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WALL TEMPERATURE DISTRIBUTION CALCULATION FOR A ROCKET NOZZLE CONTOUR

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16. Abstract

The JANNAF Turbulent Boundary Layer (TBL) computer program, applicable to rocket nozzles, requires a wall temperature distribution among other input parameters to determine boundary layer behavior, heat transfer, and performance degradation. The inclusion of a complete regenerative cooling cycle model with associate geometry, material and fluid property data provides a capability to internally calculate wall temperature profiles on the hot gas and coolant flow-side, as well as the coolant flow bulk temperature variation. Besides the regular heat transfer and performance degradation calculations, the new concept can be used to optimize the cooling cycle, coolant flow requirements, and cooling jacket geometry.

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Concluded)

LIST OF TABLES

DEFINITION OF SYMBOLS

Symbol	Definition
A_{tube}	Cross-sectional area of each cooling tube or channel, ft^2
C_f	Skin friction coefficient
C_H	Stanton number
D_{tube}	Equivalent tube diameter, ft
H	Enthalpy, ft^2/s^2
J	Conversion factor between thermal and work units (778.2), ft-lbf/Btu
M_∞	Mach number at boundary layer edge
$\mathfrak{M}$	Mean molecular weight at boundary layer edge, lbm/mole
P_∞	Static pressure at boundary layer edge, lbf/ft^2
$\dot{Q}_w$	Total heat transfer rate, Btu/s
P_r	Prandtl number
R_e	Reynolds number
$\mathcal{R}$	Universal gas constant
T	Temperature, °R
U_∞	Velocity at boundary layer edge, ft/s
C_p	Specific heat at constant pressure, Btu/lbm °R
g	Acceleration of gravity (32.174), ft-lbm/lbf s^2
h_0	Total enthalpy, ft^2/s^2

DEFINITION OF SYMBOLS (Continued)

Symbol	Definition
h_g	Heat transfer coefficient on the gas side, Btu/ft^2 s°R
h_ℓ	Heat transfer coefficient on the coolant side, Btu/ft^2 s°R
m_ℓ	Coolant mass flow rate, lbm/s
$\dot{q}_w$	Specific heat transfer rate, Btu/ft^2 s
$\dot{q}_w'$	Specific heat transfer rate into coolant, Btu/ft^2 s
r	Nozzle radius, ft
t	Chamber wall thickness, ft
u	Velocity within boundary layer, ft/s
x	Axial coordinate, ft or –
y	Distance normal to wall, ft or –
α	Angle between wall and nozzle axis
δ	Velocity thickness, ft
δ_r'	Distance from nth streamline to real wall, ft
δ^*	Displacement thickness, ft
Δ	Temperature thickness, ft
θ	Momentum thickness, ft
ϕ	Energy thickness, ft
μ	Dynamic viscosity, lbm/ft s

DEFINITION OF SYMBOLS (Continued)

Symbol	Definition
ρ	Density, lbm/ft^3
λ	Thermal conductivity, Btu/ft s°R
τ_w	Shear stress, lbm/s^2
η	Cooling coefficient for geometry effects
η_E	Efficiency (enhancement) factor for surface roughness and turbulence effects

Subscripts

aw	Adiabatic wall
c	Calculated value or convection
IXTAB	Final section of input tables
i	Section
j	Overall iteration number
ℓ	Coolant
N	Final section of input tables
r	Radiation
w	Wall or wall material
wg	Gas side wall
$w\ell$	Coolant side wall
∞	Free stream or boundary layer edge

DEFINITION OF SYMBOLS (Concluded)

Subscripts

0	Stagnation or approximated value
1	Section or iteration number
2	Section or iteration number

WALL TEMPERATURE DISTRIBUTION CALCULATION FOR A ROCKET NOZZLE CONTOUR

SUMMARY

A concept is presented which allows the calculation of the temperatures along a thrust chamber nozzle contour on the hot gas and on the coolant flow-side. Also considered is a regenerative coolant flowing in the opposite or the same direction to the chamber reaction products. Coupling of the boundary layer equations for the hot gas-side with the regenerative cooling equations provides the results. Since the new analytical model has been integrated into the JANNAF Turbulent Boundary Layer computer program, the thrust degradation, due to the viscous effects close to the wall, is simultaneously obtained. The calculation is started with approximated temperature distributions for the hot gas-side wall and the coolant flow. Iterations within the computer program are executed until the heat transfer rates from the boundary layer to the wall and from the wall to the coolant are equal. Kinetic inviscid flow conditions for the boundary layer edge are considered by means of table inputs representing the variation of appropriate parameters. Since the chamber wall thickness and the coolant flow channel geometry are part of the analysis, optimization studies can be performed for these parameters by consecutive computer runs. A sample calculation, utilizing the new concept for a small area ratio high pressure thrust chamber, is included.

INTRODUCTION

The calculation of various turbulent boundary layer thicknesses in the thrust chamber and the temperatures of the gas-side wall, the regenerative coolant-side wall, and the coolant fluid along the thrust chamber contour is simultaneously made, by considering the heat exchange between the combustion product flow in the thrust chamber and the coolant flow in the cooling jacket. The Turbulent Boundary Layer Computer Program TBL-I [1] has been modified to carry out the calculation by using a new concept in which the boundary layer equations are coupled with regenerative cooling equations.

The steady-state conditions that are considered require the temperatures of the combustion products, the chamber walls, and also the heat flux through the walls to remain constant at any point in time. It is assumed that heat transfer occurs only by convection and conduction from the hot combustion products to the thrust chamber wall, neglecting the radiation. However, inclusion of radiation is not difficult, if the emissivity of the combustion products and the Stefan-Boltzmann constant can be accurately determined; since the total specific heat flux from the hot gas into the chamber wall is composed of the convective $\dot{q}_c$ and the radiant $\dot{q}_r$ heat flux.

$$\dot{q} = \dot{q}_c + \dot{q}_r \quad .$$

The coolant fluid in this analysis flows through the tubes or channels in the opposite or same direction to the combustion products, receiving the heat by convection and conduction. The heat exchange takes place simultaneously in many small sections which have an arbitrary length along the contour of the thrust chamber, accounting for the gas phase turbulent combustion product flow, the temperature of the thrust chamber wall material, and the temperature of regenerative coolant flow. The temperature distributions obtained from the first iteration are internally used as initial values for the second iteration. Iterations are performed until convergence is obtained. Since the influence of the coolant transport properties on the resulting temperatures is quite significant, it is important to use pertinent values especially in the supercritical region of the coolant fluid. The empirical relationship of the heat transfer coefficient for computing the heat exchange with the coolant flow significantly affects the results as well as the Stanton number of the combustion products [1].

The methods to calculate the various turbulent boundary layer thicknesses in the thrust chamber are explained in detail in the documentations of TBL [2] and TBL-I [1], and only the fundamental equations and concepts of the calculations improving the latter TBL-I computer program are outlined in this report. The concept is demonstrated for a regenerative coolant flowing in opposite direction to the combustion products. The alternate equations for the coolant flowing in the same direction are explained in the section entitled Same Direction Coolant Flow.

FUNDAMENTAL EQUATIONS FOR THE BOUNDARY LAYER

The integral momentum and energy equations in axisymmetric form [2,3] for compressible turbulent boundary layer flow are:

$$\frac{d\theta}{dx} = \frac{C_f}{2}\left[1 + \left(\frac{dr}{dx}\right)^2\right]^{1/2} - \theta\left[\frac{1 + \frac{\delta^*}{\theta}}{U_\infty}\frac{dU_\infty}{dx} + \frac{1}{\rho_\infty U_\infty}\frac{d(\rho_\infty U_\infty)}{dx} + \frac{1}{r}\frac{dr}{dx}\right] \quad , \tag{1}$$

and

$$\frac{d\phi}{dx} = C_H\left[\frac{H_{aw} - H_w}{H_0 - H_w}\right]\left[1 + \left(\frac{dr}{dx}\right)^2\right]^{1/2} - \phi\left[\frac{1}{\rho_\infty U_\infty}\frac{d(\rho_\infty U_\infty)}{dx} + \frac{1}{r}\frac{dr}{dx} + \frac{1}{H_0 - H_w}\frac{d\left(H_0 - H_w\right)}{dx}\right] \quad , \tag{2}$$

where the displacement thickness δ^*, momentum thickness θ and energy thickness ϕ are identified as follows:

$$\delta^* = \int_0^{\delta'_r}\left(1 - \frac{\rho u}{\rho_\infty U_\infty}\right) dy \quad , \tag{3}$$

$$\theta = \int_0^{\delta'_r}\frac{\rho u}{\rho_\infty U_\infty}\left(1 - \frac{u}{U_\infty}\right) dy \quad , \tag{4}$$

$$\phi = \int_0^{\delta} r' \frac{\rho u}{\rho_\infty U_\infty} \left(1 - \frac{h_0 - H_w}{H_0 - H_w}\right) dy \quad . \tag{5}$$

The skin friction coefficient is defined as

$$C_f = \frac{2\tau_w}{\rho_\infty U_\infty^2} \quad , \tag{6}$$

and has a form of the Blasius relation [1]

$$C_f = \frac{0.025}{R_{e\theta}^{0.25}} \quad , \tag{7}$$

with the following Reynolds number based upon the momentum thickness

$$R_{e\theta} = \frac{\rho_\infty U_\infty \theta}{\mu_\infty} \quad . \tag{8}$$

The Stanton number

$$C_H = \frac{\dot{q}_w}{\rho_\infty U_\infty (H_{aw} - H_w)} \quad , \tag{9}$$

is calculated using the formula [1]

$$C_H = \frac{\dfrac{C_f\left(R_{e\phi}\right)}{2}\left(\dfrac{\phi}{\theta}\right)^{\tilde{n}}}{1 - 5\left[\dfrac{C_f\left(R_{e\phi}\right)}{2}\right]^{1/2}\left[1 - P_r + \ell n\left(\dfrac{6}{5\,P_r + 1}\right)\right]} \quad . \tag{10}$$

Velocity and enthalpy profiles across the boundary layer are assumed to follow the relationships:

$$\text{for } y \le \delta \quad \frac{u}{U_\infty} = \left(\frac{y}{\delta}\right)^{\frac{1}{n}} \quad , \tag{11}$$

$$\text{for } y > \delta \quad \frac{u}{U_\infty} = 1 \quad , \tag{12}$$

$$\text{for } y \le \Delta \quad \frac{h_0 - H_w}{H_0 - H_w} = \left(\frac{y}{\Delta}\right)^{\frac{1}{n}} \quad , \tag{13}$$

$$\text{for } y > \Delta \quad \frac{h_0 - H_w}{H_0 - H_w} = 1 \quad . \tag{14}$$

The definition of enthalpy is

$$H = \int_0^T C_p \, dT \quad , \tag{15}$$

$$h_0 = H + \frac{u^2}{2} \quad , \tag{16}$$

$$H_w = \int_0^{T_{wg}} C_p \, dT \quad . \tag{17}$$

The adiabatic wall enthalpy H_{aw} is defined as

$$\frac{H_{aw}}{H_0} = \frac{H_\infty + \left(P_r\right)^{1/3} \frac{U_\infty^2}{2}}{H_\infty + \frac{U_\infty^2}{2}} \quad . \tag{18}$$

The density ρ within the boundary layer is obtained from the perfect gas equation, assuming that the pressure is constant across the boundary layer:

$$\frac{\rho}{\rho_\infty} = \frac{T_\infty}{T} \quad , \tag{19}$$

where the temperature T is calculated via the velocity and enthalpy distributions, equations (11), (12), (13), (14), and (16). The boundary layer calculations use the Runge-Kutta Gill solution method for given parameters at the boundary layer edge such as x, r, M_∞, P_∞, T_∞, U_∞, and $\mathfrak{M}$. The only unknown parameter is the wall temperature T_{wg} in equation (17).

EQUATIONS FOR THE REGENERATIVE COOLING CYCLE

As shown in Figure 1, the coolant flows in an opposite direction to the combustion products of the thrust chamber. The regenerative fluid enters downstream with a lower temperature and a higher pressure than at the injector head, since heat is continuously transferred from the combustion products to the coolant through the chamber walls. T_{wg} denotes the gas-side wall temperature, T_{w_ℓ} the coolant-side wall temperature, and T_ℓ the coolant bulk temperature at an arbitrary station x with $x = 0$ at the throat (Figs. 1 and 2). We consider the case in which the heat is transferred only by convection from the hot combustion products to the chamber wall and that the direction of heat flow is normal to it. Since steady-state conditions are treated, the temperatures of the combustion gas and wall and the specific heat flux through the walls remain constant with time at any given point.

The five fundamental equations representing the cooling cycle, including an empirical relation for the heat transfer coefficient of the coolant, are as follows:

1. Specific heat transfer rate on the gas-side,

$$\dot{q}_{w1} = h_g \left(T_{aw} - T_{wg}\right) \quad , \tag{20}$$

where h_g is the heat transfer coefficient in a gas and T_{aw} is the adiabatic wall temperature.

2. Heat transfer coefficient in a gas related to the Stanton number which is calculated in TBL-I,

$$h_g = \rho_\infty U_\infty C_H \frac{H_{aw} - H_w}{T_{aw} - \left[T_{wg}\right]_j} \quad , \tag{21}$$

where

ρ_∞ is the free stream density,

U_∞ is the free stream velocity,

C_H is the Stanton number,

H_{aw} is the adiabatic wall enthalpy,

H_w is the wall enthalpy,

T_{aw} is the adiabatic wall temperature,

and

$\left[T_{wg}\right]_j$ is the input wall temperature or calculated wall temperature.

3. Specific heat transfer rate through the wall by conduction,

$$\dot{q}_{w2} = \lambda_w \frac{T_{wg} - T_{w_\ell}}{t} \quad , \tag{22}$$

where λ_w is the thermal conductivity of the wall material and t is the wall thickness.

4. Specific heat transfer rate into the coolant,

$$\dot{q}_{w3} = h_\ell \left(T_{w_\ell} - T_\ell\right) \quad , \tag{23}$$

where h_ℓ is the heat transfer coefficient for the coolant.

5. Empirical relation of the heat transfer coefficient for the hydrogen coolant flow [4] is a modified Colburn equation. For any other coolant flow, a similar relationship must be utilized including the effects of curvature, associated turbulence, and surface roughness of the tubes represented by the enhancement factor η_E. The accuracy of the enhancement factor significantly

affects the heat transfer calculation and the resulting wall temperatures. Since this effect is coupled with the cooling fluid heat transfer coefficient, it is evident that the physical property information must be very precise.

$$h_{\ell} = 0.025 \frac{\lambda_{\ell}}{D_{tube}} R_{e_{\ell}}^{0.8} P_{r_{\ell}}^{0.4} \left(\frac{T_{\ell}}{T_{w_{\ell}}}\right)^{0.55} \eta_E \quad . \tag{24}$$

The above equation is valid for temperature ratios $T_{w_{\ell}}/T_{\ell}$ between 1.44 to 9.2, where the Reynolds number and the Prandtl number of the coolant are defined as follows:

$$\text{Reynolds number,} \quad R_{e_{\ell}} = \frac{\rho_{\ell} U_{\ell} D_{tube}}{\mu_{\ell}} \quad . \tag{25}$$

$$\text{Prandtl number,} \quad P_{r_{\ell}} = \frac{\mu_{\ell} C_{p\ell}}{\lambda_{\ell}} \quad . \tag{26}$$

$$\text{Mass flow density,} \quad \rho_{\ell} U_{\ell} = \rho_{\ell}(x) U_{\ell}(x) \quad . \tag{27}$$

$$\text{Equivalent tube diameter,} \quad D_{tube} = 2\left(A_{tube}/\pi\right)^{1/2} \quad . \tag{28}$$

$$\text{Coolant bulk viscosity,} \quad \mu_{\ell} = \mu_{\ell}\left(T_{\ell}, \ \text{Pressure}\right) \quad . \tag{29}$$

Coolant bulk specific heat, $C_{p\ell} = C_{p\ell}\left(T_\ell \quad , \quad \text{Pressure}\right)$. (30)

Coolant bulk thermal conductivity, $\lambda_\ell = \lambda_\ell\left(T_\ell \quad , \quad \text{Pressure}\right)$. (31)

For steady-state conditions, the heat flux through all three realms must be constant,

$$\dot{q}_{w1} = \dot{q}_{w2} = \dot{q}_{w3} = \dot{q}_w' = \text{constant} \quad . \tag{32}$$

Unknowns in equations (20) through (24) are $\dot{q}_w'$, T_{wg} , T_{w_ℓ} and T_ℓ . In equation (21) h_g is independently calculated when T_{wg} is given. Combining equations (20), (22), (23), and (32) results in

$$T_{w_\ell} = \frac{h_\ell\left(1 + \frac{\lambda_w}{t\,h_g}\right)T_\ell + \frac{\lambda_w}{t}\,T_{aw}}{\frac{\lambda_w}{t} + h_\ell\left(1 + \frac{\lambda_w}{t\,h_g}\right)} \quad , \tag{33}$$

and

$$T_{wg} = \frac{h_g\,T_{aw} + \frac{\lambda_w}{t}\,T_{w_\ell}}{h_g + \frac{\lambda_w}{t}} \quad . \tag{34}$$

Derivations of the above equations are shown in Appendix A. Thus, the solution can be obtained by considering equations (20), (21), (24), (33), and (34), (Table 1). The flow chart to compute $T_{w_\ell}(x)$, $T_{wgc}(x)$, $T_{\ell c}(x)$, and

$\dot{q}_w'(x)$ is shown in Figure 3 where the subscript c denotes the internally calculated temperature.

At the beginning of the calculation, the coolant bulk temperature distribution is approximated. The coolant-side wall temperature T_{w_ℓ} at an axial distance x is obtained according to iterations in statement (2) of Figure 3a. The gas-side wall temperature T_{wg} is calculated from equation (34); however, to differentiate between the input table values of T_{wg}, the subscript c is added in statement (3) of Figure 3a. The term $\dot{q}_w'$, which differs from the $\dot{q}_w$ output of TBL-I, should coincide with $\dot{q}_w$ after the iteration is complete. In statement (5) of Figure 3a the coolant temperature is calculated by using its previous iteration values. The derivation of the equation in statement (5) is shown in the section entitled Internally Calculated Coolant Bulk Temperature.

After obtaining $T_{wgc}(x)$ and $T_{\ell c}(x)$ at each table point of x, the values of $T_\ell(x)$ and $T_{wg}(x)$ to be input for a successive iteration are determined as follows:

$$\left[T_\ell(x)\right]_2 = \frac{T_{\ell c}(x) + \left[T_\ell(x)\right]_1}{2} , \tag{35}$$

and

$$\left[T_{wg}(x)\right]_2 = \frac{T_{wgc}(x) + \left[T_{wg}(x)\right]_1}{2} \tag{36}$$

In repeating the preceding calculation, we obtain values of $\left[T_\ell(x)\right]_3$ and $\left[T_{wg}(x)\right]_3$. This operation is applied until a desired convergence outlined in a later section is achieved.

INTERNALLY CALCULATED COOLANT BULK TEMPERATURE

For simplicity, assume that the inner wall of the thrust chamber consists of a single wall and not of tubes. Let us consider an arbitrary section i in Figure 4 and calculate the coolant temperature at x_i, which is the distance along the nozzle axis. Section i contains the surface area between B and D, as shown in Figure 4,

$$x_{i-1} = x_i - \Delta x_{i1} \text{, which is } x_A \quad , \tag{37}$$

and

$$x_{i+1} = x_i + \Delta x_{i2} \text{, which is } x_E \quad , \tag{38}$$

where the step sizes Δx_{i1} and Δx_{i2} are arbitrary.

The inlet temperature of the coolant at section i is $T_\ell\left(x_i + \frac{\Delta x_{i2}}{2}\right)$, and the outlet temperature is $T_\ell\left(x_i - \frac{\Delta x_{i1}}{2}\right)$. The heat transfer rate through the cylindrical surface area of section i between B and D is

$$\dot{Q}_w(x_i) = \frac{2\pi\, r(x_i)\, \dot{q}_w{}'(x_i)\, \Delta \bar{x}_i}{\cos \alpha\,(x_i)} \quad , \tag{39}$$

where

$$\Delta \bar{x}_i = \frac{\Delta x_{i1} + \Delta x_{i2}}{2} \quad , \tag{40}$$

and $\alpha(x_i)$ is the angle between the chamber wall and the nozzle axis at x_i. The wall radius is $r(x_i)$ and $\dot{q}_w'(x_i)$ is the specific heat transfer rate as shown in equation (32). The outlet temperature of the coolant at $x = x_i - \frac{\Delta x_{i1}}{2}$ in section i is calculated by

$$T_\ell\left(x_i - \frac{\Delta x_{i1}}{2}\right) = \frac{\left[T_\ell(x_i)\right]_j + \left[T_\ell(x_i + \Delta x_{i2})\right]_j}{2} + \frac{\dot{Q}_w(x_i)}{\dot{m}_\ell \, C_{p\ell}(x_i)} , \quad (41)$$

where $\left[T_\ell(x_i)\right]_j$ and $\left[T_\ell(x_i + \Delta x_{i2})\right]_j$ are either previously determined coolant bulk temperatures or initial input values. The value $\dot{m}_\ell$ is the coolant flow rate and $C_{p\ell}(x_i)$ the mean specific heat of the coolant between B and D. Then $T_{\ell c}(x_i)$ is approximated as

$$T_{\ell c}(x_i) = \frac{T_\ell\left(x_i - \frac{\Delta x_{i1}}{2}\right) + \frac{\left[T_\ell(x_i)\right]_j + \left[T_\ell(x_i + \Delta x_{i2})\right]_j}{2}}{2} , \quad (42)$$

where the subscript c denotes a calculated value compared with a previously determined value or the initial input number. Combining the above three equations results in

$$T_{\ell c}(x_i) = \frac{\left[T_\ell(x_i)\right]_j + \left[T_\ell(x_i + \Delta x_{i2})\right]_j}{2} + \frac{\pi \, r(x_i) \, \dot{q}_w'(x_i) \, \Delta \bar{x}_i}{\dot{m}_\ell \, C_{p\ell}(x_i) \cos \alpha(x_i)} . \quad (43)$$

This is the internally calculated coolant bulk temperature. For real thrust chambers composed of tubes or channels, a cooling efficiency η should be applied to the second term on the right side of equation (43) to account for the real geometry effect. Thus,

$$T_{\ell c}(x_i) = \frac{\left[T_\ell(x_i)\right]_j + \left[T_\ell(x_i + \Delta x_{i2})\right]_j}{2} + \eta \frac{\pi\, r(x_i)\, \dot{q}_w{}'(x_i)\, \Delta \bar{x}_i}{\dot{m}_\ell\, C_{p\ell}(x_i)\, \cos \alpha(x_i)} \quad . \qquad (44)$$

However, the cooling efficiency η should be equal to one, if the empirical relationship in equation (24) is based upon real thrust chamber data and not upon a single tube experiment.

To start the calculation, a coolant flow temperature distribution must be given or approximated to obtain $T_{\ell c}(x_i)$ through iteration by equation (44). The initial value $\left[T_\ell(x_i)\right]_2$ for successive iterations can be obtained internally from

$$\left[T_\ell(x_i)\right]_2 = \frac{T_{\ell c}(x_i) + \left[T_\ell(x_i)\right]_1}{2} \quad . \qquad (45)$$

Successive iterations are made until the desired convergency is obtained, i.e., the computation is completed when the total heat transfer rate through the chamber wall on the gas side SUMQDA in TBL-I and that on the coolant side [equation (48)] (represented by SUMQWI in the present computer program) become equal. The specific heat transfer rates through the walls on the gas side ($\dot{q}_w$ = QW in TBL-I) and the coolant side ($\dot{q}_w{}'$ = QWI in the present computer program) at each section are simultaneously equal. Now the coupling of the regenerative cooling cycle and TBL-I [1] is completed.

SEQUENCE OF CALCULATION

The numbers of the items that follow in this topic correspond to those in Figure 3a. The calculation sequence at station $x = x_1$ progresses as follows:

1. As shown in the flow chart of Figure 3a, the coolant bulk temperature $\left[T_\ell(x)\right]_0$ and the gas-side wall temperature distribution $\left[T_{wg}(x)\right]_0$ must be

input to initiate the computation, where the subscript 0 denotes the first approximated value. The gas-side wall temperature $\left[T_{wg}(x)\right]_0$ is used to obtain the heat transfer coefficient on the gas side $h_g(x)$ at each station according to the equation below:

$$h_g(x) = \rho_\infty(x)\; U_\infty(x)\; C_H(x)\; \frac{H_{aw}(x) - H_w(x)}{T_{aw}(x) - \left[T_{wg}(x)\right]_j} \quad , \qquad (46)$$

where $j = 0$ denotes the first overall iteration loop. Each parameter except $\left[T_{wg}(x)\right]_j$, on the right side of the above equation, is calculated by the equations shown in equations (1) through (19), or is input. The velocity $U_\infty(x)$ is the only input parameter in equation (46) which remains constant during all iteration at each local station.

2. The wall temperature on the coolant side T_{w_ℓ} and the heat transfer coefficient of the coolant flow h_ℓ are calculated by small internal iteration loops, because equation (33) is implicit,

$$T_{w_\ell} = \frac{h_\ell\left(1 + \frac{\lambda_w}{t\,h_g}\right)[T_\ell]_j + \frac{\lambda_w}{t}\,T_{aw}}{h_\ell\left(1 + \frac{\lambda_w}{t\,h_g}\right) + \frac{\lambda_w}{t}} \qquad \text{(equation 33)}$$

and

$$h_\ell = 0.025\,\frac{\lambda_\ell}{D_{tube}}\,R_{e_\ell}^{0.8}\,P_{r_\ell}^{0.4}\left(\frac{[T_\ell]_j}{T_{w_\ell}}\right)^{0.55}\eta_E \quad . \qquad \text{(equation 24)}$$

Since each parameter in the previous equations is a function of the axial distance x , the argument x is dropped for simplicity purposes. The subscript j identifies the iteration number with $j = 0$ indicating the first iteration.

3. The new gas-side wall temperature T_{wgc} is obtained from equation (34)

$$T_{wgc} = \frac{h_g T_{aw} + \frac{\lambda_w}{t} T_{w_\ell}}{h_g + \frac{\lambda_w}{t}} \quad , \qquad \text{(equation 34)}$$

where the subscript c denotes a calculated value. The h_g in equation (34) is still based upon the input wall temperature on the gas side $\left[T_{wg}\right]_j$. The coolant-side wall temperature T_{w_ℓ} in equation (34) has been obtained previously.

4. The specific heat transfer rate is obtained by any one of equations (20), (22), or (23) because of their equivalence represented by equation (32). Equation (20) is selected here,

$$\dot{q}_w' = h_g \left(T_{aw} - T_{wgc}\right) \quad . \qquad \text{(equation 20)}$$

Another specific heat transfer rate based upon the input gas-side wall temperature is obtained from

$$\dot{q}_w = h_g \left(T_{aw} - \left[T_{wg}\right]_j\right) \quad .$$

The h_g term in both equations is based on the temperature $\left[T_{wg}\right]_j$. When the overall iterations are completed, the following condition must be satisfied: $\dot{q}_w = \dot{q}_w'$, because $T_{wgc} = \left[T_{wg}\right]_j$.

5. The coolant bulk temperature has to be corrected at this point by considering the heat transferred at section i with the respective $x = x_i$ and the input coolant bulk temperatures.

$$T_{\ell c} = \frac{\left[T_\ell(x_i)\right]_j + \left[T_\ell(x_i + \Delta x_{i2})\right]_j}{2} + \eta \frac{\pi r \dot{q}_w' \Delta \bar{x}_i}{\dot{m}_\ell C_{p\ell} \cos \alpha} \quad . \qquad \text{(equation 44)}$$

Derivation of this equation was shown previously.

6. New temperature approximations for the bulk coolant and the gas-side wall are predicted, for use in the succeeding overall iterations, from

$$\left[T_\ell(x)\right]_{j+1} = \frac{T_{\ell c}(x) + \left[T_\ell(x)\right]_j}{2} \quad ,$$

and

$$\left[T_{wg}(x)\right]_{j+1} = \frac{T_{wgc}(x) + \left[T_{wg}(x)\right]_j}{2} \quad .$$

The above procedure from steps 1 through 6 is repeated at each local station $x = x_i$, and the two total heat transfer rates through the wall are compared at the end of every overall iteration loop station $x = x_{IXTAB}$ (Fig. 3b). A solution is obtained when the two values fall within a small tolerance,

$$\left| \frac{\sum_{i=1}^{N} \tilde{\dot{Q}}_w - \sum_{i=1}^{N} \dot{Q}_w}{\sum_{i=1}^{N} \dot{Q}_w} \right| \lesssim \text{Tolerance} \quad ,$$

The expression $\sum_{i=1}^{N} \dot{Q}_w$ will be described in equations (47) through (51) and is identified as SUMQWI in the computer program, whereas $\sum_{i=1}^{N} \tilde{\dot{Q}}_w$ is based upon $\dot{q}_w$ and denoted as SUMQGA. As long as convergence is not attained, iterations must be continued with new estimates of $\left[T_\ell(x)\right]_{j+1}$ and $\left[T_{wg}(x)\right]_{j+1}$.

TOTAL HEAT TRANSFER RATE

The heat transfer rate through section i, between B and D in Figure 4 is $\dot{Q}_w(x_i)$ according to equation (39). The surface area of this wall section is

$$\frac{2\pi\, r(x_i)\, \Delta \bar{x}_i}{\cos \alpha(x_i)} \quad . \tag{47}$$

Summation of the heat transferred up to section $i = N$ is equal to

$$\sum_{i=1}^{N} \dot{Q}_w\,(x_i) \quad . \tag{48}$$

This amount is the heat which is transferred through the chamber walls between $x = x_1$ and $x = x_N + \frac{\Delta x_{N2}}{2}$ into the coolant per unit time, and not up to $x = x_N$.

The heat transfer rates through the initial and the final section of the contour are those through the area between C and D, and B and C, respectively, Figure 4. Heat transfer rate through the initial section $i = 1$ between $x = x_1$ and $x = x_1 + \frac{\Delta x_{12}}{2}$ is

$$\dot{Q}_w(x_1) = \frac{\pi\, r(x_1)\, \dot{q}_w'(x_1)\, \Delta x_{12}}{\cos\alpha(x_1)} , \tag{49}$$

whereas for the final section at $x = x_{IXTAB}$

$$\dot{Q}_w\left(x_{IXTAB}\right) = \frac{\pi\, r\left(x_{IXTAB}\right) \dot{q}_w'\left(x_{IXTAB}\right) \Delta x_{IXTAB\ 1}}{\cos\alpha\left(x_{IXTAB}\right)} . \tag{50}$$

Integrating the heat transferred from point x_1 to x_{IXTAB} per unit time results in

$$\eta\left[\dot{Q}_w(x_1) + \sum_{i=2}^{IXTAB-1} \dot{Q}_w(x_i) + \dot{Q}_w\left(x_{IXTAB}\right)\right] . \tag{51}$$

The coefficient η is used to account for surface area geometry effects; i.e., $\eta = 0.5$ for double pass cooling if only one path is considered. The above amount at $x = x_{IXTAB}$ must coincide with the total heat transfer rate calculated from the gas phase final iteration value. The latter amount has been denoted as "SUMQGA" = "SUMQDA*η" whereas the former, equation (51), will be designated as "SUMQWI". These two values are not the same at an intermediate section $x = x_i$ because "SUMQGA" in TBL-I is the amount between $x = x_1$ and $x = x_i$, whereas "SUMQWI" is obtained between $x = x_1$ and $x = x_i + \frac{\Delta x_{i2}}{2}$. Iterations are performed until the following convergence is obtained:

$$\left| \frac{SUMQGA - SUMQWI}{SUMQWI} \right| < \text{Tolerance} \quad .$$

SAME DIRECTION COOLANT FLOW

We have considered the case of the coolant flowing in an opposite direction to the combustion products. Now the coolant bulk temperature calculations are described for the coolant flowing in the same direction as the combustion products. Since rocket nozzles have been built with coolant flow passages in either direction and combinations thereof, the up and downstream coolant flow simulation of this new concept provides a capability for sectional treatment of changing the cooling cycle patterns. Equations in the section entitled Internally Calculated Coolant Bulk Temperature which must be replaced for the downpath simulation, are shown as follows: In changing the arrow of the coolant flow to point in the same direction as the combustion products in Figure 4, the temperature of the coolant leaving section i can be determined by

$$T_\ell\left(x_i + \frac{\Delta x_{i2}}{2}\right) = \frac{\left[T_\ell(x_{i-1})\right]_j + \left[T_\ell(x_i)\right]_j}{2} + \frac{\dot{Q}_w(x_i)}{\dot{m}_\ell \, C_{p\ell}(x_i)} \quad , \tag{52}$$

where the argument $x_i + \dfrac{\Delta x_{i2}}{2}$ represents the coordinate at the coolant outlet location in section i. This equation must replace equation (41).

The coolant bulk temperature to be calculated at $x = x_i$ is obtained in a way similar to equations (42) and (44),

$$T_\ell(x_i) = \frac{T_\ell\left(x_i + \dfrac{\Delta x_{i2}}{2}\right) + \dfrac{\left[T_\ell(x_{i-1})\right]_j + \left[T_\ell(x_i)\right]_j}{2}}{2} \tag{53}$$

$$= \frac{\left[T_\ell(x_{i-1})\right]_j + \left[T_\ell(x_i)\right]_j}{2} + \eta \, \frac{\dot{Q}_w(x_i)}{2\dot{m}_\ell \, C_{p\ell}(x_i)} \quad , \tag{54}$$

with η as the cooling efficiency due to geometry effects. Since the coolant flow temperature in this case increases toward the nozzle exit, the temperature input tables must be arranged correspondingly.

DOUBLE PASS COOLING

In carrying out the calculation for a double pass cooling jacket with coolant flowing downstream initially and upstream afterwards, we assume, at first, that the nozzle wall consists only of down-pass tubes engaged in the heat transfer process. A correction is made to the analysis by a cooling coefficient η which represents the surface area exposed to the hot gas covered by the downstream cooling tubes, compared to the total surface area. Then, the upstream pass calculation is executed in the same fashion neglecting the downstream coolant flow part. With each heat transfer calculation process, a wall temperature profile is provided. In order to determine the real temperature profile for the nozzle wall on the hot gas side, an average from the two temperature profiles can be determined.

The cooling coefficient η is usually less than unity for the double pass cooling jacket. For coolant flowing in one direction, the cooling coefficient may exceed a value of one, since the wall surface area per unit length may be greater than the circumferential area due to the ripples formed between adjacent cooling tubes.

In the computer program an option indicator will identify which type of coolant flow direction should be considered in the analysis:

IDUMP = 0 Coolant flow upstream

IDUMP = 1 Coolant flow downstream

Modifications made to the existing TBL program are shown in Appendix B.

EXAMPLE

In this section of the paper the previously described new concept is applied to a thrust chamber nozzle similar to the Space Shuttle's main engine. A common chamber down to an area ratio of $\epsilon = 7$ is coupled with different nozzle extensions expanding the combustion products to an area ratio of $\epsilon = 35$ or $\epsilon = 150$ depending on low altitude or vacuum operating conditions, Figure 5. The nozzle contours were optimized according to Rao's method [5, 6] to provide maximum performance. Since a common chamber, Figure 6, was considered for both engines, the orbiter contour had to be modified as indicated by the dotted line in Figure 5. In the thrust chamber liquid hydrogen and oxygen react at a mixture ratio of 6.0 at a pressure of 3020 psia (212.33 kgf/cm^2), resulting in a stagnation temperature of 6600°R (3667°K). The free stream inviscid flow parameters serving as boundary layer edge conditions such as Mach number M_∞, static pressure P_∞, static temperature T_∞ and mean molecular weight $\mathfrak{M}$, were obtained from the Two-Dimensional Kinetics (TDK) computer program [7].

First, only the combustion chamber expanding the reaction products to an area ratio of $\epsilon = 7$ is considered. In this section the chamber wall is regeneratively cooled with liquid hydrogen which flows in an opposite direction to the combustion products. The input data for the modified computer program are shown in Table 2 and Figure 7. The cross-sectional area variation of an individual cooling tube, assumed values for the gas-side wall temperature, and coolant bulk temperature as functions of the axial nozzle length, are presented in Table 2 and Figures 8 and 9. When a study is performed to optimize the cooling jacket geometry, the cross-sectional area in Table 2 and Figure 8 must be changed in each separate analysis. From such a parametric analysis, the best cooling tube geometry can then be selected. In the present example, however, the jacket geometry is fixed. Table 3 represents the relationship between the specific heat at constant pressure and temperature of the combustion products in the boundary layer. In order to determine the coolant flow heat transfer coefficient, the specific heat, thermal conductivity and viscosity for an expected pressure range between 4500 psia and 6000 psia (316.38 kgf/cm^2 and 421.84 kgf/cm^2) for the coolant fluid must be established as functions of temperature. The input data based upon References 4 and 8 are specified in Table 4. Additionally required input data can be found in Table 5. The calculated temperature distributions on the hot gas-side, liquid coolant-side and the coolant are plotted in Figure 10. The total heat transferred through the chamber wall without considering an enhancement factor is 10 580 kcal/sec (42 000 Btu/sec), whereas the local specific heat flux is exhibited in Figure 11. The velocity and temperature boundary layer thicknesses are presented in Figure 12 and the momentum and energy thicknesses are plotted in Figure 13.

The most important result from a performance aspect is the boundary layer displacement thickness δ^*, Figure 14. This parameter, significantly affected by the wall temperature, reveals by how much the wall contour, identical to the inviscid flow border streamline, must be displaced to allow the same mass flow condition. A negative sign of δ^* means a displacement of the inviscid-flow contour towards the thrust chamber centerline.

If the density across the boundary layer is constant, the profile of the mass flow density ρu is in principle similar to the velocity profile, Figure 15a. However, if the density varies the mass flow density overshoots its free stream value $\rho_\infty U_\infty$, especially when the wall is highly cooled, Figure 15b. The dotted line in either schematic denotes the mass flow density profile for inviscid flow. Results from the present analysis indicate that the displacement thickness δ^* is negative for the most part of the combustion chamber to compensate for the strong cooling effect, Figure 14. The performance deficiency represented by a thrust loss, Figure 16, down to an expansion ratio of $\epsilon = 7$ is already quite large according to the equation [1, 2, 3]

$$\Delta F_{B.L.} = \left[2\pi r \, \rho_\infty' \, U_\infty'^2 \, \theta \cos \alpha\right]_{exit} \left[1 - \frac{\delta^*}{\theta} \frac{P_\infty'}{\rho_\infty' \, U_\infty'^2}\right]_{exit} .$$

The corresponding loss in specific impulse is shown in Figure 17.

To investigate the effect of variable and constant properties necessary to calculate the coolant flow heat transfer coefficient, an additional analysis was performed using constant values for the specific heat $C_{p\ell} = 3.75$ Btu/lbm°R, thermal conductivity $\lambda_\ell = 0.0000288$ Btu/ft s °R and the dynamic viscosity $\mu_\ell = 0.0000065$ lbm/ft s which represents mean values between the temperatures of 50°R and 550°R. In comparing the results in Figure 18 with the ones obtained for variable properties in Figure 10, it is evident that the wall temperatures are higher at the throat and lower at an expansion ratio of $\epsilon = 7$. This study clearly outlines that most accurate input data must be used to perform a reliable analysis.

Only the chamber section down to an area ratio of $\epsilon = 7$ has been discussed. Now, the nozzle extension for the booster engine ranging from an area ratio $\epsilon = 7$ to $\epsilon = 35$ is treated. For convenience, this nozzle contour has been selected, although an analysis for the orbiter nozzle contour would be similar. The booster nozzle wall is also cooled by the hydrogen in a double pass cycle. The coolant enters 564 tubes of an area ratio of $\epsilon = 7$, flows toward the nozzle exit area ($\epsilon = 35$) and is then turned upstream. The wall thickness of each tube varies from 0.18 to 0.25 mm toward the nozzle exit. All required input data for the downstream and upstream analysis are shown in Tables 6, 7, and 8. The resulting wall temperature distributions presented in Figure 19 are considerably different for both cooling paths and exhibit a minimum in the down-pass section, where the coolant bulk temperature reaches a value of approximately 140°K (250°R). At this state the hydrogen possesses a maximum specific heat or highest cooling capacity. In the real nozzle the temperature differences between the down and up-pass cooling tube will come to an equilibrium temperature through lateral heat transfer at each local station. Therefore, an arithmetic mean of the different temperatures will represent the real nozzle temperature more realistically, Figure 20. The individual displacement and momentum thicknesses are presented in Table 9, whereas their averaged values are plotted in Figures 21 and 22. The total performance degradation, expressed in thrust and specific impulse loss at the nozzle exit, resulted in $\Delta F_{B.L.} = 4.742$ tons (10 470 lbf) and $\Delta ISP = 7.687$ s (Fig. 23). Heat absorbed by the coolant fluid between the injector face and the nozzle exit ($\epsilon = 35$) amounts to 27 000 kcal/s (107 000 Btu/s). This method was also applied to identify the area of ice formation (wall temperatures less than 460°R) inside the J-2 engine; since deposition of ice crystals along the nozzle exit periphery were observed during altitude simulation test firings.[1]

CONCLUSION

A new method has been presented by which the hot gas-side and the coolant flow-side wall temperature distributions, as well as the coolant fluid temperature variation of a regeneratively cooled thrust chamber, can be determined. The analytical formulation is based upon a coupling of the boundary layer equations with the heat transfer process through the nozzle wall and the coolant flow heat absorption. The new concept has been incorporated into the existing JANNAF Turbulent Boundary Layer (TBL) computer program. A sample case showing the application of the new calculation process for a thrust chamber similar to the Space Shuttle booster engine, has also been outlined. Since several empirical relationships such as the friction coefficient of the hot gas-side wall, the Stanton number, and Colburn's equation for the

1. Analytical Prediction of Ice Formation Inside the J-2 Engine Nozzle Contour (200 K Thrust Level). Memorandum S&E-ASTN-PP (72M-5) NASA, Marshall Space Flight Center, January 1972.

coolant flow heat transfer coefficient were used and no adjustments for the coolant flow turbulence and channel curvature were made, the results are only approximate. In addition, this new model could serve as a convenient tool for the design of an optimum cooling path and channel geometry concept.

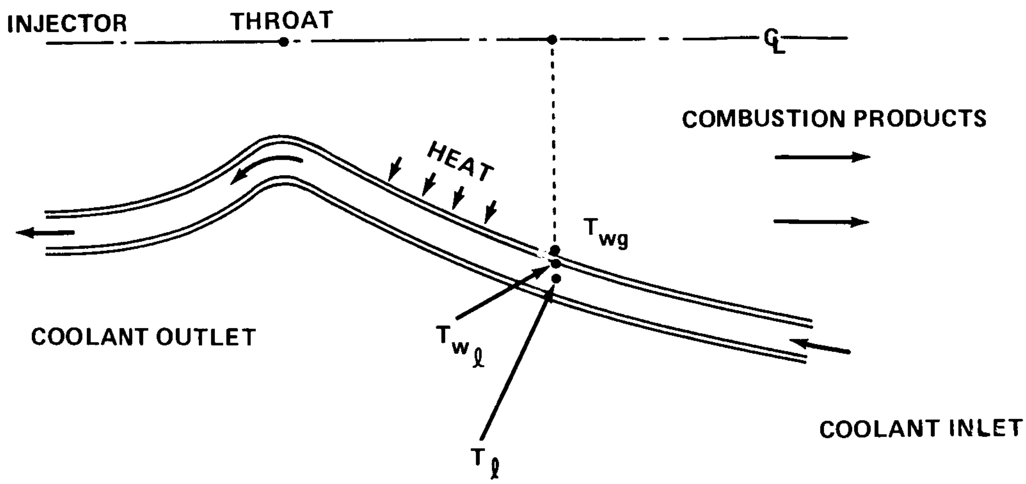


Figure 1. Regeneratively cooled combustor flow model.

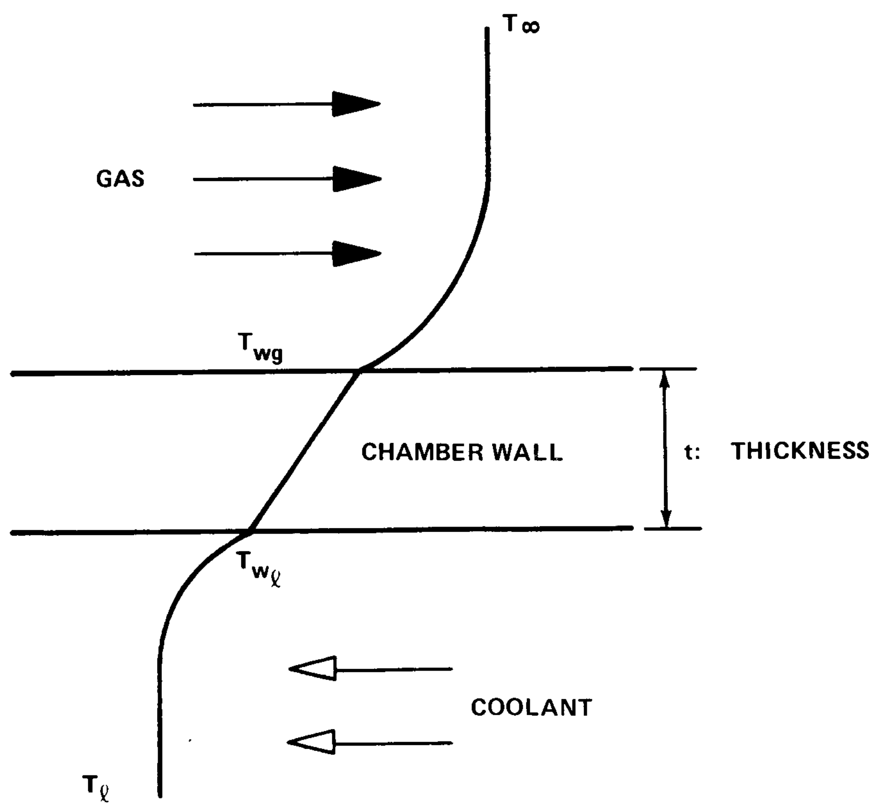


Figure 2. Model of temperature profile.

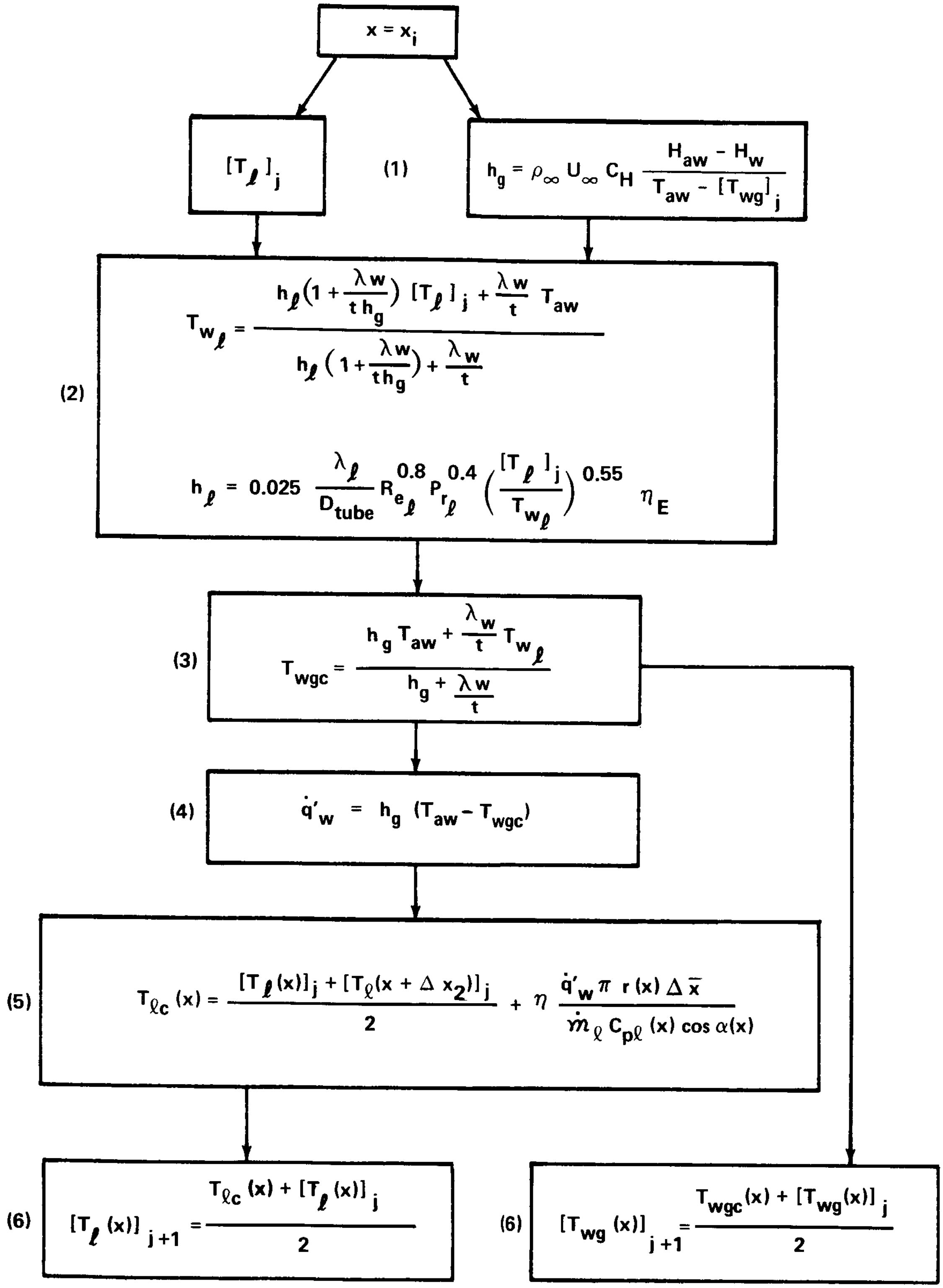


Figure 3.a. Flow chart indicating the calculation procedure at each station $x = x_i$.

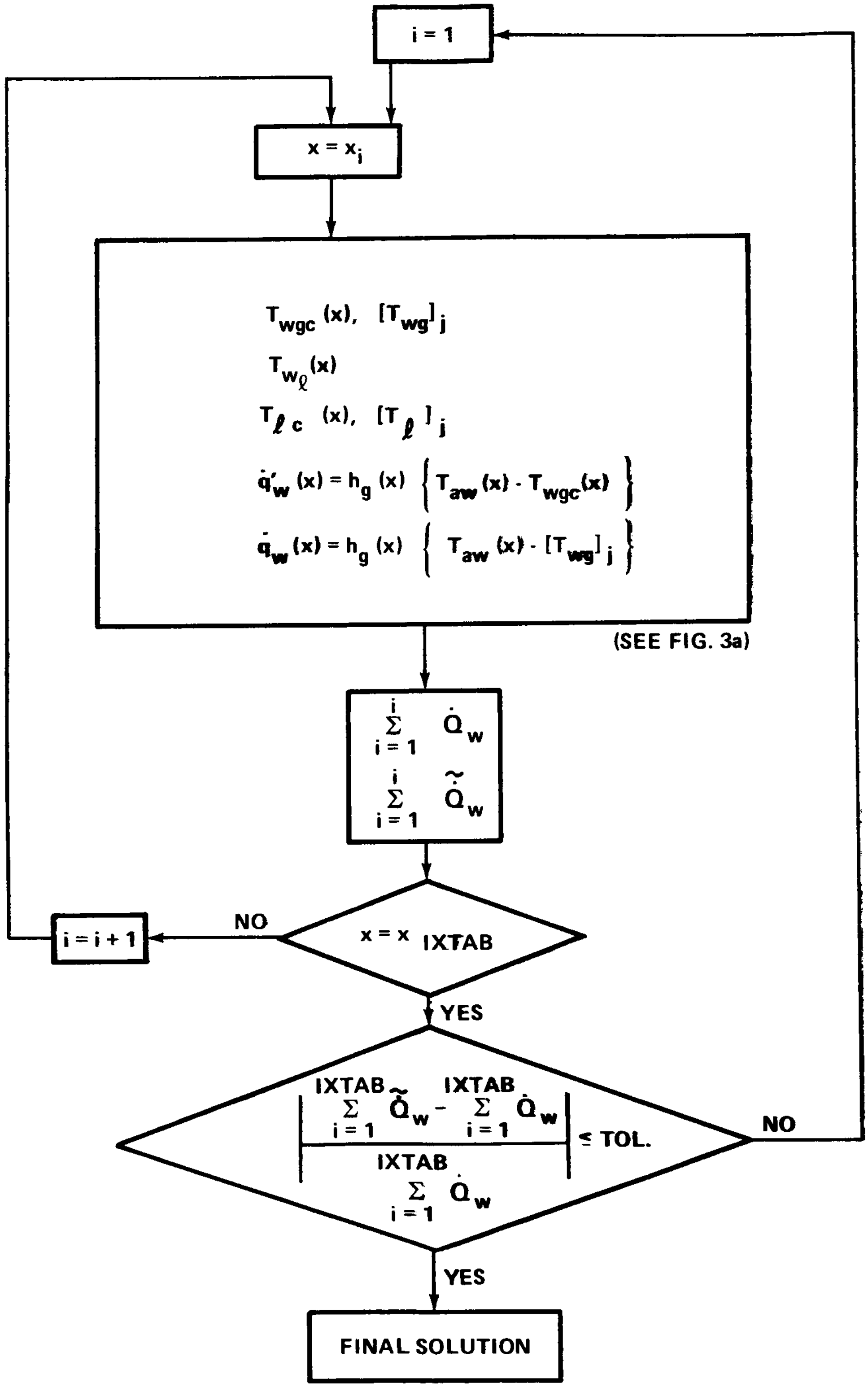


Figure 3. b. Overall flow diagram.

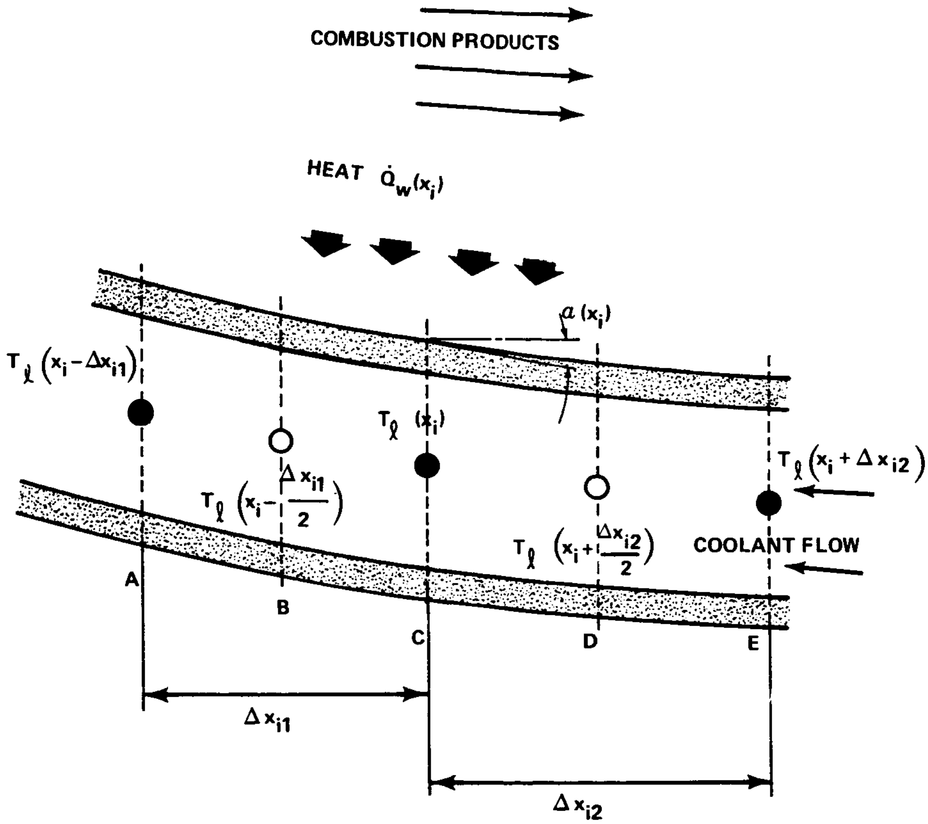


Figure 4. Schematic identifying temperatures used in the coolant flow temperature analysis.

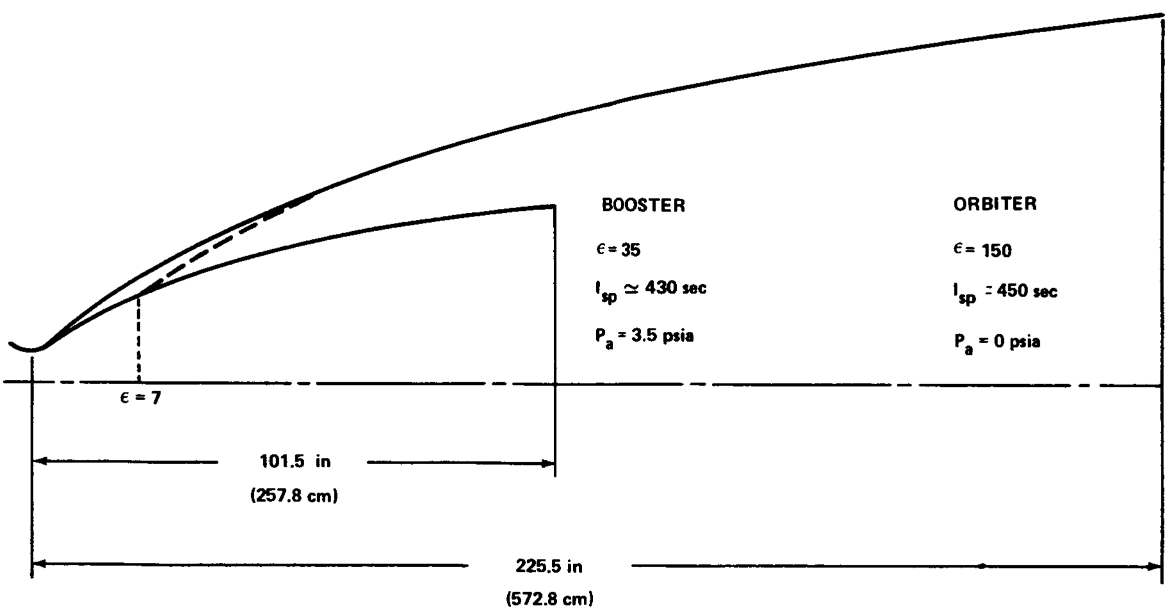


Figure 5. Shuttle engine nozzle contour determined by Rao's method.

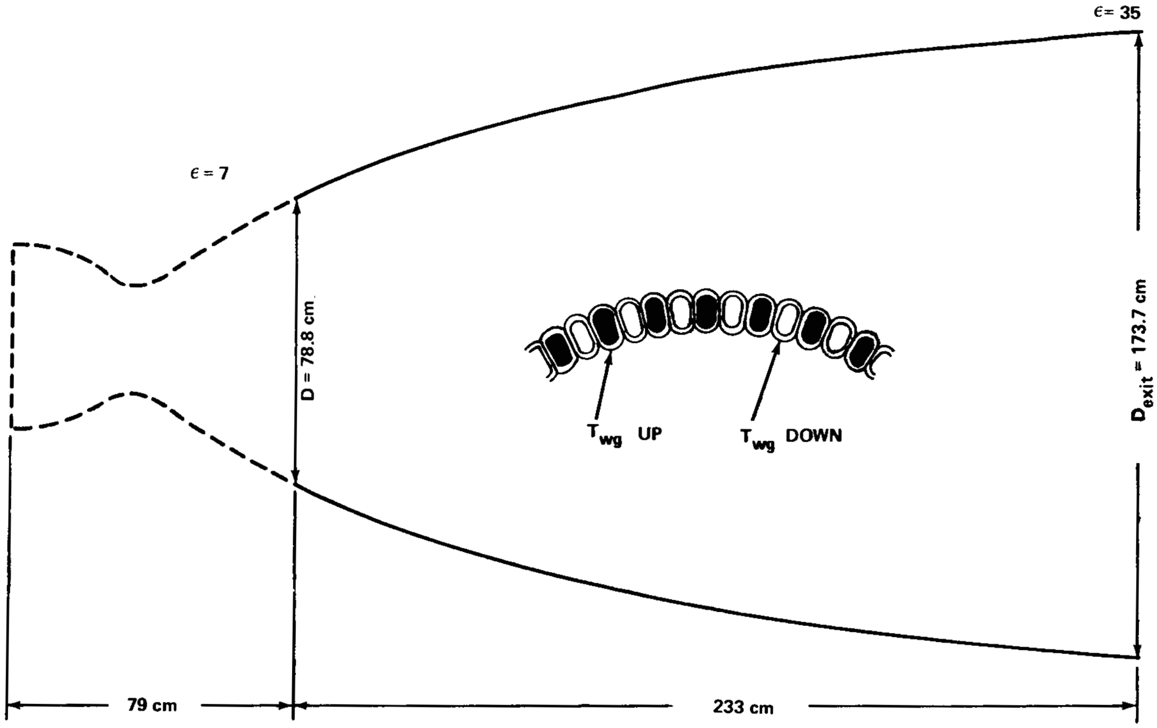


Figure 6. Booster engine contour.

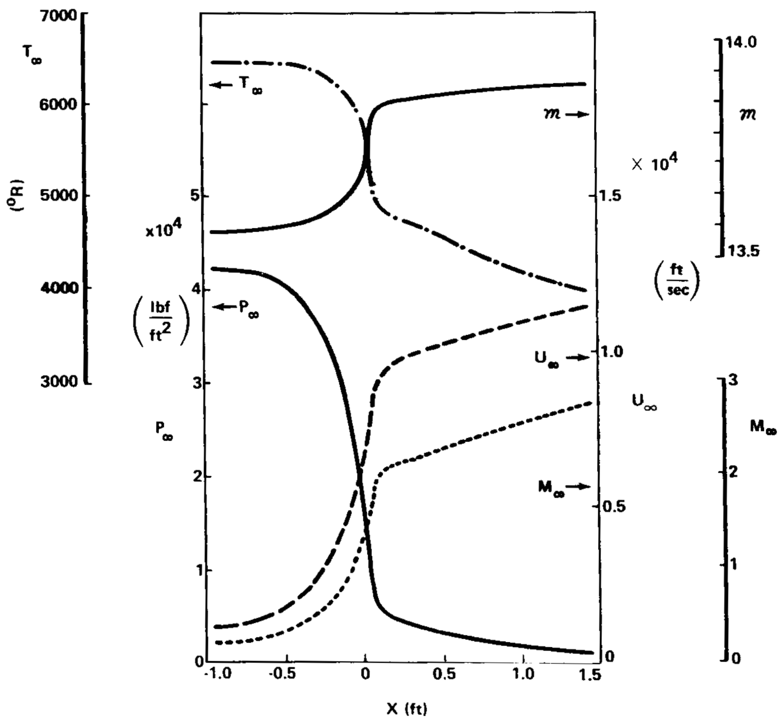


Figure 7. Input freestream parameters (obtained from TDK analysis).

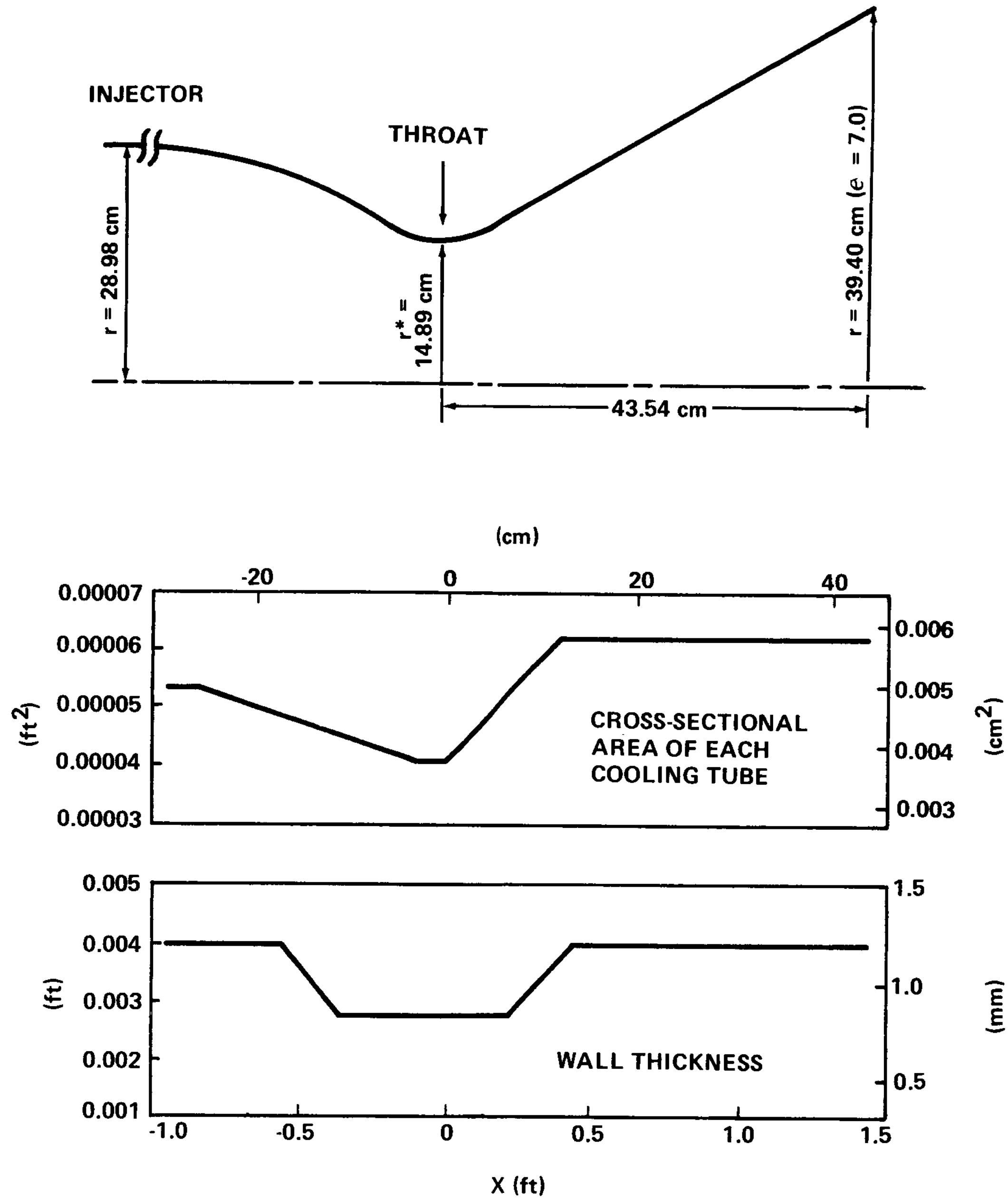


Figure 8. Combustor cooling geometry.

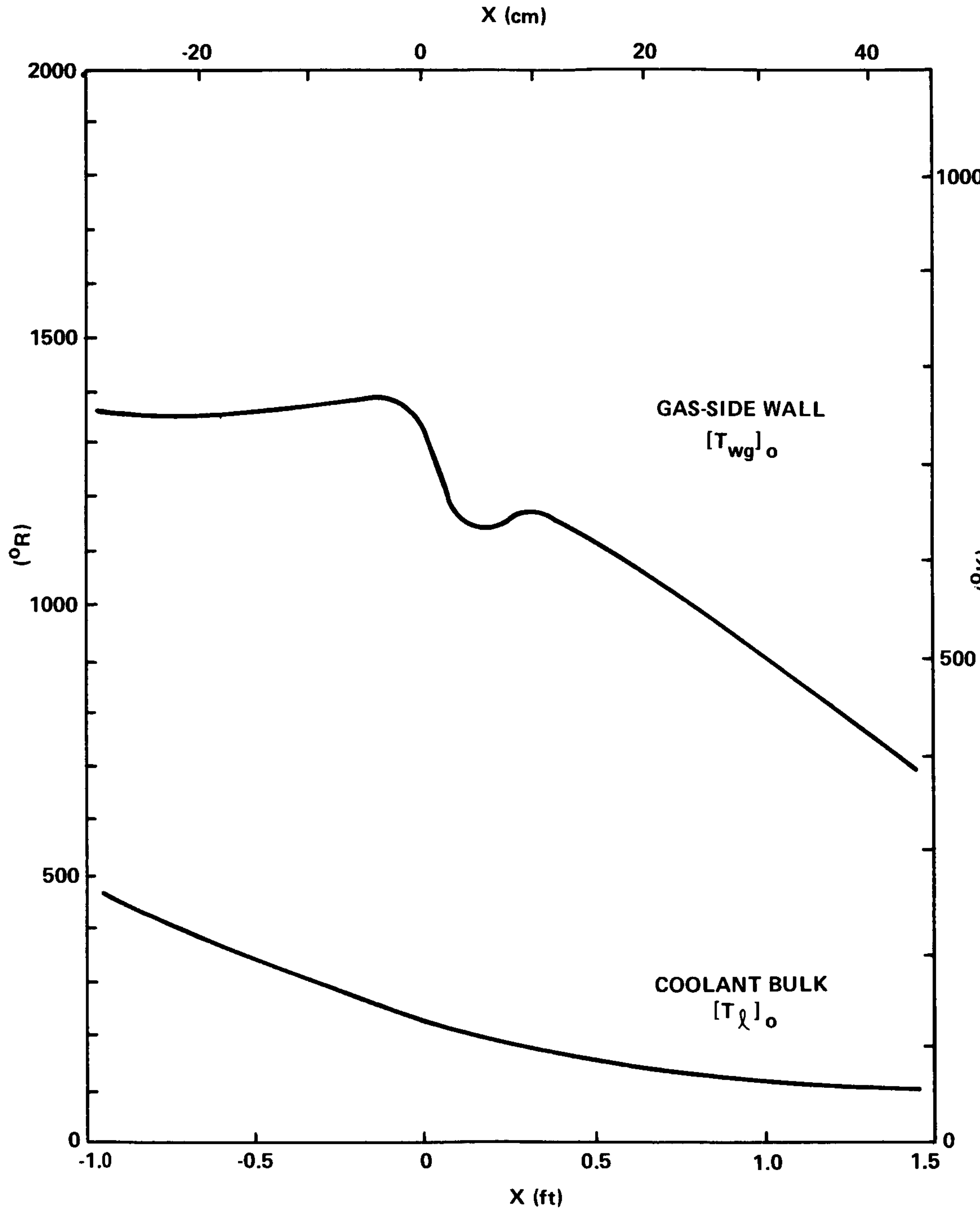


Figure 9. Input temperatures to initiate calculation.

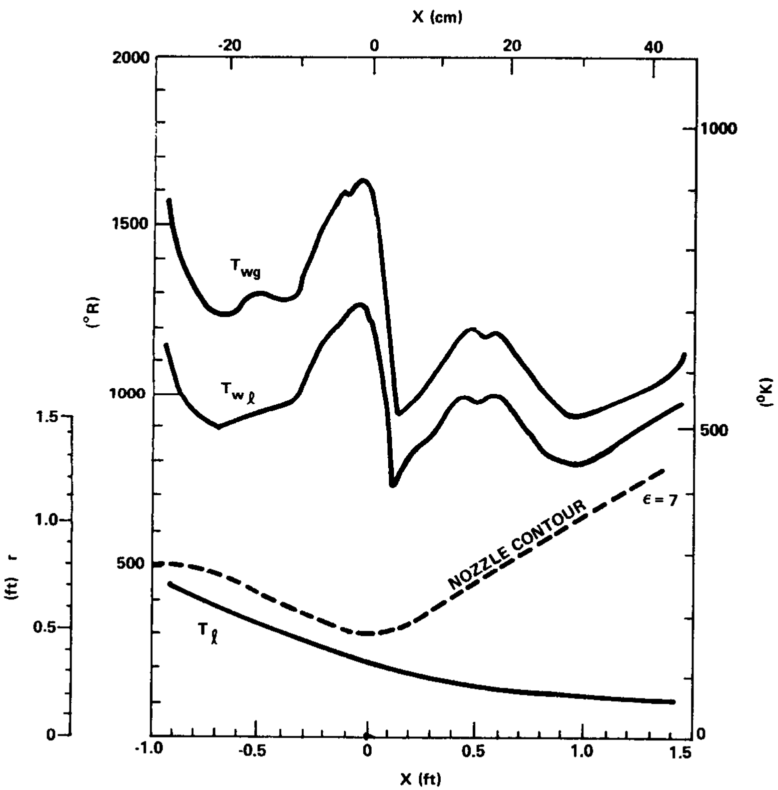


Figure 10. Calculated temperatures.

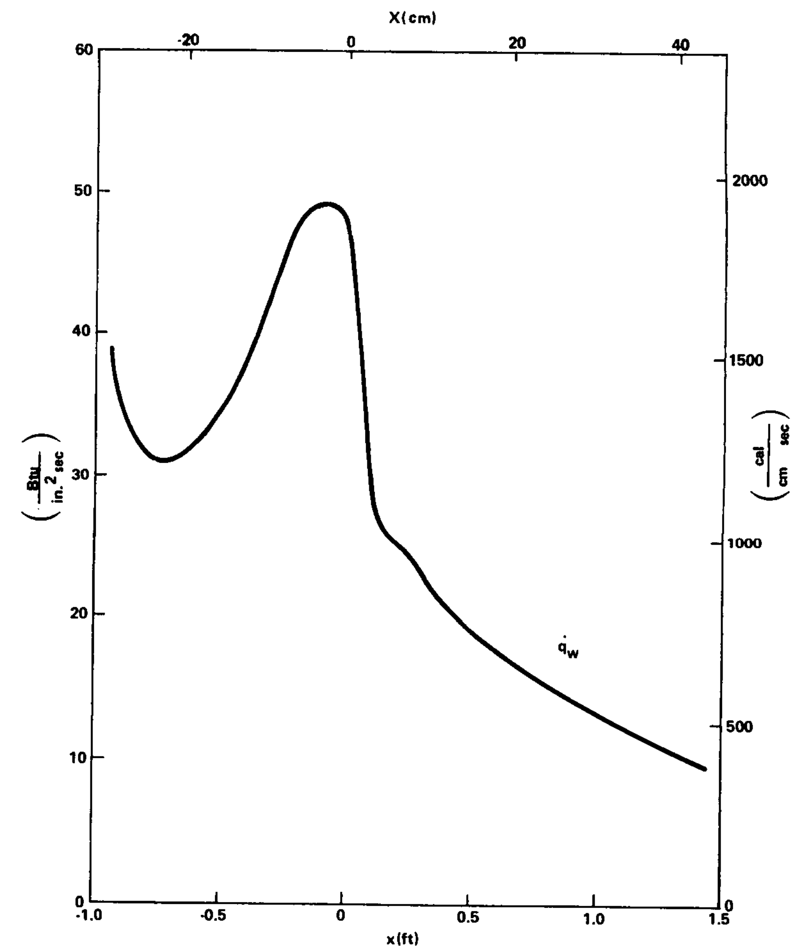


Figure 11. Specific heat transfer rate.

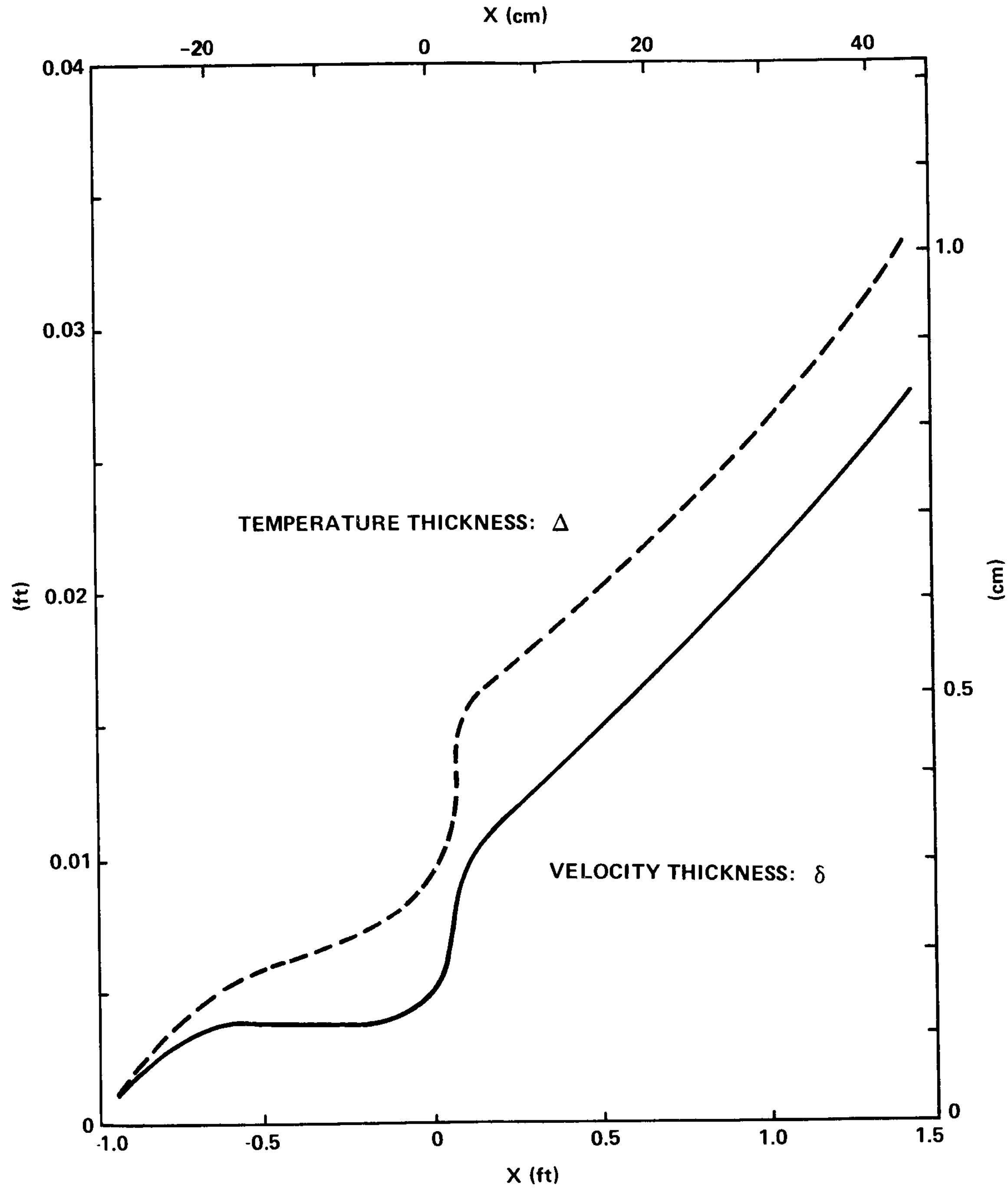


Figure 12. Velocity and temperature thicknesses.

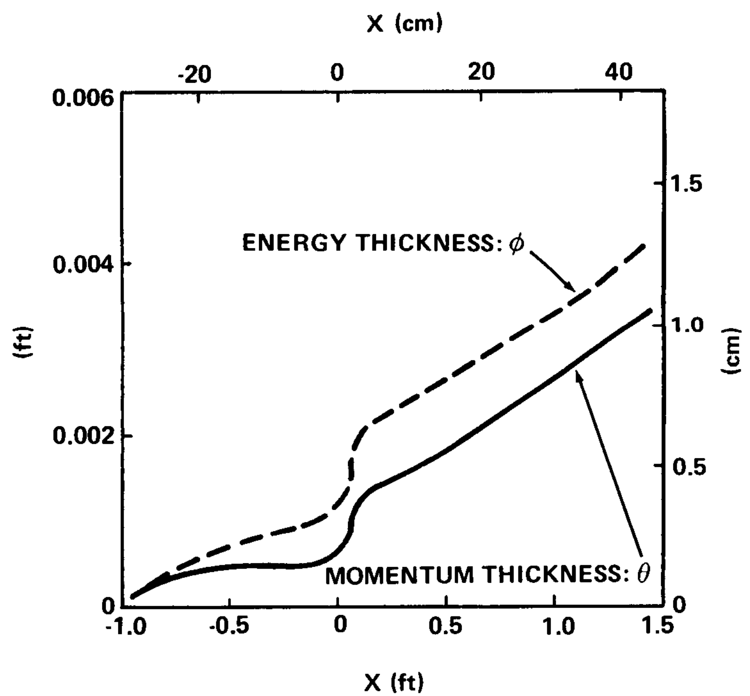


Figure 13. Momentum and energy thicknesses.

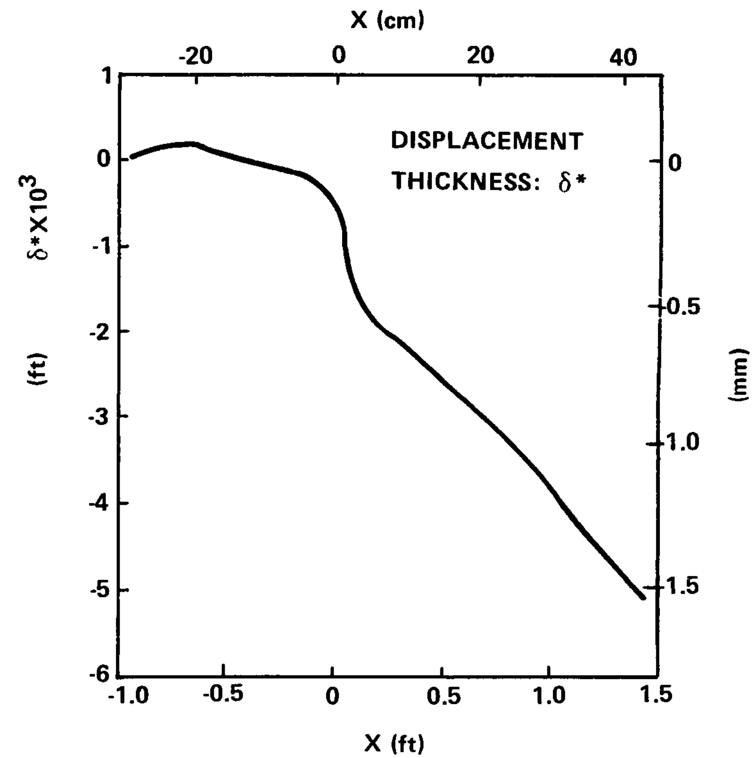


Figure 14. Displacement thickness.

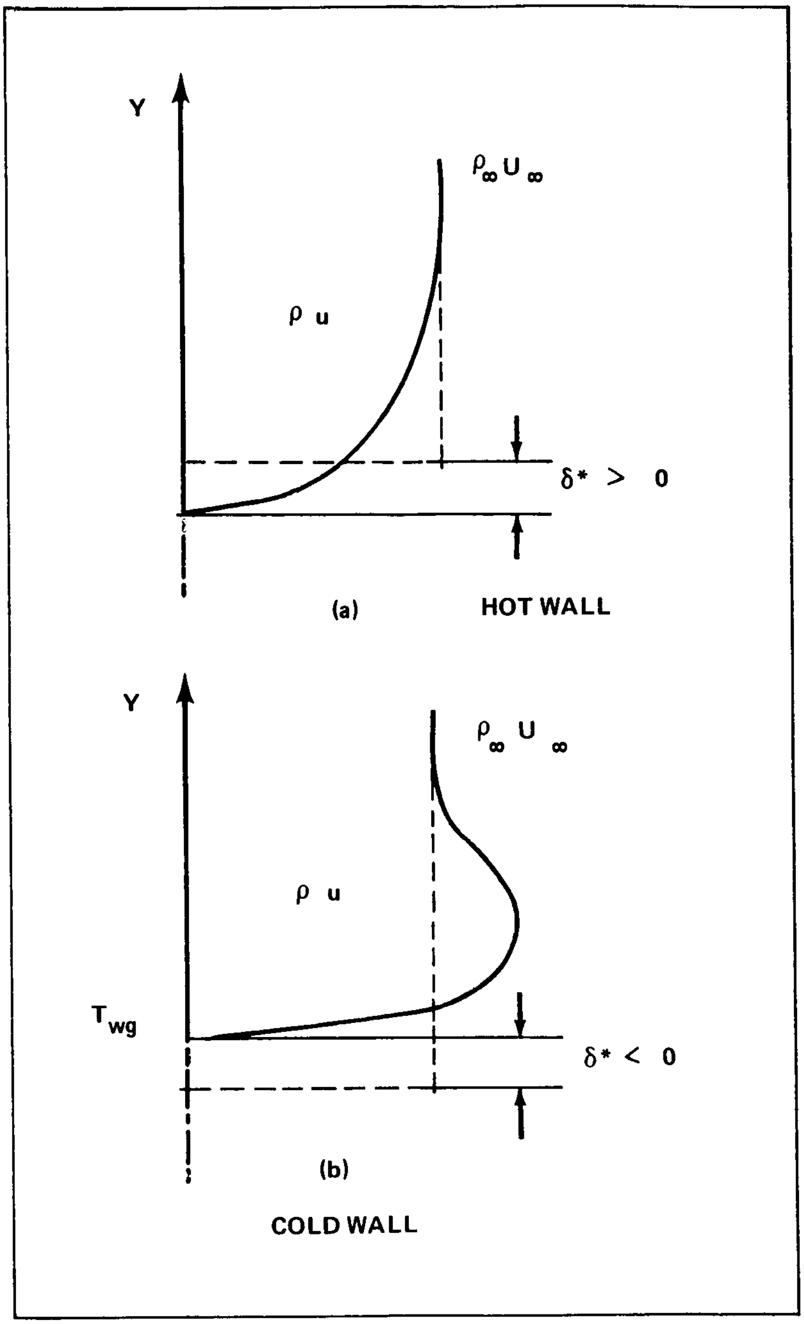


Figure 15. Displacement thickness (hot wall and cold wall).

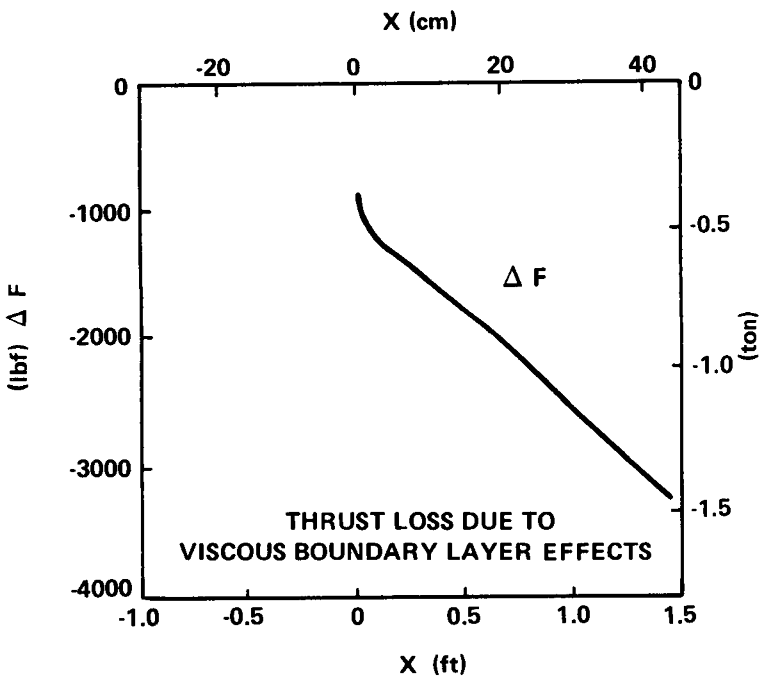


Figure 16. Thrust loss due to viscous boundary layer effects.

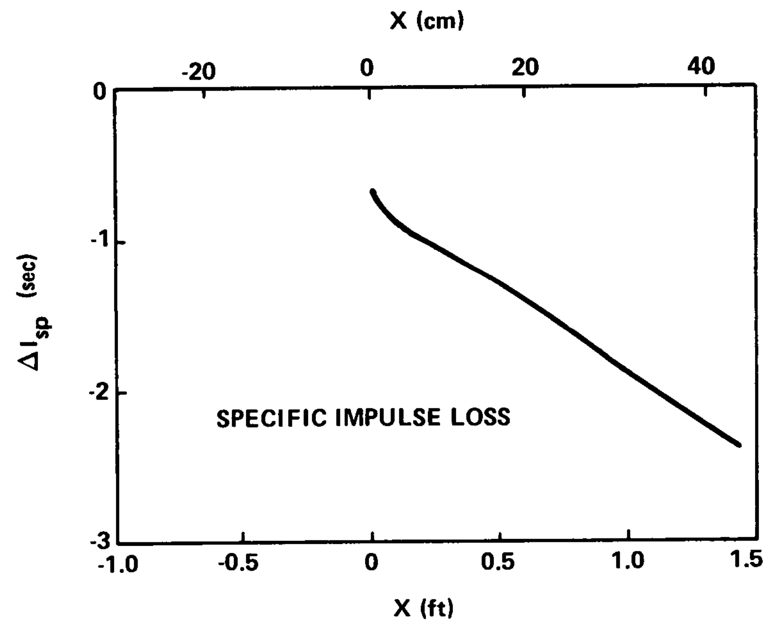


Figure 17. Loss of specific impulse due to boundary layer effects.

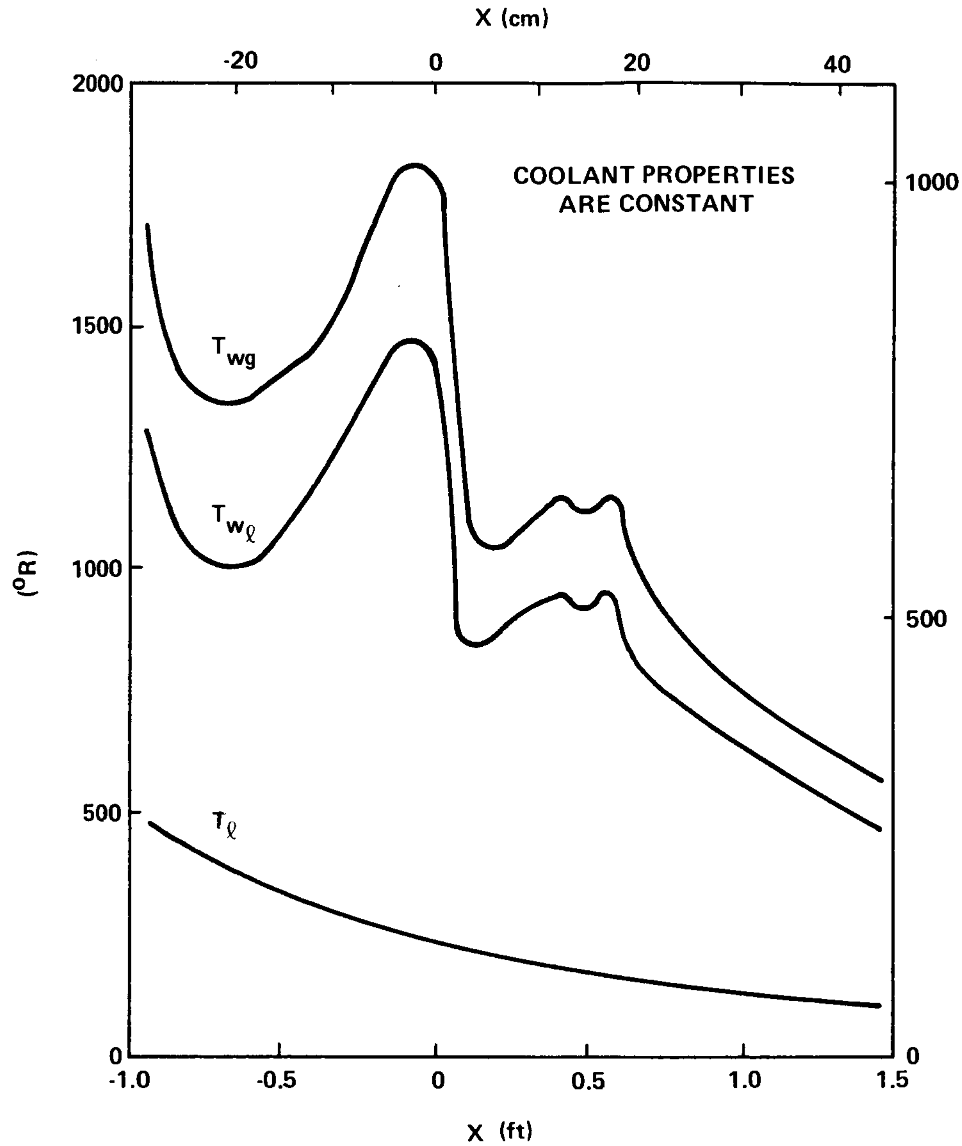


Figure 18. Calculated temperatures.

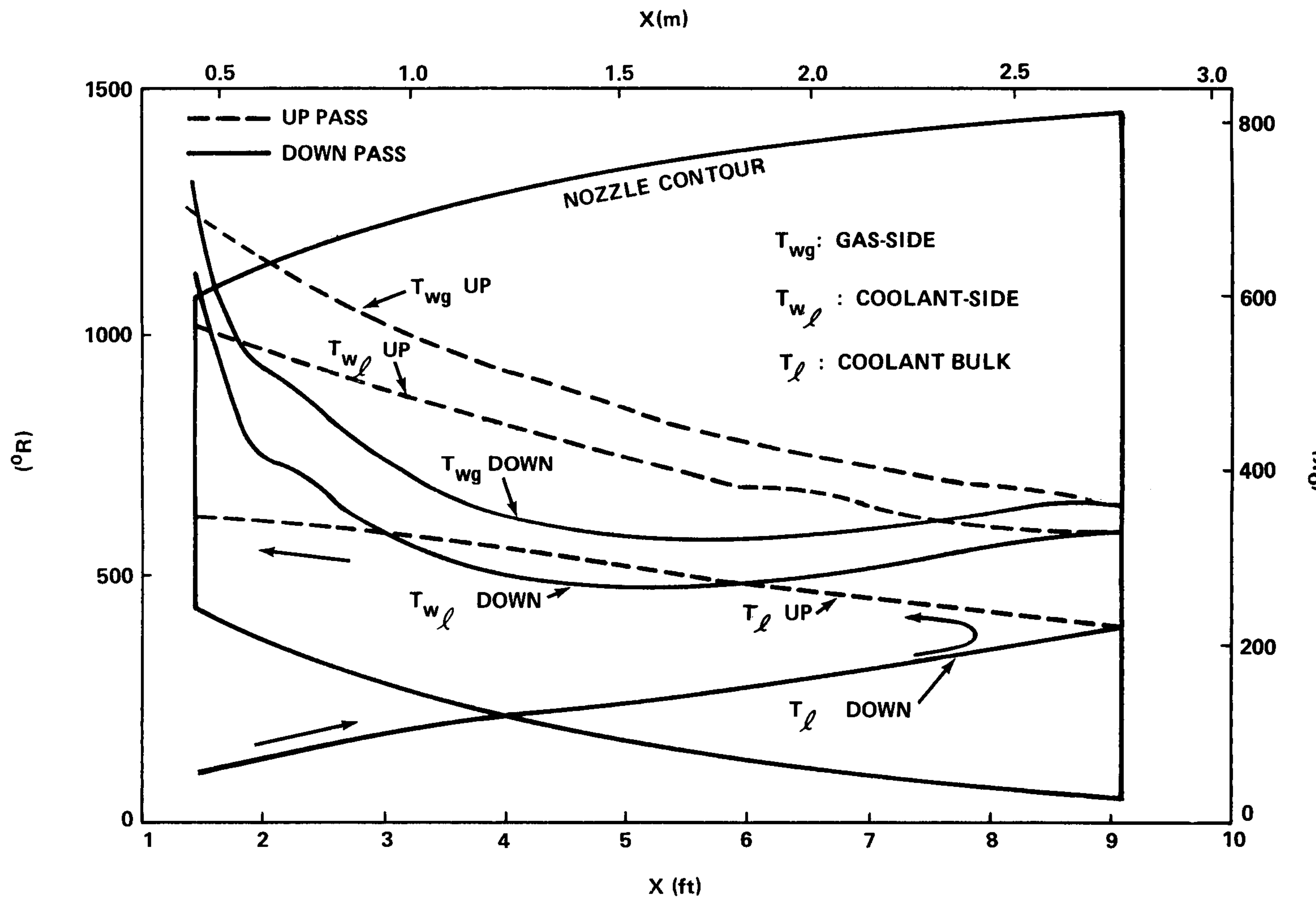


Figure 19. Nozzle temperatures calculated.

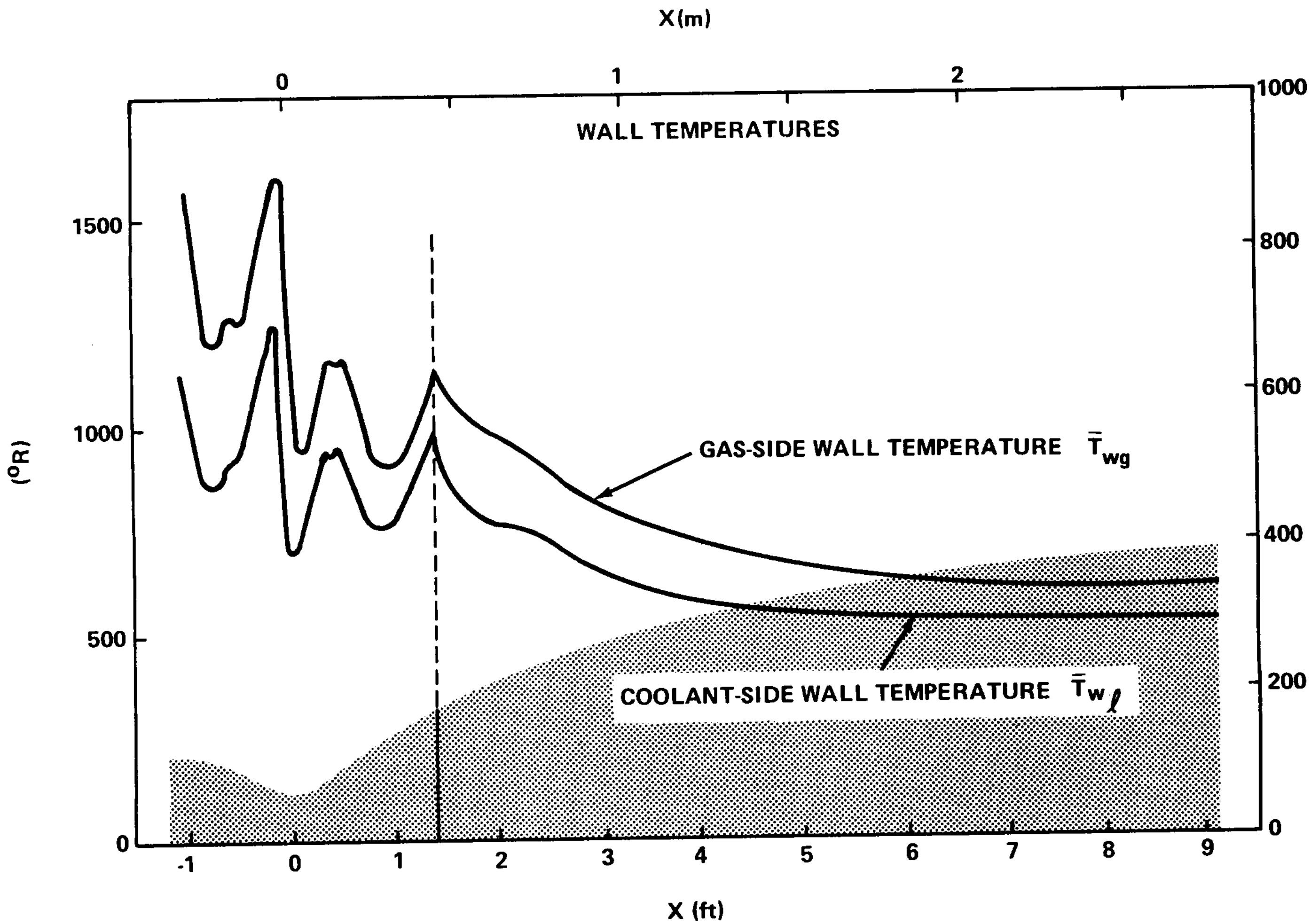


Figure 20. Averaged nozzle wall temperatures.

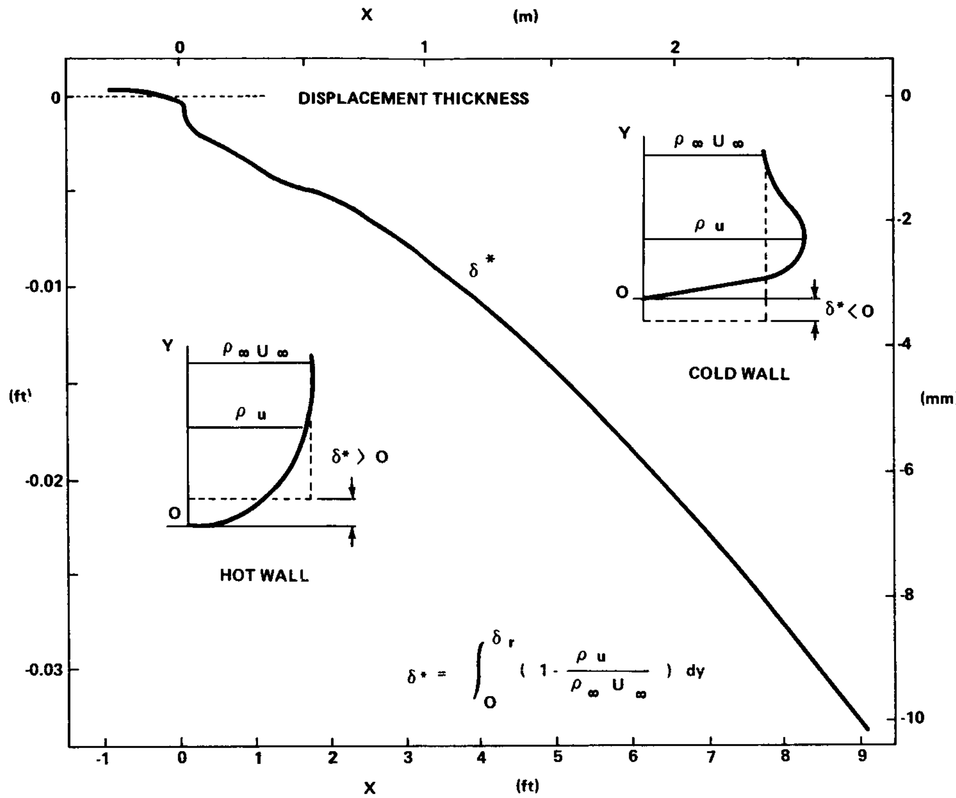


Figure 21. Displacement thickness.

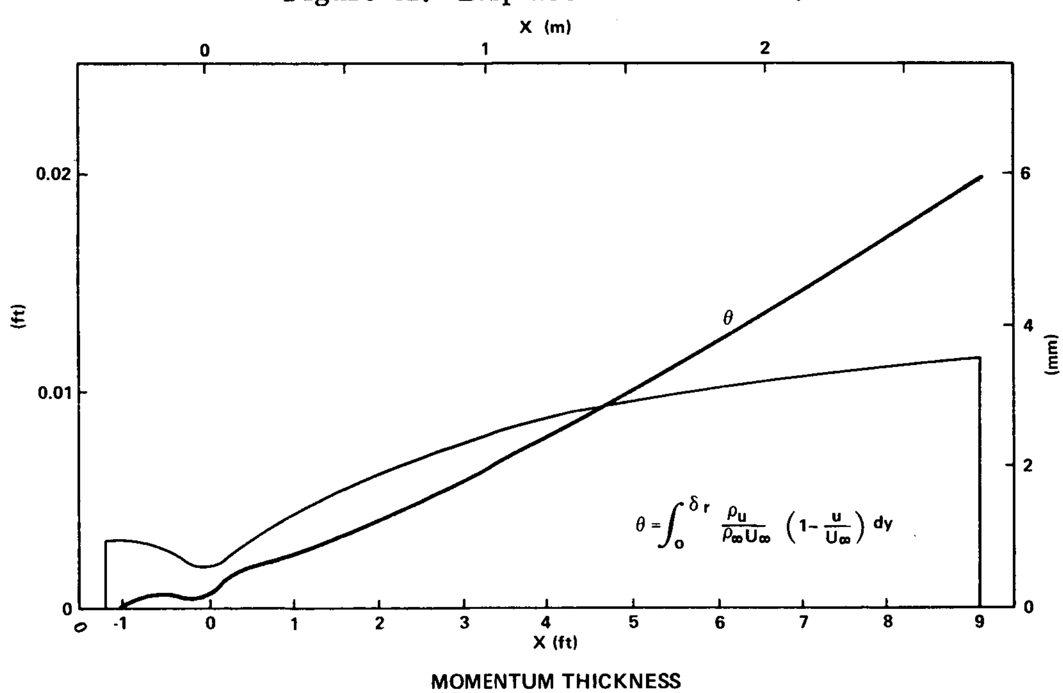
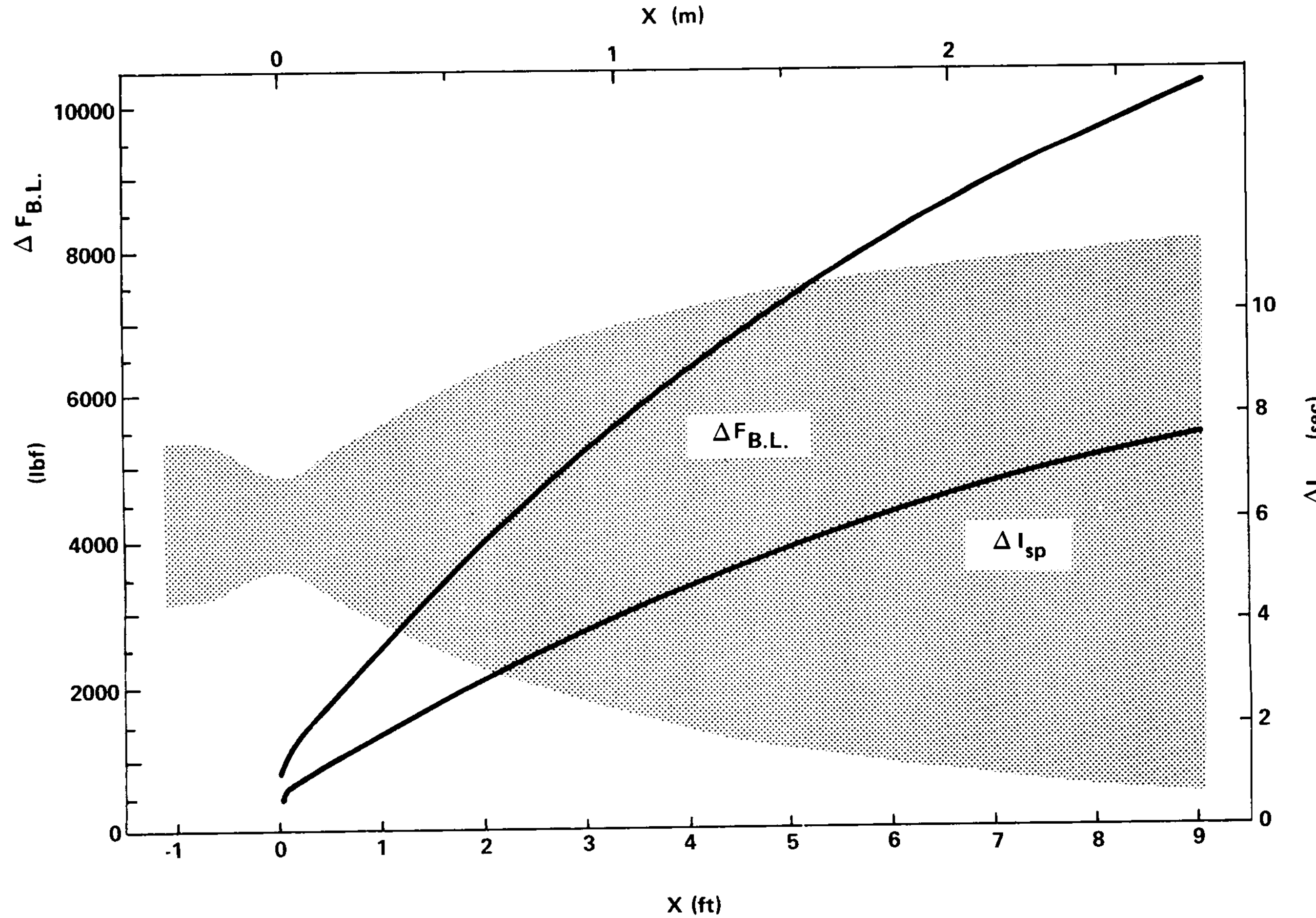


Figure 22. Momentum thickness.



$$\Delta F_{B.L.} = \left[2\pi r\ \rho_\infty U_\infty^2\ \theta\ \cos\alpha\right]_{exit} \left[1 - \frac{\delta^*}{\theta}\frac{p_\infty}{\rho_\infty\ U_\infty^2}\right]_{exit}$$

Figure 23. Thrust loss due to viscous boundary layer effects.

TABLE 1. REGENERATIVE COOLING EQUATIONS

$$\dot{q}_w' = h_g (T_{aw} - T_{wg}) \qquad \text{(equation 20)}$$

$$h_g = \rho_\infty U_\infty C_H \frac{H_{aw} - H_w}{T_{aw} - \left[T_{wg}\right]_j} \qquad \text{(equation 21)}$$

$$h_\ell = 0.025 \frac{\lambda_\ell}{D_{tube}} R_{e_\ell}^{0.8} P_{r_\ell}^{0.4} \left(\frac{\left[T_\ell\right]_j}{T_{w_\ell}} \right)^{0.55} \eta_E \qquad \text{(equation 24)}$$

$$T_{w_\ell} = \frac{h_\ell \left(1 + \frac{\lambda_w}{t\, h_g}\right) \left[T_\ell\right]_j + \frac{\lambda_w}{t} T_{aw}}{\frac{\lambda_w}{t} + h_\ell \left(1 + \frac{\lambda_w}{t\, h_g}\right)} \qquad \text{(equation 33)}$$

$$T_{wg} = \frac{h_g T_{aw} + \frac{\lambda_w}{t} T_{w_\ell}}{h_g + \frac{\lambda_w}{t}} \qquad \text{(equation 34)}$$

TABLE 2. INPUT DATA FOR COMBUSTOR

1	X	Y	Mach Number	Pressure	Static Temperature
1	-0.950725	0.802083	0.220976	422396.766	6476.894
2	-0.914726	0.801277	0.221523	422122.793	6476.810
3	-0.842728	0.794779	0.225972	421622.242	6475.952
4	-0.770730	0.781616	0.235435	420527.219	6474.074
5	-0.734732	0.772440	0.242420	419691.812	6472.632
6	-0.662734	0.748573	0.262271	417197.340	6468.317
7	-0.590736	0.716937	0.292080	413116.426	6461.215
8	-0.554738	0.699832	0.309721	410519.758	6456.660
9	-0.518739	0.682727	0.329208	407496.906	6451.318
10	-0.446740	0.648511	0.375117	399765.176	6437.497
11	-0.410741	0.631406	0.402511	394762.754	6428.419
12	-0.374742	0.614301	0.433805	388714.000	6417.295
13	-0.302744	0.580085	0.513023	371954.164	6385.611
14	-0.266745	0.562980	0.565406	359875.809	6361.932
15	-0.230746	0.545875	0.628830	344318.844	6330.417
16	-0.194747	0.529072	0.696138	327004.102	6293.651
17	-0.158749	0.515094	0.766393	308263.379	6251.739
18	-0.122750	0.504252	0.839565	288302.387	6204.368
19	-0.086751	0.496347	0.915600	267383.355	6151.280
20	-0.057200	0.491945	0.980160	249697.223	6103.208
21	0.000000	0.488583	1.193460	193860.369	5926.078
22	0.003573	0.488618	1.227370	185645.486	5888.241
23	0.007256	0.488720	1.260930	177689.357	5850.416
24	0.011012	0.488901	1.293320	169966.758	5814.319
25	0.014858	0.489160	1.325760	162435.506	5777.151
26	0.018786	0.489507	1.358830	155083.424	5738.689
27	0.022785	0.489942	1.392170	147900.947	5699.396
28	0.030987	0.491104	1.459980	134013.490	5617.924
29	0.035185	0.491842	1.494590	127297.204	5575.459
30	0.043767	0.493650	1.565680	114299.943	5486.489
31	0.048149	0.494735	1.602360	108015.929	5439.801
32	0.057091	0.497290	1.678320	95879.731	5431.590
33	0.061650	0.498775	1.717660	90029.727	5289.898
34	0.070945	0.502210	1.799740	78774.162	5180.797
35	0.080477	0.506314	1.887080	68127.430	5063.229
36	0.095255	0.513926	2.005430	55677.686	4903.150
37	0.110036	0.522159	2.016620	54371.307	4891.896
38	0.125698	0.531066	2.035810	52354.768	4868.906
39	0.150196	0.545269	2.056660	50226.030	4845.773
40	0.186436	0.566752	2.087750	47251.451	4810.424
41	0.222098	0.588215	2.108640	45296.231	4788.942
42	0.257291	0.609630	2.133830	43109.654	4760.864
43	0.292175	0.631064	2.157400	41165.610	4734.703
44	0.326872	0.652552	2.183230	39155.333	4704.890
45	0.361499	0.674113	2.206210	37436.992	4678.748
46	0.396154	0.695748	2.228720	35824.066	4652.945
47	0.430941	0.717480	2.251510	34260.629	4626.427
48	0.465973	0.739363	2.274500	32744.594	4599.258
49	0.501365	0.761452	2.297430	31295.269	4571.973
50	0.537202	0.783776	2.321400	29851.381	4543.057

TABLE 2. (Continued)

1	X	Y	Velocity	Molecular Weight	Coolant Area	Coolant Temperature	Wall Temperature
1	-0.950725	0.802083	1175.830	13.590460	0.000053330	460.000	1360.000
2	-0.914726	0.801277	1178.720	13.597353	0.000053330	450.000	1360.000
3	-0.842728	0.794779	1202.300	13.597646	0.000053330	430.000	1360.000
4	-0.770730	0.781616	1252.440	13.598282	0.000053000	410.000	1360.000
5	-0.734732	0.772440	1289.430	13.598768	0.000052500	398.000	1360.000
6	-0.662734	0.748573	1394.480	13.600157	0.000051100	380.000	1360.000
7	-0.590736	0.716937	1551.980	13.602585	0.000049800	366.000	1360.000
8	-0.554738	0.699832	1645.040	13.604074	0.000049100	350.000	1360.000
9	-0.518739	0.682727	1747.700	13.605855	0.000048500	340.000	1360.000
10	-0.446740	0.648511	1988.940	13.610415	0.000047100	320.000	1360.000
11	-0.410741	0.631406	2132.440	13.613397	0.000046500	312.000	1360.000
12	-0.374742	0.614301	2295.920	13.617002	0.000045800	303.000	1360.000
13	-0.302744	0.580085	2707.390	13.627159	0.000044400	287.000	1364.000
14	-0.266745	0.562980	2977.420	13.634497	0.000043700	280.000	1368.000
15	-0.230746	0.545875	3301.920	13.646259	0.000043000	270.000	1370.000
16	-0.194747	0.529072	3643.090	13.658344	0.000042400	262.000	1372.000
17	-0.158749	0.515094	3995.360	13.672035	0.000041700	255.000	1374.000
18	-0.122750	0.504252	4357.770	13.687345	0.000041000	247.000	1380.000
19	-0.086751	0.496347	4729.150	13.704345	0.000040868	240.000	1380.000
20	-0.057200	0.491945	5040.040	13.719516	0.000040868	232.000	1375.000
21	0.000000	0.488583	6035.780	13.765060	0.000040868	222.000	1320.000
22	0.003573	0.488618	6186.780	13.768245	0.000040868	221.000	1310.000
23	0.007256	0.488720	6334.890	13.771604	0.000040868	220.000	1300.000
24	0.011012	0.488901	6473.390	13.790009	0.000040868	219.500	1295.000
25	0.014858	0.489160	6612.360	13.799884	0.000040868	219.000	1285.000
26	0.018786	0.489507	6752.420	13.809909	0.000040868	218.000	1280.000
27	0.022785	0.489942	6891.970	13.820396	0.000040868	217.000	1272.000
28	0.030987	0.491104	7170.700	13.842066	0.000040868	216.000	1255.000
29	0.035185	0.491842	7310.530	13.852492	0.000040868	215.000	1250.000
30	0.043767	0.493650	7592.250	13.872702	0.000041000	214.000	1235.000
31	0.048149	0.494735	7734.490	13.883344	0.000041100	213.000	1225.000
32	0.057091	0.497290	8022.470	13.905751	0.000041400	211.000	1220.000
33	0.061650	0.498775	8168.540	13.915809	0.000042000	210.000	1210.000
34	0.070945	0.502210	8456.700	13.936370	0.000042400	209.000	1200.000
35	0.080477	0.506314	8770.780	13.958197	0.000043200	207.000	1188.000
36	0.095255	0.513926	9166.640	13.987167	0.000044000	205.000	1180.000
37	0.110036	0.522159	9205.220	13.993980	0.000045200	202.000	1170.000
38	0.125698	0.531066	9270.930	13.996067	0.000046000	199.000	1155.000
39	0.150196	0.545269	9342.800	14.000566	0.000047700	194.000	1145.000
40	0.186436	0.566752	9449.400	14.003944	0.000050000	188.000	1145.000
41	0.222098	0.588215	9522.320	14.006823	0.000052500	182.000	1160.000
42	0.257291	0.609630	9607.770	14.009449	0.000055000	178.000	1180.000
43	0.292175	0.631064	9686.870	14.012815	0.000057200	172.000	1180.000
44	0.326872	0.652552	9771.880	14.015822	0.000059400	167.000	1170.000
45	0.361499	0.674113	9847.080	14.018885	0.000061800	163.000	1164.000
46	0.396154	0.695748	9919.870	14.021893	0.000064000	160.000	1150.000
47	0.430941	0.717480	9992.570	14.024915	0.000064000	155.000	1140.000
48	0.465973	0.739363	10065.200	14.027241	0.000064000	152.000	1125.000
49	0.501365	0.761452	10136.800	14.029441	0.000064000	150.000	1113.000
50	0.537202	0.783776	10210.600	14.031649	0.000064000	144.000	1100.000

TABLE 2. (Continued)

1	X	Y	Mach Number	Pressure	Static Temperature	Velocity
51	0.573587	0.806348	2.343910	28549.828	4516.006	10279.200
52	0.610587	0.829199	2.366190	27316.291	4489.143	10346.400
53	0.648296	0.852358	2.388870	26120.937	4461.624	10413.800
54	0.686772	0.875849	2.414570	24838.084	4429.732	10488.700
55	0.726084	0.899687	2.437690	23733.271	4401.310	10555.500
56	0.766270	0.923882	2.460560	22689.907	4373.128	10620.700
57	0.807399	0.948448	2.482860	21710.558	4345.459	10683.900
58	0.849451	0.973326	2.509180	20618.095	4312.209	10757.000
59	0.892476	0.998528	2.531090	19741.943	4284.989	10817.600
60	0.936517	1.024076	2.553870	18875.053	4256.567	10879.600
61	0.981554	1.049966	2.581530	17880.656	4221.445	10953.300
62	1.027623	1.076202	2.605860	17046.165	4190.827	11017.500
63	1.074732	1.102816	2.630650	16238.506	4159.610	11081.800
64	1.122882	1.129785	2.653380	15529.652	4131.084	11140.100
65	1.171950	1.156931	2.679960	14741.519	4097.262	11207.300
66	1.388564	1.272066	2.766310	12451.571	3989.778	11420.100
67	1.428417	1.292666	2.775000	12100.000	3970.000	11457.000

(The enhancement factor η_E is assumed 1.0).

TABLE 2. (Concluded)

1	X	Y	Molecular Weight	Coolant Area	Coolant Temperature	Wall Temperature
51	0.573587	0.806348	14.033758	0.000064000	140.000	1090.000
52	0.610587	0.829199	14.035868	0.000064000	137.000	1075.000
53	0.648296	0.852358	14.038372	0.000064000	133.000	1060.000
54	0.686772	0.875849	14.040570	0.000064000	130.000	1048.000
55	0.726084	0.899687	14.042853	0.000064000	127.000	1030.000
56	0.766270	0.923882	14.045460	0.000064000	125.000	1010.000
57	0.807399	0.948448	14.046940	0.000064000	121.000	990.000
58	0.849451	0.973326	14.048340	0.000064000	120.000	980.000
59	0.892476	0.998528	14.049712	0.000064000	117.000	954.000
60	0.936517	1.024076	14.051524	0.000064000	115.000	935.000
61	0.981554	1.049966	14.052984	0.000064000	113.000	920.000
62	1.027623	1.076202	14.054569	0.000064000	110.000	900.000
63	1.074732	1.102816	14.056434	0.000064000	108.000	880.000
64	1.122882	1.129785	14.057979	0.000064000	106.000	850.000
65	1.171950	1.156931	14.058947	0.000064000	103.000	830.000
66	1.388564	1.272066	14.065845	0.000064000	95.000	720.000
67	1.428417	1.292666	14.066350	0.000064000	92.000	700.000

(The enhancement factor η_E is assumed 1.0).

TABLE 3. C_p-T RELATIONSHIP OF COMBUSTION PRODUCTS

I	Specific Heat (Btu/lbm s)	Temperature (°R)
1	0.6199999973	400.000
2	0.6550000012	800.000
3	0.6799999997	1200.000
4	0.6950000003	1400.000
5	0.7049999982	1600.000
6	0.7199999988	2000.000
7	0.7282169983	2500.000
8	0.7282169983	3000.000
9	0.7282169983	4000.000
10	0.7282169983	5000.000
11	0.7282169983	5850.000
12	0.7282169983	5926.078
13	0.8833189979	6103.208
14	0.8843249977	6151.280
15	0.8854160011	6204.368
16	0.8893399984	6403.409
17	0.8902480006	6451.318
18	0.8906119987	6470.760
19	0.8907269984	6476.894
20	0.8920999989	8000.000

TABLE 4. PHYSICAL PROPERTIES OF LIQUID HYDROGEN

Coolant Temperature (°R)	Coolant Specific Heat (Btu/lbm• °R)	Conductivity (Btu/ft s °R)	Viscosity (lbm/ft s)
50.000	1.950000	0.0000234000	0.0000648000
100.000	2.850000	0.0000235200	0.0000120000
150.000	3.550000	0.0000249000	0.0000062400
200.000	3.950000	0.0000276000	0.0000054000
250.000	4.200000	0.0000288000	0.0000051600
300.000	4.200000	0.0000300000	0.0000051600
350.000	4.050000	0.0000306000	0.0000062400
400.000	3.900000	0.0000318000	0.0000057600
450.000	3.800000	0.0000327600	0.0000061200
500.000	3.700000	0.0000342000	0.0000064800
550.000	3.600000	0.0000357600	0.0000067200
600.000	3.550000	0.0000375600	0.0000069600
650.000	3.530000	0.0000390000	0.0000073200
700.000	3.510000	0.0000410400	0.0000076800
750.000	3.500000	0.0000428400	0.0000079200
800.000	3.500000	0.0000444000	0.0000081600
850.000	3.480000	0.0000464400	0.0000084000
900.000	3.470000	0.0000482400	0.0000087600
950.000	3.460000	0.0000504000	0.0000090000
1000.000	3.460000	0.0000528000	0.0000093600

TABLE 5. INPUT DATA OF THRUST CHAMBER

MZETA	=	VELOCITY PROFILE POWER LAW EXPONENT	=	7
IPRINT	=	PRINT AT EVERY CALCULATED POINT (=1) OR AT INPUT INTERVALS (=0)	=	0
ITWTAB	=	NUMBER OF POINTS IN X . VS. Y . VS. M TABLES	=	67
ICTAB	=	NUMBER OF POINTS IN CP . VS. T TABLE	=	20
ITWTAB	=	WALL TEMP. OPTION - - ADIABATIC (=-1), CONSTANT (=0), TABLE (=1)	=	1
T0	=	FREE STREAM STAGNATION TEMPERATURE	=	6.6000000+03
P0	=	FREE STREAM STAGNATION PRESSURE	=	4.3488000+05
GAM0	=	STAGNATION RATIO OF SPECIFIC HEATS	=	1.1130000+00
ZMU0	=	STAGNATION VISCOSITY	=	5.9330000-05
ZMVIS	=	EXPONENT OF VISCOSITY - TEMPERATURE LAW	=	7.5000000-01
ZNSTAN	=	BOUNDARY LAYER INTERACTION EXPONENT	=	1.0000000-01
DXMAX	=	MAXIMUM STEP SIZE	=	2.0000000-02
THETAI	=	INITIAL VALUE OF MOMENTUM THICKNESS	=	1.0000000-04
PHII	=	INITIAL VALUE OF ENERGY THICKNESS	=	1.0000000-04
EPSZ	=	GEOMETRY . . . AXISYMMETRIC (=1.), PLANE (=0.)	=	1.0000000+00
RBAR	=	GAS CONSTANT AT STAGNATION	=	1.1370900+02
FJ	=	CONVERSION BETWEEN THERMAL AND WORK UNITS	=	7.7820000+02
G	=	PROPORTIONALITY CONSTANT IN EQUATION - - F=M/G*A	=	3.2174000+01
SCALE	=	CONTOUR SCALE FACTOR	=	4.8858333-01
ITZTAB	=	NUMBER OF POINTS IN T . VS. CPL . VS. RAMDL . VS. ZMYUL TABLES	=	20
IDUMP	=	COOLANT FLOW OPTION - - SAME DIRECTION (=1), REVERSE (=0)	=	0
FLOWRT	=	COMBUSTION CHAMBER MASS FLOW RATE (LBM/SEC)	=	1.3620300+03
MASSL	=	COOLANT MASS FLOW RATE (LBM/SEC)	=	3.8310000+01
RAMDW	=	HEAT CONDUCTIVITY OF THE CHAMBER WALL	=	5.2800000-02
COEFCL	=	COEFFICIENT OF COOLING	=	9.5000000-01
TUBEN	=	TUBE NUMBER	=	3.2000000+02

(Regenerative cooling in the opposite direction; Injector to $\epsilon = 7$)

TABLE 6. INPUT DATA OF SSME BOOSTER NOZZLE (DOWN PASS)

MZETA	=	VELOCITY PROGILE POWER LAW EXPONENT	=	7
IPRINT	=	PRINT AT EVERY CALCULATED POINT (=1) OR AT INPUT INTERVALS (=0)	=	0
IXTAB	=	NUMBER OF POINTS IN ~ X .VS. Y .VS. M TABLES	=	19
ICTAB	=	NUMBER OF POINTS IN CP .VS. T TABLE	=	20
ITWTAB	=	WALL TEMP. OPTION - - ADIABATIC (=-1), CONSTANT (=0), TABLE (=1)	=	1
T0	=	FREE STREAM STAGNATION TEMPERATURE	=	6.6000000+03
P0	=	FREE STREAM STAGNATION PRESSURE	=	4.3488000+05
GAM0	=	STAGNATION RATIO OF SPECIFIC HEATS	=	1.1130000+00
ZMU0	=	STAGNATION VISCOSITY	=	5.9330000-05
ZMVIS	=	EXPONENT OF VISCOSITY -TEMPERATURE LAW	=	7.5000000-01
ZNSTAN	=	BOUNDARY LAYER INTERACTION EXPONENT	=	1.0000000-01
DXMAX	=	MAXIMUM STEP SIZE	=	2.0000000-02
THETAI	=	INITIAL VALUE OF MOMENTUM THICKNESS	=	3.3948700-03
PHII	=	INITIAL VALUE OF ENERGY THICKNESS	=	4.2186860-03
EPSZ	=	GEOMETRY . . . AXISYMMETRIC (=1.), PLANE (=0.)	=	1.0000000+00
RBAR	=	GAS CONSTANT AT STAGNATION	=	1.1370900+02
FJ	=	CONVERSION BETWEEN THERMAL AND WORK UNITS	=	7.7820000+02
G	=	PROPORTIONALITY CONSTANT IN EQUATION - - F=M/G*A	=	3.2174000+01
SCALE	=	CONTOUR SCALE FACTOR	=	4.8858333-01
ITZTAB	=	NUMBER OF POINTS IN T .VS. CPL .VS. RAMDL .VS. ZMYUL TABLES	=	20
IDUMP	=	COOLANT FLOW OPTION - - SAME DIRECTION (=1), REVERSE (=0)	=	1
FLOWRT	=	COMBUSTION CHAMBER MASS FLOW RATE (LBM/SEC)	=	1.3620300+03
MASSL	=	COOLANT MASS FLOW RATE (LBM/SEC)	=	3.6000000+01
RAMDW	=	HEAT CONDUCTIVITY OF THE CHAMBER WALL	=	3.6800000-03
COEFCL	=	COEFFICIENT OF COOLING	=	5.0000000-01
TUBEN	=	TUBE NUMBER	=	5.6400000+02

(SSME Booster Engine Double Pass Cooling from $\epsilon = 7.0$ to 35.0)

TABLE 6. (Continued)

I	X	Y	Mach Number	Pressure	Static Temperature	Velocity	Molecular Weight
1	1.428417	1.292666	2.775000	12100.000	3970.000	11457.000	14.066350
2	1.619703	1.386746	2.834430	10888.482	3905.792	11582.400	14.068051
3	1.889127	1.507026	2.890390	9749.662	3837.881	11712.300	14.069824
4	2.238669	1.645798	2.969260	8353.958	3741.841	11887.500	14.071408
5	2.685791	1.800835	3.069210	6877.540	3621.335	12097.900	14.072373
6	3.230000	1.963167	3.173570	5618.780	3497.795	12305.600	14.073443
7	3.565095	2.051659	3.233430	5005.382	3428.143	12419.400	14.072809
8	3.943175	2.142785	3.300140	4406.465	3351.785	12541.400	14.073171
9	4.377819	2.237555	3.369150	3863.639	3274.160	12663.200	14.073800
10	4.876321	2.335077	3.442460	3361.705	3193.403	12787.500	14.074077
11	5.453665	2.435373	3.524560	2880.836	3105.011	12920.700	14.074358
12	6.125760	2.537448	3.605940	2474.389	3019.491	13047.200	14.074749
13	6.499184	2.588275	3.652070	2270.413	2972.016	13116.300	14.074811
14	6.899334	2.638599	3.694760	2098.009	2928.753	13178.800	14.074976
15	7.332024	2.688542	3.739500	1932.268	2884.092	13242.500	14.075116
16	7.799891	2.737806	3.786160	1773.636	2838.125	13307.600	14.075269
17	8.306454	2.786073	3.830220	1636.414	2795.375	13367.500	14.075416
18	8.855280	2.832933	3.875800	1506.255	2751.858	13427.900	14.075552
19	9.071527	2.849970	3.895190	1454.047	2733.559	13453.100	14.075584

(The enhancement factor η_E is assumed 1.0)

TABLE 6. (Concluded)

I	X	Y	Coolant Area	Coolant Temperature	Wall Temperature
1	1.428417	1.292666	0.000050000	95.000	1460.000
2	1.619703	1.386746	0.000054000	103.000	1445.000
3	1.889127	1.507026	0.000060000	115.000	1425.000
4	2.238669	1.645798	0.000068000	130.000	1400.000
5	2.685791	1.800835	0.000078000	145.000	1370.000
6	3.230000	1.963167	0.000091000	167.000	1325.000
7	3.565095	2.051659	0.000098000	180.000	1295.000
8	3.943175	2.142785	0.000108000	195.000	1260.000
9	4.377819	2.237555	0.000118000	213.000	1210.000
10	4.876321	2.335077	0.000131000	232.000	1145.000
11	5.453665	2.435373	0.000147000	255.000	1072.000
12	6.125760	2.537448	0.000166000	282.000	985.000
13	6.499184	2.588275	0.000178000	295.000	940.000
14	6.899334	2.638599	0.000190000	312.000	895.000
15	7.332024	2.688542	0.000205000	330.000	846.000
16	7.799891	2.737806	0.000220000	350.000	800.000
17	8.306454	2.786073	0.000238000	367.000	750.000
18	8.855280	2.832933	0.000258000	389.000	700.000
19	9.071527	2.849970	0.000266000	400.000	680.000

TABLE 7. INPUT DATA OF SSME BOOSTER NOZZLE (UP PASS)

MZETA	=	VELOCITY PROFILE POWER LAW EXPONENT	=	7
IPRINT	=	PRINT AT EVERY CALCULATED POINT (=1) OR AT INPUT INTERVALS (=0)	=	0
IXTAB	=	NUMBER OF POINTS IN X . VS. Y . VS. M TABLES	=	19
ICTAB	=	NUMBER OF POINTS IN CP . VS. T TABLE	=	20
ITWTAB	=	WALL TEMP. OPTION - - ADIABATIC (=-1), CONSTANT (=0), TALBE (=1)	=	1
T0	=	FREE STREAM STAGNATION TEMPERATURE	=	6.6000000+03
P0	=	FREE STREAM PRESSURE	=	4.3488000+05
GAM0	=	STAGNATION RATIO OF SPECIFIC HEATS	=	1.1130000+00
ZMU0	=	STAGNATION VISCOSITY	=	5.9330000-05
ZMVIS	=	EXPONENT OF VISCOSITY - TEMPERATURE LAW	=	7.5000000-01
ZNSTAN	=	BOUNDARY LAYER INTERACTION EXPONENT	=	1.0000000-01
DXMAX	=	MAXIMUM STEP SIZE	=	2.0000000-02
THETAI	=	INITIAL VALUE OF MOMENTUM THICKNESS	=	3.3948700-03
PHII	=	INITIAL VALUE OF ENERGY THICKNESS	=	4.2186860-03
EPSZ	=	GEOMETRY . . . AXISYMMETRIC (=1.), PLANE (=0.)	=	1.0000000+00
RBAR	=	GAS CONSTANT AT STAGNATION	=	1.1370900+02
FJ	=	CONVERSION BETWEEN THERMAL AND WORK UNITS	=	7.7820000+02
G	=	PROPORTIONALITY CONSTANT IN EQUATION - - F=M/G*A	=	3.2174000+01
SCALE	=	CONTOUR SCALE FACTOR	=	4.8858333-01
ITZTAB	=	NUMBER OF POINTS IN T . VS. CPL . VS. RAMDL . VS. ZMYUL TALBES	=	20
IDUMP	=	COOLANT FLOW OPTION - - SAME DIRECTION (=1), REVERSE (=0)	=	0
FLOWRT	=	COMBUSTION CHAMBER MASS FLOW RATE (LBM/SEC)	=	1.3620300+03
MASSL	=	COOLANT MASS FLOW RATE (LBS/SEC)	=	3.6000000+01
RAMDW	=	HEAT CONDUCTIVITY OF THE CHAMBER WALL	=	3.6800000-03
COEFCL	=	COEFFICIENT OF COOLING	=	5.0000000-01
TUBEN	=	TUBE NUMBER	=	5.6400000+02

(SSME Booster Engine Double Pass Cooling from $\epsilon = 7.0$ to 35.0)

TABLE 7. (Continued)

I	X	Y	Mach Number	Pressure	Static Temperature	Velocity	Molecular Weight
1	1.428417	1.292666	2.775000	12100.000	3970.000	11457.000	14.066350
2	1.619703	1.386746	2.834430	10888.482	3905.792	11582.400	14.068051
3	1.889127	1.507026	2.890390	9749.662	3837.881	11712.300	14.069824
4	2.238669	1.645798	2.969260	8353.958	3741.841	11887.500	14.071408
5	2.685791	1.800835	3.069210	6877.540	3621.335	12097.900	14.072373
6	3.230000	1.963167	3.173570	5618.780	3497.795	12305.600	14.073443
7	3.565095	2.051659	3.233430	5005.382	3428.143	12419.400	14.072809
8	3.943175	2.142785	3.300140	4406.465	3351.785	12541.400	14.073171
9	4.377819	2.237555	3.369150	3863.639	3274.160	12663.200	14.073800
10	4.876321	2.335077	3.442460	3361.705	3193.403	12787.500	14.074077
11	5.453665	2.435373	3.524560	2880.836	3105.011	12920.700	14.074358
12	6.125760	2.537448	3.605940	2474.389	3019.491	13047.200	14.074749
13	6.499184	2.588275	3.652070	2270.413	2972.016	13116.300	14.074811
14	6.899334	2.638599	3.694760	2098.009	2928.753	13178.800	14.074976
15	7.332024	2.688542	3.739500	1932.268	2884.092	13242.500	14.075116
16	7.799891	2.737806	3.786160	1773.636	2838.125	13307.600	14.075269
17	8.306454	2.786073	3.830220	1636.414	2795.375	13367.500	14.075416
18	8.855280	2.832933	3.875800	1506.255	2751.858	13427.900	14.075552
19	9.071527	2.849970	3.895190	1454.047	2733.559	13453.100	14.075584

TABLE 7. (Concluded)

I	X	Y	Coolant Area	Coolant Temperature	Wall Temperature
1	1.428417	1.292666	0.000093750	610.000	1460.000
2	1.619703	1.386746	0.000096000	600.000	1445.000
3	1.889127	1.507026	0.000101000	592.000	1425.000
4	2.238669	1.645798	0.000107800	580.000	1400.000
5	2.685791	1.800835	0.000116000	570.000	1370.000
6	3.230000	1.963167	0.000126000	550.000	1325.000
7	3.565095	2.051659	0.000132500	540.000	1295.000
8	3.943175	2.142785	0.000140000	530.000	1260.000
9	4.377819	2.237555	0.000149200	515.000	1210.000
10	4.876321	2.335077	0.000160000	500.000	1145.000
11	5.453665	2.435373	0.000162000	483.000	1072.000
12	6.125760	2.537448	0.000187800	460.000	985.000
13	6.499184	2.588275	0.000196000	450.000	940.000
14	6.899334	2.638599	0.000206100	437.000	895.000
15	7.332024	2.688542	0.000217000	425.000	846.000
16	7.799891	2.737806	0.000230000	410.000	783.000
17	8.306454	2.786073	0.000245000	393.000	722.000
18	8.855280	2.832933	0.000260000	377.000	660.000
19	9.071527	2.849970	0.000266000	370.000	630.000

(The enhancement factor is assumed 1.0)

TABLE 8. INPUT DATA OF SSME BOOSTER NOZZLE (UP AND DOWN PASSES)

I	Specific Heat	Temperature	Coolant Temperature	Coolant Specific Heat	Conductivity	Viscosity
1	0.6199999973	400.000	50.000	1.950000	0.0000234000	0.0000648000
2	0.6550000012	800.000	100.000	2.850000	0.0000235200	0.0000120000
3	0.6799999997	1200.000	150.000	3.550000	0.0000249000	0.0000062400
4	0.6950000003	1400.000	200.000	3.950000	0.0000276000	0.0000054000
5	0.7049999982	1600.000	250.000	4.200000	0.0000288000	0.0000051600
6	0.7199999988	2000.000	300.000	4.200000	0.0000300000	0.0000051600
7	0.7282169983	2500.000	350.000	4.050000	0.0000306000	0.0000062400
8	0.7282169983	3000.000	400.000	3.900000	0.0000318000	0.0000057600
9	0.7282169983	4000.000	450.000	3.800000	0.0000327600	0.0000061200
10	0.7282169983	5000.000	500.000	3.700000	0.0000342000	0.0000064800
11	0.7282169983	5850.000	550.000	3.600000	0.0000357600	0.0000067200
12	0.7282169983	5926.078	600.000	3.550000	0.0000375600	0.0000069600
13	0.8833189979	6103.208	650.000	3.530000	0.0000390000	0.0000073200
14	0.8843249977	6151.280	700.000	3.510000	0.0000410400	0.0000076800
15	0.8854160011	6204.368	750.000	3.500000	0.0000428400	0.0000079200
16	0.8893399984	6403.409	800.000	3.500000	0.0000444000	0.0000081600
17	0.8902480006	6451.318	850.000	3.480000	0.0000464400	0.0000084000
18	0.8906119987	6470.760	900.000	3.470000	0.0000482400	0.0000087600
19	0.8907269984	6476.894	950.000	3.460000	0.0000504000	0.0000090000
20	0.8920999989	8000.000	1000.000	3.460000	0.0000528000	0.0000093600

TABLE 9. CALCULATED DISPLACEMENT AND MOMENTUM THICKNESSES ALONG NOZZLE WALL

x (ft)	δ^*_{down}	δ^*_{up}	$\bar{\delta}^*$	θ_{down}	θ_{up}	$\bar{\theta}$
1.428417	-0.004536	-0.004805	-0.004671	0.003395	0.003395	0.003395
1.619903	-0.004488	-0.005164	-0.004826	0.003642	0.003647	0.003645
1.889127	-0.004672	-0.005606	-0.005139	0.003933	0.003947	0.003940
2.238669	-0.005425	-0.006357	-0.005891	0.004421	0.004449	0.004435
2.686791	-0.006477	-0.007505	-0.006991	0.005158	0.005204	0.005181
3.230000	-0.007881	-0.008983	-0.008432	0.006087	0.006152	0.006120
3.565095	-0.008844	-0.009975	-0.009410	0.006704	0.006781	0.006743
3.943175	-0.010083	-0.011208	-0.010646	0.007460	0.007550	0.007505
4.377819	-0.011551	-0.012660	-0.012106	0.008338	0.008443	0.008391
4.876321	-0.013393	-0.014426	-0.013909	0.009392	0.009511	0.009452
5.453665	-0.015773	-0.016597	-0.016185	0.010720	0.010854	0.010787
6.125760	-0.018604	-0.019305	-0.018955	0.012235	0.012385	0.012310
6.499184	-0.020425	-0.020933	-0.020679	0.013184	0.013342	0.013263
6.899334	-0.022331	-0.022607	-0.022469	0.014133	0.014298	0.014216
7.332023	-0.024556	-0.024488	-0.024522	0.015201	0.015371	0.015286
7.799891	-0.027096	-0.026620	-0.026858	0.016403	0.016579	0.016491
8.306454	-0.029727	-0.028881	-0.029304	0.017642	0.017820	0.017731
8.855280	-0.032634	-0.031474	-0.032055	0.019027	0.019207	0.019118
9.071527	-0.033966	-0.032616	-0.033291	0.019645	0.019824	0.019735

DESCRIPTION OF PROGRAM INPUT

Input Data

MZETA = n	Exponent in velocity profile power law
IPRINT	Print option at every calculated point (= 1) or at input intervals (= 0)
IXTAB	Number of points in $x = f(y)$ and $x = g(M_\infty)$ tables
ICTAB	Number of points in $C_p = f(T)$ table
ITWTAB	Wall temperature option = 1 (must be input)
T0 = T_0	Stagnation temperature, °R
P0 = P_0	Stagnation pressure, lbf/ft^2
GAM0 = γ_0	Stagnation specific heat ratio
ZMU0 = μ_0	Stagnation viscosity, lbm/ft-s
ZMVIS	Exponent of viscosity temperature law
ZNSTAN	Boundary layer interaction exponent
DXMAX	Maximum step size
THETAI = θ_i	Initial value of momentum thickness, ft
PHII = ϕ_i	Initial value of energy thickness, ft
EPSZ	Geometry option - Axisymmetric = 1. Plane = 0.
RBAR	Gas constant at stagnation, ft-lbf/°R-lbm
FJ = J	Conversion factor between thermal and work units = 778.2, ft-lbf/Btu
G = g	Acceleration of gravity = 32.174, ft-lbm/lbf-s^2

SCALE	Contour scale factor
ITZTAB	Number of points in temperature versus $C_{p\ell}$, λ_ℓ and μ_ℓ table
IDUMP	Coolant flow option Same direction = 1 Reverse flow = 0
FLOWRT	Combustion chamber mass flow rate, lbm/s
MASSL = $\dot{m}_\ell$	Coolant mass flow rate, lbm/s
RAMDW = λ_w	Thermal conductivity of the chamber wall, Btu/ft–s°R
COEFCL = η	Cooling coefficient (surface area effect)
TUBEN	Number of cooling tubes

Input Tables

(i) Specific C_p (CPTAB) versus temperature T (TITAB)

(ii)	XITAB	Axial distance, ft
	YITAB	Radius, ft
	ZMTAB	Mach number M_∞ at boundary layer edge
	PETAB	Static pressure P_∞ at boundary layer edge, lbf/ft^2
	TETAB	Static temperature T_∞ at boundary layer edge, °R
	UETAB	Velocity U_∞ at boundary layer edge, ft/s
	SMTAB	Mean molecular weight $\mathfrak{M}$ at boundary layer edge
	ALTAB	Cross-sectional area of each cooling tube, ft^2
	TLTAB	Assumed coolant temperature $\left[T_\ell\right]_0$, °R

	TWTAB	Assumed wall temperature on the gas-side $\left[T_{wg}\right]_0$, °R
	THITAB	Wall thickness of the cooling jacket, ft
(iii)	TZTAB	Coolant temperature table used to obtain $C_{p\ell}$, λ_ℓ and μ_ℓ, °R
	CPLTAB	Coolant specific heat $C_{p\ell}$, Btu/lbm-°R
	RAMTAB	Thermal conductivity of coolant λ_ℓ, Btu/ft-s°R
	ZMYTAB	Viscosity of coolant μ_ℓ, lbm/ft-s

DESCRIPTION OF PROGRAM OUTPUT

The following parameters are printed out in addition to the original TBL computer program results [3]:

RBAR $= \mathcal{R}/\mathfrak{M}$	Specific gas constant, ft-lbf/lbm°R
PRANDT = Pr	Prandtl number of the free stream
GAME $= \gamma_\infty$	Specific heat ratio at the boundary layer edge
SMOL $= \mathfrak{M}$	Mean molecular weight, lbm
COSAL $= \cos \alpha(x)$	Cosine of the wall angle
DELFA $= \Delta F_{B.L.}$	Thrust degradation due to turbulent boundary layer effects downstream of the throat only, lbf
THRUST = F	Vacuum thrust, lbf
DEFTHR $= \Delta F/F \times 100$	Percent of thrust degradation
TBLISP $= -\Delta I_{sp}$	Specific impulse loss due to turbulent boundary layer effects, s
THRUSA	Thrust at sea level, lbf
VISP $= I_{sp_{vacuum}}$	Vacuum specific impulse downstream of the throat only, s

AISP = $I_{sp_{\text{sea level}}}$	Specific impulse at sea level of the throat only, s
DMASSL = $\rho_\ell U_\ell$	Mass flow density of the coolant fluid, lbm/ft^2-s
HL = h_ℓ	Heat transfer coefficient of the coolant fluid, Btu/ft^2-s°R
QWI = $\dot{q}_w'$	Specific heat transfer rate based upon calculations for the coolant flow side, Btu/ft^2-s
REYL = R_{e_ℓ}	Reynolds number of the coolant fluid based upon tube diameters
SUMQGA	Total heat transfer rate, Btu/s
SUMQWI	Total heat transfer rate (includes cooling flow calculation), Btu/s
TEMPRL = T_{w_ℓ}/T_ℓ	Temperature ratio
TLCA = $T_{\ell c}$	Calculated coolant temperature,°R
TWGCA = T_{wgc}	Calculated wall temperature on the gas side, °R
TWL = T_{w_ℓ}	Calculated wall temperature on the coolant side, °R
DIATUB = $2\sqrt{A_{tube}/\pi}$	Equivalent diameter of the cooling jacket, ft
THICK = t	Chamber wall thickness (input value), ft

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Marshall Space Flight Center, Alabama, February 11, 1972

APPENDIX A

DERIVATION OF EQUATIONS (33) AND (34)

Using equations (20) and (22) with equation (32), we obtain

$$h_g(T_{aw} - T_{wg}) = \frac{\lambda_w}{t}(T_{wg} - T_{w_\ell}) \quad .$$

Rewrite the above equation, as

$$T_{wg} = \frac{h_g T_{aw} + \frac{\lambda_w}{t} T_{w_\ell}}{h_g + \frac{\lambda_w}{t}} \quad . \qquad \text{(equation 34)}$$

Equations (20) and (23) reduce to

$$h_g(T_{aw} - T_{wg}) = h_\ell\left(T_{w_\ell} - T_\ell\right) \quad ,$$

so that

$$T_{wg} = T_{aw} - \frac{h_\ell}{h_g}\left(T_{w_\ell} - T_\ell\right) \quad .$$

Substitute equation (34) into the above equation, then

$$h_g T_{aw} + \frac{\lambda_w}{t} T_{w_\ell} = \left(h_g + \frac{\lambda_w}{t}\right)\left[T_{aw} - \frac{h_\ell}{h_g}\left(T_{w_\ell} - T_\ell\right)\right] \quad .$$

$$\left[\frac{\lambda_w}{t} + \left(h_g + \frac{\lambda_w}{t}\right)\frac{h_\ell}{h_g}\right] T_{w_\ell} = \frac{\lambda_w}{t}\, T_{aw} + \left(h_g + \frac{\lambda_w}{t}\right)\frac{h_\ell}{h_g}\, T_\ell \quad .$$

Therefore,

$$T_{w_\ell} = \frac{h_\ell\left(1 + \frac{\lambda_w}{t\,h_g}\right) T_\ell + \frac{\lambda_w}{t}\, T_{aw}}{\frac{\lambda_w}{t} + h_\ell\left(1 + \frac{\lambda_w}{t\,h_g}\right)} \quad . \qquad \text{(equation 33)}$$

APPENDIX B

TBL MODIFIED COMPUTER PROGRAM LISTING (TBLREG)

TPFS.BARCON

```
      SUBROUTINE BARCON                                                 BARC0001
C
C -- BARCON -- CONTROLLING SUBROUTINE                                   BARC0002
C
      COMMON /COOL/  ICOOL,IDUMP,ITZTAB,AL,COEFCL,CPL,DELXBA,DIATUB,    /COOL/
     1               FLOWRT,MASSL,PRANDL,RAMDL,RAMDW,REYL,SUMQGA,SUMQWI, /COOL/
     2               THICK,TLO,TL1,TL2,TLCA,TOLITE,TUBEN,TWGCA,ZMYUL,   /COOL/
     3               CPLTAB(20),RAMTAB(20),TZTAB(20),ZMYTAB(20),        /COOL/
     4               ALTAB(100),THITAB(100),TLCTAB(100),TLTAB(100),     /COOL/
     5               TWGTAB(100)                                        /COOL/
      REAL MASSL                                                        /COOL/
C
      COMMON /INPUT/  IDXMAX,ICTAB,IPRINT,ITWTAB,IXTAB,MZETA,DXMAX,     /INPUT/
     A                EPSZ,FJ,G,GAMO,PO,PHII,PIE,PRANDT,RBAR,SCALE,TO,  /INPUT/
     K                THETAI,TOLCFA,TOLZET,TOLZME,ZMUO,ZMVIS,ZNSTAN     /INPUT/
C
      COMMON /INTER/  CFAGT,CFAGP,CHPAR1,DX,DXRHO,HE,HW,IBEG,MZETAM,    /INTER/
     A                OOMZET,PHIP,PRE103,RHOE,RHOUE,RMZETA,THETAP,      /INTER/
     K                XIBASE,XIEND,ZETATM,ZMZETA,ZMZETM,ZMZETP          /INTER/
C
      COMMON /LOOKUP/ ICX,IMX,IPX,IRX,ISX,ITPOS,ITWX,ITX,IUX,IXPOS,IYX, /LOOKUP/
     1                IZX,CCX(6),CMX(6),CPX(6),CRX(6),CSX(6),CTWX(6),   /LOOKUP/
     2                CTX(6),CUX(6),CYX(6),CZX(6)                       /LOOKUP/
C
      COMMON /NHANCE/ IEX,CEX(6),ENHTAB(100)                            /NHANCE/
C
      COMMON /OUTPUT/ BDELTA,CF,CH,DELTA,DELSOT,DELSTR,FLAT,FORCE,HG,   /OUTPUT/
     A                PE,PHI,QW,SUMQDA,TE,THETA,TW,UE,X,XLARC,YR,Z1,    /OUTPUT/
     K                Z2,Z3,Z4,Z5,ZETA,ZME                              /OUTPUT/
C
      COMMON /TABLES/ PETAB(100),SMTAB(100),TETAB(100),TWTAB(100),      /TABLES/
     1                UETAB(100),XITAB(100),YITAB(100),ZMTAB(100)       /TABLES/
C
      DIMENSION DPHIRK(4),DTHERK(4),XCCP(100),YCCP(100)
C
      IF (ICOOL .EQ. 0)  GO TO 11
      ITER = 0
   10 ITER = ITER + 1
      WRITE (6,1) ITER
    1 FORMAT (1H1,35X,54HREGENERATIVE COOLING WALL TEMPERATURE ITERATION
     1 NUMBER,I3//////////)
   11 MZETAM = MZETA - 1
      ZMZETA=MZETA                                                      BARC0031
      ZMZETP=ZMZETA+1.                                                  BARC0032
      ZMZETM=ZMZETA-1.                                                  BARC0033
      RMZETA=1./ZMZETP                                                  BARC0034
      OOMZET=1./ZMZETA                                                  BARC0035
      X=XITAB(1)                                                        BARC0036
      DX=0.                                                             BARC0037
      XLARC=0.                                                          BARC0038
      SUMQDA=0.                                                         BARC0039
      SUMQGA = 0.0
      SUMQWI = 0.0
      FORCE=0.                                                          BARC0040
      FLAT=0.                                                           BARC0041
```

```
      QW              = 0.0                                                  BARC0042
      HG              = 0.0                                                  BARC0043
      IXPOS=1                                                                BARC0044
      ITPOS = 1
      ICX = 0
      IEX = 0
      IRX = 0
      ISX = 0
      IUX = 0
      IZX = 0
      IMX=0                                                                  BARC0045
      ITX=0                                                                  BARC0046
      IPX=0                                                                  BARC0047
      IYX=0                                                                  BARC0048
      ITWX=0                                                                 BARC0049
      DXRHO=0.                                                               BARC0050
      IBEG            = 2                                                    BARC0051
      CFAGT           = .002                                                 BARC0052
      ISTART          = 0                                                    BARC0053
      IF (THETAI .LE. 0.0)  GO TO 2
      ZETA = (PHII/THETAI)**RMZETA
      GO TO 3                                                                BARC0056
    2 CALL START                                                             BARC0057
      ISTART          = 1                                                    BARC0058
    3 CFAGP           = CFAGT                                                BARC0059
      IF (ICOOL .EQ. 0)  GO TO 4
      DELXOL = 0.0
      DELXNE = ABS(XITAB(2) - XITAB(1))
      DELXBA = (DELXOL + DELXNE)/2.0
      AL = ALTAB(1)
      TL1 = TLTAB(1)
      THICK = THITAB(1)
      TL2 = TLTAB(2)
      TLO = TL1
      CALL XNTERP (TL1,ZMYUL,ZP,IZX,TZTAB,ZMYTAB,ITZTAB,CZX,ITPOS)
      ITPOS = IZX
      DIATUB = 2.0*SQRT(AL/PIE)
      REYL = MASSL*DIATUB/(AL*TUBEN*ZMYUL)
    4 PHI = PHII
      THETA = THETAI
      XIBASE          = XITAB(1)                                             BARC0062
      XIEND           = XITAB(IXTAB)                                         BARC0063
      IF (IXTAB .LE. 1)  GO TO 15
      DXRHO = (XITAB(2) - XIBASE)/10.0
   15 CALL BARPRO(1)                                                         BARC0066
      CALL BARPRO(5)                                                         BARC0067
      TWGTAB(1) = TWGCA
      TLCTAB(1) = TLCA
      CALL XNTERP ( X, YR, YRP, IYX, XITAB, YITAB, IXTAB, CYX, IMX )         BARC0068
C                                                                            BARC0069
C     SAVE INITIAL Y AND DELSTR.                                             BARC0070
C                                                                            BARC0071
      DEL = DELSTR                                                           BARC0072
      YMIN = YR                                                              BARC0073
C                                                                            BARC0074
      ONOC            = SQRT( 1. + YRP * YRP )                               BARC0075
```

```
      XCCP(1)         = X + DELSTR * YRP / ONOC                              BARC0076
      YCCP(1)         = YR - DELSTR / ONOC                                   BARC0077
      IF (IXTAB .LE. 1)  RETURN
      DO 20 I = IBEG,IXTAB
      XNEW=XITAB(I)                                                          BARC0080
      IF (ICOOL .EQ. 0)  GO TO 16
      AL = ALTAB(I)
      THICK = THITAB(I)
      DELXOL = ABS(XITAB(I) - XITAB(I-1))
      IF (I .GE. IXTAB)  GO TO 3000
      DELXNE = ABS(XITAB(I+1) - XITAB(I))
      TL0 = TLTAB(I-1)
      TL1 = TLTAB(I)
      TL2 = TLTAB(I+1)
      GO TO 3001
 3000 DELXNE = 0.0
      TL0 = TLTAB(I-1)
      TL1 = TLTAB(I)
      TL2 = TL1
 3001 DELXBA = (DELXOL + DELXNE)/2.0
   16 XMAG = (ABS(XNEW) + ABS(X))/2.0
      DXINT=XNEW-X                                                           BARC0082
      NX              = DXINT / DXMAX + 0.99                                 BARC0083
      IF (NX .GT. 0)  GO TO 18
      NX = 1
   18 ZNX=NX                                                                 BARC0086
      DX=DXINT/ZNX                                                           BARC0087
      DXO2=DX/2.                                                             BARC0088
      DXRHO=DX/10.                                                           BARC0089
      DO 30 INX=1,NX                                                         BARC0090
      PHIOLD=PHI                                                             BARC0091
      THEOLD=THETA                                                           BARC0092
      XOLD=X                                                                 BARC0093
      DPHIRK(1)=DX*PHIP                                                      BARC0094
      DTHERK(1)=DX*THETAP                                                    BARC0095
      X=XOLD+DXO2                                                            BARC0096
      DO 40 IRK=2,4                                                          BARC0097
      IF (IRK .NE. 4)  GO TO 44
      X = XOLD + DX
      IF (ABS((X - XNEW)/XMAG) .GT. 1.0E-6)  GO TO 43
      X = XNEW
   43 PHI = PHIOLD + DPHIRK(IRK - 1)
      THETA=THEOLD+DTHERK(IRK-1)                                             BARC0104
      GO TO 45                                                               BARC0105
   44 PHI = PHIOLD + DPHIRK(IRK - 1)*0.50
      THETA=THEOLD+DTHERK(IRK-1)*.5                                          BARC0108
   45 IF (PHI .LE. 0.0)  GO TO 62
      IF (THETA .LE. 0.0)  GO TO 62
      CALL BARPRO(IRK)                                                       BARC0113
      DPHIRK(IRK)=DX*PHIP                                                    BARC0114
   40 DTHERK(IRK) = DX*THETAP
      PHI=PHIOLD+(DPHIRK(1)+2.*DPHIRK(2)+2.*DPHIRK(3)+DPHIRK(4))/6.          BARC0117
      THETA=THEOLD+(DTHERK(1)+2.*DTHERK(2)+2.*DTHERK(3)+DTHERK(4))/6.        BARC0118
      IF (PHI .LE. 0.0)   GO TO 62
      IF (THETA .GT. 0.0)  GO TO 72
   62 WRITE(6,63) X, ZME, THETA, PHI                                         BARC0121
```

```
   63 FORMAT ( 41H **BARCON FAILURE... AXIAL DISTANCE  X = , 1PE14.7,    BARC0122
     1         5X,  11HMACH NO. = , E14.7, 2X, 8HTHETAI =, E14.7, 2X,     BARC0123
     2         6HPHII =, E14.7 / 44H THETAI OR PHII COMPUTED AS NEGATIVEBARC0124
     3 OR ZERO / 64H  *CHECK CONTOUR AND MACH NUMBER DISTRIBUTION TABLESBARC0125
     4 FOR ERRORS./ 110H  *MORE INPUT POINTS MAY BE REQUIRED TO ADEQUATEBARC0126
     5LY DESCRIBE DERIVATIVE VALUES ALONG THE CONTOUR AT THIS POINT. /  BARC0127
     6  96H  *A SMALLER RUNGE-KUTTA STEP SIZE MAY BE REQUIRED TO ADEQUATBARC0128
     7ELY APPROXIMATE INTEGRATION VALUES                                BARC0129
      CALL [illegible](5)                                               BARC0130
      CALL QUITS                                                        BARC0131
   72 CALL BARPRO(1)
C                                                                       BARC0134
C                                                                       BARC0135
C     SELECT MINIMUM Y AND ITS CORRESPONDING DELSTR.                    BARC0136
C                                                                       BARC0137
      IF(YR.GT.YMIN) GO TO 29                                           BARC0138
      DEL = DELSTR                                                      BARC0139
      YMIN = YR                                                         BARC0140
C                                                                       BARC0142
   29 IF (IPRINT .LE. 0)  GO TO 30
      CALL BARPRO(5)
   30 CONTINUE                                                          BARC0145
      CALL XNTERP ( X, YR, YRP, IYX, XITAB, YITAB, IXTAB, CYX, IMX )    BARC0146
      ONOC           = SQRT( 1. + YRP * YRP )                           BARC0147
      XCCP(I)        = X + DELSTR * YRP / ONOC                          BARC0148
      YCCP(I)        = YR - DELSTR / ONOC                               BARC0149
      IF (IPRINT .GT. 0)  GO TO 20
      CALL BARPRO(5)
      TWGTAB(I) = TWGCA
      TLCTAB(I) = TLCA
   20 CONTINUE                                                          BARC0153
C                                                                       BARC0154
C     YMIN  = MINIMUM Y VALUE FOR NOZZLE.                               BARC0155
C     DEL   = DELSTR CORRESPONDING TO MINIMUM Y (THROAT).               BARC0157
C     RPOT  = THE POTENTIAL THROAT RADIUS.                              BARC0158
C                                                                       BARC0159
      RPOT = YMIN          - DEL                                        BARC0160
C                                                                       BARC0161
      WRITE(6,1000) RPOT                                                BARC0162
C                                                                       BARC0163
C     NORMALIZE TABLE OF CORRECTED CONTOUR POINTS USING THE POTENTIAL   BARC0164
C     THROAT RADIUS.                                                    BARC0165
C                                                                       BARC0166
      XCCP(1) = XCCP(1) / RPOT                                          BARC0167
      YCCP(1) = YCCP(1) / RPOT                                          BARC0168
      DO 79 I = IBEG,IXTAB                                              BARC0169
      XCCP(I) = XCCP(I) / RPOT                                          BARC0170
   79 YCCP(I) = YCCP(I)/RPOT
C                                                                       BARC0173
      WRITE(6,1001)                                                     BARC0174
      IF (ISTART .LE. 0)  GO TO 85
      WRITE (6,1010) XCCP(1),YCCP(1),(I,XCCP(I),YCCP(I),I=IBEG,IXTAB)
      GO TO 86
   85 WRITE(6,1020) ( I, XCCP(I), YCCP(I), I = 1, IXTAB )               BARC0179
   86 IF (ICOOL .EQ. 0)  RETURN
      IF (ABS((SUMQDA*COEFCL - SUMQWI)/SUMQWI) .LT. TOLITE)  RETURN
```

```
      DO 87 I = 1,IXTAB
      TWTAB(I) = (TWTAB(I) + TWGTAB(I))/2.0
   87 TLTAB(I) = (TLTAB(I) + TLCTAB(I))/2.0
      GO TO 10
 1000 FORMAT(1H1,29X,41HTHROAT RADIUS CORRECTED FOR DISPLACEMENT ,       BARC0181
     1 11HTHICKNESS =,1PE15.8//)                                          BARC0182
 1001 FORMAT(1H0,29X,48HTABLE OF NORMALIZED CONTOUR POINTS CORRECTED FORBARC0183
     1 23H DISPLACEMENT THICKNESS // 37X,10HDATA POINT,10X,1HX,24X,1HY/)BARC0184
 1010 FORMAT ( 40X, 6HM = 1., 4X, 1PE15.8, 10X, E15.8 / ( 40X, I5,       BARC0185
     1           5X, E15.8, 10X, E15.8 ) )                                BARC0186
 1020 FORMAT ( 40X, I5, 5X, 1PE15.8, 10X, E15.8 )                        BARC0187
      END                                                                 BARC0188
```

```
      SUBROUTINE BARPRO (IND)
C
      COMMON /COFIIF/ IFINT,AFINT,BFINT,CFINT,MMINT,TFINT                /COFIIF/
C
      COMMON /COOL/ ICOOL,IDUMP,ITZTAB,AL,COEFCL,CPL,DELXBA,DIATUB,      /COOL/
     1              FLOWRT,MASSL,PRANDL,RAMDL,RAMDW,REYL,SUMQGA,SUMQWI, /COOL/
     2              THICK,TLO,TL1,TL2,TLCA,TOLITE,IUBEN,TWGCA,ZMYUL,     /COOL/
     3              CPLTAB(20),RAMTAB(20),TZTAB(20),ZMYTAB(20),          /COOL/
     4              ALTAB(100),THITAB(100),TLCTAB(100),TLTAB(100),       /COOL/
     5              TWGTAB(100)                                          /COOL/
      REAL MASSL                                                         /COOL/
C
      COMMON /CSEVAL/ NOCTAB,IS,ROJ,FJG,CJG,GMIO2,GOGMI,POMAX,CPO,HO,    /CSEVAL/
     A                SO,TCTAB(20),CPTAB(20),BCP(20),CCP(20),DCP(20),    /CSEVAL/
     K                GTAB(20),HTAB(20),BARB1(20),BARB2(20),BARB3(20)    /CSEVAL/
C
      COMMON /INPUT/ IDXMAX,ICTAB,IPRINT,ITWTAB,IXTAB,MZETA,DXMAX,       /INPUT/
     A               EPSZ,FJ,G,GAMO,PO,PHII,PIE,PRANDT,RBAR,SCALE,TO,    /INPUT/
     K               THETAI,TOLCFA,TOLZET,TOLZME,ZMUO,ZMVIS,ZNSTAN       /INPUT/
C
      COMMON /INTER/ CFAGT,CFAGP,CHPART,DX,DXRHO,HE,HW,IBEG,MZETAM,      /INTER/
     A               OOMZET,PHIP,PRE1O3,RHOE,RHOUE,RMZETA,THETAP,        /INTER/
     K               XIBASE,XIEND,ZETATM,ZMZETA,ZMZETM,ZMZETP            /INTER/
C
      COMMON /LOOKUP/ ICX,IMX,IPX,IRX,ISX,ITPOS,ITWX,ITX,IUX,IXPOS,IYX, /LOOKUP/
     1                IZX,CCX(6),CMX(6),CPX(6),CRX(6),CSX(6),CTWX(6),   /LOOKUP/
     2                CTX(6),CUX(6),CYX(6),CZX(6)                       /LOOKUP/
C
      COMMON /NHANCE/ IEX,CEX(6),ENHTAB(100)                             /NHANCE/
C
      COMMON /OUTPUT/ BDELTA,CF,CH,DELTA,DELSOT,DELSTR,FLAT,FORCE,HG,   /OUTPUT/
     A                PE,PHI,QW,SUMQDA,TE,THETA,TW,UE,X,XLARC,YR,Z1,    /OUTPUT/
     K                Z2,Z3,Z4,Z5,ZETA,ZME                              /OUTPUT/
C
      COMMON /SAVED/ A,B,C,Z11,Z11P,Z12,Z12P,Z13,Z13P,Z14,Z15,Z16,Z17   /SAVED/
C
      COMMON /TABLES/ PETAB(100),SMTAB(100),TETAB(100),TWTAB(100),      /TABLES/
     1                UETAB(100),XITAB(100),YITAB(100),ZMTAB(100)       /TABLES/
C
      DIMENSION ZINTPR(10)
      DATA (ZINTPR(I), I = 1,10) /6HZI4  =,6HZI5  =,6HZI6  =,6HZI7  =,
     A      6HZI1P =,6HZI1  =,6HZI2  =,6HZI3  =,6HZI2P =,6HZI3P =/
C
      GO TO (4,4,3,4,5), IND
    4 CALL XNTERP(X, ZME, ZMEP, IMX, XITAB, ZMTAB, IXTAB, CMX, IXPOS)
      IXPOS=IMX
      CALL XNTERP (X,TE,TEP,ITX,XITAB,TETAB,IXTAB,CTX,IXPOS)
      CALL XNTERP (X,PE,PEP,IPX,XITAB,PETAB,IXTAB,CPX,IXPOS)
      CALL XNTERP (X,UE,UEP,IUX,XITAB,UETAB,IXTAB,CUX,IXPOS)
      CALL XNTERP (X,SMOL,SMOLP,ISX,XITAB,SMTAB,IXTAB,CSX,IXPOS)
      CALL SEVAL(1,TE,CPE,HE)
      RBAR = 1545.0/SMOL
      ROJ = RBAR/FJ
      GAME = CPE/(CPE - ROJ)
      PRANDT = 4.0*GAME/(9.0*GAME - 5.0)
      UE2O2 = UE*UE/2.0
      HEP=FJG*CPE*TEP
      RHOE=PE/TE/RBAR
*DIAGNOSTIC*  THE TEST FOR EQUALITY BETWEEN NON-INTEGERS MAY NOT BE MEANINGFUL.
      IF (DXRHO .NE. 0.0)  GO TO 201
      RHOEP = 0.0
      GO TO 210
  201 IF (X .GT. XIBASE)  GO TO 203
```

```
      Z1 = RHOE
      Z3=1.
      GO TO 204
  203 CALL XNTERP (X-DXRHO,Z4,Z4P,IPX,XITAB,PETAB,IXTAB,CPX,IXPOS)
      CALL XNTERP (X-DXRHO,Z5,Z5P,ITX,XITAB,TETAB,IXTAB,CTX,IXPOS)
      CALL XNTERP (X-DXRHO,SM1,SM1P,ISX,XITAB,SMTAB,IXTAB,CSX,IXPOS)
      R1 = 1545.0/SM1
      Z1 = Z4/Z5/R1
      Z3=.5
  204 IF (X .LT. XIEND)  GO TO 206
      Z2 = RHOE
      Z3=1.
      GO TO 207
  206 CALL XNTERP (X+DXRHO,Z4,Z4P,IPX,XITAB,PETAB,IXTAB,CPX,IXPOS)
      CALL XNTERP (X+DXRHO,Z5,Z5P,ITX,XITAB,TETAB,IXTAB,CTX,IXPOS)
      CALL XNTERP (X+DXRHO,SM1,SM1P,ISX,XITAB,SMTAB,IXTAB,CSX,IXPOS)
      R1 = 1545.0/SM1
      Z2 = Z4/Z5/R1
  207 RHOEP=(Z2-Z1)/DXRHO*Z3
  210 RHOUE = RHOE*UE
      RHOUEP=RHOE*UEP+UE*RHOEP
      ZMU=ZMUO*(TE/TO)**ZMVIS
      HO = HE + UE2O2
      HOP = HEP + UE*UEP
      PRE1O3 = PRANDT**(1.0/3.0)
      HAW=HE+PRE1O3*UE2O2
      CALL SEVAL(2,TAW,ERASE3,HAW)
      IF(ITWTAB) 11,12,13
   11 TW=TAW
      HW=HAW
      HWP=HEP+PRE1O3*UE*UEP
      GO TO 14
   12 TW=TWTAB(1)
      HW=TWTAB(2)
      HWP=0.
      GO TO 14
   13 CALL XNTERP ( X, TW, TWP, ITWX, XITAB, TWTAB, IXTAB, CTWX, IXPOS )
      CALL SEVAL(1,TW,CPW,HW)
      HWP=FJG*CPW*TWP
   14 IF (TW .LE. TAW)  GO TO 170
      WRITE(6,155) TW,TAW
  155 FORMAT ( 45HO**BARPRO FAILURE... WALL TEMPERATURE ( TW = , F8.2,
     1 62H ) CALCULATED GREATER THAN ADIABATIC WALL TEMPERATURE ( TAW =
     2,F8.2, 3H ). )
      WRITE(6,106) X, ZME, THETA, PHI
  106 FORMAT ( 23H   AXIAL DISTANCE  X = , 1PE14.7, 5X, 11HMACH NO. = ,
     1 E14.7, 5X, 8HTHETAI =, E14.7, 5X, 6HPHII =, E14.7 )
      WRITE(6,250)
  250 FORMAT ( 64H  *CHECK CONTOUR AND MACH NUMBER DISTRIBUTION TABLES F
     1OR ERRORS. / 110H  *MORE INPUT POINTS MAY BE REQUIRED TO ADEQUATEL
     2Y DESCRIBE DERIVATIVE VALUES ALONG THE CONTOUR AT THIS POINT. /
     396H  *A SMALLER RUNGE-KUTTA STEP SIZE MAY BE REQUIRED TO ADEQUATEL
     4Y APPROXIMATE INTEGRATION VALUES. // )
      CALL QUITS
  170 A             = HW
      B=HO-HW
```

```
      C=-UE202
      TFINT=TE
 3    CALL ZETAIT
      CREY=RHOUE/ZMU
      RTHE=CREY*THETA
      RPHI=CREY*PHI
      CF = 0.0250/(RTHE**0.250)
      CFAG = 0.0250/(RPHI**0.250)
      CHPAR1 = 1.0 - PRANDT + ALOG(6.0/(5.0*PRANDT + 1.0))
      CH=(PHI/THETA)**ZNSTAN*(CFAG/2.)/(1.-5.*SQRT(CFAG/2.)*CHPAR1)
      IF (ITWTAB .LT. 0)  CH = 0.0
      ERASE1 = RHOUEP/RHOUE
      ERASE2=(1.+DELSOT)/UE*UEP
      CALL XNTERP ( X, YR, YRP, IYX, XITAB, YITAB, IXTAB, CYX, IXPOS )
      DARC=SQRT(1.+YRP*YRP)
      CDFORC=RHOUE/G*UE/DARC*CF/2.
      IF (EPSZ .LE. 0.0)  GO TO 40
      ERASE1 = ERASE1 + EPSZ/YR*YRP
 40   THETAP = CF/2.0*DARC - THETA*(ERASE2 + ERASE1)
      ERASE2=H0-HW
      PHIP = CH*DARC/ERASE2*(HAW-HW) - PHI*(ERASE1 - (H0P-HWP)/ERASE2)
      IF (IND .NE. 1)  RETURN
      IF (ITWTAB .LT. 0)  GO TO 66
      QW = RHOUE/FJ*CH/G*(HAW - HW)
      HG=QW/(TAW-TW)
 66   QDA0          = QDA
      DFORC0=DFORCE
      DFLAT0=DFLAT
      IF (EPSZ .LE. 0.0)  GO TO 44
      ERASE1 = PIE*YR
      QDA           = ERASE1 * QW
      DFORCE=ERASE1*CDFORC
      DFLAT=0.
      GO TO 45
 44   QDA = QW
      DFORCE=CDFORC/2.
      DFLAT=DFORCE*YRP
 45   Y0ARC = Y2ARC
      Y2ARC=DARC
      IF (DX .LE. 0.0)  RETURN
      CALL XNTERP(X - DX/2.0, ERASE1, ERASE2, IYX, XITAB, YITAB,
     A               IXTAB, CYX, IXPOS)
      Y1ARC=SQRT(1.+ERASE2*ERASE2)
      DXLARC=(Y0ARC+4.*Y1ARC+Y2ARC)/6.*DX
      XLARC=XLARC+DXLARC
      SUMQDA=SUMQDA+DXLARC*(QDA+QDA0)
      IF (ICOOL .EQ. 0)  GO TO 2
      SUMQGA = COEFCL*SUMQDA
      CALL XNTERP (TL1,ZMYUL,ZP,IZX,TZTAB,ZMYTAB,ITZTAB,CZX,ITPOS)
      ITPOS = IZX
      DIATUB = 2.0*SQRT(AL/PIE)
      REYL = MASSL*DIATUB/(AL*TUBEN*ZMYUL)
 2    FORCE = FORCE + DXLARC*(DFORCE + DFORC0)
      FLAT=FLAT+DXLARC*(DFLAT+DFLAT0)
      RETURN
 5    RXLN = CREY*XLARC
```

```
      RDLS=CREY*DELSTR
      IF (ZETA .GE. 1.0)  GO TO 62
      I = 1
      Z1=Z14
      Z2=Z15
      Z3=Z16
      Z4=Z17
      Z5=Z11P
      GO TO 63
   62 I=6
      Z1=Z11
      Z2=Z12
      Z3=Z13
      Z4=Z12P
      Z5=Z13P
   63 WRITE(6,51)
   51 FORMAT (1H0/1X,16HCONTOUR PROPERTIES,5X,15HFLOW PROPERTIES,8X,
     A          14HBOUNDARY LAYER,9X,13HHEAT TRANSFER,7X,
     K          18HINTERNAL INTEGRALS,7X,12HCOEFFICIENTS/)
      WRITE(6,52) X,ZME,DELTA,HG,ZETA,CF
   52 FORMAT (1X,7HX      =,F11.6,3X,7HZME    =,F12.6,3X,7HDELTA =,
     A          1PE13.6,3X,7HHG     =,0PF12.6,3X,6HZETA =,1PE14.6,3X,
     K          6HCF    =,1PE13.6)
      WRITE(6,53) XLARC,TE,BDELTA,QW,ZINTPR(I),Z1,CH
   53 FORMAT (1X,7HXLARC =,F11.6,3X,7HTE     =,F12.6,3X,7HBDELTA=,
     A          1PE13.6,3X,7HQW     =,1PE12.6,3X,A6,1PE14.6,3X,6HCH    =,
     K          1PE13.6)
      WRITE(6,54) YR,TW,DELSTR,SUMQDA,ZINTPR(I+1),Z2,RTHE
   54 FORMAT (1X,7HYR     =,F11.6,3X,7HTW     =,F12.6,3X,7HDELSTR=,
     A          1PE13.6,3X,7HSUMQDA=,1PE12.6,3X,A6,1PE14.6,3X,6HRTHE =,
     K          1PE13.6)
      WRITE(6,55) YRP,TAW,THETA,FORCE,ZINTPR(I+2),Z3,RXLN
   55 FORMAT (1X,7HYRP    =,F11.7,3X,7HTAW    =,F12.6,3X,7HTHETA =,
     A          1PE13.6,3X,7HFORCE =,0PF12.6,3X,A6,1PE14.6,3X,6HRXLN =,
     K          1PE13.6)
      YRDELS = YR - DELSTR
      WRITE (6,56) YRDELS,ZMEP,PHI,FLAT,ZINTPR(I+3),Z4,RPHI
   56 FORMAT (1X,7HYRDELS=,F11.8,3X,7HZMEP   =,F12.6,3X,7HPHI    =,
     1 1PE13.6,3X,7HFLAT   =,0PF12.6,3X,A6,1PE14.6,3X,6HRPHI =,1PE13.6)
      WRITE (6,57) UE,DELSOT,RBAR,ZINTPR(I+4),Z5,RDLS
   57 FORMAT (22X,7HUE     =,F12.6,3X,7HDELSOT=,F13.6,3X,7HRBAR   =,F12.6,
     A          3X,A6,1PE14.6,3X,6HRDLS =,1PE13.6)
      WRITE (6,58) PE,RHOE,PRANDT,GAME,SMOL
   58 FORMAT (22X,7HPE     =,1PE12.6,3X,7HRHOE   =,0PF13.6,3X,7HPRANDT=,
     A          F12.10,3X,6HGAME =,F14.8,3X,6HSMOL =,F13.6)
      COSAL = 1.0/DARC
      IF (EPSZ .LE. 0.0)  GO TO 500
      DELF1 = 2.0*PIE*YR*RHOUE*THETA*UE*COSAL/G
      DELF2 = 1.0 - DELSOT*PE/(RHOUE*UE/G)
      DELFA = DELF1*DELF2
      THRUST = PIE*YR**2*(RHOUE*UE/G + PE)
      DEFTHR = 100.0*DELFA/THRUST
      THRUSA = PIE*YR**2*(RHOUE*UE/G + PE - 2116.2240)
      ZMASSR = PIE*(YR + DELSTR*COSAL)**2*RHOUE
      XMASSR = PIE*YR**2*RHOUE
      GO TO 510
```

```
C
C     THE TWO DIMENSIONAL CASE ASSUMES A WIDTH OF ONE FOOT
C
  500 DELF1 = 2.0*RHOUE*THETA*UE*COSAL/G
      DELF2 = 1.0 - DELSOT*PE/(RHOUE*UE/G)
      DELFA = DELF1*DELF2
      THRUST = 2.0*YR*(RHOUE*UE/G + PE)
      DEFTHR = 100.0*DELFA/THRUST
      THRUSA = 2.0*YR*(RHOUE*UE/G + PE - 2116.2240)
      ZMASSR = 2.0*(YR + DELSTR*COSAL)*RHOUE
      XMASSR = 2.0*YR*RHOUE
  510 VISP = THRUST/ZMASSR
      AISP = THRUSA/ZMASSR
      TBLISP = -DELFA/FLOWRT
      WRITE (6,1) AISP,XMASSR,THRUSA,DELFA,TBLISP,VISP,ZMASSR,THRUST,
     1            DEFTHR,COSAL
    1 FORMAT (//25X,81HTHRUST DEFICIENCY AND SPECIFIC IMPULSE DECREMENT
     1DUE TO THE BOUNDARY LAYER EFFECT//5X,6HAISP =,F10.4,5X,8HXMASSR =,
     2 F13.4,5X,8HTHRUSA =,F14.4,5X,7HDELFA =,F12.4,5X,8HTBLISP =,F11.6/
     3 5X,6HVISP =,F10.4,5X,8HZMASSR =,F13.4,5X,8HTHRUST =,F14.4,5X,
     4 8HDEFTHR =,F11.8,5X,7HCOSAL =,F12.8//)
      IF (ICOOL .EQ. 0)  RETURN
      TWL = TL1
      CALL XNTERP (TL1,CPL,CPP,ICX,TZTAB,CPLTAB,ITZTAB,CCX,ITPOS)
      CALL XNTERP (TL1,RAMDL,RP,IRX,TZTAB,RAMTAB,IIZTAB,CRX,ITPOS)
      CALL XNTERP (TL1,ZMYUL,ZP,IZX,TZTAB,ZMYTAB,IIZTAB,CZX,ITPOS)
      CALL XNTERP (X,ENHA,ENHAP,IEX,XITAB,ENHTAB,IXTAB,CEX,IXPOS)
      PRANDL = CPL*ZMYUL/RAMDL
   70 TWLG = TWL
      HL = 0.0250*RAMDL/DIATUB*REYL**0.80*PRANDL**0.40*(TL1/TWL)**0.550
      HL = HL*ENHA
      SA1 = HL*(1.0 + RAMDW/(THICK*HG))
      SA2 = RAMDW/THICK
      TWL = (SA1*TL1 + SA2*TAW)/(SA1 + SA2)
      IF (ABS(TWLG - TWL) .GT. 0.010)  GO TO 70
      TEMPRL = TWL/TL1
      TWGCA = (HG*TAW + RAMDW/THICK*TWL)/(HG + RAMDW/THICK)
      QWI = HG*(TAW - TWGCA)
      IF (EPSZ .LE. 0.0)  GO TO 600
      SST = PIE*YR*QWI*DELXBA*DARC*COEFCL
      GO TO 610
  600 SST = QWI*DELXBA*DARC*COEFCL
  610 TLCA = (TL1 + TL2)/2.0 + SST/(CPL*MASSL)
      IF (IDUMP .GT. 0)  TLCA = (TL0 + TL1)/2.0 + SST/(CPL*MASSL)
      DMASSL = MASSL/(AL*TUBEN)
      SUMQWI = SUMQWI + SST*2.0
      WRITE (6,71) DMASSL,HL,QWI,REYL,SUMQWI,TEMPRL,TLCA,TWGCA,TWL,
     1             DIATUB,THICK,SUMQGA
   71 FORMAT (/50X,31HREGENERATIVE CALCULATION OUTPUT//5X,8HDMASSL =,
     1 F12.4,5X,4HHL =,F10.6,7X,5HQWI =,F12.4,5X,6HREYL =,F19.4,5X,
     2 8HSUMQWI =,F15.6/5X,8HTEMPRL =,F10.4,7X,6HTLCA =,F10.4,5X,
     3 7HTWGCA =,F10.4,5X,5HTWL =,F10.4,15X,8HDIATUB =,F15.10/
     4 5X,7HTHICK =,F10.6,81X,8HSUMQGA =,F15.6////////)
      RETURN
      END
```

BARSET

```
      SUBROUTINE BARSET
C
      COMMON /CSEVAL/ NOCTAB,IS,ROJ,FJG,CJG,GM1O2,GOGM1,PUMAX,CPO,HO,    /CSEVAL/
     A                SO,TCTAB(20),CPTAB(20),BCP(20),CCP(20),DCP(20),    /CSEVAL/
     K                GTAB(20),HTAB(20),BARB1(20),BARB2(20),BARB3(20)    /CSEVAL/
C
      COMMON /INPUT/  IDXMAX,ICTAB,IPRINT,ITWTAB,IXTAB,MZETA,DXMAX,      /INPUT/
     A               EPSZ,FJ,G,GAMO,PO,PHI1,PIE,PRANDT,RBAR,SCALE,TO,    /INPUT/
     K               THETA1,TOLCFA,TOLZET,TOLZME,ZMUO,ZNVIS,ZNSTAN       /INPUT/
C
      COMMON /TABLES/ PETAB(100),SMTAB(100),TETAB(100),TWTAB(100),       /TABLES/
     1                UETAB(100),XITAB(100),YITAB(100),ZMTAB(100)        /TABLES/
C
      PIE=3.14159265
      FJG=FJ*G
      ROJ=RBAR/FJ
      TMAX=TC
      I1=1
      IF(ITWTAB) 15,12,11
   11 I1=IXTAB
   12 DO 14 I=1,I1
      IF (TWTAB(I) .LE. TMAX)  GO TO 14
      TMAX = TWTAB(I)
   14 CONTINUE
  15  IF (ICTAB .EQ. 0)  GO TO 20
      IF (TMAX .LT. TCTAB(ICTAB))  GO TO 16
      WRITE(6,52) TMAX,TCTAB(ICTAB)
   52 FORMAT ( // 44H **BARSET ERROR**  TEMPERATURE INPUT VALUE (,
     1        1PE14.7, 29H) EXCEEDS TABLE UPPER LIMIT (, E14.7, 1H) )
      GO TO 57
   16 NOCTAB=ICTAB
      CALL BMFITS (TCTAB,CPTAB,ICTAB,BCP,CCP,DCP)
      TIE1=TCTAB(1)
      TIE2=TIE1*TIE1
      TIE3=TIE2*TIE1
      HTAB(1) = CPTAB(1)*TIE1 - BCP(1)*TIE2/2.0
      BARB1(1) = CPTAB(1) - BCP(1)*TIE1 + CCP(1)*TIE2 - DCP(1)*TIE3
      BARB2(1) = BCP(1) - 2.0*CCP(1)*TIE1 + 3.0*DCP(1)*TIE2
      BARB3(1)=(CCP(1)-3.*DCP(1)*TIE1)/2.
      GTAB(1)=-BARB1(1)*ALOG(TIE1)-BARB2(1)*TIE1-BARB3(1)*TIE2
     X        -DCP(1)/3.*TIE3
      G1=0.
      DO 19 I=2,ICTAB
      TME1=TIE1
      TME2=TIE2
      TME3=TIE3
      TIE1=TCTAB(I)
      TIE2=TIE1*TIE1
      TIE3=TIE2*TIE1
      DELT=TIE1-TME1
      HTAB(I) = HTAB(I-1) + CPTAB(I-1)*DELT + BCP(I-1)*DELT**2/2.0 +
     A          CCP(I-1)*DELT**3/3.0 + DCP(I-1)*DELT**4/4.0
      IF (I .GE. ICTAB)  GO TO 19
      BARB1(I) = CPTAB(I) - BCP(I)*TIE1 + CCP(I)*TIE2 - DCP(I)*TIE3
      BARB2(I)=BCP(I)-CCP(I)/.5*TIE1+3.*DCP(I)*TIE2
```

```
      BARB3(I)=(CCP(I)-3.*DCP(I)*TIE1)/2.                               BARS  74
      G1=G1+BARB1(I-1)*ALOG(TIE1/TME1)+BARB2(I-1)*DELT                  BARS  75
     X    +BARB3(I-1)*(TIE2-TME2)+DCP(I-1)/3.*(TIE3-TME3)               BARS  76
      G2=BARB1(I)*ALOG(TIE1)+BARB2(I)*TIE1+BARB3(I)*TIE2+DCP(I)/3.*TIE3 BARS  77
      GTAB(I)=G1-G2                                                     BARS  78
   19 CONTINUE                                                          BARS  79
      IS=ICTAB-1                                                        BARS  80
      CALL SEVAL(1,TO,CPO,HO)                                           BARS  81
      GAMO=CPO/(CPO-ROJ)                                                BARS  82
   20 IF (GAMO .GT. 1.0)  GO TO 56
      WRITE (6,54) GAMO
   54 FORMAT (    81H **BARSET ERROR**  RATIO OF SPECIFIC HEATS MUST BE BARS  86
     1GREATER THAN ONE (1).  GAMO = , E14.7 / 46H CHECK FOR INCONSISTENTBARS  87
     2 UNITS.... CP, RBAR, FJ  // )                                     BARS  88
   57 CALL QUITS                                                        BARS  89
   56 GM102 = (GAMO - 1.0)/2.0
      GOGM1=GAMO/(GAMO-1.)                                              BARS  92
      POMAX=PO                                                          BARS  93
      IF (ICTAB .GT. 0)  GO TO 30
      NOCTAB = 6                                                        BARS  99
      NOCTM1=NOCTAB-1                                                   BARS 100
      IS=NOCTM1                                                         BARS 101
      CPO=GOGM1/FJ*RBAR                                                 BARS 102
      CJG=CPO*FJG                                                       BARS 103
      HO=CJG*TO                                                         BARS 104
      DO 23 I=1,IXTAB
      TE = TETAB(I)
      IF (TE .LE. TMAX)  GO TO 23
      TMAX = TE                                                         BARS 108
   23 CONTINUE                                                          BARS 109
      TCTAB(NOCTAB)=TMAX+100.                                           BARS 110
      TCTAB(1)=1.E-10                                                   BARS 111
      Z1=NOCTM1                                                         BARS 112
      DELT=(TCTAB(NOCTAB)-TCTAB(1))/Z1                                  BARS 113
      ERASE1=-CPO*ALOG(TCTAB(1))                                        BARS 114
      DO 25 I=1,NOCTAB                                                  BARS 115
      GTAB(I)=ERASE1
      CPTAB(I) = CPO                                                    BARS 117
      BCP(I)=0.                                                         BARS 118
      CCP(I)=0.                                                         BARS 119
      DCP(I)=0.                                                         BARS 120
      BARB1(I)=CPO                                                      BARS 121
      BARB2(I)=0.                                                       BARS 122
      BARB3(I)=0.                                                       BARS 123
      HTAB(I)=CPO*(TCTAB(I)-TCTAB(1))
      IF (I .GE. NOCTM1)  GO TO 25
      TCTAB(I+1) = TCTAB(I) + DELT                                      BARS 126
   25 CONTINUE
   30 IF (ITWTAB .NE. 0)  GO TO 38
      CALL SEVAL(1, TWTAB(1), ERASE1, TWTAB(2))
   38 CALL SEVAL(0,TO,PO,SO)                                            BARS 132
      RETURN                                                            BARS 133
      END
```

```
BMFITS
      SUBROUTINE BMFITS (X,Y,N,BL,CL,DL)
C
      DIMENSION A(20),B(20),C(20),F(20),G(20),X(20),Y(20),
     A          BL(20),CL(20),DL(20),FL(20),YPP(20)
C
      I = 1
   11 FL(I) = X(I+1) - X(I)
      I = I + 1
      IF (I .LT. N)  GO TO 11
      I = 2
   15 B(I) = -FL(I-1)/FL(I)
      A(I) = -2.0*(FL(I) + FL(I-1))/FL(I)
      C(I) = 6.0/FL(I)*((Y(I+1) - Y(I))/FL(I) - (Y(I) - Y(I-1))/FL(I-1))
      I = I + 1
      IF (I .LT. N)  GO TO 15
      G(2) = 1.0
      F(2) = 0.0
      I = 3
   32 G(I) = A(I-1) + B(I-1)/G(I-1)
      F(I) = -(B(I-1)*F(I-1)/G(I-1) + C(I-1))
      I = I + 1
      IF (I .LE. N)  GO TO 32
      YPP(N) = F(N)/(G(N) - 1.0)
      YPP(N-1) = YPP(N)
      I = N - 2
   47 YPP(I) = (YPP(I+1) + F(I+1))/G(I+1)
      I = I - 1
      IF (I .GT. 0)  GO TO 47
      I = 1
   51 BL(I) = (Y(I+1)-Y(I))/FL(I) - (FL(I)*(YPP(I+1) + 2.0*YPP(I)))/6.0
      CL(I) = YPP(I)/2.0
      DL(I) = (YPP(I+1) - YPP(I))/(6.0*FL(I))
      I = I + 1
      IF (I .LT. N)  GO TO 51
      RETURN
      END
```

CFEVAL

```
      FUNCTION CFEVAL(CFRT)
C
      DIMENSION X(8),A(7),B(7),C(7),D(7),IX(8)
      EQUIVALENCE (X,IX),(Z,IZ)
      DATA A/-2.0791773E-2,-4.9715425E-3,1.2614392E-3,-1.0088617E-3,
     1       1.7521422E-4,-2.883630E-4,5.9985794E-6/, B/0.20915862,
     2       7.3896560E-2,-1.6794227E-2,2.9519911E-2,-1.5620821E-3,
     3       1.3318747E-2,2.1035707E-3/, C/-0.92142043,-0.53592107,
     4       -9.607530E-2,-0.41101115,-0.13904416,-0.29826897,
     5       -0.15583627/, D/-4.4457710,-4.8119952,-5.5230787,-4.8092254,
     6       -5.6024598,-5.0345585,-5.6375232/, J/1/, X/2.5099998,
     7       17.287782,127.74039,897.84729,6310.6880,44355.857,
     8       327747.91,1982759.2/, ZERO/0.0/
C
      Z=CFRT
      IF (Z .LE. 0.0)  GO TO 3
    1 IF(IZ-IX(J)) 2,7,9
    2 J=J-1
      IF ( J ) 3, 5, 1
    3 J=1
      WRITE(6,4) Z,ZERO,X(8)
    4 FORMAT (/10X,14HCFEVAL FAILURE,5X,3HZ =,1PE15.8,5X,15HLIMITS ARE F
     1ROM,5X,E18.8,2X,2HTO,E18.8)
      CALL QUITS
5     IF (Z .LE. 0.0)  GO TO 3
      J = 1
      Y=.009896/Z**.562
      GO TO 8
    7 ZL=ALOG(Z)
      YL=D(J)+ZL*(C(J)+ZL*(B(J)+ZL*A(J)))
      Y=EXP(YL)
    8 CFEVAL=Y
      RETURN
9     IF (IZ .LE. IX(J+1))   GO TO 7
      J = J + 1
      IF(J-8) 9,3,3
      END
```

```
DIRECT
      SUBROUTINE DIRECT                                                 DIRE   1
C
   10 CALL READIN                                                       DIRE   2
      CALL BARSET                                                       DIRE   3
      CALL BARCON                                                       DIRE   4
      GO TO 10
      END                                                               DIRE   7
```

```
FIIF
      FUNCTION FIIF (S)
C
      COMMON /COFIIF/ IFINT,AFINT,BFINT,CFINT,MMINT,TFINT                /COFIIF/
C
      STOM=1.                                                            FIIF   4
      IF (MMINT .LE. 0)  GO TO 12
      DO 4 I=1,MMINT                                                     FIIF   7
    4 STOM = STOM* S                                                     FIIF   8
   12 FDEN = AFINT + S*(BFINT + S*CFINT)
      IF (IFINT .GE. 2)  GO TO 2
      FNUM = STOM*(1.0 - S)
      GO TO 3                                                            FIIF  13
    2 FNUM=STOM                                                          FIIF  14
    3 CALL SEVAL(2,T,0,FDEN)                                             FIIF  15
      FIIF=FNUM/T*TFINT                                                  FIIF  16
      RETURN                                                             FIIF  17
      END                                                                FIIF  18
```

```
GETPT
      SUBROUTINE GETPT (ZME,PI,TI)
C
      COMMON /CSEVAL/ NOCTAB,IS,ROJ,FJG,CJG,GM102,GOGM1,POMAX,CPO,HO,    /CSEVAL/
     A                SO,TCTAB(20),CPTAB(20),BCP(20),CCP(20),DCP(20),    /CSEVAL/
     K                GTAB(20),HTAB(20),BARB1(20),BARB2(20),BARB3(20)    /CSEVAL/
C
      COMMON /INPUT/ IDXMAX,ICTAB,IPRINT,ITWTAB,IXTAB,MZETA,DXMAX,       /INPUT/
     A               EPSZ,FJ,G,GAMO,PO,PHII,PIE,PRANDT,RBAR,SCALE,TO,     /INPUT/
     K               THETAI,TOLCFA,TOLZET,TOLZME,ZMUO,ZMVIS,ZNSTAN        /INPUT/
C
      ZME2=ZME*ZME                                                       GETP   9
      PROD1=2./RBAR/ZME2/G                                               GETP  10
      DENM2=1.+GM102*ZME2                                                GETP  11
      TE=TO/DENM2                                                        GETP  12
      IF (ICTAB .GT. 0)  GO TO 20
      PE=PO/DENM2**GOGM1                                                 GETP  15
   15 PI = PE
      TI=TE                                                              GETP  18
      RETURN                                                             GETP  19
   20 ITER = 0
      TOL = TOLZME/ZME
   21 TEO=TEG                                                            GETP  23
      TCO=TC                                                             GETP  24
      TEG=TE                                                             GETP  25
      CALL SEVAL(1,TE,CPE,HE)                                            GETP  26
      GAME=CPE/(CPE-ROJ)                                                 GETP  27
      TC=(HO-HE)/GAME*PROD1                                              GETP  28
      IF (ABS((TC - TE)/TE) .LE. TOL)  GO TO 30
      IF (ITER .GT. 0)  GO TO 24
      TE = (2.0*TE + TC)/3.0
      GO TO 28                                                           GETP  32
   24 IF (ITER .LE. 50)  GO TO 27
      WRITE (6,26) ZME,TC,TCO,TE,TEO
   26 FORMAT ( 31HO**GETPT FAILURE... MACH NO. = , 1PE14.7 / 14X,        GETP  35
     1        17HT (CALCULATED) = , 2E16.7 / 14X, 17HT (GUESSED)     = ,GETP  36
     2        2E16.7 // )                                                GETP  37
      GO TO 30                                                           GETP  38
   27 ZK=(TC-TCO)/(TE-TEO)                                               GETP  39
      TE=(TC-ZK*TE)/(1.-ZK)                                              GETP  40
      IF (ABS((TE - TEG)/TE) .LT. TOL)  GO TO 29
      IF (ITER .LT. 10)  GO TO 28
      IF (ABS((TE - TEO)/TE) .LT. TOL)  GO TO 29
   28 ITER=ITER+1                                                        GETP  44
      GO TO 21                                                           GETP  45
   29 TE=(TE+TEG)/2.                                                     GETP  46
   30 CALL SEVAL(-1,TE,PE,SO)
      GO TO 15                                                           GETP  49
      END                                                                GETP  50
```

```
INTZET
      SUBROUTINE INTZET (X1,X2,ZINT)
C
C  -  INTZET  -  QUADRATIC FOUR POINT INTEGRATION SCHEME  -  ZETA(BARTZ)INTZ   2
C
      DIMENSION XC(21),YC(21),YM(4)                                     INTZ   3
C
      DX21=X2-X1                                                        INTZ   7
      SUMINT=0.                                                         INTZ   8
      IF (DX21 .EQ. 0.0)  GO TO 15
      DXC=DX21/20.                                                      INTZ  11
      IMAX=-9999                                                        INTZ  12
      FMAX=-1.E30                                                       INTZ  13
      DO 10 I=1,21                                                      INTZ  14
      XC(I)=X1+FLOAT(I-1)*DXC                                           INTZ  15
      YC(I)=FIIF(XC(I))                                                 INTZ  16
      IF (YC(I) .LE. FMAX)  GO TO 10
      IMAX = I
      XMAX=XC(I)                                                        INTZ  19
      FMAX=YC(I)                                                        INTZ  20
   10 CONTINUE                                                          INTZ  22
      IF (DX21 .GT. 0.10)  GO TO 17
      SUMINT=10.*YC(1)+16.*YC(2)-2.*YC(3)                               INTZ  25
      DO 14 I=2,19                                                      INTZ  26
      PARINT=13.*(YC(I)+YC(I+1))-YC(I-1)-YC(I+2)                        INTZ  27
   14 SUMINT = SUMINT + PARINT
      SUMINT=SUMINT+10.*YC(21)+16.*YC(20)-2.*YC(19)                     INTZ  30
      SUMINT=SUMINT/24.*DXC                                             INTZ  31
   15 ZINT=SUMINT                                                       INTZ  32
      RETURN                                                            INTZ  33
   17 FBRK = FMAX*0.20
      SUAINT=0.                                                         INTZ  35
      SUBINT=0.                                                         INTZ  36
      IF (IMAX .LE. 2)  GO TO 21
      DO 19 I=2,IMAX                                                    INTZ  39
      IF (YC(I) .LE. FBRK)  GO TO 19
      IBRK = I - 1
      GO TO 20                                                          INTZ  42
   19 CONTINUE                                                          INTZ  43
      IBRK=IMAX-1                                                       INTZ  44
   20 IF (IBRK .GT. 1)  GO TO 22
   21 IBRK=1                                                            INTZ  46
      IBRKM1=0                                                          INTZ  47
      GO TO 25                                                          INTZ  48
   22 IBRKM1=IBRK-1                                                     INTZ  49
      SUAINT=10.*YC(1)+16.*YC(2)-2.*YC(3)                               INTZ  50
      IF (IBRK .LE. 2)  GO TO 204
      DO 23 I=2,IBRKM1                                                  INTZ  53
      PARINT=13.*(YC(I)+YC(I+1))-YC(I-1)-YC(I+2)                        INTZ  54
   23 SUAINT = SUAINT + PARINT
  204 SUAINT = SUAINT/24.0*DXC
   25 DXM = DXC/3.0
      IF (IBRKM1 .GT. 0)  GO TO 206
      K = 2
      JS = 2                                                            INTZ  63
      GO TO 207                                                         INTZ  64
```

```
 206 K = 3                                                          INTZ  65
     JS = 1                                                         INTZ  66
 207 DO 26 I = 2,4
     XM=XC(IBRK)+FLOAT(I-K)*DXM                                     INTZ  69
  26 YM(I) = FIIF(XM)
     IF (IBRKM1 .GT. 0)  GO TO 209
     SUBINT = 10.0*YM(2) + 16.0*YM(3) - 2.0*YM(4)
 209 DO 27 I = IBRK,19
     DO 28 J=JS,3                                                   INTZ  76
     YM(1)=YM(2)                                                    INTZ  77
     YM(2)=YM(3)                                                    INTZ  78
     YM(3)=YM(4)                                                    INTZ  79
     XM=XM+DXM                                                      INTZ  80
     YM(4)=FIIF(XM)                                                 INTZ  81
     PARINT=13.*(YM(2)+YM(3))-YM(1)-YM(4)                           INTZ  82
  28 SUBINT = SUBINT + PARINT
     JS = 1                                                         INTZ  85
  27 XM = XC(I+1) + DXM
     DO 29 J=1,2                                                    INTZ  88
     YM(1)=YM(2)                                                    INTZ  89
     YM(2)=YM(3)                                                    INTZ  90
     YM(3)=YM(4)                                                    INTZ  91
     XM=XM+DXM                                                      INTZ  92
     YM(4)=FIIF(XM)                                                 INTZ  93
     PARINT=13.*(YM(2)+YM(3))-YM(1)-YM(4)                           INTZ  94
  29 SUBINT = SUBINT + PARINT
     SUBINT=SUBINT+10.*YM(4)+16.*YM(3)-2.*YM(2)                     INTZ  97
     SUBINT=SUBINT/24.*DXM                                          INTZ  98
     SUMINT=SUAINT+SUBINT                                           INTZ  99
     GO TO 15                                                       INTZ 100
     END                                                            INTZ 101
```

```
MAINTB
C     I C R P G REFERENCE PROGRAM  TBL
C     DECK SEQUENCED BY SUBROUTINE
C
      COMMON /INPUT/ IDXMAX,ICTAB,IPRINT,ITWTAB,IXTAB,MZETA,DXMAX,       /INPUT/
     A               EPSZ,FJ,G,GAMO,PO,PHII,PIE,PRANDT,RBAR,SCALE,TO,    /INPUT/
     K               THETAI,TOLCFA,TOLZET,TOLZME,ZMUO,ZMVIS,ZNSTAN       /INPUT/
C
      IDXMAX = 0
      CALL DIRECT                                                        TBL    1
      END                                                                TBL    3
```

QUITS

```
      SUBROUTINE QUITS                                                  QUIT   1
C
      COMMON /COFIIF/ IFINT,AFINT,BFINT,CFINT,MMINT,TFINT               /COFIIF/
C
      COMMON /COOL/ ICOOL,IDUMP,ITZTAB,AL,COEFCL,CPL,DELXBA,DIATUB,     /COOL/
     1              FLOWRT,MASSL,PRANDL,RAMDL,RAMDW,REYL,SUMQGA,SUMQWI, /COOL/
     2              THICK,TL0,TL1,TL2,TLCA,TOLITE,TUBEN,TWGCA,ZMYUL,    /COOL/
     3              CPLTAB(20),RAMTAB(20),TZTAB(20),ZMYTAB(20),         /COOL/
     4              ALTAB(100),THITAB(100),TLCTAB(100),TLTAB(100),      /COOL/
     5              TWGTAB(100)                                         /COOL/
      REAL MASSL                                                        /COOL/
C
      COMMON /CSEVAL/ NOCTAB,IS,ROJ,FJG,CJG,GM1O2,GOGM1,POMAX,CPO,HO,   /CSEVAL/
     A                SO,TCTAB(20),CPTAB(20),BCP(20),CCP(20),DCP(20),   /CSEVAL/
     K                GTAB(20),HTAB(20),BARB1(20),BARB2(20),BARB3(20)   /CSEVAL/
C
      COMMON /INPUT/ IDXMAX,ICTAB,IPRINT,ITWTAB,IXTAB,MZETA,DXMAX,      /INPUT/
     A              EPSZ,FJ,G,GAMO,PO,PHII,PIE,PRANDT,RBAR,SCALE,TO,    /INPUT/
     K              THETAI,TOLCFA,TOLZET,TOLZME,ZMUO,ZMVIS,ZNSTAN       /INPUT/
C
      COMMON /INTER/ CFAGT,CFAGP,CHPAR1,DX,DXRHO,HE,HW,IBEG,MZETAM,     /INTER/
     A              OOMZET,PHIP,PRE1O3,RHOE,RHOUE,RMZETA,THETAP,        /INTER/
     K              XIBASE,XIEND,ZETATM,ZMZETA,ZMZETM,ZMZETP            /INTER/
C
      COMMON /LOOKUP/ ICX,IMX,IPX,IRX,ISX,ITPOS,ITWX,ITX,IUX,IXPOS,IYX, /LOOKUP/
     1                IZX,CCX(6),CMX(6),CPX(6),CRX(6),CSX(6),CTWX(6),   /LOOKUP/
     2                CTX(6),CUX(6),CYX(6),CZX(6)                       /LOOKUP/
C
      COMMON /NHANCE/ IEX,CEX(6),ENHTAB(100)                            /NHANCE/
C
      COMMON /OUTPUT/ BDELTA,CF,CH,DELTA,DELSOT,DELSTR,FLAT,FORCE,HG,   /OUTPUT/
     A                PE,PHI,QW,SUMQDA,TE,THETA,TW,UE,X,XLARC,YR,Z1,    /OUTPUT/
     K                Z2,Z3,Z4,Z5,ZETA,ZME                              /OUTPUT/
C
      COMMON /SAVED/ A,B,C,Z11,Z11P,Z12,Z12P,Z13,Z13P,Z14,Z15,Z16,Z17   /SAVED/
C
      COMMON /TABLES/ PETAB(100),SMTAB(100),TETAB(100),TWTAB(100),      /TABLES/
     1                UETAB(100),XITAB(100),YITAB(100),ZMTAB(100)       /TABLES/
C
      WRITE(6,1)                                                        QUIT   7
    1 FORMAT(34H1QUITS COMMON DIAGNOSTIC OUTPUT...)                     QUIT   8
      WRITE(6,5) IFINT,AFINT,BFINT,CFINT,MMINT,TFINT                    QUIT   9
    5 FORMAT (//50X,21HCOMMON BLOCK /COFIIF//25X,I10,1P3E20.8,I10,E20.8)
      WRITE (6,2) IDXMAX,ICTAB,IPRINT,ITWTAB,IXTAB,MZETA,DXMAX,EPSZ,FJ,
     A            G,GAMO,PO,PHII,PIE,PRANDT,RBAR,SCALE,TO,THETAI,
     K            TOLCFA,TOLZET,TOLZME,ZMUO,ZMVIS,ZNSTAN
    2 FORMAT (//50X,20HCOMMON BLOCK /INPUT///3X,6I6,5(4X,1PE13.6)/5X,
     A   7(4X,1PE13.6)/5X,7(4X,1PE13.6)/)
      WRITE (6,10) BDELTA,CF,CH,DELTA,DELSOT,DELSTR,FLAT,FORCE,HG,PE,
     A             PHI,QW,SUMQDA,TE,THETA,TW,UE,X,XLARC,YR,Z1,Z2,Z3,
     K             Z4,Z5,ZETA,ZME
   10 FORMAT (//50X,21HCOMMON BLOCK /OUTPUT///4(5X,7(4X,1PE13.6)/)/)
      WRITE (6,3) NOCTAB,IS,ROJ,FJG,CJG,GM1O2,GOGM1,POMAX,CPO,HO,SO,
     A            TCTAB,CPTAB,BCP,CCP,DCP,GTAB,HTAB,BARB1,BARB2,BARB3
    3 FORMAT (//50X,21HCOMMON BLOCK /CSEVAL///3X,2I5,1P9E13.6/
```

```
     A          (10(1X,1PE12.6)))
      WRITE (6,4) CFAGT,CFAGP,CHPAR1,DX,DXRHO,HE,HW,IBEG,MZETAM,OOMZET,
     A                  PHIP,PRE103,RHOE,RHOUE,RMZETA,THETAP,XIBASE,
     K                  XIEND,ZETATM,ZMZETA,ZMZETM,ZMZETP
    4 FORMAT (//50X,20HCOMMON BLOCK /INTER///5X,7(5X,1PE13.6)/5X,2I9,
     A          6(5X,1PE13.6)/5X,7(5X,1PE13.6)/)
      WRITE (6,9) A,B,C,ZI1,ZI1P,ZI2,ZI2P,ZI3,ZI3P,ZI4,ZI5,ZI6,ZI7
    9 FORMAT (//50X,20HCOMMON BLOCK /SAVED///5X,7(5X,1PE13.6)/5X,
     A          6(5X,1PE13.6)/)
      WRITE (6,6) ICX,IMX,IPX,IRX,ISX,ITPOS,ITWX,ITX,IUX,IXPOS,IYX,IZX,
     1                  CCX,CMX,CPX,CRX,CSX,CTWX,CTX,CUX,CYX,CZX
    6 FORMAT (//50X,21HCOMMON BLOCK /LOOKUP///10X,12(I5,5X)/
     1          (5X,6(5X,1PE15.8)))
      IF (IXTAB .LE. 0)  GO TO 100
      IF (IXTAB .LT. 100)  GO TO 22
      I3 = 95
      GO TO 23
   22 I3 = IXTAB
   23 I3 = 10*(I3/10 + 1)
      WRITE  (6,7)
    7 FORMAT (//24X,77HCOMMON BLOCK /TABLES/  PETAB, SMTAB, TETAB, TWTAB
     1, UETAB, XITAB, YITAB, ZMTAB/)
    8 FORMAT (5X,I3,1P10E12.5)
      DO 24 I = 1,I3,10
      K = I + 9
   24 WRITE (6,8) I,(PETAB(J), J = I,K)
      DO 26 I = 1,I3,10
      K = I + 9
   26 WRITE (6,8) I,(SMTAB(J), J = I,K)
      DO 27 I = 1,I3,10
      K = I + 9
   27 WRITE (6,8) I,(TETAB(J), J = I,K)
      DO 28 I = 1,I3,10
      K = I + 9
   28 WRITE (6,8) I,(TWTAB(J), J = I,K)
      DO 29 I = 1,I3,10
      K = I + 9
   29 WRITE (6,8) I,(UETAB(J), J = I,K)
      DO 30 I = 1,I3,10
      K = I + 9
   30 WRITE (6,8) I,(XITAB(J), J = I,K)
      DO 31 I = 1,I3,10
      K = I + 9
   31 WRITE (6,8) I,(YITAB(J), J = I,K)
      DO 32 I = 1,I3,10
      K = I + 9
   32 WRITE (6,8) I,(ZMTAB(J), J = I,K)
      WRITE (6,11) ICOOL,IDUMP,ITZTAB,AL,COEFCL,CPL,DELXBA,DIATUB,
     1                  FLOWRT,MASSL,PRANDL,RAMDL,RAMDW,REYL,SUMQGA,SUMQWI,
     2                  THICK,TL0,TL1,TL2,TLCA,TOLITE,TUBEN,TWGCA,ZMYUL,
     3                  CPLTAB,RAMTAB,TZTAB,ZMYTAB
   11 FORMAT (//51X,19HCOMMON BLOCK /COOL///55X,I1,3X,I1,3X,I2/
     1           11(2X,1PE10.4)/11(2X,E10.4)/(10(2X,E11.5)))
      DO 33 I = 1,I3,10
      K = I + 9
   33 WRITE (6,8) I,(ALTAB(J), J = I,K)
```

```
      DO 34 I = 1,13,10
      K = I + 9
   34 WRITE (6,8) I,(TLTAB(J), J = I,K)
      DO 35 I = 1,13,10
      K = I + 9
   35 WRITE (6,8) I,(THITAB(J), J = I,K)
      DO 36 I = 1,13,10
      K = I + 9
   36 WRITE (6,8) I,(TWGTAB(J), J = I,K)
      DO 37 I = 1,13,10
      K = I + 9
   37 WRITE (6,8) I,(TLCTAB(J), J = I,K)
      WRITE (6,12) IEX,CEX
   12 FORMAT (//50X,21HCOMMON BLOCK /NHANCE///3X,I3,6(5X,1PE15.8))
      DO 38 I = 1,13,10
      K = I + 9
   38 WRITE (6,8) I, (ENHTAB(J), J = I,K)
  100 CALL DIRECT
      END                                                       QUIT  41
```

READIN

```
      SUBROUTINE READIN                                                 READ0001
C
      COMMON /COOL/ ICOOL,IDUMP,ITZTAB,AL,COEFCL,CPL,DELXBA,DIATUB,     /COOL/
     1              FLOWRT,MASSL,PRANDL,RAMDL,RAMDW,REYL,SUMQGA,SUMQWI, /COOL/
     2              THICK,TLO,TLI,TL2,TLCA,TOLITE,TUBEN,TWGCA,ZMYUL,    /COOL/
     3              CPLTAB(20),RAMTAB(20),TZTAB(20),ZMYTAB(20),         /COOL/
     4              ALTAB(100),THITAB(100),TLCTAB(100),TLTAB(100),      /COOL/
     5              TWGTAB(100)                                         /COOL/
      REAL MASSL                                                        /COOL/
C
      COMMON /CSEVAL/ NOCTAB,IS,ROJ,FJG,CJG,GM102,GOGM1,POMAX,CPO,HO,   /CSEVAL/
     A                SO,TCTAB(20),CPTAB(20),BCP(20),CCP(20),DCP(20),   /CSEVAL/
     K                GTAB(20),HTAB(20),BARB1(20),BARB2(20),BARB3(20)   /CSEVAL/
C
      COMMON /INPUT/ IDXMAX,ICTAB,IPRINT,ITWTAB,IXTAB,MZETA,DXMAX,      /INPUT/
     A               EPSZ,FJ,G,GAMO,PO,PHII,PIE,PRANDT,RBAR,SCALE,TO,   /INPUT/
     K               THETAI,TOLCFA,TOLZET,TOLZME,ZMUO,ZMVIS,ZNSTAN      /INPUT/
C
      COMMON /NHANCE/ IEX,CEX(6),ENHTAB(100)                            /NHANCE/
C
      COMMON /TABLES/ PETAB(100),SMTAB(100),TETAB(100),TWTAB(100),      /TABLES/
     1                UETAB(100),XITAB(100),YITAB(100),ZMTAB(100)       /TABLES/
C
      DIMENSION PITAB(100),TITAB(100),TITLE(13),VITAB(100)
      EQUIVALENCE (PETAB,PITAB),(TETAB,TITAB),(UETAB,VITAB)
C
      NAMELIST /NAM1/ ALTAB,COEFCL,CPLTAB,CPTAB,DXMAX,ENHTAB,EPSZ,FJ,    /NAM1/
     1                FLOWRT,G,GAMO,ICOOL,ICTAB,IDUMP,IPRINT,ITWTAB,     /NAM1/
     2                ITZTAB,IXTAB,MASSL,MZETA,PO,PETAB,PHII,PITAB,      /NAM1/
     3                RAMDW,RAMTAB,RBAR,SCALE,SMTAB,TO,TCTAB,TETAB,      /NAM1/
     4                THETAI,THITAB,TITAB,TLTAB,TOLCFA,TOLITE,TOLZET,    /NAM1/
     5                TOLZME,TUBEN,TWTAB,TZTAB,UETAB,VITAB,XITAB,YITAB,  /NAM1/
     6                ZMTAB,ZMUO,ZMVIS,ZMYTAB,ZNSTAN                     /NAM1/
C
      SCALE = 1.0                                                       READ0026
      MZETA        = 7                                                  READ0027
      ZNSTAN       = 0.1                                                READ0028
      FJ           = 778.2                                              READ0029
      G            = 32.174                                             READ0030
      TOLCFA       = 1.0E-04                                            READ0031
      TOLITE = 0.0020
      TOLZME       = 1.0E-07                                            READ0032
      TOLZET       = 0.0003                                             READ0033
      DXMAXO       = DXMAX                                              READ0034
      DXMAX        = -28982.0                                           READ0035
      READ(5,2) TITLE                                                   READ0036
    2 FORMAT (13A6)
      READ(5,NAM1)                                                      READ0038
      IF (DXMAX .NE. -28982.0)   GO TO 411
      IF (IDXMAX .EQ. 0)   GO TO 415
      DXMAX = DXMAXO
      GO TO 416                                                         READ0043
  411 IF (DXMAX .LE. 0.0)   GO TO 414
      IDXMAX = 1
      GO TO 416                                                         READ0045
```

```
 414 IDXMAX        = 0                                                   READ0046
 415 DXMAX        =( ( XITAB(IXTAB) - XITAB(1) ) / 100.0 ) * SCALE       READ0047
416  IF (EPSZ .LE. 0.0)  WRITE (6,7)
 7   FORMAT (//////////56X,19H*** INFORMATION ***//30X,44H1.  THIS CASE
    1 CONSIDERS TWO-DIMENSIONAL FLOW//30X,32H2.  THE NOZZLE WIDTH IS ON
    2E FOOT//30X,59H3.  THE SIDE WALLS ARE ASSUMED TO BE ADIABATIC AND
    3INVISCID//30X,68H4.  HEAT TRANSFER OCCURS ONLY THROUGH THE ONE FOO
    4T WIDE CURVED WALLS//30X,59H5.  THE CALCULATED THRUST LOSS IS BASE
    5D ON TWO CURVED WALLS//30X,65H6.  THE CALCULATED THRUST IS BASED O
    6N AN AREA OF ONE BY 2*YR FEET//30X,55H7.  CHECK THE INPUT VALUES F
    7OR FLOWRT, MASSL, AND TUBEN/)
     WRITE (6,3) TITLE
 3   FORMAT (1H1,27X,13A6//)
     IERROR        = 0                                                   READ0050
     WRITE(6,102) MZETA                                                  READ0051
 102 FORMAT(45H MZETA  = VELOCITY PROFILE POWER LAW EXPONENT27X1H=I4)    READ0052
     IF (MZETA .GE. 0)  GO TO 25
     WRITE (6,300)
 300 FORMAT ( 47H **ERROR** VALUE MUST BE GREATER THAN ZERO (0). // )    READ0055
     IERROR        = 1                                                   READ0056
  25 WRITE(6,103) IPRINT                                                 READ0057
 103 FORMAT(73H IPRINT = PRINT AT EVERY CALCULATED POINT(=1) OR AT INPUREAD0058
    1T INTERVALS(=0) =I4)                                                READ0059
     IF (IPRINT .EQ. 1 .OR. IPRINT .EQ. 0)  GO TO 513
     WRITE (6,502)
 502 FORMAT ( 45H **ERROR** VALUE MUST BE ZERO (0) OR ONE (1).  // )     READ0063
     IERROR        = 1                                                   READ0064
513  WRITE(6,104) IXTAB
 104 FORMAT(52H IXTAB  = NUMBER OF POINTS IN X .VS. Y .VS. M TABLES20X1READ0067
    1H=I4)                                                               READ0068
     IF (IXTAB .GE. 4 .AND. IXTAB .LE. 100)  GO TO 30
     WRITE (6,304)
304  FORMAT (/2X,104H** ERROR ** VALUE MUST BE GREATER THAN OR EQUAL TO
    1 FOUR (4) OR LESS THAN OR EQUAL TO ONE HUNDRED (100). //)
     IERROR        = 1                                                   READ0076
  30 WRITE(6,105) ICTAB                                                  READ0077
 105 FORMAT(45H ICTAB  = NUMBER OF POINTS IN CP .VS. T TABLE27X1H=I4)    READ0078
     IF (ICTAB .EQ. 0)  GO TO 37
     IF (ICTAB .GE. 3 .AND. ICTAB .LE. 20)  GO TO 37
     WRITE (6,306)
306  FORMAT (/2X,98H** ERROR ** VALUE MUST BE GREATER THAN OR EQUAL TO
    1THREE (3) OR LESS THAN OR EQUAL TO TWENTY (20).///)
     IERROR        = 1                                                   READ0089
  37 WRITE(6,106) ITWTAB                                                 READ0090
 106 FORMAT(73H ITWTAB = WALL TEMP. OPTION -- ADIABATIC(=-1), CONSTANT(READ0091
    1=0), TABLE(=1)  =I4)                                                READ0092
     IF (IABS(ITWTAB) .EQ. 1 .OR. ITWTAB .EQ. 0)  GO TO 523
     WRITE (6,512)
 512 FORMAT ( 67H **ERROR** VALUE MUST BE ZERO (0), PLUS ONE (1), OR MIREAD0096
    1NUS ONE (-1).    // )                                               READ0097
     IERROR        = 1                                                   READ0098
523  WRITE(6,111) TO
 111 FORMAT(48H TO     = FREE STREAM STAGNATION TEMPERATURE    24X1H=1PREAD0101
    1E15.7)                                                              READ0102
     IF (TO .GT. 0.0)  GO TO 41
     WRITE (6,300)
```

```
      IERROR        = 1                                                 READ0105
   41 WRITE(6,112) PO                                                   READ0106
  112 FORMAT(50H PO      = FREE STREAM STAGNATION PRESSURE          22X1H=READ0107
     11PE15.7)                                                          READ0108
      IF (PO .GT. 0.0)  GO TO 43
      WRITE (6,300)
      IERROR        = 1                                                 READ0111
   43 WRITE(6,113) GAMO                                                 READ0112
  113 FORMAT(44H GAMO    = STAGNATION RATIO OF SPECIFIC HEATS28X1H=1PE15.READ0113
     17)                                                                READ0114
      IF (ICTAB .NE. 0)  GO TO 47
      IF (GAMO .GT. 1.0)  GO TO 47
      WRITE (6,541)
  541 FORMAT ( 48H **ERROR** VALUE MUST BE GREATER THAN ONE (1.0).  // )READ0118
      IERROR        = 1                                                 READ0119
   47 WRITE (6,115) ZMUO
  115 FORMAT(38H ZMUO    = STAGNATION VISCOSITY        34X1H=1PE15.7)   READ0126
      IF (ZMUO .GT. 0.0)  GO TO 51
      WRITE (6,300)
      IERROR        = 1                                                 READ0129
   51 WRITE(6,116) ZMVIS                                                READ0130
  116 FORMAT(47H ZMVIS   = EXPONENT OF VISCOSITY-TEMPERATURE LAW25X1H=1PEREAD0131
     115.7)                                                             READ0132
      WRITE(6,117) ZNSTAN                                               READ0133
  117 FORMAT(45H ZNSTAN = BOUNDARY LAYER INTERACTION EXPONENT27X1H=1PE15READ0134
     1.7)                                                               READ0135
      WRITE(6,118) DXMAX                                                READ0136
  118 FORMAT(31H DXMAX   = MAXIMUM STEP SIZE    41X1H=1PE15.7)          READ0137
      IF (THETAI .LT. 0.0)  GO TO 44
      WRITE (6,119) THETAI
  119 FORMAT(49H THETAI = INITIAL VALUE OF MOMENTUM THICKNESS   23X1H=1READ0140
     1PE15.7)                                                           READ0141
      WRITE (6,120) PHII
  120 FORMAT(47H PHII    = INITIAL VALUE OF ENERGY THICKNESS    25X1H=1PEREAD0143
     115.7)                                                             READ0144
   44 WRITE(6,121) EPSZ
  121 FORMAT(51H EPSZ    = GEOMETRY... AXISYMMETRIC(=1.), PLANE(=0.)21X1HREAD0147
     1=1PE15.7)                                                         READ0148
      IF (EPSZ .EQ. 0.0 .OR. EPSZ .EQ. 1.0)  GO TO 533
      WRITE (6,502)
      IERROR        = 1                                                 READ0152
  533 WRITE(6,122) RBAR
  122 FORMAT (1X,35HRBAR    = GAS CONSTANT AT STAGNATION,36X,1H=,1PE15.7)
      IF (RBAR .GT. 0.0)  GO TO 53
      WRITE (6,300)
      IERROR        = 1                                                 READ0158
   53 WRITE(6,123) FJ                                                   READ0159
  123 FORMAT(51H FJ      = CONVERSION BETWEEN THERMAL AND WORK UNITS21X1HREAD0160
     1=1PE15.7)                                                         READ0161
      IF (FJ .GT. 0.0)  GO TO 55
      WRITE (6,300)
      IERROR        = 1                                                 READ0164
   55 WRITE(6,124) G                                                    READ0165
  124 FORMAT(57H G       = PROPORTIONALITY CONSTANT IN EQUATION -- F=M/G*READ0166
     1A15X1H=1PE15.7)                                                   READ0167
      IF (G .GT. 0.0)  GO TO 420
```

```
      WRITE (6,300)
      IERROR         = 1                                                READ0170
  420 WRITE(6,421) SCALE                                                READ0171
  421 FORMAT ( 30H SCALE  = CONTOUR SCALE FACTOR, 42X, 1H=, 1PE15.7 )   READ0172
      IF (TOLCFA .EQ. 1.0E-4)  GO TO 402
      WRITE (6,401) TOLCFA
  401 FORMAT ( 47H TOLCFA = TOLERANCE FOR SKIN FRICTION ITERATION, 25X, READ0175
     1          1H=, 1PE15.7 )                                          READ0176
 402  IF (TOLZET .EQ. 0.0003)  GO TO 405
      WRITE (6,404) TOLZET
  404 FORMAT ( 49H TOLZET = TOLERANCE FOR SHAPE PARAMETER ITERATION,    READ0179
     1          23X, 1H=, 1PE15.7 )                                     READ0180
 405  IF (TOLZME .EQ. 1.0E-7)  GO TO 205
      WRITE (6,407) TOLZME
  407 FORMAT ( 65H TOLZME = TOLERANCE FOR MACH NO. - TEMPERATURE RELATIOREAD0183
     1N ITERATION, 7X, 1H=, 1PE15.7 )                                   READ0184
 205  WRITE (6,900) ITZTAB,IDUMP,FLOWRT,MASSL,RAMDW,COEFCL,TUBEN,
     1              TOLITE,ICOOL
 900  FORMAT (1X,68HITZTAB = NUMBER OF POINTS IN T .VS. CPL .VS. RAMDL .
     1VS. ZMYUL TABLES,3X,1H=,I4/1X,63HIDUMP  = COOLANT FLOW OPTION -- S
     2AME DIRECTION(=1), REVERSE(=0),8X,1H=,I4/1X,52HFLOWRT = COMBUSTION
     3 CHAMBER MASS FLOW RATE (LBM/SEC),19X,1H=,1PE15.7/1X,41HMASSL  = C
     4OOLANT MASS FLOW RATE (LBM/SEC),30X,1H=,E15.7/1X,46HRAMDW  = HEAT
     5CONDUCTIVITY OF THE CHAMBER WALL,25X,1H=,E15.7/1X,31HCOEFCL = COEF
     6FICIENT OF COOLING,40X,1H=,E15.7/1X,20HTUBEN  = TUBE NUMBER,51X,
     7 1H=,E15.7/1X,52HTOLITE = TOLERANCE FOR TOTAL HEAT TRANSFER ITERAT
     8ION,19X,1H=,E15.7/1X,64HICOOL  = COOLING OPTION -- WITH COOLING(=1
     9), WITHOUT COOLING(=0),7X,1H=,I4)
      IF (ICTAB .LE. 0 .AND. ITZTAB .LE. 0)  GO TO 11
      WRITE (6,131)
 131  FORMAT (//2X,1HI,5X,13HSPECIFIC HEAT,5X,11HTEMPERATURE,5X,
     1 12HCOOLANT TEMP,5X,10HCOOLANT CP,5X,12HCONDUCTIVITY,5X,
     2 9HVISCOSITY)
      IMAX = AMAX1(ICTAB,ITZTAB)
      DO 133 I = 1,IMAX
      IF (I .LE. ICTAB .AND. I .LE. ITZTAB)  GO TO 130
      IF (ICTAB .GT. ITZTAB)  GO TO 132
      WRITE (6,1) I,TZTAB(I),CPLTAB(I),RAMTAB(I),ZMYTAB(I)
 1    FORMAT (I3,41X,F9.3,6X,F10.6,5X,F12.10,3X,F12.10)
      GO TO 133
 130  WRITE (6,4) I,CPTAB(I),TCTAB(I),TZTAB(I),CPLTAB(I),RAMTAB(I),
     1             ZMYTAB(I)
 4    FORMAT (I3,5X,F13.10,6X,F9.3,8X,F9.3,6X,F10.6,5X,F12.10,3X,F12.10)
      GO TO 133
 132  WRITE (6,5) I,CPTAB(I),TCTAB(I)
 5    FORMAT (I3,5X,F13.10,6X,F9.3)
 133  CONTINUE
      IF (ICTAB .LE. 0)  GO TO 11
      II             = ICTAB - 1                                        READ0193
      DO 59  I = 1, II                                                  READ0194
      IF (TCTAB(I+1) .GT. TCTAB(I))  GO TO 59
      WRITE (6,310)
 310  FORMAT (/2X,99H** ERROR ** TABLE OF SPECIFIC HEATS - TEMPERATURE V
     1ALUES MUST BE IN MONATONICALLY INCREASING ORDER.//)
      IERROR         = 1                                                READ0201
   59 CONTINUE                                                          READ0202
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```
      IF (TCTAB(1) .GT. 0.0)  GO TO 61
      WRITE(6,312)                                                      READ0205
  312 FORMAT (/2X,87H** ERROR ** TABLE OF SPECIFIC HEATS - TEMPERATURE V
     1ALUES MUST BE GREATER THAN ZERO (0).//)
      IERROR = 1
   61 DO 63 I = 1,ICTAB
      IF (CPTAB(I) .GT. 0.0)  GO TO 63
      WRITE(6,313)                                                      READ0211
  313 FORMAT (/2X,89H** ERROR ** TABLE OF SPECIFIC HEATS - SPECIFIC HEAT
     1 VALUES MUST BE GREATER THAN ZERO (0).//)
      IERROR       = 1                                                  READ0214
   63 CONTINUE                                                          READ0215
   11 DO 65 I = 1,IXTAB
      IF (ZMTAB(I) .GT. 0.0)  GO TO 65
      WRITE (6,314)
  314 FORMAT (/2X,97H** ERROR ** TABLE OF MACH NUMBER DISTRIBUTION - MAC
     1H NUMBER VALUES MUST BE GREATER THAN ZERO (0).//)
      IERROR       = 1                                                  READ0223
   65 CONTINUE                                                          READ0224
      II           = IXTAB - 1                                          READ0225
      DO 67 I = 1, II                                                   READ0226
      IF (XITAB(I+1) .GE. XITAB(I))  GO TO 67
      WRITE (6,316)
  316 FORMAT ( 40H **ERROR** TABLE OF CONTOUR DESCRIPTION. / 69H AXIAL DREAD0229
     1ISTANCE VALUES (X) MUST BE IN MONOTONICALLY INCREASING ORDER. // )READ0230
      IERROR       = 1                                                  READ0231
   67 CONTINUE                                                          READ0232
      IF(ITWTAB) 14,13,12                                               READ0233
   12 DO 69  I = 1, IXTAB                                               READ0234
      IF (TWTAB(I) .GT. 0.0)  GO TO 69
      WRITE (6,317)
  317 FORMAT (/2X,102H** ERROR ** TABLE OF WALL TEMPERATURE DISTRIBUTION
     1 - TEMPERATURE VALUES MUST BE GREATER THAN ZERO (0).//)
      IERROR       = 1                                                  READ0239
   69 CONTINUE                                                          READ0240
      GO TO 14                                                          READ0241
   13 IF (TWTAB(1) .GT. 0.0)  GO TO 14
      WRITE (6,317)
      IERROR       = 1                                                  READ0245
   14 IF (SCALE .EQ. 1.0)  GO TO 424
      DO 423 I = 1,IXTAB
      XITAB(I)       = XITAB(I) * SCALE                                 READ0250
  423 YITAB(I)       = YITAB(I) * SCALE                                 READ0251
  424 IF (ITWTAB) 137,135,140
  135 WRITE (6,136) TWTAB(1)
  136 FORMAT (//2X,18HWALL TEMPERATURE =,F20.8)
  137 WRITE (6,6)
    6 FORMAT (1H1)
      WRITE (6,138)
  138 FORMAT (3X,1HI,12X,5HAXIAL,11X,6HRADIAL,10X,4HMACH,9X,8HPRESSURE,
     1 4X,11HSTATIC TEMP,7X,8HVELOCITY,6X,9HMOLECULAR/15X,6H(FEET),11X,
     2 6H(FEET),9X,6HNUMBER,8X,8H(LB/FT2),4X,11H(DEGREES R),7X,
     3 8H(FT/SEC),8X,6HWEIGHT)
      WRITE (6,139) (I,XITAB(I),YITAB(I),ZMTAB(I),PETAB(I),TETAB(I),
     1                 UETAB(I),SMTAB(I), I = 1,IXTAB)
  139 FORMAT (I4,6X,F11.6,6X,F11.6,6X,F9.6,6X,F10.3,6X,F9.3,6X,F9.3,6X,
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```
  1          F9.6)
      GO TO 145                                                         READ0260
140   WRITE (6,6)
      WRITE (6,142)
142   FORMAT (3X,1HI,12X,5HAXIAL,11X,6HRADIAL,10X,4HMACH,9X,8HPRESSURE,
     1 4X,11HSTATIC TEMP,7X,8HVELOCITY,6X,9HMOLECULAR,6X,9HWALL TEMP/
     2 15X,6H(FEET),11X,6H(FEET),9X,6HNUMBER,8X,8H(LB/FT2),4X,
     3 11H(DEGREES R),7X,8H(FT/SEC),8X,6HWEIGHT,5X,11H(DEGREES R))
      WRITE (6,141) (I,XITAB(I),YITAB(I),ZMTAB(I),PETAB(I),TETAB(I),
     1                 UETAB(I),SMTAB(I),TWTAB(I), I = 1,IXTAB)
141   FORMAT (I4,6X,F11.6,6X,F11.6,6X,F9.6,6X,F10.3,6X,F9.3,6X,F9.3,6X,
     1          F9.6,6X,F9.3)
145   IF (ICOOL .GT. 0)  WRITE (6,33) (I,ALTAB(I),TLTAB(I),THITAB(I),
     1                                 ENHTAB(I), I = 1,IXTAB)
 33   FORMAT (1H1,5X,1HI,5X,17HCOOLANT TUBE AREA,5X,19HCOOLANT TEMPERATU
     1RE,5X,14HWALL THICKNESS,5X,11HENHANCEMENT/16X,13H(SQUARE FEET),7X,
     2 17H(DEGREES RANKINE),13X,6H(FEET),7X,7HFACTORS/(4X,I3,11X,F11.8,
     2 14X,F10.3,8X,F11.8,5X,F11.8))
      IF (IXTAB .LE. 1)  GO TO 260
      DO 257 I = 2,IXTAB
      IF (XITAB(I) .GT. XITAB(I-1))  GO TO 257
      WRITE (6,212)
 212  FORMAT ( 33H **ERROR** TABLE OF XITAB VALUES. // )                READ0269
      IERROR      = 1                                                   READ0270
 257  CONTINUE                                                          READ0271
260   IF (ITWTAB .LT. 0)  GO TO 77
      IF (THETAI .GE. 0.0)  GO TO 77
      WRITE(6,76)
  76  FORMAT ( // 99H **ERROR** MACH ONE START DOES NOT PRODUCE REASONABREAD0276
     1LE VALUES FOR OTHER THAN AN ADIABATIC WALL CASE.  // )            READ0277
      IERROR      = 1                                                   READ0278
77    IF (IERROR .LE. 0)  RETURN
      CALL QUITS
      END                                                               READ0284
```

SEVAL

```
      SUBROUTINE SEVAL (IND1,AA,BB,CC)
C
      COMMON /CSEVAL/ NOCTAB,IS,ROJ,FJG,CJG,GM1O2,GOGM1,POMAX,CPO,HO,    /CSEVAL/
     A                SO,TCTAB(20),CPTAB(20),BCP(20),CCP(20),DCP(20),    /CSEVAL/
     K                GTAB(20),HTAB(20),BARB1(20),BARB2(20),BARB3(20)    /CSEVAL/
C
      COMMON /INPUT/ IDXMAX,ICTAB,IPRINT,ITWTAB,IXTAB,MZETA,DXMAX,       /INPUT/
     A               EPSZ,FJ,G,GAMO,PO,PHI1,PIE,PRANDT,RBAR,SCALE,TO,    /INPUT/
     K               THETAI,TOLCFA,TOLZET,TOLZME,ZMUO,ZMVIS,ZNSTAN       /INPUT/
C
C         DEFINE THE FUNCTION ROUTINE TO BE USED BY SEVAL
C
      GAPF(T,G,A1,B1,C1,D1) = G+A1*ALOG(T)+(B1+(C1+D1/3.*T)*T)*T-PR      SEVA  16
            T = AA                                                       SEVA  19
            A = BB                                                       SEVA  20
            B = CC                                                       SEVA  21
      IF(IND1-2)3,1,155                                                  SEVA  22
    1 B = B/FJG
      IF (ICTAB .GT. 0)  GO TO 35
      T = B/CPO
      A = CPO
      GO TO 600                                                          SEVA  27
    3 IF (IND1 .LT. 1)  GO TO 10
      IF (ICTAB .GT. 0)  GO TO 10
      A = CPO
      B = CJG*T
      GO TO 600                                                          SEVA  32
  155 PR = ROJ*ALOG(A/POMAX)
  160 STAB = GAPF(TCTAB(IS),GTAB(IS),BARB1(IS),BARB2(IS),BARB3(IS),
     A            DCP(IS))
      IF (B .GE. STAB)  GO TO 175
      IS = IS - 1
      IF (IS .LE. 0)  GO TO 17
      GO TO 160                                                          SEVA  38
  175 STAB = GAPF(TCTAB(IS+1),GTAB(IS),BARB1(IS),BARB2(IS),BARB3(IS),
     A            DCP(IS))
      IF (B .LT. STAB)  GO TO 190
      IS = IS + 1
      IF (IS .GE. 20)  GO TO 17
      GO TO 175                                                          SEVA  43
  190 IF (IS .GE. NOCTAB .OR. IS .LE. 0)  GO TO 17
      TTP = TCTAB(IS)
      FP = GAPF(TCTAB(IS),GTAB(IS),BARB1(IS),BARB2(IS),BARB3(IS),
     D            DCP(IS))
      TTPP = TCTAB(IS+1)
          FPP = STAB                                                     SEVA  50
      GO TO 75                                                           SEVA  51
   10 IF (T .GE. TCTAB(IS))  GO TO 15
      IS = IS - 1
      IF (IS .LE. 0)  GO TO 17
      GO  TO 10                                                          SEVA  54
   15 IF (T .LT. TCTAB(IS+1))  GO TO 16
      IS = IS + 1
      IF (IS .GE. 20)  GO TO 17
       GO  TO  15                                                        SEVA  57
```

```
16  IF (IS .GT. 0)  GO TO 19
 17 WRITE(6,18) IS,IND1,T,A,B
18  FORMAT (17HOSEVAL FAILURE...,5X,4HIS =,I4,5X,6HIND1 =,I2,5X,
   A        3HT =,1PE15.7,5X,3HA =,1PE15.7,5X,3HB =,1PE15.7)
    CALL QUITS
19  IF (IS .GE. NOCTAB)  GO TO 17
    IF (IND1) 70,65,60
60  DELT = T - TCTAB(IS)
    B = HTAB(IS) + CPTAB(IS)*DELT + 0.5*BCP(IS)*DELT**2 +
   A    CCP(IS)/3.0*DELT**3 + 0.25*DCP(IS)*DELT**4
    B = B*FJG
    GO TO 141
65  PR = ROJ*ALOG(A/POMAX)
    B = GAPF(T,GTAB(IS),BARB1(IS),BARB2(IS),BARB3(IS),DCP(IS))
    GO TO 600
70  A = POMAX*EXP((GTAB(IS) + BARB1(IS)*ALOG(T) + (BARB2(IS) +
   A              (BARB3(IS) + DCP(IS)/3.0*T)*T)*T - B)/ROJ)
    GO TO 600
35  IF (B .GE. HTAB(IS))  GO TO 50
    IS = IS - 1
    IF (IS .LE. 0)  GO TO 17
    GO TO 35
50  IF (B .LT. HTAB(IS+1))  GO TO 51
    IS = IS + 1
    IF (IS .GE. 20)  GO TO 17
    GO TO 50
51  IF (IS .GE. NOCTAB .OR. IS .LE. 0)  GO TO 17
    TTP = TCTAB(IS)
    FP = HTAB(IS)
    TTPP = TCTAB(IS+1)
    FPP = HTAB(IS+1)
 75 TTO  = (TTP * (FPP - B ) -  TTPP * (FP - B )) /( FPP - FP)
    IF (IND1 .GT. 2)  GO TO 215
    DELT = TTO - TCTAB(IS)
    FO = HTAB(IS) + CPTAB(IS)*DELT + 0.5*BCP(IS)*DELT**2 +
   A    CCP(IS)/3.0*DELT**3 + 0.25*DCP(IS)*DELT**4
    GO TO 220
215 FO = GAPF(TTO,GTAB(IS),BARB1(IS),BARB2(IS),BARB3(IS),DCP(IS))
220 TT1P = (TTO * (FPP - B )  - TTPP *(FO - B)) /( FPP - FO)
    TT1PP   =    (TTO   * ( FP - B ) - TTP * ( FO - B))/( FP   - FO)
    N = -1
    TAU   =    TTO
    SF    =    FO
104 IF (ABS((SF - B)/B) .LE. 1.0E-7)  GO TO 100
    IF (SF .LE. B)  GO TO 135
    TTPP = TAU
    FPP = SF
    GO TO 130
100 T   =  TAU
    GO TO 225
135 TTP    =   TAU
     FP    =   SF
130  IF ( N )115 , 120 , 125
115  N  =  0
     TAU   =   TT1P
     GO  TO 85
```

```
 120  N     =   1                                                      SEVA 112
      TAU   =   TT1PP                                                  SEVA 113
 85   IF (TAU .LE. TTP .OR. TAU .GE. TTPP)  GO TO 130
      IF (IND1 .LE. 2)  GO TO 95
      SF = GAPF(TAU,GTAB(IS),BARB1(IS),BARB2(IS),BARB3(IS),DCP(IS))
      GO TO 104                                                        SEVA 118
 95   DELT = TAU - TCTAB(IS)
      SF = HTAB(IS) + CPTAB(IS)*DELT + 0.5*BCP(IS)*DELT**2 +
     A     CCP(IS)/3.0*DELT**3 + 0.25*DCP(IS)*DELT**4
      GO TO 104                                                        SEVA 122
125   IF (((FPP - FP)/(FP + FPP)) .GT. 0.0010)  GO TO 75
      T = (TTP*(FPP - B) - TTPP*(FP - B))/(FPP - FP)
225   IF (IND1 .GT. 2)  GO TO 600
      DELT = T - TCTAB(IS)
141   A = CPTAB(IS) + BCP(IS)*DELT + CCP(IS)*DELT**2 + DCP(IS)*DELT**3
600   AA = T
           BB = A                                                      SEVA 130
      IF (IND1 .EQ. 2)  RETURN
      CC = B
      RETURN
      END                                                              SEVA 134
```

START

```
      SUBROUTINE START                                                  STAR   1
C
      COMMON /COFIIF/ IFINT,AFINT,BFINT,CFINT,MMINT,TFINT               /COFIIF/
C
      COMMON /CSEVAL/ NOCTAB,IS,ROJ,FJG,CJG,GM102,GOGM1,POMAX,CPO,HO,   /CSEVAL/
     A                SO,TCTAB(20),CPTAB(20),BCP(20),CCP(20),DCP(20),   /CSEVAL/
     K                GTAB(20),HTAB(20),BARB1(20),BARB2(20),BARB3(20)   /CSEVAL/
C
      COMMON /INPUT/ IDXMAX,ICTAB,IPRINT,ITWTAB,IXTAB,MZETA,DXMAX,      /INPUT/
     A               EPSZ,FJ,G,GAMO,PO,PHII,PIE,PRANDT,RBAR,SCALE,TO,   /INPUT/
     K               THETAI,TOLCFA,TOLZET,TOLZME,ZMUO,ZMVIS,ZNSTAN      /INPUT/
C
      COMMON /INTER/ CFAGT,CFAGP,CHPAR1,DX,DXRHO,HE,HW,IBEG,MZETAM,     /INTER/
     A               OOMZET,PHIP,PREI03,RHOE,RHOUE,RMZETA,THETAP,       /INTER/
     K               XIBASE,XIEND,ZETATM,ZMZETA,ZMZETM,ZMZETP           /INTER/
C
      COMMON /LOOKUP/ ICX,IMX,IPX,IRX,ISX,ITPOS,ITWX,ITX,IUX,IXPOS,IYX, /LOOKUP/
     1                IZX,CCX(6),CMX(6),CPX(6),CRX(6),CSX(6),CTWX(6),   /LOOKUP/
     2                CTX(6),CUX(6),CYX(6),CZX(6)                       /LOOKUP/
C
      COMMON /OUTPUT/ BDELTA,CF,CH,DELTA,DELSOT,DELSTR,FLAT,FORCE,HG,   /OUTPUT/
     A                PE,PHI,QW,SUMQDA,TE,THETA,TW,UE,X,XLARC,YR,Z1,    /OUTPUT/
     K                Z2,Z3,Z4,Z5,ZETA,ZME                              /OUTPUT/
C
      COMMON /SAVED/ A,B,C,ZI1,ZI1P,ZI2,ZI2P,ZI3,ZI3P,ZI4,ZI5,ZI6,ZI7   /SAVED/
C
      COMMON /TABLES/ PETAB(100),SHTAB(100),TETAB(100),TWTAB(100),      /TABLES/
     1                UETAB(100),XITAB(100),YITAB(100),ZMTAB(100)       /TABLES/
C
      IMX           = -1                                                STAR  35
      IYS = -1
      ITWX          = -1                                                STAR  37
      I             = 0                                                 STAR  38
    5 I             = I + 1                                             STAR  39
      IF ( ZMTAB(I) - 1. ) 10, 20, 15                                   STAR  40
   10 IF (I .LT. IXTAB)  GO TO 5
   25 WRITE (6,1000)
 1000 FORMAT (/35X,62H** START FAILURE ** MACH NUMBER TABLE DOES NOT INC
     1LUDE M = 1.0//)
      CALL QUITS
   20 X             = XITAB(I)                                          STAR  43
      IBEG          = I + 1                                             STAR  44
      GO TO 50                                                          STAR  45
   15 IF (I .LE. 1)  GO TO 25
      XG = XITAB(I)
      ZME           = ZMTAB(I)                                          STAR  49
      X             = XITAB(I-1) + ( XITAB(I) - XITAB(I-1) ) / ( ZMTAB(I)STAR  50
     1                - ZMTAB(I-1) ) * ( 1. - ZMTAB(I-1) )              STAR  51
      J             = 0                                                 STAR  52
      IBEG          = I                                                 STAR  53
   35 J             = J + 1                                             STAR  54
      XO            = XG                                                STAR  55
      ZMO           = ZME                                               STAR  56
      XG            = X                                                 STAR  57
      CALL XNTERP ( X, ZME, ZMEP, IMX, XITAB, ZMTAB, IXTAB, CMX, IMX )  STAR  58
```

```
      IF (ABS(ZME - 1.0) .LE. TOLCFA)  GO TO 50
      ZMX = (XG - XO)/(ZME - ZMO)
      X             = XO + ( 1. - ZMO ) * ZMX                             STAR  61
      IF (J .LE. 50)  GO TO 35
      WRITE (6,1010)
 1010 FORMAT ( 64H **START FAILURE... MACH NO. CALCULATION EXCEEDED 50 ISTAR  25
     1TERATIONS. // )                                                     STAR  26
   50 CALL XNTERP ( X, ZME, ZMEP, IMX, XITAB, ZMTAB, IXTAB, CMX, IMX )   STAR  64
      CALL XNTERP (X,YR,YRP,IYS,XITAB,YITAB,IXTAB,CYX,IMX)
      CALL GETPT (ZME,PSE,TE)
      CALL SEVAL ( 1, TE, CPE, HE )                                       STAR  67
      GAME          = CPE / ( CPE - RBAR / FJ )                           STAR  68
      HB            = HO - HE                                             STAR  69
      UE            = SQRT( 2.* HB )                                      STAR  70
      RHSE = PSE/TE/RBAR
      ZMU           = ZMUO * ( TE / TO ) ** ZMVIS                         STAR  72
      HAW           = HE +(PRANDT ** ( 1./ 3. )) * HB                     STAR  73
      CALL SEVAL ( 2, TAW, CPAW, HAW )                                    STAR  74
      IF ( ITWTAB ) 55, 60, 65                                            STAR  75
   55 HW            = HAW                                                 STAR  76
      TW            = TAW                                                 STAR  77
      GO TO 70                                                            STAR  78
   60 HW = TWTAB(2)
      TW            = TWTAB(1)                                            STAR  80
      GO TO 70                                                            STAR  81
   65 CALL XNTERP ( X, TW, TWP, ITWX, XITAB, TWTAB, IXTAB, CTWX, IMX )   STAR  82
      CALL SEVAL ( 1, TW, CPW, HW )                                       STAR  83
   70 AFINT         = HW                                                  STAR  84
      BFINT         = HO - HW                                             STAR  85
      CFINT         = - HB                                                STAR  86
      TFINT         = TE                                                  STAR  87
      MMINT         = MZETA                                               STAR  88
      IFINT         = 1                                                   STAR  89
      CALL INTZET ( 0., 1., ZI1 )                                         STAR  90
      IFINT         = 2                                                   STAR  91
      CALL INTZET ( 0., 1., ZI2 )                                         STAR  92
      DELSOT        = ( 1. / ZMZETA - ZI2 ) / ZI1                         STAR  93
      IF (EPSZ .EQ. 0.0)  GO TO 72
      ERASE5 = YRP/YR
      GO TO 73                                                            STAR  96
   72 ERASE5        = 1.0                                                 STAR  97
   73 ERASE4        = ( 1. + DELSOT ) / ( 1. + ( GAME - 1. ) / 2. ) *    STAR  98
     1                  ZMEP + ERASE5                                     STAR  99
      IF (ERASE4 .NE. 0.0)  GO TO 80
      WRITE (6,1020)
 1020 FORMAT (/2X,74H** START FAILURE ** INITIAL VALUES FOR PHII AND THE
     1TAI CANNOT BE COMPUTED./3X,55H* CHECK SLOPES OF MACH NUMBER AND CO
     2NTOUR INPUT TABLES.//)
   80 ERASE1        = 17.2 * ( TO - TAW ) / TAW                           STAR 103
      ERASE2        = 305. * ( TE - TO ) / TAW                            STAR 104
      CTHET = 0.50*SQRT(1.0 + YRP**2)/ERASE4
      CRT2 = (TAW/TE)**(1.0 - ZMVIS)*RHSE*UE/(ZMU*CTHET)
      ERASE3        = TAW / TE                                            STAR 108
      CFA           = .001                                                STAR 109
      JE            = 0                                                   STAR 110
   85 JE            = JE + 1                                              STAR 111
```

```
      CFG            = CFA                                                STAR 112
      THETA          = CFG * CTHET                                        STAR 113
      CR             = CRT2 * THETA * THETA                               STAR 114
      CFB = CFEVAL(CR)                                                    STAR 115
      TTAW = 1.0 + ERASE1*SQRT(CFB/2.0) + ERASE2*CFB/2.0
      IF (TTAW .GT. 0.0)  GO TO 120
      CFA = 3.0*CFG
  105 Z4             = CFA                                                STAR 119
      Z2             = CFG                                                STAR 120
  110 IF (JE .LE. 50)  GO TO 85
      WRITE(6,1030)                                                       STAR 123
 1030 FORMAT (/2X,74H** START FAILURE ** INITIAL VALUES FOR PHII AND THE
     1TAI CANNOT BE COMPUTED./3X,27H* CHECK SKIN FRICTION DATA.//)
      GO TO 140                                                           STAR 124
  120 CFA            = CFB / ( ERASE3 * TTAW ** ZMVIS )                   STAR 125
      IF (ABS((CFA - CFG)/(CFA + CFG)) .LE. TOLCFA)  GO TO 140
      IF (JE .LT. 2)  GO TO 105
      Z3 = Z4
      Z1             = Z2                                                 STAR 129
      Z4             = CFA                                                STAR 130
      Z2             = CFG                                                STAR 131
      ZS5 = (Z4 - Z3)/(Z2 - Z1)
      CFA = (Z4 - ZS5*Z2)/(1.0 - ZS5)
      GO TO 110                                                           STAR 134
  140 THETAI = CFA*CTHET
      PHII = THETAI
      CFAGT          = CFA                                                STAR 138
      ZETA           = 1.                                                 STAR 139
      WRITE (6,1040) X,YR,THETAI,PHII
 1040 FORMAT ( 94H0INITIAL VALUES FOR ENERGY ( PHII) AND MOMENTUM ( THETSTAR  30
     1AI) THICKNESSES CALCULATED AT THROAT...  / 5H X = , 1PE14.7, 5X,  STAR  31
     2 4HY = , E14.7, 5X, 8HTHETAI =, E14.7, 5X, 6HPHII =, E14.7 // )   STAR  32
      RETURN                                                              STAR 141
      END                                                                 STAR 142
```

```
XNTERP
      SUBROUTINE XNTERP (X,Y,YP,IXIN,XAR,YAR,IAR,CAR,IPOS)
C
      DIMENSION C(6),CAR(6),XAR(IAR),XI(4),YAR(IAR),YI(4)
C
      IXO=IXIN                                                          XNTE   4
      IXMAX=IAR-1                                                       XNTE   5
      IX=IPOS                                                           XNTE   6
      DO 11 I = 1,6
   11 C(I)=CAR(I)                                                       XNTE  21
      IF (IXO .GT. 0)  GO TO 13
   12 IFIRST=1                                                          XNTE  23
      IXO=IXMAX+2                                                       XNTE  24
      IX=1                                                              XNTE  25
   13 IF (IX .LE. 0)  GO TO 12
   20 IF (X .GE. XAR(IX))  GO TO 25
      IX = IX - 1
      IF (IX .GT. 0)  GO TO 20
   22 WRITE(6,23) X, XAR(1), XAR(IXMAX+1), YAR(1), YAR(IXMAX+1)         XNTE  30
   23 FORMAT ( 28H0XNTERP OUT OF RANGE...,  X =, 1PE15.7, 8H, X(1) =,   XNTE  31
     1          E15.7, 8H, X(N) =, E15.7 / 43X, 8H, Y(1) =, E15.7,      XNTE  32
     2          8H  Y(N) =, E15.7 // )                                  XNTE  33
      CALL QUITS                                                        XNTE  34
   25 IF (X .LE. XAR(IX+1))  GO TO 27
      IX = IX + 1
      IF(IX-IXMAX) 25,25,22                                             XNTE  37
   27 DO 28 I=1,4                                                       XNTE  38
      I1=IX-2+I                                                         XNTE  39
      XI(I)=XAR(I1)                                                     XNTE  40
   28 YI(I)=YAR(I1)                                                     XNTE  41
      DX2 = X - XI(2)
      DX32=XI(3)-XI(2)                                                  XNTE  49
      IF (IX - IXO) 40,31,60
   31 IXOGO=0                                                           XNTE  51
      IF (IX .GT. 1)  GO TO 33
   32 IGO=-1                                                            XNTE  53
      GO TO 101                                                         XNTE  54
   33 IF (IX .LT. IXMAX)  GO TO 35
      IF (IFIRST .EQ. 0)  GO TO 34
      IFIRST = 0
      IGO=1                                                             XNTE  58
      GO TO 45                                                          XNTE  59
   34 IGO=1                                                             XNTE  60
      GO TO 100                                                         XNTE  61
   35 IGO=0                                                             XNTE  62
      GO TO 100                                                         XNTE  63
   40 IXOGO=-1                                                          XNTE  64
      IF (IX .LT. IXO - 1)  GO TO 42
      C(4) = C(1)
      C(5)=C(2)                                                         XNTE  67
      C(6)=C(3)                                                         XNTE  68
      GO TO 43                                                          XNTE  69
   42 C(4)=YI(2)                                                        XNTE  70
      DX42=XI(4)-XI(2)                                                  XNTE  71
      DY32=YI(3)-YI(2)                                                  XNTE  72
      DYOX32=DY32/DX32                                                  XNTE  73
```

```
      C(6)=(DYOX32-(YI(4)-YI(2))/DX42)/(XI(3)-XI(4))                    XNTE  74
      C(5)=DYOX32-C(6)*DX32                                             XNTE  75
      IF (IXOGO .GT. 0)  GO TO 100
   43 IF (IX .LE. 1)  GO TO 32
      IGO = 0
   45 C(1)=YI(1)                                                        XNTE  79
      DX21=XI(2)-XI(1)                                                  XNTE  80
      DX31=XI(3)-XI(1)                                                  XNTE  81
      DY21=YI(2)-YI(1)                                                  XNTE  82
      DYOX21=DY21/DX21                                                  XNTE  83
      C(3)=(DYOX21-(YI(3)-YI(1))/DX31)/(XI(2)-XI(3))                    XNTE  84
      C(2)=DYOX21-C(3)*DX21                                             XNTE  85
      IF(IXOGO) 100,100,62                                              XNTE  86
   60 IXOGO=1                                                           XNTE  87
      IF (IX .GT. IXO + 1)  GO TO 45
      C(1) = C(4)
      C(2)=C(5)                                                         XNTE  90
      C(3)=C(6)                                                         XNTE  91
   62 IF (IX .GE. IXMAX)  GO TO 34
      IGO = 0
      GO TO 42                                                          XNTE  94
  100 DX1 = X - XI(1)
      YB1=(C(3)*DX1+C(2))*DX1+C(1)                                      XNTE  97
      YPB1=C(3)/.5*DX1+C(2)                                             XNTE  98
      IF (IGO .GT. 0)  GO TO 110
  101 YB2 = (C(6)*DX2 + C(5))*DX2 + C(4)
      YPB2=C(6)/.5*DX2+C(5)                                             XNTE 102
      IF (IGO .LT. 0)  GO TO 120
      U1 = DX2/DX32
      U2=U1*U1                                                          XNTE 106
      U3=U2*U1                                                          XNTE 107
      A1=3.*U2-2.*U3                                                    XNTE 108
      A1P=6.*(U1-U2)/DX32                                               XNTE 109
      Y=(1.-A1)*YB1+A1*YB2                                              XNTE 110
      YP=(1.-A1)*YPB1-A1P*(YB1-YB2)+A1*YPB2                             XNTE 111
  105 IXIN=IX                                                           XNTE 112
      IF (IXOGO .EQ. 0)  RETURN
      DO 107 I = 1,6
  107 CAR(I)=C(I)                                                       XNTE 117
      RETURN
  110 Y=YB1                                                             XNTE 119
      YP=YPB1                                                           XNTE 120
      GO TO 105                                                         XNTE 121
  120 Y=YB2                                                             XNTE 122
      YP=YPB2                                                           XNTE 123
      GO TO 105                                                         XNTE 124
      END                                                               XNTE 125
```

ZETAIT

```
      SUBROUTINE ZETAIT                                                  ZETA    1
C
      COMMON /COFIIF/ IFINT,AFINT,BFINT,CFINT,MMINT,TFINT               /COFIIF/
C
      COMMON /INPUT/ IDXMAX,ICTAB,IPRINT,ITWTAB,IXTAB,MZETA,DXMAX,      /INPUT/
     A               EPSZ,FJ,G,GAMO,PO,PHII,PIE,PRANDT,RBAR,SCALE,TO,   /INPUT/
     K               THETAI,TOLCFA,TOLZET,TOLZME,ZMUO,ZMVIS,ZNSTAN      /INPUT/
C
      COMMON /INTER/ CFAGT,CFAGP,CHPAR1,DX,DXRHO,HE,HW,IBEG,MZETAM,     /INTER/
     A               OOMZET,PHIP,PRE103,RHOE,RHOUE,RMZETA,THETAP,       /INTER/
     K               XIBASE,XIEND,ZETATM,ZMZETA,ZMZETM,ZMZETP           /INTER/
C
      COMMON /OUTPUT/ BDELTA,CF,CH,DELTA,DELSOT,DELSTR,FLAT,FORCE,HG,   /OUTPUT/
     A                PE,PHI,QW,SUMQDA,TE,THETA,TW,UE,X,XLARC,YR,Z1,    /OUTPUT/
     K                Z2,Z3,Z4,Z5,ZETA,ZME                              /OUTPUT/
C
      COMMON /SAVED/ A,B,C,ZI1,ZI1P,ZI2,ZI2P,ZI3,ZI3P,ZI4,ZI5,ZI6,ZI7   /SAVED/
C
      ERASE1=PHI/THETA                                                   ZETA   16
      IFINT=1                                                            ZETA   17
      DO  30  I = 1, 50                                                  ZETA   18
      MMINT=MZETA                                                        ZETA   19
      AFINT=A                                                            ZETA   20
      ZETAG=ZETA                                                         ZETA   21
      IF (ZETA .GE. 1.0)  GO TO 32
      BFINT = B
      CFINT=C*ZETA*ZETA                                                  ZETA   24
      CALL INTZET(0.,1.,ZI1P)                                            ZETA   25
      BFINT=B/ZETA                                                       ZETA   26
      CFINT=C                                                            ZETA   27
      CALL INTZET(0.,ZETA,ZI4)                                           ZETA   28
      AFINT=A+B                                                          ZETA   29
      BFINT=0.                                                           ZETA   30
      CALL INTZET(ZETA,1.,ZI5)                                           ZETA   31
      ZETA=(ERASE1/ZI1P*(ZI4+ZI5))**RMZETA                               ZETA   32
      GO TO 33                                                           ZETA   33
   32 BFINT=B/ZETA                                                       ZETA   34
      CFINT=C                                                            ZETA   35
      CALL INTZET(0.,1.,ZI1)                                             ZETA   36
      BFINT=B                                                            ZETA   37
      CFINT=C*ZETA*ZETA                                                  ZETA   38
      ERASE2=1./ZETA                                                     ZETA   39
      CALL INTZET(0.,ERASE2,ZI2P)                                        ZETA   40
      MMINT=MZETAM                                                       ZETA   41
      AFINT=A+C                                                          ZETA   42
      CFINT=0.                                                           ZETA   43
      CALL INTZET(ERASE2,1.,ZI3P)                                        ZETA   44
      ZETA=(ERASE1/(ZI2P+ZI3P/ZETA)*ZI1)**RMZETA                         ZETA   45
   33 DZETA = (ZETA - ZETAG)/ZETAG
      IF (ABS(DZETA) .LT. TOLZET)  GO TO 35
      IF (I .GE. 2)  GO TO 76
      Z4=ZETA
      Z2=ZETAG                                                           ZETA   50
      GO TO 30                                                           ZETA   51
   76 Z3=Z4                                                              ZETA   52
```

```
      Z1=Z2
      Z4=ZETA
      Z2=ZETAG
      Z5=(Z4-Z3)/(Z2-Z1)
      ZETA=(Z4-Z5*Z2)/(1.-Z5)
   30 CONTINUE
      WRITE(6,34) X, ZME, THETA, PHI
   34 FORMAT ( 57H0**ZETAIT FAILURE... SHAPE PARAMETER ITERATION FAILURE
     1... / 22H0  AXIAL DISTANCE  X =, 1PE14.7, 5X, 11HMACH NO. = ,
     2 E14.7, 5X, 8HTHETAI =, E14.7, 5X, 6HPHII =, E14.7 )
      WRITE(6,50) Z1, Z2, ZETA, Z3, Z4
   50 FORMAT (  20H ZETA (GUESSED)     =,1P3E16.7 / 20H ZETA (CALCULATED)
     1 =, 2E16.7 // )
   35 IFINT = 2
      MMINT=MZETA
      AFINT=A
      BFINT=B/ZETA
      CFINT=C
      ZETATM=ZETA**ZMZETA
      IF (ZETA .GE. 1.0)  GO TO 37
      CALL INTZET(0.,ZETA,Z16)
      AFINT=A+B
      BFINT=0.
      CALL INTZET(ZETA,1.,Z17)
      ERASE2=Z14+Z15
      DELSOT=(OOMZET-Z16-Z17)/ERASE2
      DELTA=THETA/ZMZETA/ERASE2
      GO TO 38
   37 CALL INTZET(0.,1.,Z12)
      MMINT=MZETAM
      AFINT=A+C
      CFINT=0.
      CALL INTZET(1.,ZETA,Z13)
      DELTA=THETA/ZMZETA/Z11
      DELSOT=(ZETATM/ZMZETA-Z13-Z12)/Z11
   38 BDELTA = ZETATM*DELTA
      DELSTR=THETA*DELSOT
      RETURN
      END
```

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