  9.73190E-03       0.
RECOVERY/AMBIENT TEMP.     DEG. R.                             5140.852              0.

HEAT FLUX (CONVECTION)     BTU/SQ-IN-SEC.                    1.37076E 00      -0.
HEAT FLUX (RADIATION)      BTU/SQ-IN-SEC.                   -1.86164E-01      -0.
HEAT FLUX (ARBITRARY)      BTU/SQ-IN-SEC.                    0.                0.

STABILITY NODE  49        2.28636181E-01

                        ********** TEMPERATURE PROFILE **********

        3          4          5          6          7          8          9         10         11         12
 5000.000   4543.226   2580.333   1346.468    962.529    781.933    662.367    595.816    561.255    544.094

       13         14         15         16         17         18         19         20         21         22
  536.004    532.411    530.912    530.325    530.109    530.034    530.010    530.003    530.001    530.000

       23         24         25         26         27         28         29         30         31         32
  530.000    530.000    530.000    530.000    530.000    530.000    530.000    530.000    530.000    530.000

       33         34         35         36         37         38         39         40         41         42
  530.000    530.000    530.000    530.000    530.000    530.000    530.000    530.000    530.000    530.000

       43         44         45         46         47         48         49         50
  530.000    530.000    530.000    530.000    530.000    530.000    530.000    530.000
```

```
......... FIRE PERIOD    1 IN PROGRESS  ---   70.00 SEC. OF FIRE FOLLOWS .........

ELAPSED TIME IN DUTY CYCLE                  20.00 SEC.     ELAPSED TIME THIS PERIOD      20.00 SEC
CHAR-DEPTH WITH RESPECT TO      C/L       4.4056 INCHES    TOTAL CHAR-DEPTH             0.2656 IN.
ABLATION DEPTH WITH RESPECT TO  C/L       4.3030 INCHES.   TOTAL DIMENSIONAL ABLATION   0.1630 IN.


                                                        -- INTERIOR --    -- EXTERIOR --

CONVECTION COEFFICIENT     BTU/SQ-IN-SEC-R.                9.39084E-03      0.
RECOVERY/AMBIENT TEMP.     DEG. R.                           5140.852             0.

HEAT FLUX (CONVECTION)     BTU/SQ-IN-SEC.                  1.32272E 00     -0.
HEAT FLUX (RADIATION)      BTU/SQ-IN-SEC.                 -1.86164E-01     -0.
HEAT FLUX (ARBITRARY)      BTU/SQ-IN-SEC.                 0.                0.

STABILITY NODE  49      2.28636181E-01

                        ********** TEMPERATURE PROFILE **********

         6         7         8         9        10        11        12        13        14        15
  5000.000  4206.076  2490.808  1458.417  1013.442   844.247   724.214   645.489   597.197   568.299

        16        17        18        19        20        21        22        23        24        25
   551.314   541.557   536.100   533.132   531.563   530.758   530.357   530.163   530.072   530.031

        26        27        28        29        30        31        32        33        34        35
   530.013   530.005   530.002   530.001   530.000   530.000   530.000   530.000   530.000   530.000

        36        37        38        39        40        41        42        43        44        45
   530.000   530.000   530.000   530.000   530.000   530.000   530.000   530.000   530.000   530.000

        46        47        48        49        50
   530.000   530.000   530.000   530.000   530.000
```

```
   ......... FIRE PERIOD    1 IN PROGRESS  ---   60.00 SEC. OF FIRE FOLLOWS .........

ELAPSED TIME IN DUTY CYCLE                 30.00 SEC.      ELAPSED TIME THIS PERIOD      30.00 SEC
CHAR-DEPTH WITH RESPECT TO       C/L      4.4994 INCHES    TOTAL CHAR-DEPTH             0.3594 IN.
ABLATION DEPTH WITH RESPECT TO   C/L      4.3894 INCHES.   TOTAL DIMENSIONAL ABLATION   0.2494 IN.


                                                         -- INTERIOR --    -- EXTERIOR --

CONVECTION COEFFICIENT     BTU/SQ-IN-SEC-R.               9.07873E-03       0.
RECOVERY/AMBIENT TEMP.     DEG. R.                          5140.852              0.

HEAT FLUX (CONVECTION)     BTU/SQ-IN-SEC.                 1.27876E 00      -0.
HEAT FLUX (RADIATION)      BTU/SQ-IN-SEC.                -1.86164E-01      -0.
HEAT FLUX (ARBITRARY)      BTU/SQ-IN-SEC.                 0.                0.

STABILITY NODE  49       2.28636181E-01

                              ********** TEMPERATURE PROFILE **********

          9        10        11        12        13        14        15        16        17        18
   5000.000  3776.719  2299.819  1340.534  1014.986   859.041   740.736   662.450   612.518   580.837

         19        20        21        22        23        24        25        26        27        28
    560.879   548.467   540.868   536.291   533.580   532.002   531.100   530.593   530.313   530.163

         29        30        31        32        33        34        35        36        37        38
    530.083   530.041   530.020   530.009   530.004   530.002   530.001   530.000   530.000   530.000

         39        40        41        42        43        44        45        46        47        48
    530.000   530.000   530.000   530.000   530.000   530.000   530.000   530.000   530.000   530.000

         49        50
    530.000   530.000
```

```
.......... FIRE PERIOD    1 IN PROGRESS  ---   50.00 SEC. OF FIRE FOLLOWS .........

ELAPSED TIME IN DUTY CYCLE                   40.00 SEC.     ELAPSED TIME THIS PERIOD      40.00 SEC
CHAR-DEPTH WITH RESPECT TO      C/L         4.5727 INCHES   TOTAL CHAR-DEPTH             0.4327 IN.
ABLATION DEPTH WITH RESPECT TO  C/L         4.4716 INCHES.  TOTAL DIMENSIONAL ABLATION   0.3316 IN.


                                                         -- INTERIOR --    -- EXTERIOR --

CONVECTION COEFFICIENT     BTU/SQ-IN-SEC-R.               8.79709E-03       0.
RECOVERY/AMBIENT TEMP.     DEG. R.                          5140.852              0.

HEAT FLUX (CONVECTION)     BTU/SQ-IN-SEC.                 1.23909E 00      -0.
HEAT FLUX (RADIATION)      BTU/SQ-IN-SEC.                -1.86164E-01      -0.
HEAT FLUX (ARBITRARY)      BTU/SQ-IN-SEC.                 0.                0.

STABILITY NODE  49      2.28636181E-01

                          ********** TEMPERATURE PROFILE **********

        12        13        14        15        16        17        18        19        20        21
  5000.000  3276.866  2066.518  1260.000  1016.552   847.226   736.006   664.005   616.693   585.555

        22        23        24        25        26        27        28        29        30        31
   565.229   552.105   543.721   538.423   535.110   533.063   531.814   531.060   530.611   530.348

        32        33        34        35        36        37        38        39        40        41
   530.195   530.108   530.059   530.031   530.016   530.008   530.004   530.002   530.001   530.000

        42        43        44        45        46        47        48        49        50
   530.000   530.000   530.000   530.000   530.000   530.000   530.000   530.000   530.000
```

```
......... FIRE PERIOD    1 IN PROGRESS  ---   40.00 SEC. OF FIRE FOLLOWS .........


ELAPSED TIME IN DUTY CYCLE                  50.00 SEC.     ELAPSED TIME THIS PERIOD      50.00 SFC
CHAR-DEPTH WITH RESPECT TO        C/L      4.6556 INCHES   TOTAL CHAR-DEPTH             0.5156 IN.
ABLATION DEPTH WITH RESPECT TO    C/L      4.5531 INCHES.  TOTAL DIMENSIONAL ABLATION   0.4131 IN.


                                                         -- INTERIOR --   -- EXTERIOR --

CONVECTION COEFFICIENT    BTU/SQ-IN-SEC-R.                8.53113E-03      0.
RECOVERY/AMBIENT TEMP.    DEG. R.                           5140.852            0.

HEAT FLUX (CONVECTION)    BTU/SQ-IN-SEC.                  1.20163E 00     -0.
HEAT FLUX (RADIATION)     BTU/SQ-IN-SEC.                 -1.86164E-01     -0.
HEAT FLUX (ARBITRARY)     BTU/SQ-IN-SEC.                  0.               0.

STABILITY NODE  49      2.28636181E-01

                    ********** TEMPERATURE PROFILE **********

       14        15        16        17        18        19        20        21        22        23
 5000.000  4303.786  2737.293  1769.285  1182.149   955.052   814.122   721.079   657.633   614.437

       24        25        26        27        28        29        30        31        32        33
  585.394   566.072   553.313   544.947   539.503   535.989   533.741   532.315   531.419   530.861

       34        35        36        37        38        39        40        41        42        43
  530.517   530.307   530.181   530.105   530.060   530.034   530.019   530.010   530.006   530.003

       44        45        46        47        48        49        50
  530.001   530.001   530.000   530.000   530.000   530.000   530.000
```

```
......... FIRE PERIOD    1 IN PROGRESS  ---   30.00 SEC. OF FIRE FOLLOWS .........

ELAPSED TIME IN DUTY CYCLE                   60.00 SEC.     ELAPSED TIME THIS PERIOD      60.00 SEC
CHAR-DEPTH WITH RESPECT TO       C/L        4.7494 INCHES   TOTAL CHAR-DEPTH             0.6094 IN.
ABLATION DEPTH WITH RESPECT TO   C/L        4.6301 INCHES.  TOTAL DIMENSIONAL ABLATION   0.4901 IN.


                                                     -- INTERIOR --    -- EXTERIOR --

CONVECTION COEFFICIENT    BTU/SQ-IN-SEC-R.               8.29108E-03      0.
RECOVERY/AMBIENT TEMP.    DEG. R.                           5140.852          0.

HEAT FLUX (CONVECTION)    BTU/SQ-IN-SEC.                 1.16781E 00     -0.
HEAT FLUX (RADIATION)     BTU/SQ-IN-SEC.                -1.86164E-01     -3.00169E-09
HEAT FLUX (ARBITRARY)     BTU/SQ-IN-SEC.                 0.               0.

STABILITY NODE  49      2.28636181E-01

                          ********** TEMPERATURE PROFILE **********

        17        18        19        20        21        22        23        24        25        26
  5000.000  3459.542  2215.354  1415.716  1048.445   899.188   785.336   703.099   646.607   608.268

        27        28        29        30        31        32        33        34        35        36
   582.281   564.716   552.906   545.016   539.778   536.323   534.060   532.588   531.637   531.027

        37        38        39        40        41        42        43        44        45        46
   530.640   530.395   530.242   530.147   530.088   530.052   530.031   530.018   530.010   530.006

        47        48        49        50
   530.003   530.002   530.002   530.002
```

```
.......... FIRE PERIOD    1 IN PROGRESS  ---   20.00 SEC. OF FIRE FOLLOWS .........

ELAPSED TIME IN DUTY CYCLE                  70.00 SEC.     ELAPSED TIME THIS PERIOD       70.00 SEC
CHAR-DEPTH WITH RESPECT TO      C/L        4.8119 INCHES   TOTAL CHAR-DEPTH               0.6719 IN.
ABLATION DEPTH WITH RESPECT TO  C/L        4.7061 INCHES.  TOTAL DIMENSIONAL ABLATION     0.5661 IN.


                                                         -- INTERIOR --   -- EXTERIOR --

CONVECTION COEFFICIENT     BTU/SQ-IN-SEC-R.                 8.06497E-03      0.
RECOVERY/AMBIENT TEMP.     DEG. R.                            5140.852              0.

HEAT FLUX (CONVECTION)     BTU/SQ-IN-SEC.                   1.13597E 00     -0.
HEAT FLUX (RADIATION)      BTU/SQ-IN-SEC.                  -1.86164E-01     -3.09229E-08
HEAT FLUX (ARBITRARY)      BTU/SQ-IN-SEC.                   0.               0.

STABILITY NODE  49      2.28636181E-01

                     ********** TEMPERATURE PROFILE **********

        19        20        21        22        23        24        25        26        27        28
  5000.000  4154.888  2726.229  1812.325  1230.767   996.209   847.418   748.655   680.613   633.168

        29        30        31        32        33        34        35        36        37        38
   600.230   577.546   562.026   551.461   544.305   539.482   536.249   534.094   532.666   531.725

        39        40        41        42        43        44        45        46        47        48
   531.109   530.708   530.449   530.283   530.177   530.110   530.068   530.043   530.028   530.020

        49        50
   530.017   530.017
```

```
......... FIRE PERIOD    1 IN PROGRESS  ---   10.00 SEC. OF FIRE FOLLOWS .........

ELAPSED TIME IN DUTY CYCLE                  80.00 SEC.      ELAPSED TIME THIS PERIOD      80.00 SEC
CHAR-DEPTH WITH RESPECT TO      C/L        4.9056 INCHES    TOTAL CHAR-DEPTH             0.7656 IN.
ABLATION DEPTH WITH RESPECT TO  C/L        4.7779 INCHES.   TOTAL DIMENSIONAL ABLATION   0.6379 IN.


                                                          -- INTERIOR --    -- EXTERIOR --

CONVECTION COEFFICIENT     BTU/SQ-IN-SEC-R.                7.85987E-03       0.
RECOVERY/AMBIENT TEMP.     DEG. R.                           5140.852              0.

HEAT FLUX (CONVECTION)     BTU/SQ-IN-SEC.                  1.10708E 00      -0.
HEAT FLUX (RADIATION)      BTU/SQ-IN-SEC.                 -1.86164E-01      -1.72432E-07
HEAT FLUX (ARBITRARY)      BTU/SQ-IN-SEC.                  0.                0.

STABILITY NODE  22       1.45327252E-01

                    ********** TEMPERATURE PROFILE **********

        21        22        23        24        25        26        27        28        29        30
  5000.000  4791.736  3180.080  2089.932  1340.979  1050.471   911.808   798.764   716.471   659.021

        31        32        33        34        35        36        37        38        39        40
   619.097   591.307   571.997   558.634   549.432   543.125   538.823   535.901   533.928   532.601

        41        42        43        44        45        46        47        48        49        50
   531.713   531.123   530.733   530.477   530.311   530.206   530.142   530.108   530.097   530.097
```

```
                   .......... FIRE PERIOD    1 HAS ENDED    ..........

ELAPSED TIME IN DUTY CYCLE                  90.00 SEC.     ELAPSED TIME THIS PERIOD      90.00 SEC
CHAR-DEPTH WITH RESPECT TO      C/L        4.9681 INCHES   TOTAL CHAR-DEPTH              0.8281 IN.
ABLATION DEPTH WITH RESPECT TO  C/L        4.8487 INCHES.  TOTAL DIMENSIONAL ABLATION    0.7087 IN.


                                                         -- INTERIOR --   -- EXTERIOR --

CONVECTION COEFFICIENT    BTU/SQ-IN-SEC-R.                 7.66591E-03      0.
RECOVERY/AMBIENT TEMP.    DEG. R.                            5140.852           0.

HEAT FLUX (CONVECTION)    BTU/SQ-IN-SEC.                   1.07976E 00     -0.
HEAT FLUX (RADIATION)     BTU/SQ-IN-SEC.                  -1.86164E-01     -7.07767E-07
HEAT FLUX (ARBITRARY)     BTU/SQ-IN-SEC.                   0.               0.

STABILITY NODE  49      2.28636181E-01

                      ********** TEMPERATURE PROFILE **********

      24        25        26        27        28        29        30        31        32        33
 5000.000  3562.602  2391.124  1631.158  1156.457   965.401   838.962   749.423   684.684   638.307

      34        35        36        37        38        39        40        41        42        43
  605.484   582.411   566.252   554.974   547.132   541.703   537.961   535.394   533.641   532.451

      44        45        46        47        48        49        50
  531.650   531.116   530.769   530.555   530.438   530.400   530.399
```

```
......... SOAK PERIOD    1 IS BEGINNING --- 1000.00 SEC. OF SOAK FOLLOWS .........

ELAPSED TIME IN DUTY CYCLE                    90.00 SEC.     ELAPSED TIME THIS PERIOD      0.   SEC
CHAR-DEPTH WITH RESPECT TO      C/L          4.9681 INCHES   TOTAL CHAR-DEPTH            0.8281 IN.
ABLATION DEPTH WITH RESPECT TO  C/L          4.8487 INCHES.  TOTAL DIMENSIONAL ABLATION  0.7087 IN.


                                                          -- INTERIOR --   -- EXTERIOR --

CONVECTION COEFFICIENT     BTU/SQ-IN-SEC-R.                 0.               0.
RECOVERY/AMBIENT TEMP.     DEG. R.                                0.               0.

HEAT FLUX (CONVECTION)     BTU/SQ-IN-SEC.                   1.07976E 00     -0.
HEAT FLUX (RADIATION)      BTU/SQ-IN-SEC.                  -1.86164E-01     -7.07767E-07
HEAT FLUX (ARBITRARY)      BTU/SQ-IN-SEC.                   0.               0.

STABILITY NODE  49       2.28636181E-01

                       ********** TEMPERATURE PROFILE **********

        24        25        26        27        28        29        30        31        32        33
  5000.000  3562.602  2391.124  1631.158  1156.457   965.401   838.962   749.423   684.684   638.307

        34        35        36        37        38        39        40        41        42        43
   605.484   582.411   566.252   554.974   547.132   541.703   537.961   535.394   533.641   532.451

        44        45        46        47        48        49        50
   531.650   531.116   530.769   530.555   530.438   530.400   530.399
```

```
          .......... SOAK PERIOD    1 HAS ENDED    ..........


ELAPSED TIME IN DUTY CYCLE                 1090.00 SEC.      ELAPSED TIME THIS PERIOD    1000.00 SEC
CHAR-DEPTH WITH RESPECT TO       C/L        5.0306 INCHES    TOTAL CHAR-DEPTH              0.8906 IN.
ABLATION DEPTH WITH RESPECT TO   C/L        4.8504 INCHES.   TOTAL DIMENSIONAL ABLATION    0.7104 IN.


                                                       -- INTERIOR --   -- EXTERIOR --

CONVECTION COEFFICIENT     BTU/SQ-IN-SEC-R.              0.                0.
RECOVERY/AMBIENT TEMP.     DEG. R.                             0.                0.

HEAT FLUX (CONVECTION)     BTU/SQ-IN-SEC.                0.               -0.
HEAT FLUX (RADIATION)      BTU/SQ-IN-SEC.               -8.66749E-05      -7.29389E-04
HEAT FLUX (ARBITRARY)      BTU/SQ-IN-SEC.                0.                0.

STABILITY NODE  49       2.28636181E-01

                  ********** TEMPERATURE PROFILE **********

          24        25        26        27        28        29        30        31        32        33
     779.846   780.062   780.203   780.206   780.070   779.796   779.386   779.013   778.535   777.953

          34        35        36        37        38        39        40        41        42        43
     777.267   776.478   775.587   774.597   773.507   772.319   771.035   769.656   768.183   766.618

          44        45        46        47        48        49        50
     764.962   763.216   761.383   759.465   757.461   755.375   754.314
```

```
                         **** DUTY CYCLE HAS ENDED ****

          MAXIMUM EXTERIOR TEMPERTURE OCCURED AT  438.09 SECONDS INTO DUTY CYCLE

                         ----- TEMPERATURE PROFILE -----

      24        25        26        27        28        29        30        31        32        33
 850.345   850.563   850.447   849.941   849.057   847.815   846.236   844.966   843.466   841.751

      34        35        36        37        38        39        40        41        42        43
 839.839   837.748   835.499   833.109   830.598   827.985   825.289   822.527   819.715   816.868

      44        45        46        47        48        49        50
 813.998   811.119   808.238   805.364   802.501   799.653   798.234
```

## SAMPLE PROBLEM NO. 5 ($\approx$ 2 MIN)

Using the data obtained from sample Problem 4. (throat diameter versus time) the station of interest has now been selected at an area ratio of 10/1. For this case "BARTZ SHEET 2" must be included. Mach number and free stream temperature have been specified as functions of A/A*. A table of throat diameter versus time has been input on Sheet 1; this data was obtained from sample Problem 4. The interior nozzle radius has been input on "Basic Input Sheet 1" as 13.09 INCHES.

Keypunch all printed
and handwritten data
enclosed in ☐; if
the line is preceded
by *, omit all others.

## AEROJET-GENERAL CORPORATION CHARRING AND DIMENSIONAL ABLATION PROGRAM

BASIC INPUT ---- Sheet 1

1) This sheet must be completed for all cases.
2) Sheet 2 must be completed if the temperature frofile at start time is not uniform.

PAGE 1 OF 7

TITLE CARD-79 CHARACTERS

* T SAMPLE PROBLEM NO. 5 BARTZ EQUATION AREA RATIO 10/1

* Number of Materials ≤ 8 [1] Number of Nodes. ≤ 500 [20] Enter(T) if nozzle station is throat. [ ]

* Inside radius from ℄ IN. [13.09] Initial Char Depth IN. From Internal Surface [ . ] Liner temperature if uniform °R [530.0]

* Ablation Temperature °R [5000.0] Heat of ablation BTU/lb of CHAR [+1.5 +04]

MATERIAL SPECIFICATIONS

| | MATERIAL 1 | MATERIAL 2 | MATERIAL 3 | MATERIAL 4 | MATERIAL 5 | MATERIAL 6 | MATERIAL 7 | MATERIAL 8 |
|---|---|---|---|---|---|---|---|---|
| * Thickness Inches | 1.5 | . | . | . | . | . | . | . |
| * $C_p$-Laminate BTU/LB-°R | .029 | . | . | . | . | . | . | . |
| * $C_p$-Char BTU/LB-°R | .029 | . | . | . | . | . | . | . |
| * K-Laminate B/IN-SEC-R | 1.07 -05 | . – | . – | . – | . – | . – | . – | . – |
| * K-Char B/IN-SEC-R | 6.97 -06 | . – | . – | . – | . – | . – | . – | . – |
| * ρ-Laminate LB/IN$^3$ | .052 | . | . | . | . | . | . | . |
| * ρ-Char LB/IN$^3$ | .043 | . | . | . | . | . | . | . |
| * T-Char °R | 1240.0 | . | . | . | . | . | . | . |
| * Q-Char BTU/LB | 3.74 +02 | . + | . + | . + | . + | . + | . + | . + |

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Keypunch all printed
and handwritten data
enclosed in ☐; if
the line is preceded
by *, omit all others.

## AEROJET-GENERAL CORPORATION CHARRING AND DIMENSIONAL ABLATION PROGRAM

## FIRE PERIOD DESCRIPTION

PAGE 2 OF 7

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

| | Duration(sec.) | Print(sec.) | $\Delta\theta$ min. | $\Delta\theta$ max. |
|---|---|---|---|---|
| *FIRE | 90.0 | 10.0 | .01 | 5.0 |

The word "FIRE" must be input in Columns 1 - 4. A duration must be input.

$$q/A = a \sin(b + kt) + c + dt + ft^2 + ge^{ht}$$

ARB-Q

Input Block 1 Arbitrary Heat Flux

| | a | b | k | c | d | f | g | h |
|---|---|---|---|---|---|---|---|---|
| 1 at interior | | | | | | | | |
| 2 at exterior | | | | | | | | |

INTERIOR

Input Block 2 Interior Convection

1 Recovery Temp. °R .

2 Convection Coefficient . - BTU/in$^2$-sec °R

Input convection coefficient value only if constant.

| | Time | h BTU/in$^2$-sec °R |
|---|---|---|
| The final entry | | . - |
| of this table | | . - |
| must have a "1" | | . - |
| in Column 1. | | . - |
| Add more cards | | . - |
| as required up | | . - |
| to 50. | | . - |

If the interior convection coefficient is time dependent complete this table. Card 2 above must be input with value left blank

| | |
|---|---|
| ENDFIRE | Include this card at the end of a fire period description. |
| ENDDUTY | Include this card after the final period of the duty cycle. |

Keypunch all printed
and handwritten data
enclosed in ☐ ; if
the line is preceded
by *, omit all others.

# AEROJET-GENERAL CORPORATION CHARRING AND DIMENSIONAL ABLATION PROGRAM

## INPUT BLOCK 5 - BARTZ EQUATION -- Sheet 1 of 2

Include this block as required to describe fire periods.

PAGE 3 OF 7

* BARTZ

| | | | | | | |
|---|---|---|---|---|---|---|
| $k$ (gas) BTU/sec-IN-°R | $\mu$ #sec/in² | $C_p$ BTU/LB°R | Pr | Pc PSIA | Dt in | $\gamma$ |
| * 6.9 -06 | .88 -08 | .874 - | .4242 - | 1.00 +02 | 8.28 | .348 |

| | | | | | | |
|---|---|---|---|---|---|---|
| $r_c$ *IN/SEC | K | $\gamma$ | $P_t$ PSIA | $\dot{w}$ LB/sec | To °R | If station |
| * 8.28 - | .30 - | 1.3 - | 1.50 +02 | 2.06 +01 | 5528.0 | is throat |

| | | | |
|---|---|---|---|
| T∞ | MACH NO | Include this card only | omit remain- |
| . | . | if station is throat. | ing cards. |

* 1 THROAT DIAMETER Enter value if constant(in) ☐ .

| | Time Sec. | THROAT DIAMETER in | |
|---|---|---|---|
| * | 0.0 | 8.28 | If throat diameter is |
| * | 10.0 | 8.427 | constant omit this table. |
| * The final entry of | 20.0 | 8.606 | If variable, include |
| * this table must have | 30.0 | 8.779 | throat diameter card and |
| * a "1" in Column 1. | 40.0 | 8.943 | leave value blank. |
| * Add more cards as | 50.0 | 9.106 | |
| * required up to 50. | 60.0 | 9.260 | |
| * | 70.0 | 9.412 | |
| * | 80.0 | 9.556 | |
| * 1 | 90.0 | 9.697 | |
| | | . | |
| | | . | |

| | |
|---|---|
| ENDFIRE | Include this card at the end of a fire period description |
| ENDDUTY | Include this card after the final period of the duty cycle. |

Keypunch all printed
and handwritten data
enclosed in ☐; if
the line is preceded
by *, omit all others.

## AEROJET-GENERAL CORPORATION CHARRING AND DIMENSIONAL ABLATION PROGRAM

### INPUT BLOCK 5 - BARTZ EQUATION -- Sheet 2 of 2

Include this block as required to describe fire periods.

PAGE 4 OF 7

* 2 MACH NO. | . | Free stream temperature °R | . |

| | | A/A* | MACH NO. | $T_\infty$ °R | |
|---|---|---|---|---|---|
| * | | 2.95 | 4.875 | 2398.0 | If MACH NO. and T are |
| * | The final entry | 5.16 | 3.000 | 2352.0 | constant, omit this |
| * | of this table | 9.11 | 3.500 | 1948.0 | table. If either is |
| * | 1 must contain a | 15.94 | 4.00 | 1626.0 | variable, complete the |
| | "1" in Column 1. | | . | . | A/A* table along with |
| | Add more cards | | . | . | the variable MACH No., |
| | as required up | | . | . | $T_\infty$ or both. |
| | to 50. | | . | . | |
| * | — blank card — | | . | . | |
| | | | . | . | |
| | | | . | . | |
| | | | . | . | |
| | | | . | . | |
| | | | . | . | |
| | | | . | . | |
| | | | . | . | |
| | | | . | . | |
| | | | . | . | |
| | | | . | . | |
| | | | . | . | |
| | | | . | . | |

| | |
|---|---|
| ENDFIRE | Include this card at the end of a fire period description |
| ENDDUTY | Include this card after the final period of the duty cycle |

Keypunch all printed
and handwritten data
enclosed in ☐ ; if
the line is preceded
by *, omit all others.

## AEROJET-GENERAL CORPORATION CHARRING AND DIMENSIONAL ABLATION PROGRAM

### INPUT BLOCK 3 - RADIATION

Include this block as required to describe a fire and/or soak period.

PAGE 5 OF 7

*RADIATE

| | | Emissivity | Shape Factor | Sink Temp °R |
|---|---|---|---|---|
| * | 1 Interior Term 1 | .9 | .1 | 530.0 |
| | 2 Interior Term 2 | . | . | . |
| * | 3 Exterior Term 1 | .9 | 1.0 | 530.0 |
| | 4 Exterior Term 2 | . | . | . |
| | 5 Exterior Term 3 | . | . | . |
| | 6 Exterior Term 4 | . | . | . |
| | 7 Exterior Term 5 | . | . | . |

If any sink temperature is intended to be 0 °R enter .001.

* — blank card —

8 Include this card if any exterior sink temperatures are to be time dependent

If all exterior radiation is to constant sink temperatures, omit these cards.

| | Time (sec.) | Sink 1 °R | Sink 2 °R | Sink 3 °R | Sink 4 °R | Sink 5 °R |
|---|---|---|---|---|---|---|
| The final entry | | . | . | . | . | . |
| of this table | | . | . | . | . | . |
| must have a "1" | | . | . | . | . | . |
| in Column 1. | | . | . | . | . | . |
| Add more cards | | . | . | . | . | . |
| as required up | | . | . | . | . | . |
| to 50. | | . | . | . | . | . |
| | | . | . | . | . | . |
| | | . | . | . | . | . |

Enter tabular values for all time varying exterior sink temperatures.

| | |
|---|---|
| ENDFIRE | Include this card if this is the final input block for a fire period. |
| ENDSOAK | Include this card if this is the final input block for a soak period. |
| ENDDUTY | If this is the final fire or soak period of the duty cycle, include this card. |

Keypunch all printed
and handwritten data
enclosed in ☐ ; if
the line is preceded
by *, omit all others.

AEROJET-GENERAL CORPORATION CHARRING AND DIMENSIONAL ABLATION PROGRAM

## SOAK PERIOD DESCRIPTION

PAGE 6 OF 7

| | Duration (sec.) | Print (sec.) | $\Delta\theta$ min. | $\Delta\theta$ max. | T-EXT °R | Steady State °R/sec. | Reset °R | |
|---|---|---|---|---|---|---|---|---|
| * SOAK | 1000.0 | | .01 | 100.0 | | | | the word "SOAK" must be input in Columns 1 - 4. |

(T-EXT °R) The SOAK period will end if the exterior temperature reaches this value.

(STEADY STATE) The SOAK period will end if all the nodal temperatures are changing at a rate less than this input value.
If (T-EXT °R) is negative, the SOAK period will end when the exterior temperature peaks.

(RESET) The temperature profile will be set to this input value at the end of the soak period.

ARB-Q

---- Input Block 1 Arbitrary heat flux----

| | a | b | k | c | d | f | g | h |
|---|---|---|---|---|---|---|---|---|
| 1 At interior | | | | | | | | |
| 2 At exterior | | | | | | | | |

ENDSOAK Include this card at the end of a soak period description.

ENDDUTY Include this card after the final period of the duty cycle.

Keypunch all printed
and handwritten data
enclosed in ☐ ; if
the line is preceded
by *, omit all others.

## AEROJET-GENERAL CORPORATION CHARRING AND DIMENSIONAL ABLATION PROGRAM

### INPUT BLOCK 3 - RADIATION

Include this block as required to describe a fire and/or soak period.

PAGE 7 OF 7

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

* RADIATE

| | | Emissivity | Shape Factor | Sink Temp °R | |
|---|---|---|---|---|---|
| * 1 | Interior Term 1 | .9 | .1 | 530.0 | If any sink |
| 2 | Interior Term 2 | . | . | . | temperature is |
| * 3 | Exterior Term 1 | .9 | 1.0 | 530.0 | intended to be |
| 4 | Exterior Term 2 | . | . | . | 0 °R enter .001. |
| 5 | Exterior Term 3 | . | . | . | |
| 6 | Exterior Term 4 | . | . | . | |
| 7 | Exterior Term 5 | . | . | . | |

* — blank card —

8 Include this card if any exterior sink temperatures are to be time dependent

If all exterior radiation is to constant sink temperatures, omit these cards.

| | Time (sec.) | Sink 1 °R | Sink 2 °R | Sink 3 °R | Sink 4 °R | Sink 5 °R |
|---|---|---|---|---|---|---|
| The final entry | | . | . | . | . | . |
| of this table | | . | . | . | . | . |
| must have a "1" | | . | . | . | . | . |
| in Column 1. | | . | . | . | . | . |
| Add more cards | | . | . | . | . | . |
| as required up | | . | . | . | . | . |
| to 50. | | . | . | . | . | . |
| | | . | . | . | . | . |
| | | . | . | . | . | . |
| | | . | . | . | . | . |

Enter tabular values for all time varying exterior sink temperatures.

ENDFIRE Include this card if this is the final input block for a fire period.

* ENDSOAK Include this card if this is the final input block for a soak period.

* ENDDUTY If this is the final fire or soak period of the duty cycle, include this card.

```
                        **** AEROJET-GENERAL CORPORATION ****
                        -------------------------------------

                     CHARRING AND DIMENSIONAL ABLATION PROGRAM

               SAMPLE PROBLEM NO. 5  BARTZ EQUATION AREA RATIO 10/1

                           --- LINER DESCRIPTION ---

LINER IS COMPOSED OF  1 MATERIAL(S)
NUMBER OF NODES =  50
RADIUS FROM NOZZLE CENTER-LINE = 13.0900 INCHES.
RADIUS TO LINER EXTERIOR = 14.5900 INCHES.
TOTAL LINER THICKNESS =  1.5000 INCHES.
RADIAL INCREMENT = 0.03125 INCHES.
HEAT OF ABLATION =  1.5000E 04 BTU/LB.
ABLATION TEMPERATURE = 5000.00 DEG.-R

                              MATERIAL SPECIFICATIONS

                          MATERIAL 1  MATERIAL 2  MATERIAL 3  MATERIAL 4  MATERIAL 5  MATERIAL 6  MA ER

 THICKNESS        INCHES.         1.5000
 SP-HEAT LAMINATE B/LB-R.     2.9000E-01
 SP-HEAT CHAR     B/LB-R.     2.9000E-01
 COND LAMINATE    B/IN-SEC-R. 1.0750E-05
 COND CHAR        B/IN-SEC-R. 6.9700E-06
 DENSITY LAMINATE LB/CU-IN.   5.2000E-02
 DENSITY CHAR     LB/CU-IN.   4.3000E-02
 CHAR TEMPERATURE DEG-R.        1260.000
 EFF. HEAT OF CHAR B/LB CHARRED 3.7400E 02
 INTERFACE NODE   NUMBER              50
```

```
......... FIRE PERIOD    1 IS BEGINNING ---   90.00 SEC. OF FIRE FOLLOWS .........

ELAPSED TIME IN DUTY CYCLE                   0.   SEC.     ELAPSED TIME THIS PERIOD      0.   SEC
CHAR-DEPTH WITH RESPECT TO      C/L    13.0900 INCHES     TOTAL CHAR-DEPTH             0.     IN.
ABLATION DEPTH WITH RESPECT TO  C/L    13.0900 INCHES.    TOTAL DIMENSIONAL ABLATION   0.     IN.


                                                       -- INTERIOR --    -- EXTERIOR --

CONVECTION COEFFICIENT    BTU/SQ-IN-SEC-R.             1.33351E-03      0.
RECOVERY/AMBIENT TEMP.    DEG. R.                        4637.295            0.

HEAT FLUX (CONVECTION)    BTU/SQ-IN-SEC.               5.47711E 00     -0.
HEAT FLUX (RADIATION)     BTU/SQ-IN-SEC.              -0.              -0.
HEAT FLUX (ARBITRARY)     BTU/SQ-IN-SEC.               0.               0.

STABILITY NODE   1      0.

                         ********** TEMPERATURE PROFILE **********

          1          2          3          4          5          6          7          8          9         10
    530.000    530.000    530.000    530.000    530.000    530.000    530.000    530.000    530.000    530.000

         11         12         13         14         15         16         17         18         19         20
    530.000    530.000    530.000    530.000    530.000    530.000    530.000    530.000    530.000    530.000

         21         22         23         24         25         26         27         28         29         30
    530.000    530.000    530.000    530.000    530.000    530.000    530.000    530.000    530.000    530.000

         31         32         33         34         35         36         37         38         39         40
    530.000    530.000    530.000    530.000    530.000    530.000    530.000    530.000    530.000    530.000

         41         42         43         44         45         46         47         48         49         50
    530.000    530.000    530.000    530.000    530.000    530.000    530.000    530.000    530.000    530.000
```

```
......... FIRE PERIOD    1 IN PROGRESS  ---   80.00 SEC. OF FIRE FOLLOWS .........

ELAPSED TIME IN DUTY CYCLE                 10.00 SEC.      ELAPSED TIME THIS PERIOD      10.00 SEC
CHAR-DEPTH WITH RESPECT TO      C/L      13.2096 INCHES    TOTAL CHAR-DEPTH             0.1196 IN.
ABLATION DEPTH WITH RESPECT TO  C/L      13.0900 INCHES.   TOTAL DIMENSIONAL ABLATION   0.     IN.


                                                          -- INTERIOR --   -- EXTERIOR --

CONVECTION COEFFICIENT    BTU/SQ-IN-SEC-R.                 8.56053E-04      0.
RECOVERY/AMBIENT TEMP.    DEG. R.                            4637.976             0.

HEAT FLUX (CONVECTION)    BTU/SQ-IN-SEC.                   3.30372E-01    -0.
HEAT FLUX (RADIATION)     BTU/SQ-IN-SEC.                  -9.73552E-02    -0.
HEAT FLUX (ARBITRARY)     BTU/SQ-IN-SEC.                   0.              0.

STABILITY NODE   1      1.46745242E-01

                          ********** TEMPERATURE PROFILE **********

         1         2         3         4         5         6         7         8         9        10
  4252.051  3735.714  2774.690  1952.277  1260.000  1003.376   817.580   693.725   618.683   575.667

        11        12        13        14        15        16        17        18        19        20
   552.277   540.265   534.462   531.829   530.708   530.258   530.089   530.029   530.009   530.003

        21        22        23        24        25        26        27        28        29        30
   530.001   530.000   530.000   530.000   530.000   530.000   530.000   530.000   530.000   530.000

        31        32        33        34        35        36        37        38        39        40
   530.000   530.000   530.000   530.000   530.000   530.000   530.000   530.000   530.000   530.000

        41        42        43        44        45        46        47        48        49        50
   530.000   530.000   530.000   530.000   530.000   530.000   530.000   530.000   530.000   530.000
```

```
......... FIRE PERIOD    1 IN PROGRESS  ---   70.00 SEC. OF FIRE FOLLOWS .........

ELAPSED TIME IN DUTY CYCLE                 20.00 SEC.      ELAPSED TIME THIS PERIOD       20.00 SEC
CHAR-DEPTH WITH RESPECT TO      C/L      13.2619 INCHES    TOTAL CHAR-DEPTH              0.1719 IN.
ABLATION DEPTH WITH RESPECT TO  C/L      13.0900 INCHES.   TOTAL DIMENSIONAL ABLATION    0.      IN.


                                                        -- INTERIOR --    -- EXTERIOR --

CONVECTION COEFFICIENT    BTU/SQ-IN-SEC-R.               8.57581E-04       0.
RECOVERY/AMBIENT TEMP.    DEG. R.                           4638.288             0.

HEAT FLUX (CONVECTION)    BTU/SQ-IN-SEC.                 2.68941E-01      -0.
HEAT FLUX (RADIATION)     BTU/SQ-IN-SEC.                -1.04181E-01      -0.
HEAT FLUX (ARBITRARY)     BTU/SQ-IN-SEC.                 0.                0.

STABILITY NODE   1       1.46436769E-01

                       ********** TEMPERATURE PROFILE **********

        1         2         3         4         5         6         7         8         9        10
 4324.684  3957.424  3247.185  2591.645  2017.942  1544.341  1170.245   989.035   854.809   755.330

       11        12        13        14        15        16        17        18        19        20
  682.205   629.698   593.255   568.892   553.193   543.422   537.539   534.109   532.174   531.116

       21        22        23        24        25        26        27        28        29        30
  530.555   530.268   530.126   530.057   530.025   530.011   530.004   530.002   530.001   530.000

       31        32        33        34        35        36        37        38        39        40
  530.000   530.000   530.000   530.000   530.000   530.000   530.000   530.000   530.000   530.000

       41        42        43        44        45        46        47        48        49        50
  530.000   530.000   530.000   530.000   530.000   530.000   530.000   530.000   530.000   530.000
```

```
    ......... FIRE PERIOD    1 IN PROGRESS  ---   60.00 SEC. OF FIRE FOLLOWS .........

ELAPSED TIME IN DUTY CYCLE                30.00 SEC.      ELAPSED TIME THIS PERIOD       30.00 SEC
CHAR-DEPTH WITH RESPECT TO      C/L     13.2931 INCHES    TOTAL CHAR-DEPTH             0.2031 IN.
ABLATION DEPTH WITH RESPECT TO  C/L     13.0900 INCHES.   TOTAL DIMENSIONAL ABLATION   0.      IN.


                                                       -- INTERIOR --   -- EXTERIOR --

CONVECTION COEFFICIENT    BTU/SQ-IN-SEC-R.                8.62789E-04      0.
RECOVERY/AMBIENT TEMP.    DEG. R.                              4648.583          0.

HEAT FLUX (CONVECTION)    BTU/SQ-IN-SEC.                  2.44002E-01     -0.
HEAT FLUX (RADIATION)     BTU/SQ-IN-SEC.                 -1.08199E-01     -0.
HEAT FLUX (ARBITRARY)     BTU/SQ-IN-SEC.                  0.               0.

STABILITY NODE   1      1.45787741E-01

                             ********** TEMPERATURE PROFILE **********

            1         2         3         4         5         6         7         8         9        10
     4365.777  4063.211  3474.296  2918.039  2408.866  1957.820  1570.301  1244.522  1075.181   941.582

           11        12        13        14        15        16        17        18        19        20
      837.180   756.150   693.805   646.472   611.182   585.433   567.076   554.292   545.595   539.809

           21        22        23        24        25        26        27        28        29        30
      536.046   533.651   532.160   531.252   530.711   530.395   530.215   530.115   530.060   530.031

           31        32        33        34        35        36        37        38        39        40
      530.015   530.007   530.003   530.002   530.001   530.000   530.000   530.000   530.000   530.000

           41        42        43        44        45        46        47        48        49        50
      530.000   530.000   530.000   530.000   530.000   530.000   530.000   530.000   530.000   530.000
```

```
  ......... FIRE PERIOD    1 IN PROGRESS  ---    50.00 SEC. OF FIRE FOLLOWS .........

ELAPSED TIME IN DUTY CYCLE                     40.00 SEC.      ELAPSED TIME THIS PERIOD      40.00 SEC
CHAR-DEPTH WITH RESPECT TO        C/L        13.3244 INCHES    TOTAL CHAR-DEPTH             0.2344 IN.
ABLATION DEPTH WITH RESPECT TO    C/L        13.0900 INCHES.   TOTAL DIMENSIONAL ABLATION   0.     IN.


                                                          -- INTERIOR --    -- EXTERIOR --

CONVECTION COEFFICIENT    BTU/SQ-IN-SEC-R.                 8.69046E-04       0.
RECOVERY/AMBIENT TEMP.    DEG. R.                             4662.786              0.

HEAT FLUX (CONVECTION)    BTU/SQ-IN-SEC.                   2.29798E-01      -0.
HEAT FLUX (RADIATION)     BTU/SQ-IN-SEC.                  -1.11466E-01      -0.
HEAT FLUX (ARBITRARY)     BTU/SQ-IN-SEC.                   0.                0.

STABILITY NODE   1      1.45046869E-01

                            ********** TEMPERATURE PROFILE **********

          1         2         3         4         5         6         7         8         9        10
   4398.360  4134.465  3617.949  3123.542  2660.997  2238.663  1862.472  1534.762  1253.591  1103.238

         11        12        13        14        15        16        17        18        19        20
    980.708   881.526   801.575   737.431   686.365   646.180   615.022   591.265   573.467   560.367

         21        22        23        24        25        26        27        28        29        30
    550.892   544.154   539.443   536.204   534.013   532.556   531.603   530.989   530.601   530.360

         31        32        33        34        35        36        37        38        39        40
    530.212   530.123   530.070   530.039   530.021   530.012   530.006   530.003   530.001   530.001

         41        42        43        44        45        46        47        48        49        50
    530.000   530.000   530.000   530.000   530.000   530.000   530.000   530.000   530.000   530.000
```

```
......... FIRE PERIOD    1 IN PROGRESS  ---    40.00 SEC. OF FIRE FOLLOWS .........

ELAPSED TIME IN DUTY CYCLE                   50.00 SEC.     ELAPSED TIME THIS PERIOD       50.00 SEC
CHAR-DEPTH WITH RESPECT TO       C/L      13.3556 INCHES    TOTAL CHAR-DEPTH               0.2656 IN.
ABLATION DEPTH WITH RESPECT TO   C/L      13.0900 INCHES.   TOTAL DIMENSIONAL ABLATION   0.       IN.


                                                           -- INTERIOR --    -- EXTERIOR --

CONVECTION COEFFICIENT     BTU/SQ-IN-SEC-R.                  8.75475E-04       0.
RECOVERY/AMBIENT TEMP.     DEG. R.                             4674.928               0.

HEAT FLUX (CONVECTION)     BTU/SQ-IN-SEC.                    2.20342E-01      -0.
HEAT FLUX (RADIATION)      BTU/SQ-IN-SEC.                   -1.14011E-01      -0.
HEAT FLUX (ARBITRARY)      BTU/SQ-IN-SEC.                    0.                0.

STABILITY NODE    1       1.44299264E-01

                     ********** TEMPERATURE PROFILE **********

       1         2         3         4         5         6         7         8         9        10
4423.246  4185.970  3719.892  3269.943  2843.072  2445.707  2083.471  1760.445  1478.053  1234.266

      11        12        13        14        15        16        17        18        19        20
1102.360   993.014   902.470   827.426   765.286   714.095   672.326   638.676   611.951   591.037

      21        22        23        24        25        26        27        28        29        30
 574.905   562.635   553.430   546.616   541.640   538.053   535.503   533.714   532.475   531.629

      31        32        33        34        35        36        37        38        39        40
 531.058   530.679   530.430   530.269   530.166   530.101   530.061   530.036   530.021   530.012

      41        42        43        44        45        46        47        48        49        50
 530.007   530.004   530.002   530.001   530.000   530.000   530.000   530.000   530.000   530.000
```

```
......... FIRE PERIOD    1 IN PROGRESS  ---   30.00 SEC. OF FIRE FOLLOWS .........

FLAPSED TIME IN DUTY CYCLE                    60.00 SEC.      ELAPSED TIME THIS PERIOD       60.00 SEC
CHAR-DEPTH WITH RESPECT TO       C/L        13.3869 INCHES    TOTAL CHAR-DEPTH              0.2969 IN.
ABLATION DEPTH WITH RESPECT TO   C/L        13.0900 INCHES.   TOTAL DIMENSIONAL ABLATION    0.     IN.


                                                          -- INTERIOR --    -- EXTERIOR --

CONVECTION COEFFICIENT     BTU/SQ-IN-SEC-R.                 8.81556E-04      0.
RECOVERY/AMBIENT TEMP.     DEG. R.                            4684.834           0.

HEAT FLUX (CONVECTION)     BTU/SQ-IN-SEC.                   2.13397E-01     -0.
HEAT FLUX (RADIATION)      BTU/SQ-IN-SEC.                  -1.16037E-01     -1.78454E-09
HEAT FLUX (ARBITRARY)      BTU/SQ-IN-SEC.                  0.                0.

STABILITY NODE   1      1.43616599E-01

                         ********** TEMPERATURE PROFILE **********

        1         2         3         4         5         6         7         8         9        10
 4442.766  4225.402  3797.458  3382.132  2984.415  2608.734  2259.326  1940.655  1657.031  1410.793

       11        12        13        14        15        16        17        18        19        20
 1200.077  1086.310   991.129   910.560   841.732   782.888   732.960   691.122   656.555   628.384

       21        22        23        24        25        26        27        28        29        30
  605.716   587.690   573.517   562.495   554.019   547.573   542.724   539.118   536.467   534.539

       31        32        33        34        35        36        37        38        39        40
  533.152   532.166   531.473   530.991   530.660   530.435   530.283   530.183   530.116   530.073

       41        42        43        44        45        46        47        48        49        50
  530.046   530.028   530.017   530.010   530.006   530.003   530.002   530.001   530.001   530.001
```

```
......... FIRE PERIOD    1 IN PROGRESS ---   20.00 SEC. OF FIRE FOLLOWS .........


ELAPSED TIME IN DUTY CYCLE                 70.00 SEC.      ELAPSED TIME THIS PERIOD      70.00 SEC
CHAR-DEPTH WITH RESPECT TO      C/L      13.4181 INCHES    TOTAL CHAR-DEPTH              0.3281 IN.
ABLATION DEPTH WITH RESPECT TO  C/L      13.0900 INCHES.   TOTAL DIMENSIONAL ABLATION    0.     IN.


                                                          -- INTERIOR --   -- EXTERIOR --

CONVECTION COEFFICIENT     BTU/SQ-IN-SEC-R.                8.87539E-04      0.
RECOVERY/AMBIENT TEMP.     DEG. R.                           4693.316            0.

HEAT FLUX (CONVECTION)     BTU/SQ-IN-SEC.                  2.08181E-01     -0.
HEAT FLUX (RADIATION)      BTU/SQ-IN-SEC.                 -1.17717E-01     -1.61036E-08
HEAT FLUX (ARBITRARY)      BTU/SQ-IN-SEC.                  0.               0.

STABILITY NODE   1      1.42957111E-01

                     ********** TEMPERATURE PROFILE **********

          1         2         3         4         5         6         7         8         9        10
   4458.755  4256.723  3858.418  3470.810  3098.158  2743.966  2410.571  2098.834  1809.078  1545.854

         11        12        13        14        15        16        17        18        19        20
   1324.066  1154.679  1066.024   987.442   915.562   850.840   794.030   745.215   703.921   669.399

         21        22        23        24        25        26        27        28        29        30
    640.820   617.372   598.306   582.942   570.679   560.983   553.390   547.502   542.981   539.542

         31        32        33        34        35        36        37        38        39        40
    536.952   535.020   533.592   532.547   531.790   531.247   530.860   530.588   530.399   530.268

         41        42        43        44        45        46        47        48        49        50
    530.178   530.117   530.076   530.049   530.032   530.021   530.014   530.010   530.009   530.009
```

```
......... FIRE PERIOD    1 IN PROGRESS  ---   10.00 SEC. OF FIRE FOLLOWS .........

ELAPSED TIME IN DUTY CYCLE                 80.00 SEC.     ELAPSED TIME THIS PERIOD       80.00 SEC
CHAR-DEPTH WITH RESPECT TO      C/L      13.4269 INCHES   TOTAL CHAR-DEPTH              0.3369 IN.
ABLATION DEPTH WITH RESPECT TO  C/L      13.0900 INCHES.  TOTAL DIMENSIONAL ABLATION    0.     IN.


                                                      -- INTERIOR --    -- EXTERIOR --

CONVECTION COEFFICIENT    BTU/SQ-IN-SEC-R.              8.93128E-04      0.
RECOVERY/AMBIENT TEMP.    DEG. R.                          4700.310            0.

HEAT FLUX (CONVECTION)    BTU/SQ-IN-SEC.                2.03960E-01     -0.
HEAT FLUX (RADIATION)     BTU/SQ-IN-SEC.               -1.19116E-01     -7.21198E-08
HEAT FLUX (ARBITRARY)     BTU/SQ-IN-SEC.                0.               0.

STABILITY NODE   1      1.42340671E-01

                     ********** TEMPERATURE PROFILE **********

        1         2         3         4         5         6         7         8         9        10
 4471.944  4282.389  3908.056  3542.561  3189.555  2852.427  2534.199  2237.345  1963.394  1712.124

       11        12        13        14        15        16        17        18        19        20
 1480.211  1260.000  1158.105  1069.831   988.019   915.392   852.283   797.969   751.469   711.843

       21        22        23        24        25        26        27        28        29        30
  678.266   650.006   626.403   606.854   590.801   577.733   567.186   558.747   552.053   546.787

       31        32        33        34        35        36        37        38        39        40
  542.680   539.503   537.067   535.214   533.817   532.772   531.997   531.428   531.012   530.712

       41        42        43        44        45        46        47        48        49        50
  530.497   530.345   530.237   530.163   530.112   530.078   530.056   530.045   530.041   530.041
```

```
                 .......... FIRE PERIOD    1 HAS ENDED    ..........

ELAPSED TIME IN DUTY CYCLE                   90.00 SEC.      ELAPSED TIME THIS PERIOD      90.00 SEC
CHAR-DEPTH WITH RESPECT TO       C/L       13.4494 INCHES    TOTAL CHAR-DEPTH              0.3594 IN.
ABLATION DEPTH WITH RESPECT TO   C/L       13.0900 INCHES.   TOTAL DIMENSIONAL ABLATION    0.     IN.


                                                        -- INTERIOR --    -- EXTERIOR --

CONVECTION COEFFICIENT    BTU/SQ-IN-SEC-R.                8.98521E-04       0.
RECOVERY/AMBIENT TEMP.    DEG. R.                            4706.295             0.

HEAT FLUX (CONVECTION)    BTU/SQ-IN-SEC.                  2.00444E-01      -0.
HEAT FLUX (RADIATION)     BTU/SQ-IN-SEC.                 -1.20321E-01      -2.27448E-07
HEAT FLUX (ARBITRARY)     BTU/SQ-IN-SEC.                  0.                0.

STABILITY NODE    1       1.41762227E-01

                    ********** TEMPERATURE PROFILE **********

        1         2         3         4         5         6         7         8         9        10
 4483.212  4304.158  3950.157  3603.643  3267.555  2944.554  2637.063  2347.377  2077.750  1830.295

       11        12        13        14        15        16        17        18        19        20
 1606.563  1406.891  1229.936  1130.664  1044.838   970.347   905.331   848.361   798.430   754.826

       21        22        23        24        25        26        27        28        29        30
  716.999   684.452   656.690   633.212   613.520   597.134   583.601   572.508   563.482   556.194

       31        32        33        34        35        36        37        38        39        40
  550.351   545.703   542.033   539.157   536.920   535.193   533.870   532.864   532.105   531.536

       41        42        43        44        45        46        47        48        49        50
  531.114   530.803   530.577   530.413   530.298   530.219   530.167   530.138   530.129   530.128
```

```
......... SOAK PERIOD    1 IS BEGINNING --- 1000.00 SEC. OF SOAK FOLLOWS .........

ELAPSED TIME IN DUTY CYCLE                      90.00 SEC.      ELAPSED TIME THIS PERIOD        0.   SEC
CHAR-DEPTH WITH RESPECT TO      C/L        13.4494 INCHES      TOTAL CHAR-DEPTH               0.3594 IN.
ABLATION DEPTH WITH RESPECT TO  C/L        13.0900 INCHES.     TOTAL DIMENSIONAL ABLATION     0.     IN.


                                                          -- INTERIOR --    -- EXTERIOR --

CONVECTION COEFFICIENT     BTU/SQ-IN-SEC-R.                  0.                0.
RECOVERY/AMBIENT TEMP.     DEG. R.                                0.                0.

HEAT FLUX (CONVECTION)     BTU/SQ-IN-SEC.                    2.00444E-01      -0.
HEAT FLUX (RADIATION)      BTU/SQ-IN-SEC.                   -1.20321E-01      -2.27448E-07
HEAT FLUX (ARBITRARY)      BTU/SQ-IN-SEC.                    0.                0.

STABILITY NODE   1       1.41762227E-01

                        ********** TEMPERATURE PROFILE **********

        1         2         3         4         5         6         7         8         9        10
 4483.212  4304.158  3950.157  3603.643  3267.555  2944.554  2637.063  2347.377  2077.750  1830.295

       11        12        13        14        15        16        17        18        19        20
 1606.563  1406.891  1229.936  1130.664  1044.838   970.347   905.331   848.361   798.430   754.826

       21        22        23        24        25        26        27        28        29        30
  716.999   684.452   656.690   633.212   613.520   597.134   583.601   572.508   563.482   556.194

       31        32        33        34        35        36        37        38        39        40
  550.351   545.703   542.033   539.157   536.920   535.193   533.870   532.864   532.105   531.536

       41        42        43        44        45        46        47        48        49        50
  531.114   530.803   530.577   530.413   530.298   530.219   530.167   530.138   530.129   530.128
```

```
                      .......... SOAK PERIOD    1 HAS ENDED    ..........

ELAPSED TIME IN DUTY CYCLE               1090.00 SEC.      ELAPSED TIME THIS PERIOD    1000.00 SEC
CHAR-DEPTH WITH RESPECT TO      C/L      13.5431 INCHES    TOTAL CHAR-DEPTH             0.4531 IN.
ABLATION DEPTH WITH RESPECT TO  C/L      13.0900 INCHES.   TOTAL DIMENSIONAL ABLATION  0.       IN.


                                                      -- INTERIOR --    -- EXTERIOR --

CONVECTION COEFFICIENT    BTU/SQ-IN-SEC-R.              0.                0.
RECOVERY/AMBIENT TEMP.    DEG. R.                            0.                0.

HEAT FLUX (CONVECTION)    BTU/SQ-IN-SEC.                0.               -0.
HEAT FLUX (RADIATION)     BTU/SQ-IN-SEC.               -2.43837E-04      -1.28857E-03
HEAT FLUX (ARBITRARY)     BTU/SQ-IN-SEC.                0.                0.

STABILITY NODE  49      2.28441077E-01

                        ********** TEMPERATURE PROFILE **********

          1         2         3         4         5         6         7         8         9        10
    973.306   973.778   974.425   974.773   974.825   974.584   974.054   973.240   972.147   970.783

         11        12        13        14        15        16        17        18        19        20
    969.155   967.271   965.141   962.775   960.183   957.376   955.397   953.264   950.983   948.563

         21        22        23        24        25        26        27        28        29        30
    946.009   943.328   940.529   937.618   934.602   931.489   928.287   925.002   921.641   918.212

         31        32        33        34        35        36        37        38        39        40
    914.721   911.175   907.581   903.944   900.271   896.567   892.838   889.088   885.323   881.547

         41        42        43        44        45        46        47        48        49        50
    877.762   873.974   870.185   866.397   862.613   858.835   855.064   851.301   847.547   845.673
```

```
                    **** DUTY CYCLE HAS ENDED ****

        MAXIMUM EXTERIOR TEMPERTURE OCCURED AT 1090.00 SECONDS INTO DUTY CYCLE

                      ----- TEMPERATURE PROFILE -----

        1         2         3         4         5         6         7         8         9        10
  973.306   973.778   974.425   974.773   974.825   974.584   974.054   973.240   972.147   970.783

       11        12        13        14        15        16        17        18        19        20
  969.155   967.271   965.141   962.775   960.183   957.376   955.397   953.264   950.983   948.563

       21        22        23        24        25        26        27        28        29        30
  946.009   943.328   940.529   937.618   934.602   931.489   928.287   925.002   921.641   918.212

       31        32        33        34        35        36        37        38        39        40
  914.721   911.175   907.581   903.944   900.271   896.567   892.838   889.088   885.323   881.547

       41        42        43        44        45        46        47        48        49        50
  877.762   873.974   870.185   866.397   862.613   858.835   855.064   851.301   847.547   845.673

END-OF-FILE READING ON SYSTEM INPUT TAPE.
RETURNING TO SYSTEM.
```

## SAMPLE PROBLEM 6. (≈ 2 MIN)

This problem demonstrates the use of the "PULSE" option. The duty cycle required for this problem is as follows:

| | | |
|---|---|---|
| Fire | 1.0 seconds | repeat 100 times |
| Soak | 2.0 seconds | |
| Soak | Until exterior temperature reaches a maximum value. | |

A "PULSE" card has been placed infornt of the "FIRE" card. The number of pulses (100.0) has been input in Columns 8 through 15. During pulsing, no online messages are printed, and the print interval (as specified on the "FIRE" card) is referred to the start of the pulse period.

Keypunch all printed
and handwritten data
enclosed in ☐ ; if
the line is preceded
by *, omit all others.

## AEROJET-GENERAL CORPORATION CHARRING AND DIMENSIONAL ABLATION PROGRAM

### BASIC INPUT ---- Sheet 1

1) This sheet must be completed for all cases.
2) Sheet 2 must be completed if the temperature frofile at start time is not uniform.

PAGE 1 OF 6

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

TITLE CARD-79 CHARACTERS

* T SAMPLE PROBLEM NO. 6 PULSE STATION

* Number of Materials ≤ 8 1 Number of Nodes. ≤ 500 20 Enter(T) if nozzle station is throat. T

* Inside radius from ¢ IN 4.14 Initial Char Depth IN. From Internal Surface . Liner temperature if uniform °R 530.0

* Ablation Temperature °R 4660.0 Heat of ablation BTU/lb of CHAR +2.6 +04

MATERIAL SPECIFICATIONS

| | MATERIAL 1 | MATERIAL 2 | MATERIAL 3 | MATERIAL 4 | MATERIAL 5 | MATERIAL 6 | MATERIAL 7 | MATERIAL 8 |
|---|---|---|---|---|---|---|---|---|
| * Thickness Inches | 1.5 | . | . | . | . | . | . | . |
| * $C_p$-Laminate BTU/LB-°R | .03 | . | . | . | . | . | . | . |
| * $C_p$-Char BTU/LB-°R | .03 | . | . | . | . | . | . | . |
| * K-Laminate B/IN-SEC-R | 2.0 -06 | . − | . − | . − | . − | . − | . − | . − |
| * K-Char B/IN-SEC-R | 6.0 -06 | . − | . − | . − | . − | . − | . − | . − |
| * ρ-Laminate LB/IN$^3$ | .052 | . | . | . | . | . | . | . |
| * ρ-Char LB/IN$^3$ | .035 | . | . | . | . | . | . | . |
| * T-Char °R | 1460.0 | . | . | . | . | . | . | . |
| * Q-Char BTU/LB | 3.7 +03 | . + | . + | . + | . + | . + | . + | . + |

Keypunch all printed
and handwritten data
enclosed in ▭; if
the line is preceded
by *, omit all others.

## AEROJET-GENERAL CORPORATION CHARRING AND DIMENSIONAL ABLATION PROGRAM

## FIRE PERIOD DESCRIPTION

PAGE 2 OF 6

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

* PULSE 100.0

| Duration(sec.) | Print(sec.) | $\Delta\theta$ min. | $\Delta\theta$ max. |
|---|---|---|---|
| FIRE 1.0 | 25.0 | .01 | .1 |

The word "FIRE" must be input in Columns 1 - 4. A duration must be input.

$q/A = a \sin(b + kt) + c + dt + ft^2 + ge^{ht}$

ARB-Q ----- Input Block 1 Arbitrary Heat Flux -----

| | a | b | k | c | d | f | g | h |
|---|---|---|---|---|---|---|---|---|
| 1 at interior | | | | | | | | |
| 2 at exterior | | | | | | | | |

* INTERIOR ----- Input Block 2 Interior Convection -----

* 1 Recovery Temp. °R 5100.0

* 2 Convection Coefficient 1.02 -03 BTU/in$^2$-sec °R

Input convection coefficient value only if constant.

* —blank card—

| | Time | h BTU/in$^2$-sec °R |
|---|---|---|
| The final entry | | . - |
| of this table | | . - |
| must have a "1" | | . - |
| in Column 1. | | . - |
| Add more cards | | . - |
| as required up | | . - |
| to 50. | | . - |

If the interior convection coefficient is time dependent complete this table. Card 2 above must be input with value left blank

ENDFIRE Include this card at the end of a fire period description.

ENDDUTY Include this card after the final period of the duty cycle.

Keypunch all printed
and handwritten data
enclosed in ☐ ; if
the line is preceded
by *, omit all others.

AEROJET-GENERAL CORPORATION CHARRING AND DIMENSIONAL ABLATION PROGRAM

INPUT BLOCK 3 - RADIATION

Include this block as required to describe a fire
and/or soak period.

PAGE 3 OF 6

* RADIATE

| | | Emissivity | Shape Factor | Sink Temp °R | |
|---|---|---|---|---|---|
| * | 1 Interior Term 1 | .9 | .1 | 530.0 | If any sink |
| | 2 Interior Term 2 | . | . | . | temperature is |
| * | 3 Exterior Term 1 | .9 | 1.0 | 530.0 | intended to be |
| | 4 Exterior Term 2 | . | . | . | 0 °R enter .001. |
| | 5 Exterior Term 3 | . | . | . | |
| | 6 Exterior Term 4 | . | . | . | |
| | 7 Exterior Term 5 | . | . | . | |

* — blank card —

8 Include this card if any exterior sink temperatures are to be time dependent

| | Time (sec.) | Sink 1 °R | Sink 2 °R | Sink 3 °R | Sink 4 °R | Sink 5 °R | |
|---|---|---|---|---|---|---|---|
| The final entry | | . | . | . | . | . | If all exterior |
| of this table | | . | . | . | . | . | radiation is to |
| must have a "1" | | . | . | . | . | . | constant sink |
| in Column 1. | | . | . | . | . | . | temperatures, |
| Add more cards | | . | . | . | . | . | omit these cards. |
| as required up | | . | . | . | . | . | Enter tabular |
| to 50. | | . | . | . | . | . | values for all |
| | | . | . | . | . | . | time varying |
| | | . | . | . | . | . | exterior sink temperatures. |

* ENDFIRE — Include this card if this is the final input block for a fire period.

ENDSOAK — Include this card if this is the final input block for a soak period.

ENDDUTY — If this is the final fire or soak period of the duty cycle, include this card.

AEROJET-GENERAL CORPORATION CHARRING AND DIMENSIONAL ABLATION PROGRAM

## SOAK PERIOD DESCRIPTION

Keypunch all printed
and handwritten data
enclosed in ☐ ; if
the line is preceded
by *, omit all others.

PAGE ~~3~~4 OF 6

| | Duration (sec.) | Print (sec.) | ΔΘ min. | ΔΘ max. | T-EXT °R | Steady State °R/sec. | Reset °R | |
|---|---|---|---|---|---|---|---|---|
| * SOAK | 2.9 | | .9 | .2 | | | | the word "SOAK" must be input in Columns 1 - 4. |

(T-EXT °R) The SOAK period will end if the exterior temperature reaches this value.

(STEADY STATE) The SOAK period will end if all the nodal temperatures are changing at a rate less than this input value.

If (T-EXT °R) is negative, the SOAK period will end when the exterior temperature peaks.

(RESET) The temperature profile will be set to this input value at the end of the soak period.

ARB-Q ---- Input Block 1, Arbitrary heat flux ----

| | a | b | k | c | d | f | g | h |
|---|---|---|---|---|---|---|---|---|
| 1 At interior | | | | | | | | |
| 2 At exterior | | | | | | | | |

ENDSOAK Include this card at the end of a soak period description.

ENDDUTY Include this card after the final period of the duty cycle.

Keypunch all printed
and handwritten data
enclosed in ☐ ; if
the line is preceded
by *, omit all others.

## AEROJET-GENERAL CORPORATION CHARRING AND DIMENSIONAL ABLATION PROGRAM

## INPUT BLOCK 3 - RADIATION

Include this block as required to describe a fire and/or soak period.

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1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

* RADIATE

|  | Emissivity | Shape Factor | Sink Temp °R |
|---|---|---|---|
| * 1 Interior Term 1 | .9 | .1 | 539.0 |
| 2 Interior Term 2 | . | . | . |
| * 3 Exterior Term 1 | .9 | 1.0 | 539.9 |
| 4 Exterior Term 2 | . | . | . |
| 5 Exterior Term 3 | . | . | . |
| 6 Exterior Term 4 | . | . | . |
| 7 Exterior Term 5 | . | . | . |

If any sink temperature is intended to be 0 °R enter .001.

* — blank card —

8 Include this card if any exterior sink temperatures are to be time dependent

|  | Time (sec.) | Sink 1 °R | Sink 2 °R | Sink 3 °R | Sink 4 °R | Sink 5 °R |
|---|---|---|---|---|---|---|
| The final entry |  | . | . | . | . | . |
| of this table |  | . | . | . | . | . |
| must have a "1" |  | . | . | . | . | . |
| in Column 1. |  | . | . | . | . | . |
| Add more cards |  | . | . | . | . | . |
| as required up |  | . | . | . | . | . |
| to 50. |  | . | . | . | . | . |
|  |  | . | . | . | . | . |
|  |  | . | . | . | . | . |

If all exterior radiation is to constant sink temperatures, omit these cards.

Enter tabular values for all time varying exterior sink temperatures.

ENDFIRE Include this card if this is the final input block for a fire period.

* ENDSOAK Include this card if this is the final input block for a soak period.

ENDDUTY If this is the final fire or soak period of the duty cycle, include this card.

AEROJET-GENERAL CORPORATION CHARRING AND DIMENSIONAL ABLATION PROGRAM

Keypunch all printed
and handwritten data
enclosed in ☐ ; if
the line is preceded
by *, omit all others.

## SOAK PERIOD DESCRIPTION

PAGE 6 OF 6

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

| | Duration (sec.) | Print (sec.) | $\Delta\theta$ min. | $\Delta\theta$ max. | T-EXT °R | Steady State °R/sec. | Reset °R |
|---|---|---|---|---|---|---|---|
| * SOAK | 1000.0 | | .01 | 5.0 | -1.0 | | |

the word "SOAK" must be input in Columns 1 - 4.

(T-EXT °R) The SOAK period will end if the exterior temperature reaches this value.

(STEADY STATE) The SOAK period will end if all the nodal temperatures are changing at a rate less than this input value.

If (T-EXT °R) is negative, the SOAK period will end when the exterior temperature peaks.

(RESET) The temperature profile will be set to this input value at the end of the soak period.

ARB-Q ---- Input Block 1 Arbitrary heat flux ----

| | a | b | k | c | d | f | g | h |
|---|---|---|---|---|---|---|---|---|
| 1 At interior | | | | | | | | |
| 2 At exterior | | | | | | | | |

* ENDSOAK Include this card at the end of a soak period description.

* ENDDUTY Include this card after the final period of the duty cycle.

```
                                   **** AEROJET-GENERAL CORPORATION ****
                                   -------------------------------------

                                 CHARRING AND DIMENSIONAL ABLATION PROGRAM

                                SAMPLE PROBLEM NO. 6  PULSE OPTION

                                        --- LINER DESCRIPTION ---

STATION OF INTEREST IS THROAT
LINER IS COMPOSED OF  1 MATERIAL(S)
NUMBER OF NODES =  20
RADIUS FROM NOZZLE CENTER-LINE =  4.1400 INCHES.
RADIUS TO LINER EXTERIOR =  5.6400 INCHES.
TOTAL LINER THICKNESS =  1.5000 INCHES.
RADIAL INCREMENT = 0.08333 INCHES.
HEAT OF ABLATION =  2.6000E 04 BTU/LB.
ABLATION TEMPERATURE = 4660.00 DEG.-R

                                          MATERIAL SPECIFICATIONS

                                      MATERIAL 1  MATERIAL 2  MATERIAL 3  MATERIAL 4  MATERIAL 5  MATERIAL 6  MATER

 THICKNESS          INCHES.              1.5000
 SP-HEAT LAMINATE   B/LB-R.          3.0000E-02
 SP-HEAT CHAR       B/LB-R.          3.0000E-02
 COND LAMINATE      B/IN-SEC-R.      2.0000E-06
 COND CHAR          B/IN-SEC-R.      6.0000E-06
 DENSITY LAMINATE   LB/CU-IN.        5.2000E-02
 DENSITY CHAR       LB/CU-IN.        3.5000E-02
 CHAR TEMPERATURE   DEG-R.             1460.000
 EFF. HEAT OF CHAR  B/LB CHARRED     3.7000E 03
 INTERFACE NODE     NUMBER                   20
```

```
                        ********** ENGINE WILL BE PULSED  100 TIMES **********

    ......... FIRE PERIOD    1 IS BEGINNING ---    1.00 SEC. OF FIRE FOLLOWS .........

ELAPSED TIME IN DUTY CYCLE                 0.   SEC.       ELAPSED TIME THIS PERIOD       0.    SEC
CHAR-DEPTH WITH RESPECT TO      C/L      4.1400 INCHES     TOTAL CHAR-DEPTH             0.      IN.
ABLATION DEPTH WITH RESPECT TO  C/L      4.1400 INCHES.    TOTAL DIMENSIONAL ABLATION   0.      IN.


                                                       -- INTERIOR --   -- EXTERIOR --

CONVECTION COEFFICIENT    BTU/SQ-IN-SEC-R.                1.02000E-03      0.
RECOVERY/AMBIENT TEMP.    DEG. R.                            5100.000            0.

HEAT FLUX (CONVECTION)    BTU/SQ-IN-SEC.                  4.66140E 00     -0.
HEAT FLUX (RADIATION)     BTU/SQ-IN-SEC.                 -0.              -0.
HEAT FLUX (ARBITRARY)     BTU/SQ-IN-SEC.                  0.               0.

STABILITY NODE   1      0.

                             ********** TEMPERATURE PROFILE **********

             1         2         3         4         5         6         7         8         9        10
       530.000   530.000   530.000   530.000   530.000   530.000   530.000   530.000   530.000   530.000

            11        12        13        14        15        16        17        18        19        20
       530.000   530.000   530.000   530.000   530.000   530.000   530.000   530.000   530.000   530.000
```

```
......... SOAK PERIOD    9 IN PROGRESS  ---    2.00 SEC. OF SOAK FOLLOWS .........

ELAPSED TIME IN DUTY CYCLE                     25.00 SEC.      ELAPSED TIME THIS PERIOD        0.    SEC
CHAR-DEPTH WITH RESPECT TO      C/L           4.2421 INCHES    TOTAL CHAR-DEPTH              0.1021 IN.
ABLATION DEPTH WITH RESPECT TO  C/L           4.1400 INCHES.   TOTAL DIMENSIONAL ABLATION    0.     IN.


                                                         -- INTERIOR --    -- EXTERIOR --

CONVECTION COEFFICIENT     BTU/SQ-IN-SEC-R.                 0.                0.
RECOVERY/AMBIENT TEMP.     DEG. R.                              0.                0.

HEAT FLUX (CONVECTION)     BTU/SQ-IN-SEC.                   0.               -0.
HEAT FLUX (RADIATION)      BTU/SQ-IN-SEC.                -1.26441E-01     -1.22020E-11
HEAT FLUX (ARBITRARY)      BTU/SQ-IN-SEC.                   0.                0.

STABILITY NODE   1       3.67562592E-02

                     ********** TEMPERATURE PROFILE **********

          1         2         3         4         5         6         7         8         9        10
   4539.150  1460.000  1281.818  1026.630   833.494   700.965   618.755   572.479   548.768   537.670

         11        12        13        14        15        16        17        18        19        20
    532.906   531.023   530.335   530.102   530.029   530.008   530.002   530.000   530.000   530.000
```

```
    ......... SOAK PERIOD   17 IN PROGRESS  ---    1.00 SEC. OF SOAK FOLLOWS .........

ELAPSED TIME IN DUTY CYCLE                50.00 SEC.      ELAPSED TIME THIS PERIOD       1.00 SEC
CHAR-DEPTH WITH RESPECT TO      C/L      4.2862 INCHES    TOTAL CHAR-DEPTH             0.1462 IN.
ABLATION DEPTH WITH RESPECT TO  C/L      4.1404 INCHES.   TOTAL DIMENSIONAL ABLATION   0.0004 IN.


                                                        -- INTERIOR --   -- EXTERIOR --

CONVECTION COEFFICIENT    BTU/SQ-IN-SEC-R.                 0.               0.
RECOVERY/AMBIENT TEMP.    DEG. R.                                0.               0.

HEAT FLUX (CONVECTION)    BTU/SQ-IN-SEC.                   0.              -0.
HEAT FLUX (RADIATION)     BTU/SQ-IN-SEC.                  -1.88997E-02     -2.53142E-07
HEAT FLUX (ARBITRARY)     BTU/SQ-IN-SEC.                   0.               0.

STABILITY NODE    1      2.81746551E-01

                             ********** TEMPERATURE PROFILE **********

             1         2         3         4         5         6         7         8         9        10
      2823.132  2698.245  1460.000  1265.368  1062.848   899.491   775.828   687.212   626.691   587.162

            11        12        13        14        15        16        17        18        19        20
       562.452   547.678   539.235   534.626   532.223   531.028   530.463   530.220   530.148   530.143
```

```
......... FIRE PERIOD   26 IN PROGRESS  ---    1.00 SEC. OF FIRE FOLLOWS .........

ELAPSED TIME IN DUTY CYCLE                   75.00 SEC.      ELAPSED TIME THIS PERIOD       0.   SEC
CHAR-DEPTH WITH RESPECT TO       C/L        4.3226 INCHES    TOTAL CHAR-DEPTH             0.1826 IN.
ABLATION DEPTH WITH RESPECT TO   C/L        4.1411 INCHES.   TOTAL DIMENSIONAL ABLATION   0.0011 IN.


                                                          -- INTERIOR --    -- EXTERIOR --

CONVECTION COEFFICIENT    BTU/SQ-IN-SEC-R.                  1.02000E-03       0.
RECOVERY/AMBIENT TEMP.    DEG. R.                              5100.000             0.

HEAT FLUX (CONVECTION)    BTU/SQ-IN-SEC.                    2.99438E 00       -0.
HEAT FLUX (RADIATION)     BTU/SQ-IN-SEC.                   -6.51328E-03      -3.44887E-06
HEAT FLUX (ARBITRARY)     BTU/SQ-IN-SEC.                    0.                0.

STABILITY NODE    1      2.80184135E-01

                       ********** TEMPERATURE PROFILE **********

          1         2         3         4         5         6         7         8         9        10
   2164.330  2085.644  1460.000  1356.000  1181.042  1028.849   901.262   798.258   718.160   658.122

         11        12        13        14        15        16        17        18        19        20
    614.707   584.389   563.926   550.572   542.149   537.034   534.084   532.552   532.006   531.933
```

```
 ......... SOAK PERIOD   34 IN PROGRESS  ---    2.00 SEC. OF SOAK FOLLOWS .........

ELAPSED TIME IN DUTY CYCLE                 100.00 SEC.      ELAPSED TIME THIS PERIOD       0.   SEC
CHAR-DEPTH WITH RESPECT TO      C/L        4.3545 INCHES    TOTAL CHAR-DEPTH             0.2145 IN.
ABLATION DEPTH WITH RESPECT TO  C/L        4.1420 INCHES.   TOTAL DIMENSIONAL ABLATION   0.0020 IN.


                                                         -- INTERIOR --    -- EXTERIOR --

CONVECTION COEFFICIENT     BTU/SQ-IN-SEC-R.                 0.                0.
RECOVERY/AMBIENT TEMP.     DEG. R.                                 0.                0.

HEAT FLUX (CONVECTION)     BTU/SQ-IN-SEC.                   0.               -0.
HEAT FLUX (RADIATION)      BTU/SQ-IN-SEC.                  -1.40456E-01      -1.43369E-05
HEAT FLUX (ARBITRARY)      BTU/SQ-IN-SEC.                   0.                0.

STABILITY NODE   2       3.95808944E-01

                         ********** TEMPERATURE PROFILE **********

         1         2         3         4         5         6         7         8         9        10
  4660.000  3784.626  2401.520  1460.000  1286.529  1127.034   994.209   885.458   797.277   726.874

        11        12        13        14        15        16        17        18        19        20
   671.883   630.004   598.955   576.570   560.916   550.365   543.634   539.784   538.203   537.903
```

```
    ......... SOAK PERIOD   42 IN PROGRESS  ---    1.00 SEC. OF SOAK FOLLOWS .........

ELAPSED TIME IN DUTY CYCLE                  125.00 SEC.     ELAPSED TIME THIS PERIOD       1.00 SEC
CHAR-DEPTH WITH RESPECT TO       C/L        4.3787 INCHES   TOTAL CHAR-DEPTH             0.2387 IN.
ABLATION DEPTH WITH RESPECT TO   C/L        4.1431 INCHES.  TOTAL DIMENSIONAL ABLATION   0.0031 IN.


                                                        -- INTERIOR --    -- EXTERIOR --

CONVECTION COEFFICIENT    BTU/SQ-IN-SEC-R.                0.               0.
RECOVERY/AMBIENT TEMP.    DEG. R.                               0.               0.

HEAT FLUX (CONVECTION)    BTU/SQ-IN-SEC.                  0.              -0.
HEAT FLUX (RADIATION)     BTU/SQ-IN-SEC.                 -3.08559E-02     -3.56525E-05
HEAT FLUX (ARBITRARY)     BTU/SQ-IN-SEC.                  0.               0.

STABILITY NODE    1       2.42093715E-01

                              ********** TEMPERATURE PROFILE **********

           1         2         3         4         5         6         7         8         9        10
    3190.800  3208.127  2502.208  1460.000  1343.704  1201.949  1074.908   964.087   869.848   791.588

          11        12        13        14        15        16        17        18        19        20
     728.022   677.476   638.133   608.198   586.021   570.157   559.408   552.841   549.791   549.046
```

```
 ......... FIRE PERIOD   51 IN PROGRESS  ---    1.00 SEC. OF FIRE FOLLOWS .........

ELAPSED TIME IN DUTY CYCLE                150.00 SEC.      ELAPSED TIME THIS PERIOD       0.   SEC
CHAR-DEPTH WITH RESPECT TO        C/L     4.4032 INCHES    TOTAL CHAR-DEPTH             0.2632 IN.
ABLATION DEPTH WITH RESPECT TO    C/L     4.1442 INCHES.   TOTAL DIMENSIONAL ABLATION   0.0042 IN.


                                                      -- INTERIOR --    -- EXTERIOR --

CONVECTION COEFFICIENT     BTU/SQ-IN-SEC-R.              1.02000E-03      0.
RECOVERY/AMBIENT TEMP.     DEG. R.                         5100.000            0.

HEAT FLUX (CONVECTION)     BTU/SQ-IN-SEC.                2.46572E 00     -0.
HEAT FLUX (RADIATION)      BTU/SQ-IN-SEC.               -1.54045E-02     -6.77187E-05
HEAT FLUX (ARBITRARY)      BTU/SQ-IN-SEC.                0.               0.

STABILITY NODE    1       2.34956110E-01

                          ********** TEMPERATURE PROFILE **********

          1         2         3         4         5         6         7         8         9        10
   2682.624  2686.909  2219.568  1460.000  1381.078  1249.928  1130.253  1023.170   929.252   848.514

         11        12        13        14        15        16        17        18        19        20
    780.483   724.306   678.878   642.963   615.314   594.751   580.232   570.889   566.044   564.628
```

```
......... SOAK PERIOD   59 IN PROGRESS  ---    2.00 SEC. OF SOAK FOLLOWS .........

ELAPSED TIME IN DUTY CYCLE                   175.00 SEC.     ELAPSED TIME THIS PERIOD       0.   SEC
CHAR-DEPTH WITH RESPECT TO      C/L          4.4277 INCHES   TOTAL CHAR-DEPTH              0.2877 IN.
ABLATION DEPTH WITH RESPECT TO  C/L          4.1454 INCHES.  TOTAL DIMENSIONAL ABLATION    0.0054 IN.


                                                         -- INTERIOR --    -- EXTERIOR --

CONVECTION COEFFICIENT     BTU/SQ-IN-SEC-R.              0.                0.
RECOVERY/AMBIENT TEMP.     DEG. R.                              0.                0.

HEAT FLUX (CONVECTION)     BTU/SQ-IN-SEC.                0.               -0.
HEAT FLUX (RADIATION)      BTU/SQ-IN-SEC.               -1.40456E-01      -1.09810E-04
HEAT FLUX (ARBITRARY)      BTU/SQ-IN-SEC.                0.                0.

STABILITY NODE   2      3.72040039E-01

                      ********** TEMPERATURE PROFILE **********

           1        2        3        4        5        6        7        8        9       10
    4660.000 3850.198 2426.193 1460.000 1411.778 1287.915 1173.818 1070.349  978.014  896.973

          11       12       13       14       15       16       17       18       19       20
     827.056  767.809  718.561  678.496  646.725  622.354  604.534  592.502  585.601  583.305
```

```
......... SOAK PERIOD   67 IN PROGRESS  ---    1.00 SEC. OF SOAK FOLLOWS .........

ELAPSED TIME IN DUTY CYCLE                  200.00 SEC.      ELAPSED TIME THIS PERIOD        1.00 SEC
CHAR-DEPTH WITH RESPECT TO        C/L       4.4455 INCHES    TOTAL CHAR-DEPTH              0.3055 IN.
ABLATION DEPTH WITH RESPECT TO  C/L       4.1467 INCHES.   TOTAL DIMENSIONAL ABLATION    0.0067 IN.


                                                       -- INTERIOR --    -- EXTERIOR --

CONVECTION COEFFICIENT     BTU/SQ-IN-SEC-R.             0.                0.
RECOVERY/AMBIENT TEMP.     DEG. R.                         0.                0.

HEAT FLUX (CONVECTION)     BTU/SQ-IN-SEC.               0.               -0.
HEAT FLUX (RADIATION)      BTU/SQ-IN-SEC.             -3.85264E-02      -1.60264E-04
HEAT FLUX (ARBITRARY)      BTU/SQ-IN-SEC.               0.                0.

STABILITY NODE    1      1.98068310E-01

                  ********** TEMPERATURE PROFILE **********

        1         2         3         4         5         6         7         8         9        10
 3372.782  3412.716  2949.559  2193.565  1460.000  1346.589  1228.066  1120.683  1025.316   941.888

       11        12        13        14        15        16        17        18        19        20
  869.784   808.202   756.326   713.372   678.587   651.238   630.618   616.052   606.909   603.559
```

```
......... FIRE PERIOD   76 IN PROGRESS  ---    1.00 SEC. OF FIRE FOLLOWS .........

ELAPSED TIME IN DUTY CYCLE                  225.00 SEC.      ELAPSED TIME THIS PERIOD       0.   SEC
CHAR-DEPTH WITH RESPECT TO      C/L         4.4636 INCHES    TOTAL CHAR-DEPTH             0.3236 IN.
ABLATION DEPTH WITH RESPECT TO  C/L         4.1480 INCHES.   TOTAL DIMENSIONAL ABLATION   0.0080 IN.


                                                        -- INTERIOR --    -- EXTERIOR --

CONVECTION COEFFICIENT     BTU/SQ-IN-SEC-R.               1.02000E-03      0.
RECOVERY/AMBIENT TEMP.     DEG. R.                          5100.000             0.

HEAT FLUX (CONVECTION)     BTU/SQ-IN-SEC.                 2.23088E 00     -0.
HEAT FLUX (RADIATION)      BTU/SQ-IN-SEC.                -2.14227E-02     -2.16979E-04
HEAT FLUX (ARBITRARY)      BTU/SQ-IN-SEC.                 0.               0.

STABILITY NODE   1      1.88681401E-01

                    ********** TEMPERATURE PROFILE **********

         1         2         3         4         5         6         7         8         9        10
  2912.862  2970.360  2702.811  2141.096  1460.000  1372.712  1262.316  1160.260  1067.436   984.345

        11        12        13        14        15        16        17        18        19        20
   911.115   847.571   793.311   747.789   710.379   680.419   657.247   640.209   628.669   624.131
```

```
    ......... SOAK PERIOD   84 IN PROGRESS  ---    2.00 SEC. OF SOAK FOLLOWS .........

ELAPSED TIME IN DUTY CYCLE               250.00 SEC.       ELAPSED TIME THIS PERIOD       0.   SEC
CHAR-DEPTH WITH RESPECT TO      C/L      4.4819 INCHES     TOTAL CHAR-DEPTH             0.3419 IN.
ABLATION DEPTH WITH RESPECT TO  C/L      4.1495 INCHES.    TOTAL DIMENSIONAL ABLATION   0.0095 IN.


                                                       -- INTERIOR --   -- EXTERIOR --

CONVECTION COEFFICIENT    BTU/SQ-IN-SEC-R.                0.               0.
RECOVERY/AMBIENT TEMP.    DEG. R.                               0.               0.

HEAT FLUX (CONVECTION)    BTU/SQ-IN-SEC.                  0.              -0.
HEAT FLUX (RADIATION)     BTU/SQ-IN-SEC.                 -1.40456E-01     -2.78405E-04
HEAT FLUX (ARBITRARY)     BTU/SQ-IN-SEC.                  0.               0.

STABILITY NODE   2      3.42076725E-01

                             ********** TEMPERATURE PROFILE **********

            1         2         3         4         5         6         7         8         9        10
     4660.000  4070.505  2885.490  2109.364  1460.000  1393.763  1288.998  1191.416  1101.732  1020.438

           11        12        13        14        15        16        17        18        19        20
      947.785   883.809   828.349   781.087   741.588   709.334   683.751   664.234   650.154   644.332
```

```
    ......... SOAK PERIOD   92 IN PROGRESS  ---    1.00 SEC. OF SOAK FOLLOWS .........

ELAPSED TIME IN DUTY CYCLE               275.00 SEC.      ELAPSED TIME THIS PERIOD      1.00 SEC
CHAR-DEPTH WITH RESPECT TO      C/L      4.5000 INCHES    TOTAL CHAR-DEPTH            0.3600 IN.
ABLATION DEPTH WITH RESPECT TO  C/L      4.1507 INCHES.   TOTAL DIMENSIONAL ABLATION  0.0107 IN.


                                                       -- INTERIOR --   -- EXTERIOR --

CONVECTION COEFFICIENT    BTU/SQ-IN-SEC-R.                MO.              0.
RECOVERY/AMBIENT TEMP.    DEG. R.                               0.               0.

HEAT FLUX (CONVECTION)    BTU/SQ-IN-SEC.                  0.              -0.
HEAT FLUX (RADIATION)     BTU/SQ-IN-SEC.                 -3.70937E-02     -3.42769E-04
HEAT FLUX (ARBITRARY)     BTU/SQ-IN-SEC.                  0.               0.

STABILITY NODE   1      1.56590869E-01

                             ********** TEMPERATURE PROFILE **********

             1         2         3         4         5         6         7         8         9        10
      3340.997  3455.222  2967.180  2205.678  1460.000  1412.086  1311.804  1217.967  1131.172  1051.856

            11        12        13        14        15        16        17        18        19        20
       980.287   916.569   860.648   812.331   771.305   737.158   709.401   687.484   670.804   663.639
```

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          .......... SOAK PERIOD  100 HAS ENDED    ..........

ELAPSED TIME IN DUTY CYCLE               300.00 SEC.      ELAPSED TIME THIS PERIOD         2.00 SEC
CHAR-DEPTH WITH RESPECT TO       C/L     4.5167 INCHES    TOTAL CHAR-DEPTH               0.3767 IN.
ABLATION DEPTH WITH RESPECT TO   C/L     4.1520 INCHES.   TOTAL DIMENSIONAL ABLATION     0.0120 IN.


                                                        -- INTERIOR --    -- EXTERIOR --

CONVECTION COEFFICIENT     BTU/SQ-IN-SEC-R.               0.                0.
RECOVERY/AMBIENT TEMP.     DEG. R.                              0.                0.

HEAT FLUX (CONVECTION)     BTU/SQ-IN-SEC.                 0.               -0.
HEAT FLUX (RADIATION)      BTU/SQ-IN-SEC.                -2.40683E-02      -4.07919E-04
HEAT FLUX (ARBITRARY)      BTU/SQ-IN-SEC.                 0.                0.

STABILITY NODE   1       1.46658368E-01

                  ********** TEMPERATURE PROFILE **********

           1         2         3         4         5         6         7         8         9        10
    2998.815  3073.385  2902.116  2475.270  1965.976  1460.000  1345.927  1245.446  1158.079  1079.949

          11        12        13        14        15        16        17        18        19        20
    1009.462   946.257   890.236   841.254   799.065   763.326   733.606   709.398   690.128   681.602
```

```
    ......... SOAK PERIOD  101 IS BEGINNING --- 1000.00 SEC. OF SOAK FOLLOWS .........

ELAPSED TIME IN DUTY CYCLE               300.00 SEC.       ELAPSED TIME THIS PERIOD        0.   SEC
CHAR-DEPTH WITH RESPECT TO      C/L      4.5167 INCHES     TOTAL CHAR-DEPTH             0.3767 IN.
ABLATION DEPTH WITH RESPECT TO  C/L      4.1520 INCHES.    TOTAL DIMENSIONAL ABLATION   0.0120 IN.


                                                       -- INTERIOR --   -- EXTERIOR --

CONVECTION COEFFICIENT    BTU/SQ-IN-SEC-R.                0.               0.
RECOVERY/AMBIENT TEMP.    DEG. R.                               0.               0.

HEAT FLUX (CONVECTION)    BTU/SQ-IN-SEC.                  0.              -0.
HEAT FLUX (RADIATION)     BTU/SQ-IN-SEC.                 -2.40683E-02     -4.07919E-04
HEAT FLUX (ARBITRARY)     BTU/SQ-IN-SEC.                  0.               0.

STABILITY NODE   1      1.46658368E-01

                             ********** TEMPERATURE PROFILE **********

            1         2         3         4         5         6         7         8         9        10
     2998.815  3073.385  2902.116  2475.270  1965.976  1460.000  1345.927  1245.446  1158.079  1079.949

           11        12        13        14        15        16        17        18        19        20
     1009.462   946.257   890.236   841.254   799.065   763.326   733.606   709.398   690.128   681.602
```

```
                  ***** EXTERIOR TEMPERTURE HAS REACHED A PEAK VALUE *****

   ......... SOAK PERIOD  101 IN PROGRESS  ---  808.85 SEC. OF SOAK FOLLOWS .........

ELAPSED TIME IN DUTY CYCLE                491.15 SEC.      ELAPSED TIME THIS PERIOD      191.15 SEC
CHAR-DEPTH WITH RESPECT TO     C/L        4.5205 INCHES    TOTAL CHAR-DEPTH              0.3805 IN.
ABLATION DEPTH WITH RESPECT TO C/L        4.1520 INCHES.   TOTAL DIMENSIONAL ABLATION    0.0120 IN.


                                                    -- INTERIOR --    -- EXTERIOR --

CONVECTION COEFFICIENT    BTU/SQ-IN-SEC-R.            0.                0.
RECOVERY/AMBIENT TEMP.    DEG. R.                           0.                0.

HEAT FLUX (CONVECTION)    BTU/SQ-IN-SEC.              0.               -0.
HEAT FLUX (RADIATION)     BTU/SQ-IN-SEC.             -3.82625E-04      -7.20227E-04
HEAT FLUX (ARBITRARY)     BTU/SQ-IN-SEC.              0.                0.

STABILITY NODE   1      1.53346598E-01

                        ********** TEMPERATURE PROFILE **********

         1         2         3         4         5         6         7         8         9        10
  1080.560  1082.285  1085.806  1087.981  1088.831  1088.386  1081.846  1069.772  1053.009  1032.190

        11        12        13        14        15        16        17        18        19        20
  1008.004   981.161   952.348   922.206   891.295   860.079   828.912   798.035   767.576   752.516
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```
                    .......... SOAK PERIOD  101 HAS ENDED    ..........

ELAPSED TIME IN DUTY CYCLE                 1300.00 SEC.      ELAPSED TIME THIS PERIOD    1000.00 SEC
CHAR-DEPTH WITH RESPECT TO      C/L         4.5205 INCHES    TOTAL CHAR-DEPTH             0.3805 IN.
ABLATION DEPTH WITH RESPECT TO  C/L         4.1520 INCHES.   TOTAL DIMENSIONAL ABLATION   0.0120 IN.


                                                          -- INTERIOR --    -- EXTERIOR --

CONVECTION COEFFICIENT     BTU/SQ-IN-SEC-R.                  0.                0.
RECOVERY/AMBIENT TEMP.     DEG. R.                                 0.                0.

HEAT FLUX (CONVECTION)     BTU/SQ-IN-SEC.                    0.               -0.
HEAT FLUX (RADIATION)      BTU/SQ-IN-SEC.                  -3.82625E-04      -7.20227E-04
HEAT FLUX (ARBITRARY)      BTU/SQ-IN-SEC.                    0.                0.

STABILITY NODE   1       1.53346598E-01

                     ********** TEMPERATURE PROFILE **********


         1         2         3         4         5         6         7         8         9        10
  1080.560  1082.285  1085.806  1087.981  1088.831  1088.386  1081.846  1069.772  1053.009  1032.190

        11        12        13        14        15        16        17        18        19        20
  1008.004   981.161   952.348   922.206   891.295   860.079   828.912   798.035   767.576   752.516
```

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                                       **** DUTY CYCLE HAS ENDED ****

                  MAXIMUM EXTERIOR TEMPERTURE OCCURED AT  491.00 SECONDS INTO DUTY CYCLE

                                     ----- TEMPERATURE PROFILE -----

                1         2         3         4         5         6         7         8         9        10
         1080.718  1082.445  1085.967  1088.143  1088.993  1088.546  1081.998  1069.911  1053.132  1032.295

               11        12        13        14        15        16        17        18        19        20
         1008.091   981.229   952.399   922.241   891.317   860.091   828.918   798.036   767.576   752.516

END-OF-FILE READING ON SYSTEM INPUT TAPE.
RETURNING TO SYSTEM.
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