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FLOWFIELD ANALYSIS FOR SUCCESSIVE OBLIQUE SHOCK WAVE-TURBULENT BOUNDARY LAYER INTERACTIONS

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16. Abstract

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FLOWFIELD ANALYSIS FOR SUCCESSIVE OBLIQUE SHOCK WAVE-TURBULENT BOUNDARY LAYER INTERACTIONS

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SUMMARY

A computation procedure is described for predicting the flowfields which develop when successive interactions between oblique shock waves and a turbulent boundary layer occur. Such interactions may occur, for example, in engine inlets for supersonic aircraft. Computations have been carried out for axisymmetric internal flows at $M_\infty = 3.82$ and 2.82. The effect of boundary layer bleed has been considered for the $M_\infty = 2.82$ flow. A control volume analysis is used to predict changes in the flow field across the interactions. Two bleed flow models have been considered. A turbulent boundary layer program has been used to compute changes in the boundary layer between the interactions. The results given are for flows with two shock wave interactions and for bleed at the second interaction site. In principle the method described may be extended to account for additional interactions. The predicted results are compared with measured results and are shown to be in good agreement when the bleed flow rate is low (on the order of 3% of the boundary layer mass flow), or when there is no bleed. As the bleed flow rate is increased, differences between the predicted and measured results become larger. Shortcomings of the bleed flow models at higher bleed flow rates are discussed.

INTRODUCTION

The interaction of an oblique shock wave with a turbulent boundary layer is known to induce drastic changes in the boundary layer properties and to cause substantial deviation of the supersonic flow field from the predicted inviscid flow. This deviation may be of sufficient magnitude to adversely affect the performance of aerodynamic devices. Suitable methods for predicting the boundary layer and the freestream flow characteristics in the presence of such disturbance are required by engineers responsible for the design of aerodynamic configurations in which shock wave boundary layer interactions occur.

A control volume method developed by Seebaugh, Paynter and Childs [1], and improved upon by Mathews [2], has been used successfully in the prediction of the boundary layer characteristics downstream of the interaction with a single oblique shock wave. However, in some aerodynamic devices such as mixed compression supersonic diffusers, the turbulent boundary layer is subjected to interactions with more than one shock wave. In this report, a computation procedure is described for predicting the flow field which develops when successive interactions of two oblique shock waves with a turbulent boundary layer occur. In principle the method described may be extended to account for additional interactions.

Computations have been carried out for axisymmetric internal flows at M_∞ = 3.82 and 2.82. Experiments have been conducted at these same Mach numbers with the interactions under study occurring at the walls of circular wind tunnels. In the Mach 2.82 study the effect of boundary layer bleed at the second interaction site has been considered. The predicted results are compared with experimentally observed results. The experimental configurations for which the analysis has been carried out are discussed in the section which follows. This is followed by a section which gives the details of the computational method.

SYMBOLS

A = $\{[(\gamma-1)/2]M_e^2/(T_w/T_e)\}^{1/2}$

a = a constant in the wall-wake profile

B = $\{(1+[(\gamma-1)/2]M_e^2)/(T_w/T_e)\}-1$

C = a constant in the Law of the Wall (usually equals 5.1)

C_f = skin friction coefficient, $\tau_w/(1/2)\rho_e u_e^2$

F = entrainment function, see Eq. (B-5)

$(H_1)_K$ = kinematic shape factor, see Eq. (B-6)

$\dot{I}_{Bx}$ = x-momentum of the bleed flow

K = a constant in the Law of the Wall (usually equals 0.4)

L = shock wave boundary layer interaction length

M = Mach number

$\dot{m}_B$ = boundary layer mass bleed rate

P = pressure

R = radial coordinate from tunnel centerline

R_B = radial coordinate of dividing stream surface separating bleed flow from main flow, (see Fig. 3)

R_e = Reynolds number

u = velocity in streamwise direction

u^* = vanDriest's generalized velocity, (u_e/A) arcsin $\{[(2A^2u/u_e) - B]/(B^2+4A^2)^{1/2}\}$

u_τ = friction velocity, $(\tau_w/\rho_w)^{1/2}$

x = axial coordinate, measured from shock generator tip

y = coordinate normal to the tunnel wall

γ = ratio of specific heats

Δ = mass flow thickness, see Eq. (B-1)

Δ_E = a thickness of freestream flow to allow for boundary layer mass entrainment, (see Fig. 3)

δ = boundary layer thickness

δ^* = displacement thickness of the boundary layer

η = y/δ

θ = momentum thickness of the boundary layer

ν = kinematic viscosity

Π = coefficient of the wake function

ρ = mass density

σ = $[(\gamma-1)/2]M_e^2/\{1+[(\gamma-1)/2]M_e^2\}$

τ = shear stress

Subscripts

e = conditions at the edge of the boundary layer

w = conditions at the wall

∞ = freestream conditions ahead of the first interaction

EXPERIMENTAL CONFIGURATION AND INSTRUMENTATION

The experimental configurations which were used to produce the successive shock waves are shown schematically in Figure 1. The Mach 3.82 tunnel had a radius of 2.58 cm and a boundary layer thickness ahead of the first interaction of 0.43 cm. The shock wave generator was installed on the centerline of the tunnel at zero angle of attack. The generator had a 10-degree half-angle conical tip which broke to 13 degrees 6.60 cm downstream of the tip. For the Mach 2.82 tunnel the tunnel radius was 2.60 cm and the boundary layer thickness ahead of the first interaction was 0.40 cm. The shock generator had a 10-degree conical tip which broke to 13 degrees 4.94 cm behind the tip. Both generators were designed to provide as large a region of freestream flow as possible between the first reflected and second incident shock waves while at the same time keeping the expansion wave off the downstream corner of the second conical surface from interfering with the second interaction.

About 7.62 cm from the tip of the Mach 2.82 shock generator, or approximately at the point where the second incident shock wave reached the wall, two rows of thirty-eight 0.132 cm diameter bleed holes were drilled around the periphery of the tunnel. The bleed system was operated in a choked flow condition. With one row of the holes open, the bleed mass flux was about 2.8 percent of the boundary layer mass flux just ahead of the second interaction. With two rows of holes open, the bleed mass flux was 5.0 percent of the boundary layer mass flux.

Both tunnels were operated with a steady supply of dry air at 300°K. The freestream unit Reynolds number for the M = 3.82 tunnel was 18.5 x 10^6 per meter, that for the M = 2.82 tunnel, 19.0 x 10^6 per meter.

Standard instrumentation was used to obtain tunnel wall static pressures and boundary layer pitot pressures profiles. Wall static pressures were taken at 0.127 cm intervals along the tunnels. Pitot profiles were taken in radial increments of 0.0127 cm at eighteen axial stations upstream of, within, and downstream of the interaction region. Miniature total head tubes, flattened to a dimension of 0.024 cm high by 0.066 cm wide were used for the pitot profiles. Velocity profiles upstream of the first incident shock wave, between the first reflected and second incident shock waves, and downstream of the second reflected shock wave were calculated from the pitot profiles assuming isoenergetic flow. A calibrated venturi meter was used to measure the bleed flow.

ANALYSIS

Figure 2 shows the flow model used in the analysis. R is the radial distance from the tunnel centerline and x is the distance downstream from the tip of the shock wave generator. Conditions at station 1 are assumed to be known. The object of the analysis, given the shock generator shape and initial conditions, is to compute the locations of the reflected shock waves and the boundary layer properties at successive stations along the wall. Reflected compression waves are treated in the analysis as a single shock wave.

The boundary layer can be divided into three subregions associated with the three steps in which the computation is carried out.

(1) Region I extends from Station 1 where the first incident shock wave reaches the boundary layer edge to Station 3 where the reflected shock wave emerges from the boundary layer. Surface 2 is the stream surface which passes through the intersection of the reflected shock wave with the boundary layer edge. Note

that this stream surface intersects the incident shock wave outside the boundary layer edge (see Fig. 3). This choice of surface 2 allows for mass entrainment into the boundary layer through the interaction region. The location of this surface and the pressure distributions along it are obtained from an inviscid conical flow solution. Using this surface, the tunnel wall, and the planes normal to the wall at 1 and 3 to define a control volume, a control volume analysis of the region may be used to determine the length of the interaction, and the boundary layer thickness and shape at 3. The method used here is quite similar to the methods used by Seebaugh [1] and Mathews [2] except for the velocity profile representations for the boundary layer. The velocity profile representation used at Stations 1 and 3 and throughout the analysis is the improved wall-wake velocity profile developed by Sun and Childs [3] (see Appendix A). For turbulent isoenergetic compressible boundary layer flow, the modified profile may be expressed in the form,

$$\frac{u}{u_e} = \frac{1}{\sigma^{\frac{1}{2}}} \sin \{\arc\sin \sigma^{\frac{1}{2}} [1 + \frac{1}{K} \frac{u_\tau}{u_e^*} (\ln \eta + \frac{2}{a} (1-\eta^a)^{\frac{1}{2}} - \frac{2}{a} \ln (1+(1-\eta^a)^{\frac{1}{2}})) - \frac{\Pi}{K} \frac{u_\tau}{u_e^*} (1+ \cos \eta \pi)]\} \quad (1)$$

where

$$\frac{\Pi}{K} = \frac{1}{2} \{(\frac{u_e^*}{u_\tau}) - (\frac{1}{K}) \ln (\frac{\delta u_\tau}{\nu_w}) - 5.1 + \frac{0.614}{a K}\} \quad (2)$$

and a = 1 is assumed.

One other variation on the earlier method has been incorporated into the present analysis. The flow direction in the boundary layer downstream of the interaction has been taken as the average of the value at the wall (i.e., zero) and that at $y = \delta_3$ as determined from the inviscid solution. In the analyses by Seebaugh [1] and Mathews [2] the flow direction downstream of an interaction was taken to be parallel to the wall. Figures 3a and 3b show the control volumes used in the present analysis. Although boundary layer bleed was not employed at the first interaction site in the experimental studies, the control volumes shown do allow for that possibility. For the control volumes shown, the continuity equation may be expressed in the form,

$$\int_{R_W-\delta_1-\Delta_E}^{R_W} 2\pi\rho u R dR = \int_{R_W-\delta_3}^{R_W} 2\pi\rho u R dR + \dot{m}_B \quad (3)$$

while the x-momentum equation may be written as,

$$\int_{R_W-\delta_1-\Delta_E}^{R_W} 2\pi p_1 R dR - \int_{R_W-\delta_1-\Delta_E}^{R_W} 2\pi p_2 R dR - \int_{R_W-\delta_3}^{R_W} \overline{p}_3 2\pi R dR - 2\pi R_W L \overline{\tau}_W$$

$$= \int_{R_W-\delta_3}^{R_W} 2\pi \rho u^2 R dR - \int_{R_W-\delta_1-\Delta_E}^{R_W} 2\pi \rho u^2 R dR + \dot{I}_{Bx} \qquad (4)$$

where

$$\tau_W = (\tau_{W_1} + \tau_{W_3})/2 \text{ and } \overline{p}_3$$

is the average static pressure over the boundary layer at 3. Comparable equations may be written for the second interaction site. Allowance for boundary layer mass entrainment in the interaction region is made by assuming an entrainment rate equal to that for the flow upstream of an interaction.

(2) Region II extends from Station 3 to Station 5. This is the region of boundary layer flow between the first reflected shock and the second incident shock. Since no shock interactions are present in this region, the axial pressure gradient is relatively low. Starting with conditions at 3 as determined by the control volume analysis of the first interaction, changes in the boundary layer properties to Station 5 are computed using a turbulent boundary layer program suggested by Paynter and Schuelle [4]. The program uses a wall-wake profile to represent the velocity profile and the entrainment function concept proposed by Green [5] to solve the boundary layer equations (see Appendix B). An inviscid flow solution is used to provide the wall static pressure distribution needed for the boundary layer solution in this region. The inviscid solution, however, is obtained in a manner which allows for the effects of the first shock interaction. The method employed was to use an artificial wall position in the interaction region which would cause the reflected inviscid shock wave position to match that determined by control volume analysis of region I. The wall static pressure distribution p(x) as determined using the artificial wall position is then assumed to exist at the actual wall and is used in the boundary layer calculations.

(3) Region III extends from Station 5 to Station 7. This region covers the interaction of the second incident shock wave with the boundary layer. The method here is similar to that for Region I, except that the flow at control surface 6 is no longer conical. Conditions along this surface were obtained from a method of characteristics solution for flow past the double-cone centerbody. In the characteristics solution the interaction of the first reflected shock with the second incident shock must be considered. The location in the flow field of the reflected shock wave was determined using the artificial wall position.

In the control volume equations (3) and (4) the mass bleed rate in $\dot{m}_B$ is assumed to be known. The x-momentum of the bleed flow depends on the manner in which the bleed flow is accomplished. In the analyses by Seebaugh [1] and Mathews [2] computations were made for three bleed models: porous wall suction, slot suction and scoop suction. Figure 3a shows the porous wall model. With this model, the x-momentum of the bleed flow, $\dot{I}_{Bx}$, was assumed to be zero. Figure 3b shows the slot suction model. With slot suction, $\dot{I}_{Bx}$ was assumed to have the same value as that possessed by the bleed mass as it entered the control volume, i.e.,

$$\dot{I}_{Bx} = \int_{R_B}^{R_W} 2\pi\rho u^2 R dR \tag{5}$$

where R_B is determined from,

$$\dot{m}_B = \int_{R_B}^{R_W} 2\pi\rho u R dR \tag{6}$$

For the Mach 2.82 flow with bleed, the bleed holes were drilled normal to the wind tunnel wall. At first thought, then, the porous wall model might appear to provide a better representation of the bleed flow. However, the bleed hole diameter of 0.132 cm was on the order of one-half the boundary thickness at Station 3. Thus, there should be x-momentum associated with the bleed flow and the bleed flow behavior might then be expected to be somewhere between that for porous-wall suction and slot suction. As will be discussed in the section on results, this appears to have been the case.

DESCRIPTION OF COMPUTATIONAL PROCEDURE

The computation of the flow at $M_\infty = 2.82$ with 2.8 percent bleed rate will be used here to illustrate the computational procedure. The computation is carried out in the following steps:

(1) The boundary layer thickness and velocity profile shape at Station 1 are known from measurements. For the example under consideration the first incident shock wave is at an angle of 22.75 degrees to the axis of the tunnel and reaches the boundary layer edge at a station approximately 5.2 cm downstream of the tip of the shock wave generator. Measurements were not taken exactly at Station 1. However, measurements were taken just upstream at x = 5.08 cm. We then assume that the boundary layer properties at Station 1 can be approximated by those obtained at x = 5.08 cm. The best representation of the boundary layer velocity distribution by the wall-wake profile, Eq. (1), is obtained by using the computer program, LEAST, listed in TABLE 1-A.

In program LEAST, the boundary layer thickness δ and the coefficient of wall friction C_f are regarded as two parameters and a double-loop-iteration scheme is used to solve for a least squares fit of the wall-wake profile to the experimental velocity distribution. This program has been written for either isoenergetic or non-isoenergetic flow. The velocity distribution can be input in the form of pitot tube pressure or Mach number distribution. The input data listed in TABLE 1-B are pitot pressure profile data. Isoenergetic flow has been assumed. The description of the input is detailed in the comment cards listed in the program LEAST. For the case under consideration, the following boundary layer properties were obtained:

$$\delta = .406 \text{ cm}, \; C_f = 0.002, \; u_\tau/u_e^* = 0.0445$$

and the freestream Reynolds number Re = 19.0 x 10^6 per meter.

(2) The control surface 2 is defined to coincide with the stream surface which extends upstream from the point of intersection of the reflected shock wave with the boundary layer edge. In the inviscid flow field behind a conical shock wave, the characteristic surfaces are conical surfaces originated from the tip of the shock generator. Therefore, the characteristics of the flow field are functions only of the half angles of the conical surfaces. Gootzait [6] developed a computer program, program CØNE, which is used to compute the flow field characteristics. The program CØNE and the input for it are listed in TABLES 2-A and 2-B. There is only one input card for the program. The input FORMAT is 7F10.6 and the input data are, in order, the specific heat ratio of the gas, the freestream Mach number, the half angle of the cone and the distance, in inches, behind the tip of the cone where the output is desired.

The conical stream surface can be described in non-dimensional form as,

$$\frac{r}{r_0} = 1 + \int_1^{x/x_0} \frac{\tan \alpha}{\tan \phi_s} \, d(x/x_0)$$

the reference point (x_0, r_0) can be any point on the shock wave as shown in Figure 4a. α is the flow deflection angle at the stream surface as measured with respect to the tunnel axis and ϕ_s is the incident shock wave angle. (Note: the final reference radius is obtained by an iterative process which allows for boundary layer mass entrainment. This is taken care of automatically in the program). Figure 4b shows the choice of reference radius r_0 and the conversion of the stream surface to control surface 2. In the numerical computation a finite number of points is used to represent the control surface and the flow conditions such as Mach number, pressure and flow angle on each point are obtained from program CØNE as functions of characteristic angle ϕ.

(3) The computer program ANAL for the control volume, originally developed by Seebaugh [7], modified by Mathews [2], and then improved upon by the present authors is used to compute boundary layer properties at Station 3. The program ANAL is listed in TABLE 3-A, the inputs in TABLE 3-B. The input values at Station 1 for u_τ/u_e^*, δ_1 and the Reynolds number based on boundary layer thickness, $u_e\delta_1/\nu_e$, are obtained in step 1 and the conditions on the control surface 2 are obtained from step 2. The flow is assumed to be isoenergetic;

therefore the recovery factor is assumed to be 1. There is no boundary layer suction in this region. The shear stress at the wall between stations 1 and 3 is assumed to be the average of the value at stations 1 and 3. The flow direction at station 3 is taken as the average of the values at the wall and at $y = \delta_3$ as determined from the inviscid solution.

In this computation, we use the shock wave angle ϕ_s, instead of the flow deflection angle α_2 across the first incident shock. We also choose to input conical flow conditions behind the first incident shock wave. The computed results include the interaction length and the boundary layer properties at station 3. The predicted boundary layer properties at station 3 include the boundary layer thickness, the coefficient of skin friction, the average static pressure across the boundary layer and the velocity distribution.

(4) The program ANAL, which is based on the control volume method, predicts only the properties of the boundary layer at the downstream and of the interaction region. For computing the boundary layer downstream of the interaction and for computations of the next interaction, the flow field outside the boundary layer must be known. This is obtained by a method of characteristics computer program. The program used here is a modified version of a program originally prepared by Cavalleri [8]. The program designates the region before the incident shock wave as region 2, the region between the incident reflected shock waves as region 3 and the region downstream of the reflected shock wave as region 4. The flow in region 2 is uniform and parallel to the centerline and the flow in region 3 is conical flow. Figure 5 shows the designated regions and input points at initial station x = 1.835 inches (4.65 cm) as used in the example under consideration. In computing the external flow field allowance must be made for the effect of the interaction. Otherwise the location of the reflected shock wave will be downstream of the actual reflected wave and the external flow field needed for downstream boundary layer calculations will be in error. In order to avoid this problem, an artificial wall location which would cause the reflected shock location to match that predicted by the control volume analysis was used. Determination of the appropriate artificial wall location is a trial and error process and for the computations which have been carried out to date has required three runs of the characteristics program. In this computation it was found that a tunnel radius of 0.99 inches (2.51 cm) caused the reflected shock wave position to match that determined by the control volume analysis. The inputs to the program are listed in Table 4. The reader should refer to reference 8 for the details of the inputs.

(5) From station 3 to station 5 we use a turbulent boundary layer program BLGRN (see Appendix B) which is a modified version of one developed earlier by Paynter and Schuelle [4] based on Green's [5] entrainment function concept. The control volume analysis in step 3 provides the initial conditions at station 3. For the boundary conditions on surface 4, we assume that the Mach number and pressure distributions are equal to those obtained along the artificial wall in the inviscid solution of step 4. We should also point out here that the computation is a two-dimensional approximation. However, in view of the ratio of boundary layer thickness to tunnel radius the results should be

applicable for the axisymmetric flow under consideration. The program, BLGRN, is listed in TABLE 5-A, the inputs in TABLE 5-B. The inputs are described in the comment cards at the beginning of the program listing.

(6) At 1.942 inches (4.94 cm) behind the tip, the shock generator broke from a 10 degree cone to 13 degrees and generated a second shock wave. The position of the second incident shock wave and the flow field characteristics behind the second shock wave are computed by using the same method of characteristics program which is used in step 4. Given the geometry of the centerbody and the inviscid solution (based on the artificial wall position) from step 4, we have the inputs for the computer program as listed in TABLE 6 and illustrated in Figure 6. As in the computation of step 4, the program designates the region before the second incident shock wave as region 2, the region between the second incident and reflected shock waves as region 3, and the region downstream of the second reflected shock wave as region 4. In region 2, unlike the situation in step 4 where the external flow is uniform, there exists a reflected shock wave. The program is not capable of solving for the intersection of two shock waves. In preparing for the input, the first reflected shock wave is replaced by a smoothed compression wave band. In the calculation described here a linear compression spaced over six input points was used. The flow between the artificial wall radius of 0.99 inch (2.51 cm) and the actual wall radius of 1.02 inches (2.60 cm) was assumed to be uniform and paralel to the wall. The result shows that the second incident shock wave has an angle of approximately 33 degrees and that it reaches the boundary layer edge at x = 2.85 inches (7.22 cm) where the boundary layer thickness is 0.125 (0.312 cm) as computed in step 5.

(7) The control surface 6 is also defined to lie along a stream surface behind the second incident shock wave, but the flow field in this region is quite complicated. Because of the nature of the characteristics program, it was necessary to run the program three separate times to determine flow properties at the three stations. The pressure and Mach number distributions at each station are obtained from the result of the previous step. At x = 2.85 inches (7.22 cm) where the second incident shock wave reaches the edge of boundary layer the cone radius is 0.552 inch (1.40 cm) while the distance from the centerline to the edge of the boundary layer is 0.895 inch (2.28 cm). The mass flux through the area between the radii is 0.412 lbm/sec (0.187 Kg/sec.). At x = 2.988 and 3.205 inches (7.60 and 8.15 cm) for the mass flux to be equal to the 0.412 lbm/sec (0.187 Kg/sec) the radii are 0.907 and 0.922 inch (2.30 and 2.34 cm) respectively. Ideally, we can compute at more stations to determine the stream surface. But the preparation of pressure and Mach number profiles is very tedious. We determine the stream surface by graphically tracing a smooth curve through the above three points. The computer program MFLX is used here to compute mass flux from the profile of pressure and Mach numbers. Program MFLX and the input to the program are listed in TABLE 7.

(8) The computer program ANAL listed in TABLE 3-A is used for computation from station 5 to station 7. The boundary layer properties at station 5 are obtained from step 5 and the location of the control surface 6 is determined

by step 7. After determining the control surface 6, the flow properties along the surface are obtained from the output of step 6. The x-coordinate should be transformed into the distance to the axial station at which the extension of the second shock wave intersects with the tunnel centerline as shown in Figure 8. For the points on the control surface the input to the program, i.e., the x-coordinates, should be normalized by distance x_0 and the r-coordinates should be normalized by radius R_0. The distance x_0 is the distance from station 5 to the intersection point of the second shock wave with the centerline and the radius R_0 is the distance from the tunnel centerline to the edge of the boundary layer at station 5. For the flow considered in the sample calculations boundary layer bleed takes place at the second interaction site. The bleed mass flux is about 2.8 percent of the boundary layer mass flux at station 5. In this computation the slot suction model has been assumed for the bleed flow. The input to the program ANAL is listed in TABLE 8. The details of the input are described in the comment cards at the beginning of program ANAL listed in TABLE 3-A.

RESULTS

The results of the analysis for three different flow cases, one at $M_{\infty} = 3.82$ with no bleed, two at $M_{\infty} = 2.82$ with bleed at the second interaction site, are shown in Figures 9 through 16. Results from the sample calculation described herein are given in Figures 12 and 13. Comparisons are made between predicted and measured results. The data for $M = 2.82$ flow are from an investigation by Teeter [9].

Figure 9 shows comparisons of the experimental and predicted shock wave patterns and boundary layer thickness for the Mach 2.82 flow. Since the predicted shock wave locations are determined by the inviscid analysis used in combination with the artificial wall position, no induced shock wave is predicted. Also shown is the pressure distribution at the tunnel side wall as a function of the distance aft of the cone tip. The triangular points shown for the analysis in the static pressure plot were determined by using the artificial wall and the inviscid flow solution. The predicted and observed values are seen to be in good agreement along the entire length of the double shock interaction.

Figure 10 shows δ^*, θ and C_f at several stations along the tunnel side wall. Here also, predicted and observed results are in good agreement. The experimental values shown for C_f have been determined by a least-squares fit of the modified wall-wake velocity profile to the experimentally determined velocity profiles.

Figure 11 shows Mach number profiles for the boundary layer at the downstream end of the second interaction. The analysis predicts the end of the second interaction to be at x = 3.75 inches. Since profiles were not taken at this specific station, profiles taken just upstream at x = 3.70 inches (9.5 cm) and just downstream at x = 3.80 inches (9.65 cm) are shown for comparison. It is apparent that the analysis leads to a profile which provides a good representation of the experimentally determined profile near the interaction end.

Figure 12 shows boundary-layer thicknesses, shock wave patterns and wall static pressure distributions for the Mach 2.82 flow with 2.8 percent boundary-layer bleed at the second interaction site. Figure 13 shows δ^*, θ, and C_f for this flow.

Two sets of predicted results are given, one for the porous-wall suction model, the other for slot suction. (For the sample calculation described in the report slot suction has been assumed). As is shown, the differences between the results for the two suction models are not large. Differences in predicted results with the two models are due solely to the differences in values assigned to the x-momentum of the bleed flux. Since the bleed rate is low, the x-momentum associated with the slot suction model is small and not too different from the zero values for porous suction. The predicted and measured results are in reasonably good agreement.

Figure 14 shows boundary-layer thickness, shock wave patterns and wall static pressure distributions for M = 2.82 with 5.0 percent bleed. Values for δ^*, θ, and C_f are shown in Figure 15, while Mach number profiles downstream of the second interaction are shown in Figure 16. The Mach number profiles represented by the solid lines in Figure 16 are predicted profiles for the two bleed flow models. They are shown on the figure at the axial positions predicted for the end of the second interaction. Since experimental profiles were not taken at these precise locations, experimental profiles taken in the neighborhood (x = 3.20, 3.30 and 3.40 inches or 8.13, 8.38 and 8.64 cm.) of the predicted locations have been shown for comparison.

The flow conditions up to the second interaction are the same as those for the flow with 2.8 percent bleed. With the higher bleed rate the difference between the results for porous wall and slot suction are much more pronounced than with 2.8 percent. The slot-suction model gives a reflected shock location which is in better agreement with the observed results. On the other hand, the values of δ^*, θ, and C_f obtained with the porous wall model agree better with experimental values than do the slot suction results. As was pointed out in the section on analysis, the bleed hole diameter of 0.132 cm was on the order of one-half of the boundary-layer thickness so that the bleed flow behavior might be expected to lie between that for porous wall suction and slot suction. The x-momentum of the bleed value might then, in turn, be expected to lie between the values used with the two models. Indeed, the use of a bleed flow momentum flux between the two limits would lead to better overall agreement between predicted and measured values of δ^*, θ, and C_f. Even then, however, the predicted interaction length would be too long. It should be remarked that in estimating I_{Bx} for the slot-suction bleed flow model, no allowance is made for the turbulent shear stress along the stream surface separating the bleed flow from the main body of the flow, nor for the wall shear stress. Nor is the pressure force along the separating stream surface considered. The effects of the pressure force and wall shear tend to cancel the effect of the turbulent shear on the separating stream surface, but the extent to which they do so is not known. It should be remarked further that no allowance is made for the roughness effect of the holes on the wall shear. Further study is needed on the details of the bleed flow behavior, including the roughness effect of the holes, before the effects of bleed configuration can be resolved.

The computation procedure reported here represents the results of a continuing effort to improve analytical methods of predicting flowfields in the inlet of supersonic aircraft. In a recent analysis of inlet flowfields by Reyhner and Hickcox [10] the effect of the shock wave interaction on the inviscid flow was taken into account by first obtaining a control volume solution for the boundary-layer properties downstream of the interaction. Then, using an effective surface defined by the boundary-layer displacement thickness upstream and downstream of the interaction, and using a patching technique across the interaction region to construct an effective displacement surface for that region, the inviscid flow solution was obtained for the effective surface. A comparable technique was tried in the work reported here but it was not as successful as the scheme of using the simple reflection off the artificial wall.

CONCLUSIONS

A control volume analysis method, employed in conjunction with a turbulent boundary-layer computation scheme, has been used to predict the flowfield downstream of successive shock wave boundary-layer interactions for flows at M_∞ = 3.82 and 2.82. The computational procedure has been outlined in detail. The effects of boundary layer bleed at the second interaction site have been considered. For flow with low bleed rates or no bleed the predicted interaction lengths and wall static pressures, as well as the boundary-layer properties downstream of the interactions show good agreement with measured results. With low bleed flow the predicted results for the slot-suction and porous-wall models differ only slightly since the momentum of the bleed flow is small. As the bleed flow rate is increased, predicted and measured results are also in reasonably good agreement. Here, however, differences between predicted results for the two suction models are larger since the difference between the momentum fluxes of the bleed flows is larger. A value of bleed flow momentum between the values used for the models would improve the agreement between predicted and measured results.

APPENDIX A

Modified Wall-Wake Profile

A simple representation of the mean velocity distribution in a turbulent boundary layer is very useful in integral analyses of turbulent flow problems. After an extensive survey of mean velocity profile measurement, Coles [11] suggested that for incompressible turbulent boundary layer flow the velocity profile may be represented by a linear combination of two universal functions in the form,

$$u/u_\tau = (1/K)\ln(yu_\tau/\delta)+C+\Pi\ W(y/\delta)/K = f(y)+g(y) \qquad \text{(A-1)}$$

where

$$f(y) = (1/K)\ln(yu_\tau/\delta) + C \qquad \text{(A-2)}$$

is the Law of the Wall and

$$g(y) = \Pi W(y/\delta)/K \qquad \text{(A-3)}$$

is the Law of the Wake.

Setting u/u_e and $W(y/\delta) = 2$ at $(y/\delta) = 1$ in Eq. (A-1) and subtracting the resulting equation from Eq. (A-1) leads to an expression for the velocity of the form,

$$u/u_e = 1+(1/K)(u_\tau/u_e)\ln(y/\delta) - (\Pi/K)(u_\tau/u_e)[(2-W(y/\delta)] \qquad \text{(A-4)}$$

Mathews et al., [12] have developed a wall-wake representation of the velocity profile in a form applicable for isoenergetic compressible boundary layers. Their profile is expressed as,

$$u/u_e = (1/\sigma^{\frac{1}{2}})\sin\{\arcsin\sigma^{\frac{1}{2}}[1+(1/K)(u_\tau/u_e^*)\ln(y/\delta) - (\Pi/K)(u_\tau/u_e^*)(1+\cos(\pi y/\delta))]\} \qquad \text{(A-5)}$$

where

$$(u_\tau/u_e^*) = [(C_f/2)\ \sigma/(1-\sigma)]^{\frac{1}{2}}/\arcsin\sigma^{\frac{1}{2}} \qquad \text{(A-6)}$$

and

$$\Pi/K = (\tfrac{1}{2})\ \{[1/(u_\tau/u_e^*)] - (1/K)\ln[Re_\delta\ (C_f/2)^{\frac{1}{2}}(1-\sigma)^{1.26}] - C\} \qquad \text{(A-7)}$$

and where (2-W) has been replaced by $1 + \cos(\pi y/\delta)$ for mathematical convenience.

Equation (A-5) has been found to provide a good representation of the boundary layer velocity profile for a range of external Mach numbers and wall static pressure gradients. However, with both Eq. (A-4) and Eq. (A-5) the velocity gradient at the boundary layer edge is found to have a non-zero value. In the modified wall-wake which is to be developed here this shortcoming is avoided.

The law of the wall may be derived from Prandtl's mixing length theory and the assumption that the shear stress is constant across the boundary layer (Cf. Schlichting [13]). However, an expression for τ of the form,

$$\tau = \tau_w \left[1 - (y/\delta)^a\right] = \tau_w (1 - \eta^a) \tag{A-8}$$

Where a is a real constant should provide a more realistic relationship for the shear stress.

Using Eq. (A-8) we may write,

$$\tau_w (1-\eta^a) = \rho K^2 y^2 (du/dy)^2 \tag{A-9}$$

Integration of Eq. (A-9) gives an expression for u/u_τ of the form,

$$u/u_\tau = (1/K)\ln \eta + (2/aK)\{(1-\eta^a)^{\frac{1}{2}} - \ln[1+(1-\eta^a)^{\frac{1}{2}}]\} + C_1 \tag{A-10}$$

Replacing f(y) in Eq. (A-1) by Eq. (A-10) we have,

$$u/u_\tau = (1/K)\ln \eta + (2/aK)\{(1-\eta^a)^{\frac{1}{2}} - \ln[1+(1-\eta^a)^{\frac{1}{2}}]\} + C_1 + (\Pi/K)\, W(\eta) \tag{A-11}$$

At the boundary layer edge ($\eta \to 1$) we have,

$$u_e/u_\tau = C_1 + (\Pi/K)\, W(1) = C_1 + 2\,\Pi/K \tag{A-12}$$

while near the wall (as $\eta \to 0^+$),

$$u/u_\tau = (1/K)\ln(yu_\tau/\nu) - (1/K)\ln(\delta u_\tau/\nu) + C_1 + 0.614/aK \tag{A-13}$$

Near the wall the expression for the law of the wall as given by Eq. (A-2) is also applicable. Equating the expression for u/u_τ we may evaluate C_1,

$$C_1 = 5.1 - (0.614/aK) + (1/K)\ln(\delta u_\tau/\nu) \tag{A-14}$$

while from Eq. (A-12)

$$\Pi/K = (1/2)\,[(u_e/u_\tau) - 5.1 - (1/K)\ln(\delta u_\tau/\nu) + 0.614/aK] \qquad \text{(A-15)}$$

Following procedures similar to those used by Van Driest [14], Maise and McDonald [15] or Mathews [12],

$$\frac{u}{u_e} = \frac{(B^2+4A^2)^{\frac{1}{2}}}{2A^2} \sin\{\arc\sin \frac{2A^2-B}{(B^2+4A^2)^{\frac{1}{2}}} [1 + \frac{1}{K}\frac{u_\tau}{u_e^*}(\ln\eta + \frac{2(1-\eta^a)^{\frac{1}{2}}}{a} - \frac{2}{a}\ln(1+(1-\eta^a)^{\frac{1}{2}}) - \frac{\Pi}{K}\frac{u_\tau}{u_e^*}(2-W(\eta))]\} + \frac{B}{2A^2} \qquad \text{(A-16)}$$

where

$$\Pi/K = (1/2)\,[(u_e^*/u_\tau) - (1/K)\ln(\delta u_\tau/\nu_w) - 5.1 + 0.614/aK] \qquad \text{(A-17)}$$

and

$$u_e^*/u_\tau = (u_e/u_\tau)\,(1/A)\,\arc\sin[(2A^2-B)/(B^2+4A^2)^{\frac{1}{2}}] \qquad \text{(A-18)}$$

For isoenergetic flow, Eqs. (A-16) and (A-18) become, respectively,

$$\frac{u}{u_e} = \frac{1}{\sigma^{\frac{1}{2}}} \sin\{\arc\sin\sigma^{\frac{1}{2}} [1 + \frac{1}{K}\frac{u_\tau}{u_e^*}(\ln\eta + \frac{2(1-\eta^a)^{\frac{1}{2}}}{a} - \frac{2}{a}\ln(1+(1-\eta^a)^{\frac{1}{2}})) - \frac{\Pi}{K}\frac{u_\tau}{u_e^*}(1+\cos\pi\eta)]\} \qquad \text{(A-19)}$$

and

$$u_\tau/u_e^* = [(C_f/2)\ \sigma/(1-\sigma)]^{\frac{1}{2}}/\arc\sin\sigma^{\frac{1}{2}} \qquad \text{(A-20)}$$

where $2-W(\eta)$ has been replaced by $1 + \cos\pi\eta$ for mathematical convenience. As $a \to \infty$ Eq. (A-11) reduces to Eq. (A-1) while Eq. (A-19) reduces to the profile proposed by Mathews et al., Eq. (A-5).

The remaining problem is the selection of the constant a. Based on measurements reported by Klebanoff [16] and Horstman and Owen [17], it appears that a = 1 represents a reasonable assumption. This amounts to the assumption of a linear shear stress distribution across the boundary layer.

The method of least squares has been used to fit the wall-wake profile, Eq. (A-19), for both a = 1 and $a \to \infty$ to a number of experimental velocity profiles by Seebaugh [7], Teeter [9] and Rose [18]. The computations can be carried out by using program LEAST listed in TABLE 1-A. An example of the results is given in Figure 17 which shows two profiles from the study by Seebaugh of an interaction between a conical shock wave and the turbulent boundary layer at the wall of an axially symmetric M = 2.82 wind tunnel. The profiles are for stations just upstream and just downstream of the interaction region and the experimental velocities have been calculated from pitot pressure and the wall static pressures under the assumption of isoenergetic flow. The 10-degree half angle cone used in the study did not produce a shock wave of sufficient strength to cause boundary layer separation. The values of C_f and δ determined by the curve fits are listed on the figure along with values for the displacement and momentum thickness δ^* and θ.

As is shown in the figure, both the modified wall-wake profile (a=1) and the profile for $a \to \infty$ provide good representations of the experimental velocity distribution over the ranges from y = 0 to the values determined for δ by the curve fits. The values of C_f, δ^* and θ determined for the two profiles differ only slightly. However, the values of δ as determined with the modified profile show much better agreement with the values of δ based on $u/u_e = 0.995$. Furthermore, the velocity gradient for the modified profile goes to zero at $y = \delta$. In all of the data examined to date the modified velocity distribution than the earlier version of the compressible wall-wake profile.

APPENDIX B

Boundary Layer Computations

For turbulent boundary layers in compressible flow, Green [5] derived from Head's (Cf. Green [5]) work for incompressible flow a procedure for simultaneously calculating the development of the momentum thickness and a quantity referred to as mass flow thickness, defined as,

$$\Delta = \int_0^\delta \frac{\rho u}{\rho_e u_e} \, dy = \delta - \delta^* \tag{B-1}$$

In this procedure the momentum-integral equation,

$$\frac{d\theta}{dx} = \frac{C_f}{2} - (H+2-M_e^2) \frac{\theta}{u_e} \frac{du_e}{dx} - j \frac{\theta}{r} \frac{dr}{dx} \tag{B-2}$$

is integrated simultaneously with an auxiliary equation which accounts for the rate at which the boundary layer entrains fluid from the free stream.

$$\frac{d}{dx} (\rho_e u_e \Delta) = \rho_e u_e F \tag{B-3}$$

In equation (B-2) the value of j is set equal to zero for two-dimensional flow, to unity for axisymmetric flow.

Equation (B-3) can be rearranged in the form,

$$\frac{d\Delta}{dx} = F + (M_e^2 - 1) \frac{\Delta}{u_e} \frac{du_e}{dx} \tag{B-4}$$

Green [5] found semi-empirically that F has the following form,

$$F = 0.0306 \quad ((H_1)_K - 3.0)^{-0.653} \tag{B-5}$$

where

$$(H_1)_K = \frac{\int_0^\delta \frac{u}{u_e} \, dy}{\int_0^\delta \frac{u}{u_e} (1 - \frac{u}{u_e}) \, dy} \tag{B-6}$$

Paynter and Schuehle [4], using empirical expressions for $(H_1)_K$ and C_f suggested by Green, developed a computer program to solve equations (B-2), (B-4) and (B-5). However, as it is suggested by Sun and Childs [3] the velocity in compressible turbulent boundary layer flow can be represented by equation (1). Using equation (1), we can solve equations (B-2), (B-4) and (B-5) without dependence on empirical formulas for $(H_1)_K$ and C_f.

From equation (B-1) we have,

$$\frac{d\theta}{dx} = \frac{\partial\theta}{\partial C_f}\frac{dC_f}{dx} + \frac{\partial\theta}{\partial\delta}\frac{d\delta}{dx} + \frac{\partial\theta}{\partial M_e}\frac{dM_e}{dx} \tag{B-7}$$

$$\frac{d\Delta}{dx} = -\frac{\partial\delta^*}{\partial C_f}\frac{dC_f}{dx} - \left(\frac{\partial\delta^*}{\partial\delta} - 1\right)\frac{d\delta}{dx} + \frac{\partial\delta^*}{\partial M_e}\frac{dM_e}{dx} \tag{B-8}$$

Solving equations (B-7) and (B-8) for $\frac{dC_f}{dx}$ and $\frac{d\delta}{dx}$ yields,

$$\frac{dC_f}{dx} = \frac{\left(1 - \frac{\partial\delta^*}{\partial\delta}\right)\left(\frac{d\theta}{dx} - \frac{\partial\theta}{\partial M_e}\frac{dM_e}{dx}\right) - \left(\frac{\partial\theta}{\partial\delta}\right)\left(\frac{d\Delta}{dx} - \frac{\partial\delta^*}{\partial M_e}\frac{dM_e}{dx}\right)}{\left(1 - \frac{\partial\delta^*}{\partial\delta}\right)\frac{\partial\theta}{\partial C_f} + \frac{\partial\delta^*}{\partial C_f}\frac{\partial\theta}{\partial\delta}} \tag{B-9}$$

$$\frac{d\delta}{dx} = \frac{\frac{\partial\theta}{\partial C_f}\left(\frac{d\Delta}{dx} - \frac{\partial\delta^*}{\partial M_e}\frac{dM_e}{dx}\right) + \frac{\partial\delta^*}{\partial C_f}\left(\frac{d\theta}{dx} - \frac{\partial\theta}{\partial M_e}\frac{dM_e}{dx}\right)}{\left(1 - \frac{\partial\delta^*}{\partial\delta}\right)\frac{\partial\theta}{\partial C_f} + \frac{\partial\delta^*}{\partial C_f}\frac{\partial\theta}{\partial\delta}} \tag{B-10}$$

To evaluate the displacement thickness and momentum thickness and their partial derivatives with respect to δ, C_f and M_e we use the expression given by Van Driest [14] for the temperature distribution through the boundary layer,

$$\frac{T}{T_e} = \frac{T_w}{T_e} + \left(1 + \frac{\gamma-1}{2}M_e^2 - \frac{T_w}{T_e}\right)\frac{u}{u_e} - \frac{\gamma-1}{2}M_e^2\left(\frac{u}{u_e}\right)^2 \tag{B-11}$$

Equation (B-11) was used in the derivation of equation (1).

The displacement thickness and its partial derivatives with respect to δ, C_f and M_e can be written as,

$$\delta^* = \int_0^\delta \left(1 - \frac{\rho u}{\rho_e u_e}\right) dy = \int_0^\delta \left(1 - \frac{T_e u}{T u_e}\right) dy \tag{B-12}$$

$$\frac{\partial \delta^*}{\partial \delta} = \left(1 - \frac{T_e}{T}\frac{u}{u_e}\right)\Big|_{y=\delta} + \int_0^\delta \frac{\partial}{\partial \delta}\left(1 - \frac{T_e u}{T u_e}\right) dy$$

$$= - \int_0^\delta \frac{\partial}{\partial \delta}\left(\frac{T_e}{T}\frac{u}{u_e}\right) dy \tag{B-13}$$

$$\frac{\partial \delta^*}{\partial C_f} = \int_0^\delta \frac{\partial}{\partial C_f}\left(1 - \frac{T_e}{T}\frac{u}{u_e}\right) dy$$

$$= \int_0^\delta \frac{\partial}{\partial C_f}\left(\frac{T_e}{T}\frac{u}{u_e}\right) dy \tag{B-14}$$

$$\frac{\partial \delta^*}{\partial M_e} = - \int_0^\delta \frac{\partial}{\partial M_e}\left(\frac{T_e}{T}\frac{u}{u_e}\right) dy \tag{B-15}$$

Similarly, we have the momentum thickness and its partial derivatives as,

$$\theta = \int_0^\delta \frac{\rho u}{\rho_e u_e}\left(1 - \frac{u}{u_e}\right) dy$$

$$= \int_0^\delta \frac{T_e u}{T u_e}\left(1 - \frac{u}{u_e}\right) dy \tag{B-16}$$

$$\frac{\partial \theta}{\partial \delta} = \int_0 \frac{\partial}{\partial \delta}\left(\frac{T_e u}{T u_e}\right) dy - \int_0^\delta \frac{\partial}{\partial \delta}\left(\frac{T_e}{T}\frac{u^2}{u_e^2}\right) dy \tag{B-17}$$

$$\frac{\partial \theta}{\partial C_f} = \int_0^\delta \frac{\partial}{\partial C_f}\left(\frac{T_e u}{T u_e}\right) dy - \int_0^\delta \frac{\partial}{\partial C_f}\left(\frac{T_e}{T}\frac{u^2}{u_e^2}\right) dy \tag{B-18}$$

$$\frac{\partial \theta}{\partial M_e} = \int_0^\delta \frac{\partial}{\partial M_e}\left(\frac{T_e u}{T u_e}\right) dy - \int_0^\delta \frac{\partial}{\partial M_e}\left(\frac{T_e}{T}\frac{u^2}{u_e^2}\right) dy \tag{B-19}$$

If initial values of δ, C_f and M_e are known an initial velocity profile can be determined by substituting values of δ, C_f and M_e into equation (1) and values of θ and δ^* and their partial derivatives can be determined. Values of $(H_1)_K$ can be computed by equation (B-6). We then use the values obtained and equations (B-2), (B-4) and (B-5) to compute d /dx and d /dx. Substituting the obtained values into equations (B-9) and (B-10) gives values for dC_f/dx and

dC_f/dx. The computations for δ and C_f may be carried out in step-by-step fashion. Let Δx be a small increment of x; then values of δ and C_f at $x + \Delta x$ may be expressed as,

$$\delta\ (x + \Delta x) = \delta(x) + \frac{d\delta}{dx}\ \Delta x \tag{B-20}$$

$$C_f\ (x + \Delta x) = C_f(x) + \frac{dC_f}{dx}\ \Delta x \tag{B-21}$$

The boundary conditions M_e and dM_e/dx are assumed to be known, or may be determined from the method of characteristics solution. By repeating the computation, the properties can be computed throughout the boundary layer flow. Program BLGRN, listed in TABLE 5-A, has been developed for the numerical computations. A sample of the results computed with this program is shown in Hirst [19]. As is shown, derivations between computed and experimental values of H, and Re_θ begin to show up as a condition of separation is approached. However, the computed values of C_f agree quite well with the data over the entire range of the computations.

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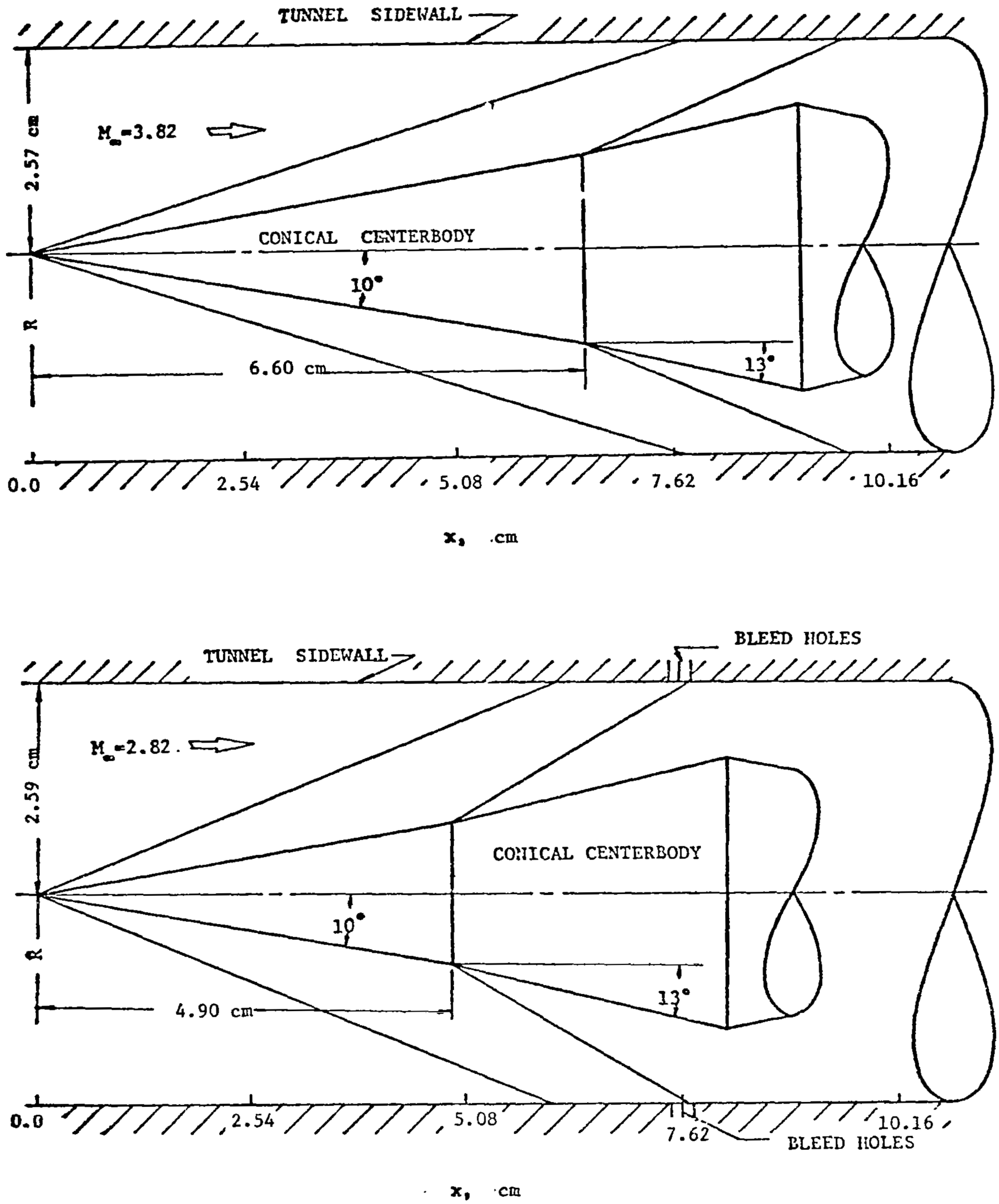


FIGURE 1. EXPERIMENTAL CONFIGURATION

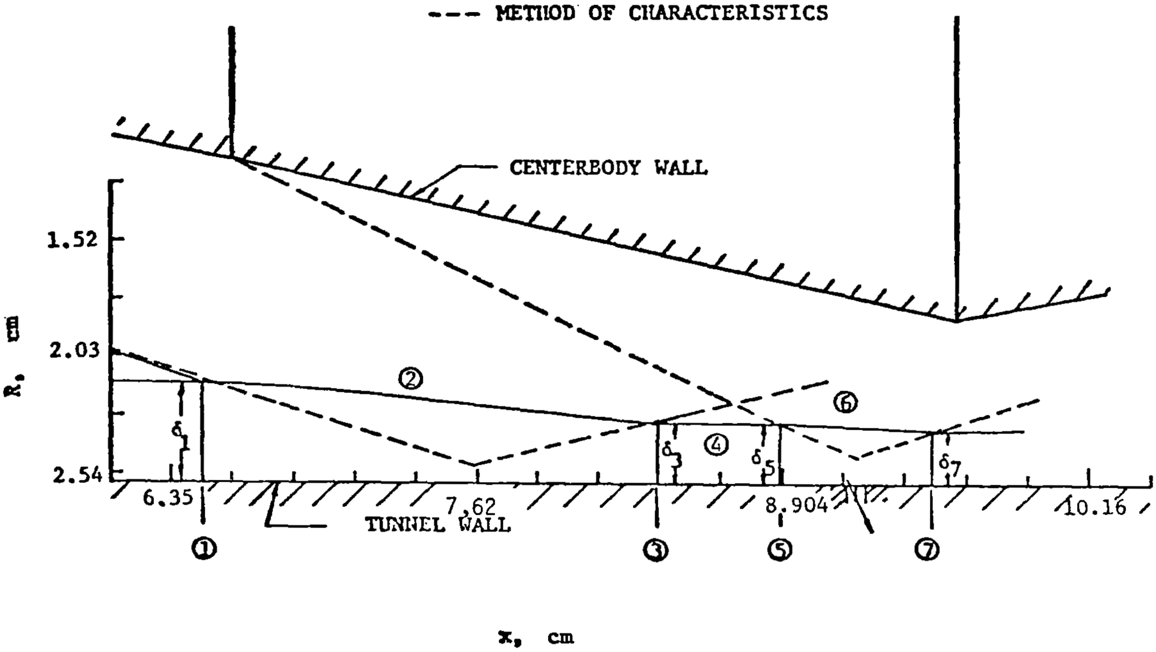
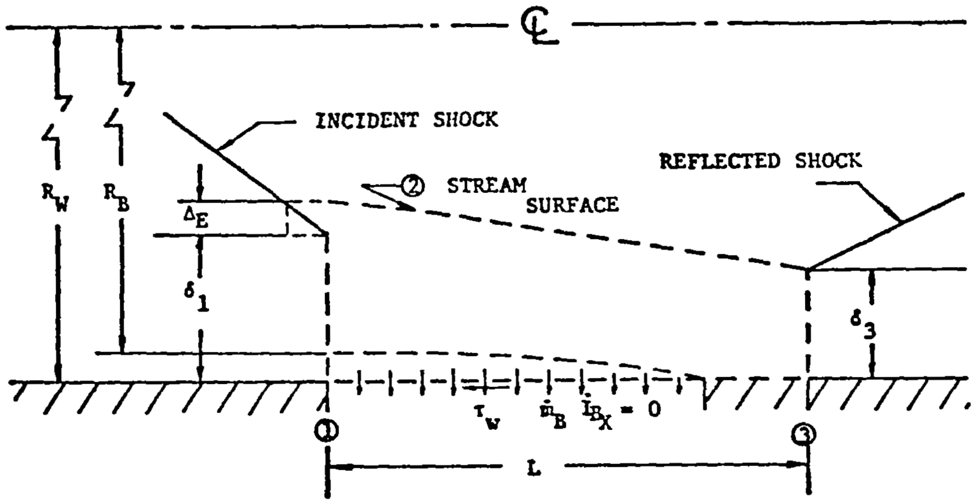
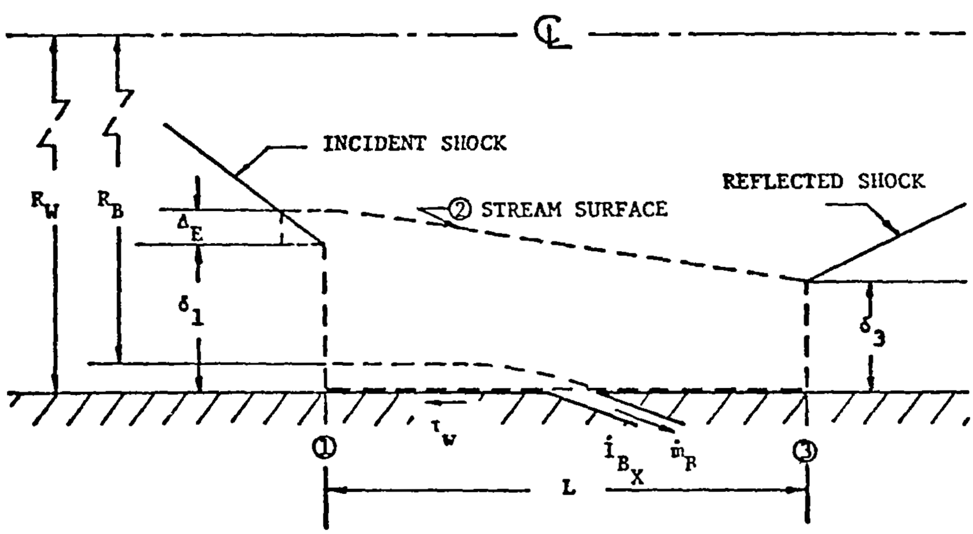


FIGURE 2. FLOW MODEL USED IN ANALYSIS

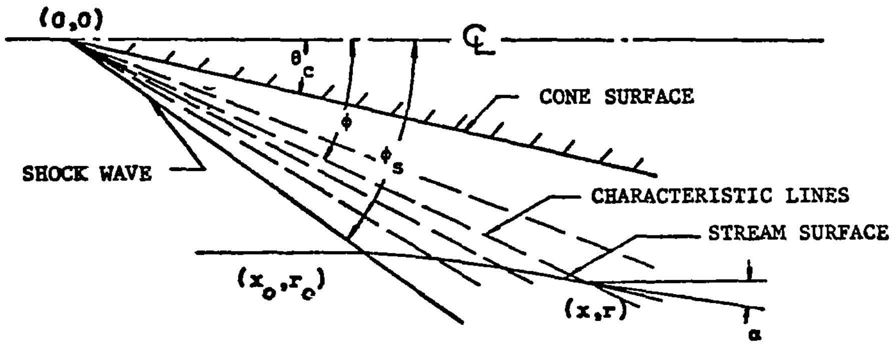


(a) POROUS WALL BLEED

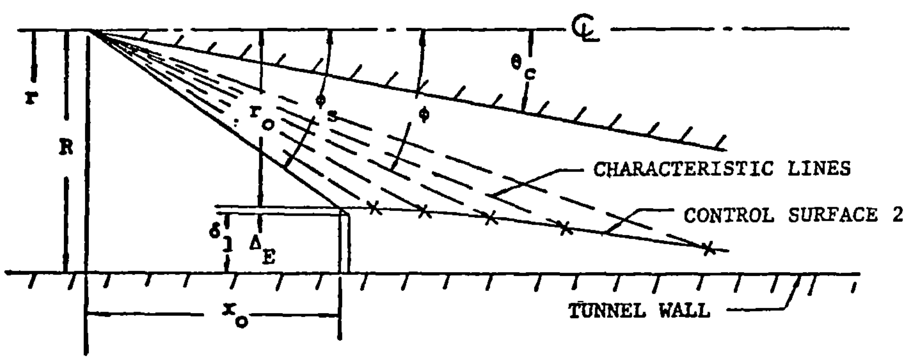


(b) SLOT BLEED

FIGURE 3. CONTROL VOLUME USED IN ANALYSIS



(a)



(b)

FIGURE 4. DETERMINATION OF STREAM SURFACE 2

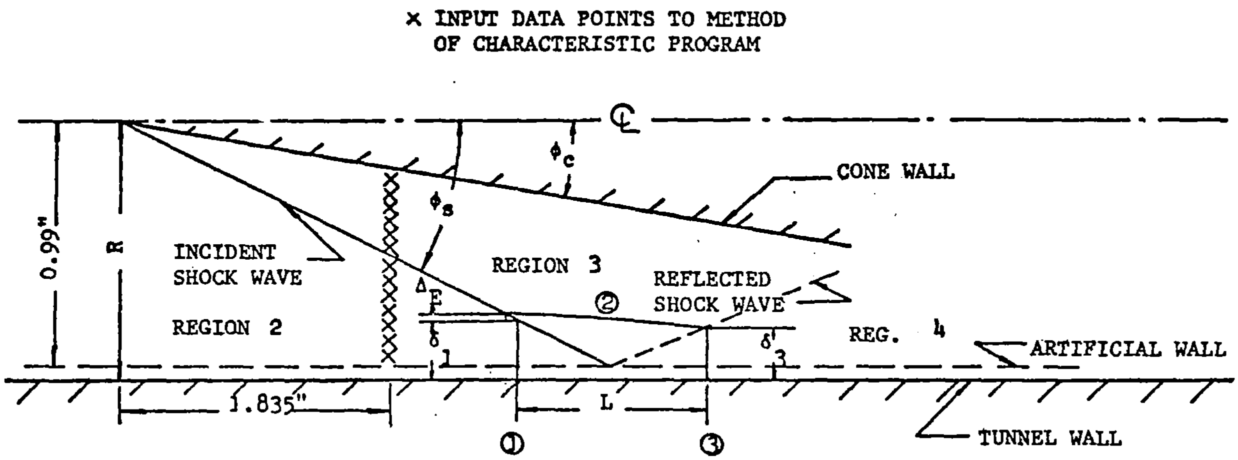


FIGURE 5. INPUT FOR COMPUTING EXTERNAL FLOW FIELD BY METHOD OF CHARACTERISTICS

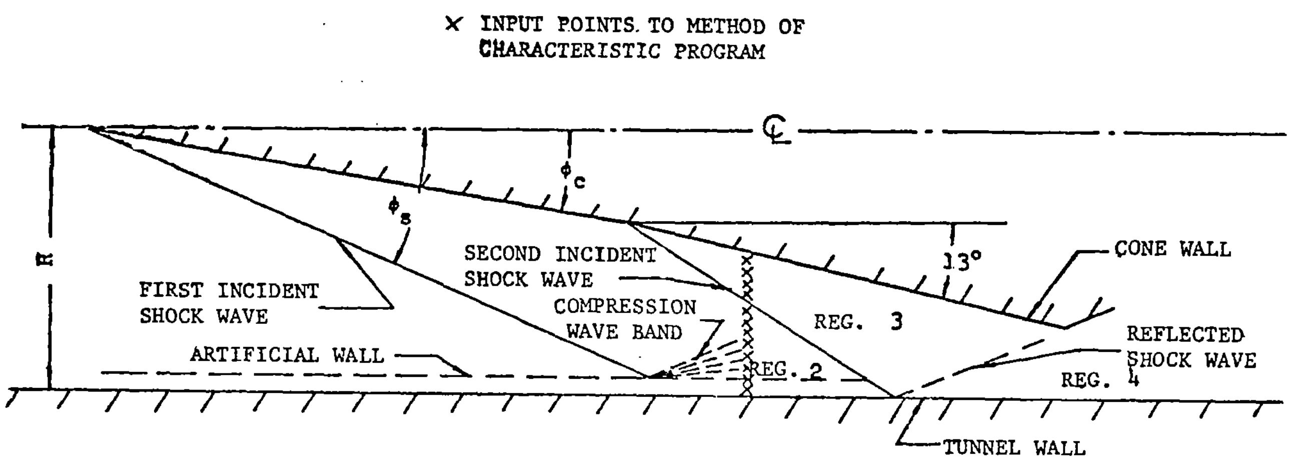


FIGURE 6. INPUT FOR COMPUTING EXTERNAL FLOW FIELD FOR SECOND INTERACTION

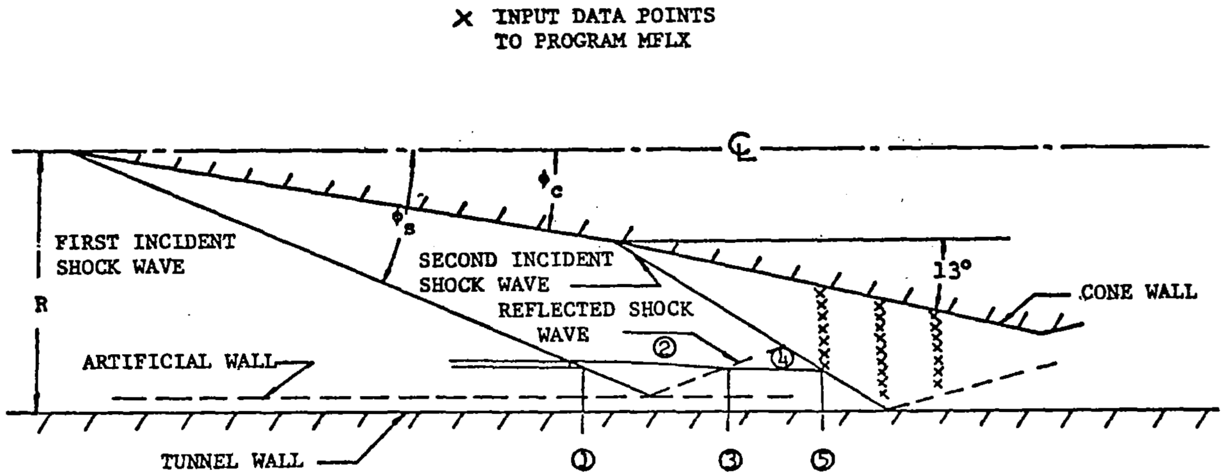


FIGURE 7. COMPUTATION OF MASS FLUX AS A FUNCTION OF RADIAL COORDINATE

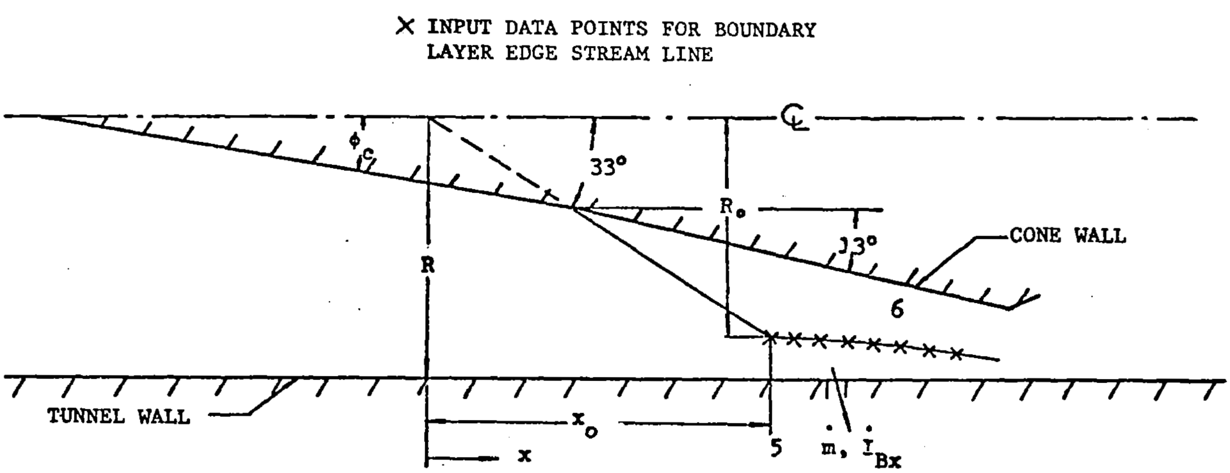


FIGURE 8. LOCATION OF STREAM SURFACES

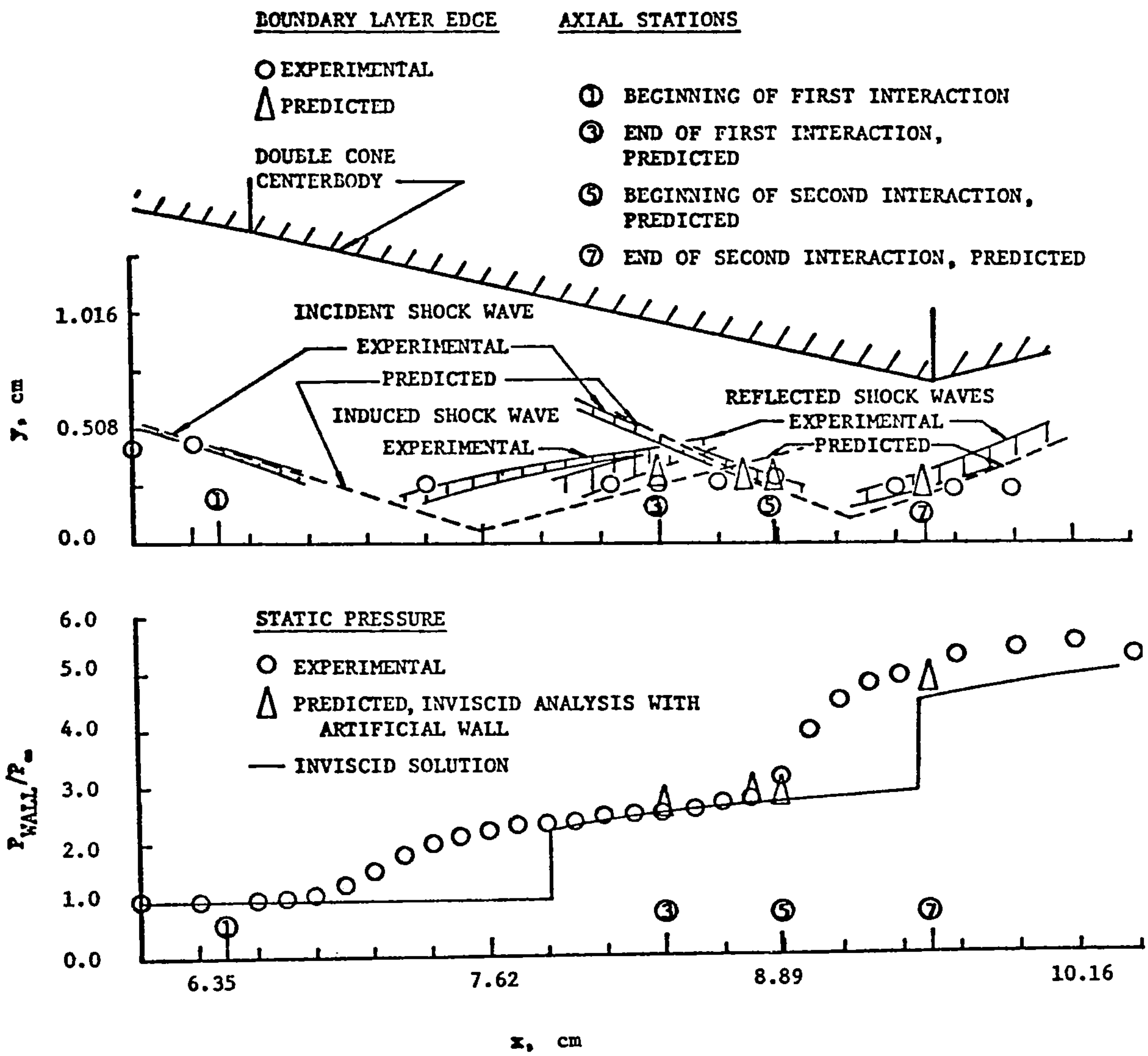


FIGURE 9. SHOCK WAVE POSITIONS, BOUNDARY LAYER THICKNESS AND WALL STATIC PRESSURES.
$M_\infty = 3.82$ NO BLEED

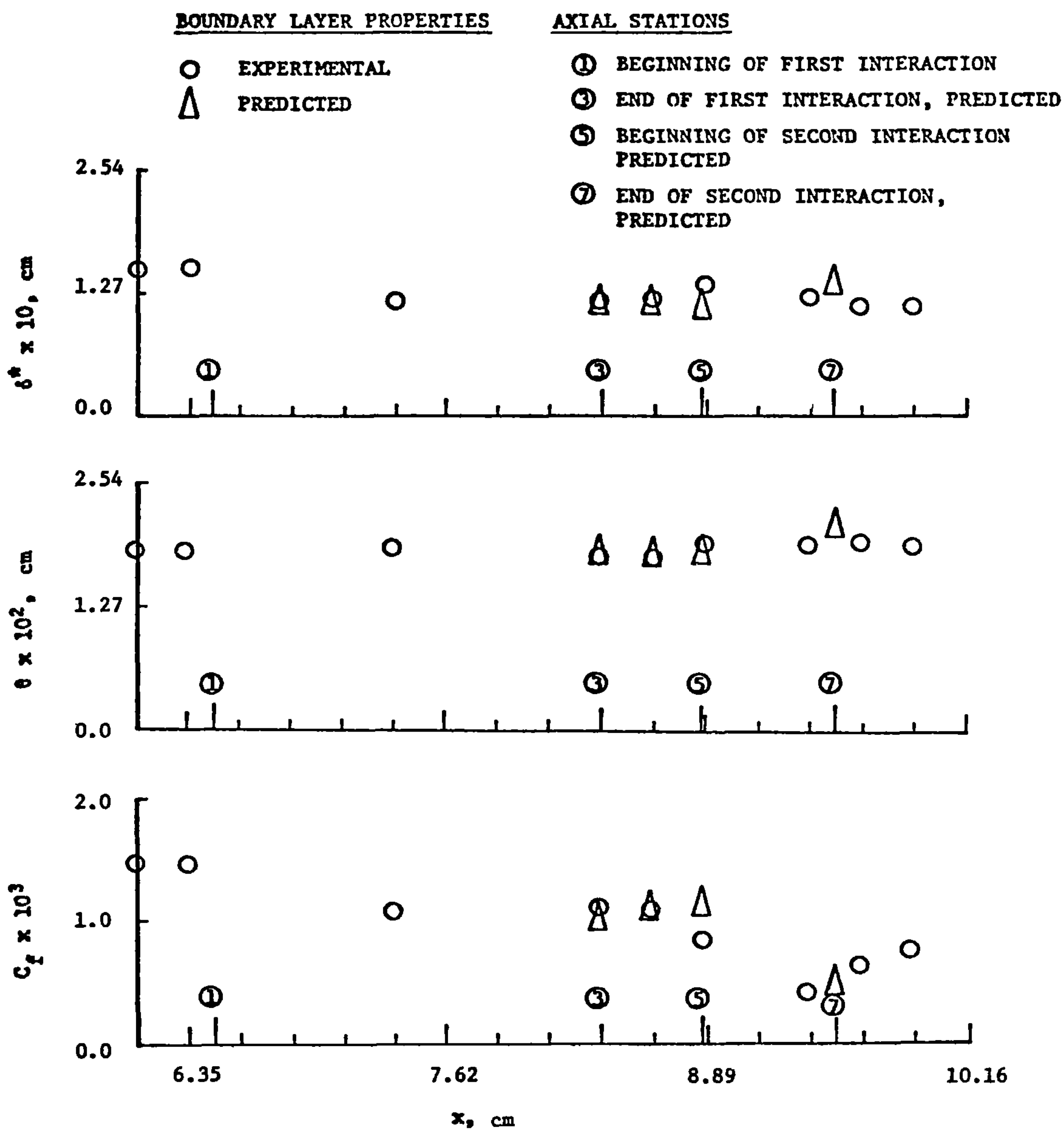


FIGURE 10. δ^*, θ AND C_f, $M_\infty = 3.82$, NO BLEED

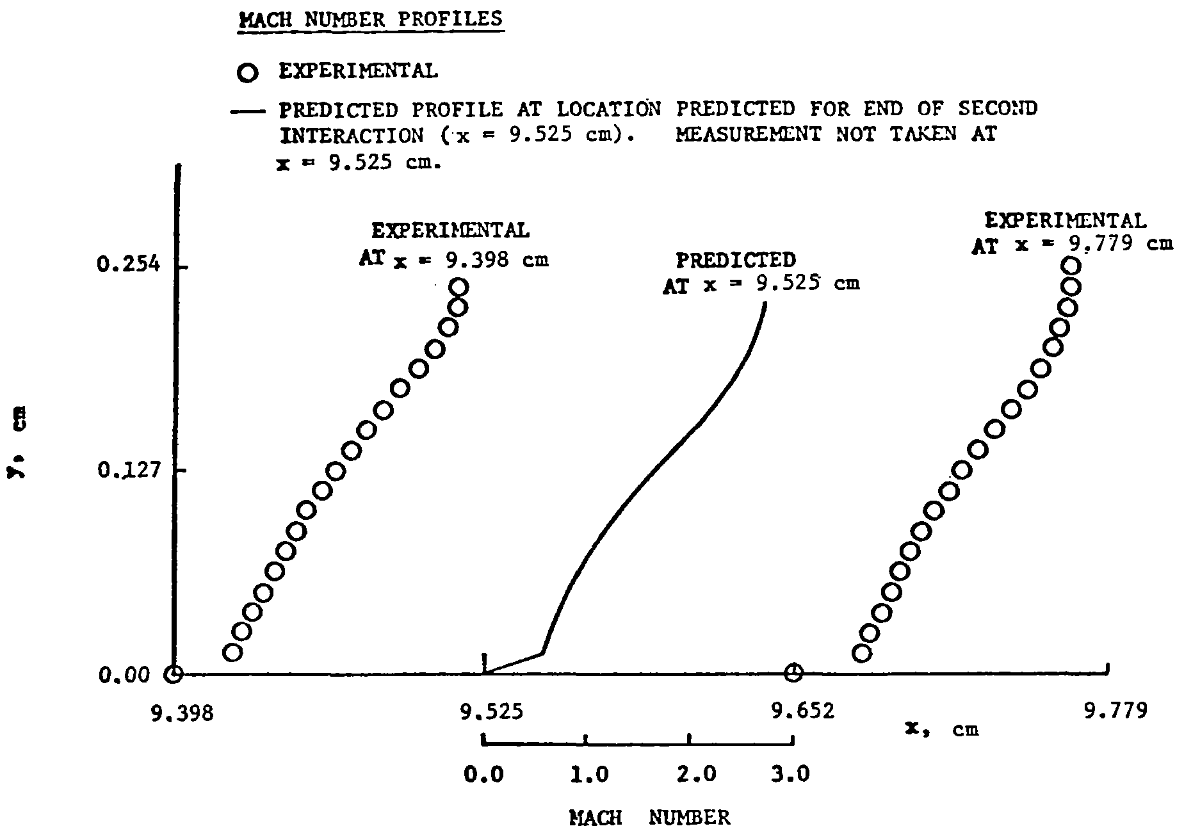


FIGURE 11. MACH NUMBER PROFILES DOWNSTREAM OF SECOND INTERACTION, M_∞ = 3.82, NO BLEED.

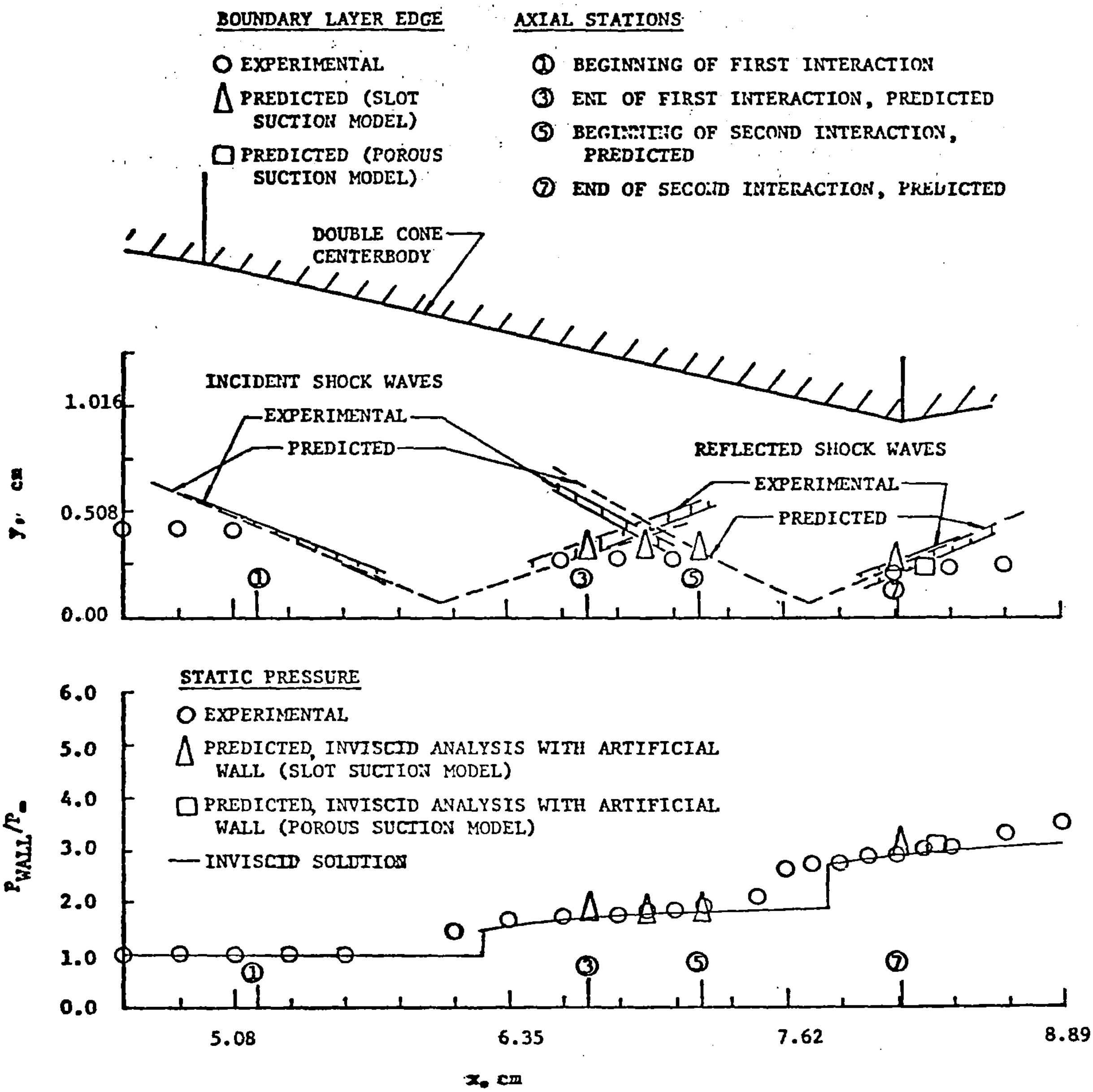


FIGURE 12. SHOCK WAVE POSITION, BOUNDARY LAYER THICKNESS AND WALL STATIC PRESSURES, $M_\infty = 2.82$. 2.82 PER CENT BLEED.

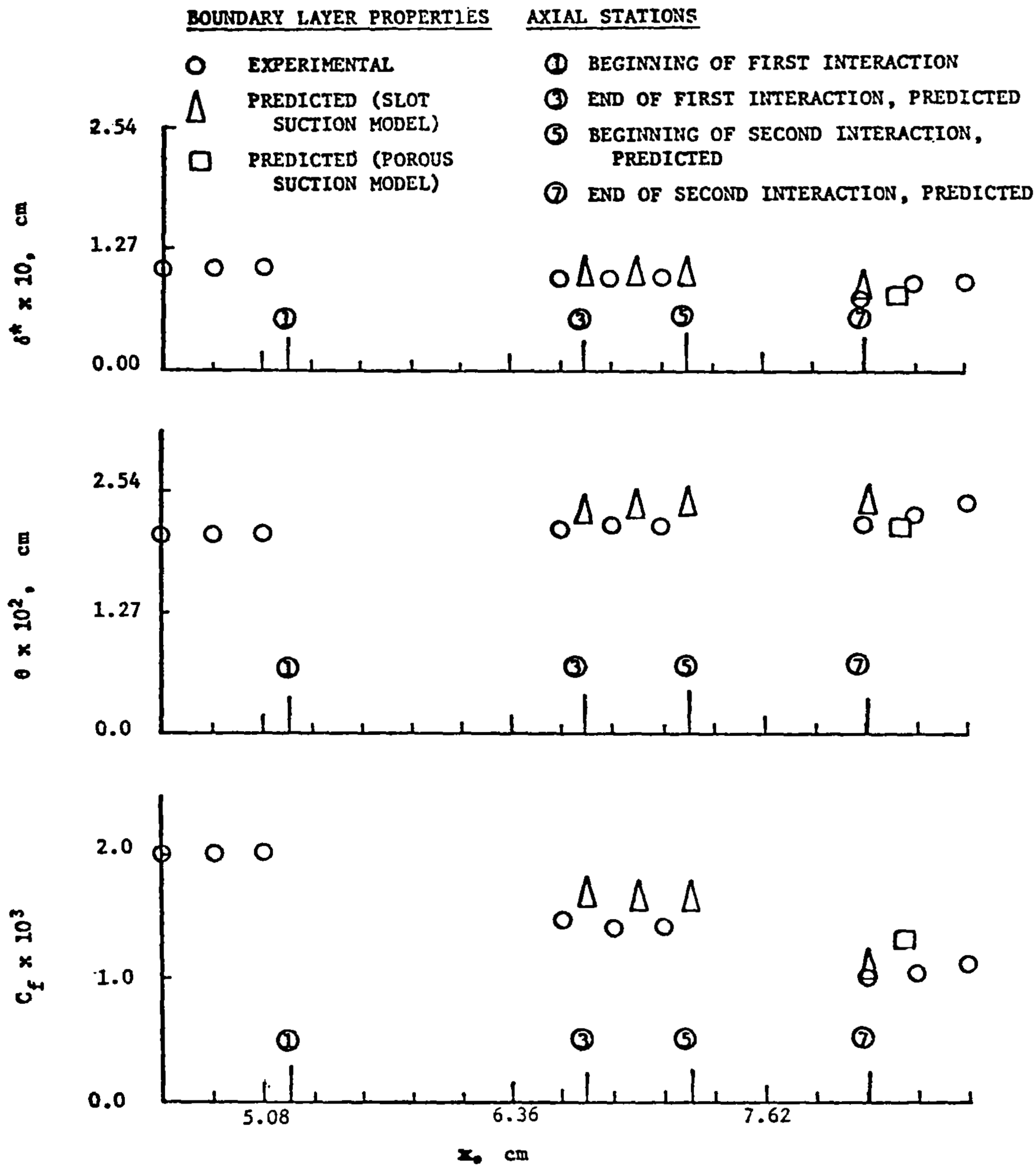


FIGURE 13. δ^*, θ, C_f, M_∞ = 2.82, 5.0 PERCENT BLEED

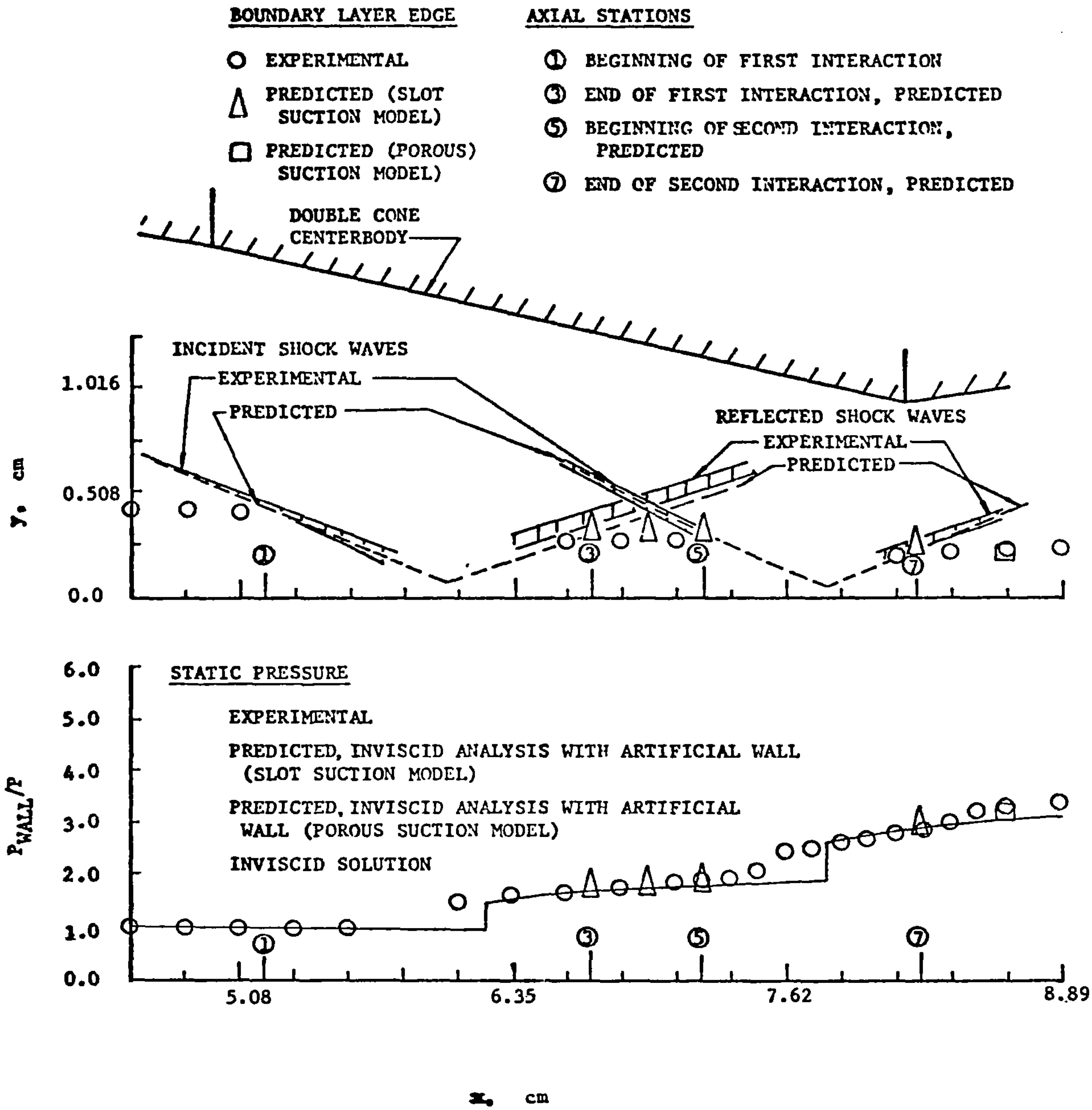


FIGURE 14. SHOCK WAVE POSITIONS. BOUNDARY LAYER THICKNESS AND WALL STATIC PRESSURES. M_∞ = 2.82, 5.0 PERCENT BLEED.

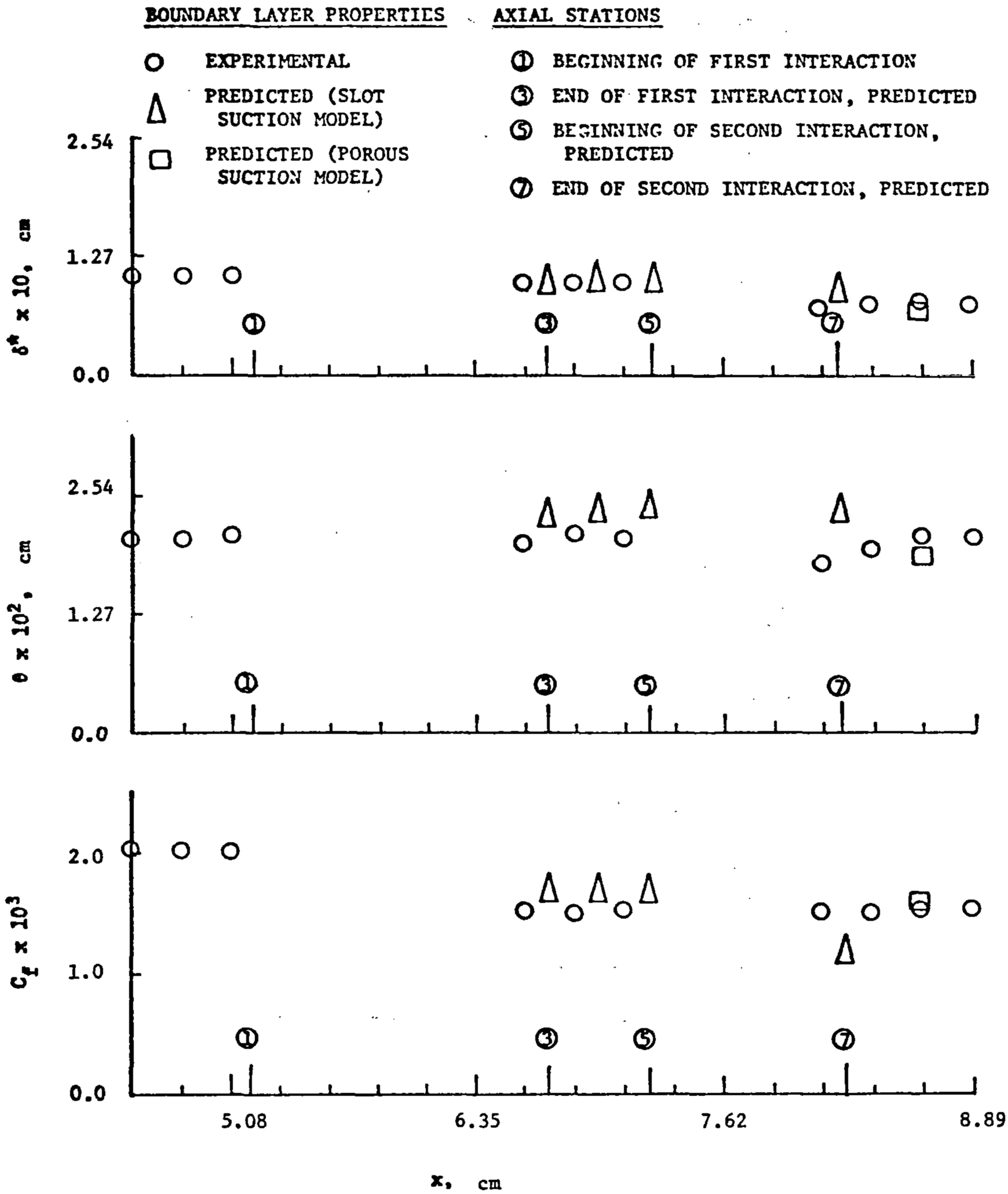


FIGURE 15. δ^*, θ, C_f. M_∞ = 2.82, 5.0 PERCENT BLEED.

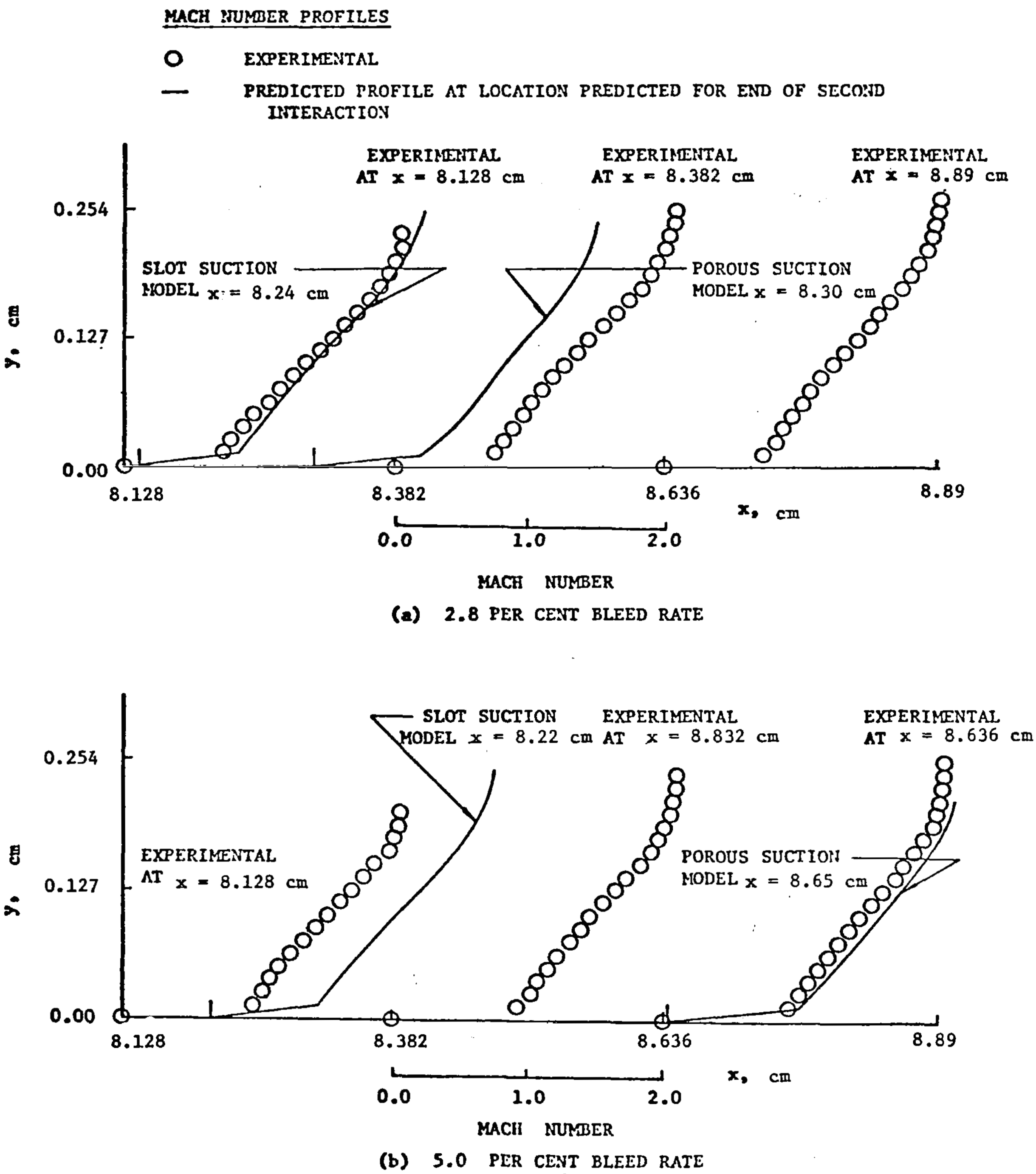


FIGURE 16. MACH NUMBER PROFILES DOWNSTREAM OF SECOND INTERACTION M_∞ = 2.82, 5.0 PERCENT BLEED

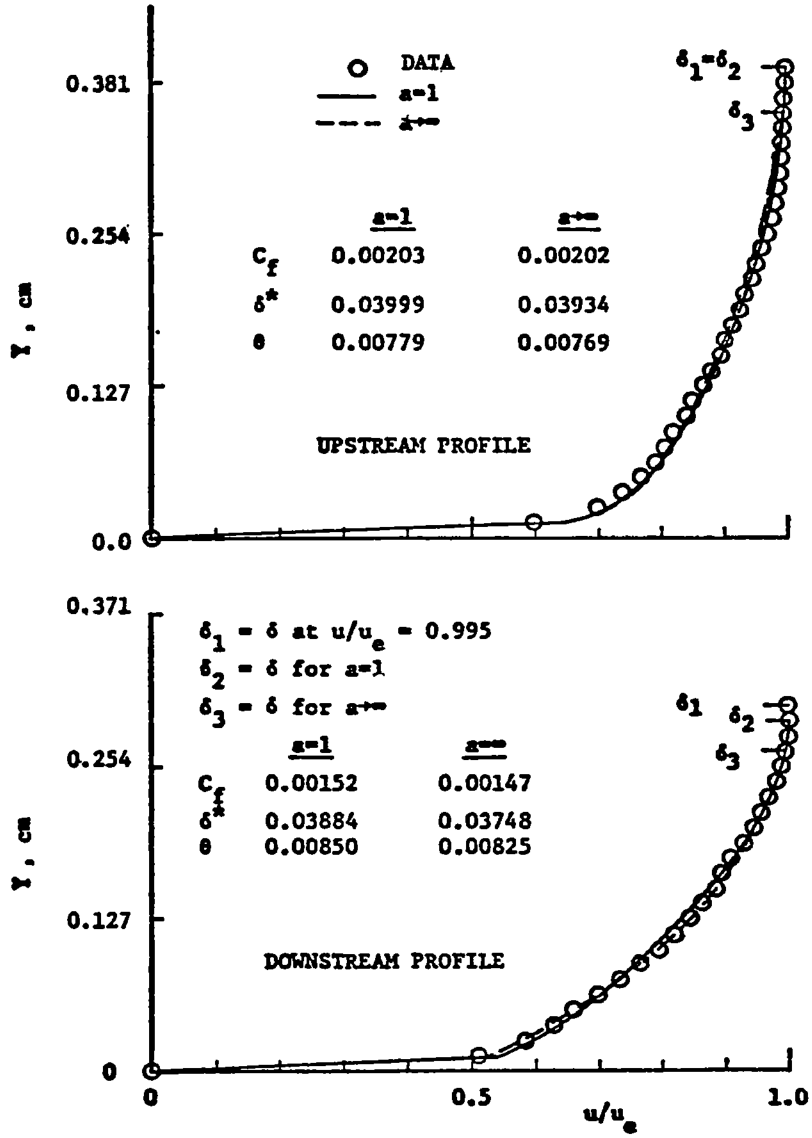


FIGURE 17. VELOCITY PROFILES UPSTREAM AND DOWNSTREAM OF A SHOCK WAVE - BOUNDARY LAYER INTERACTION.

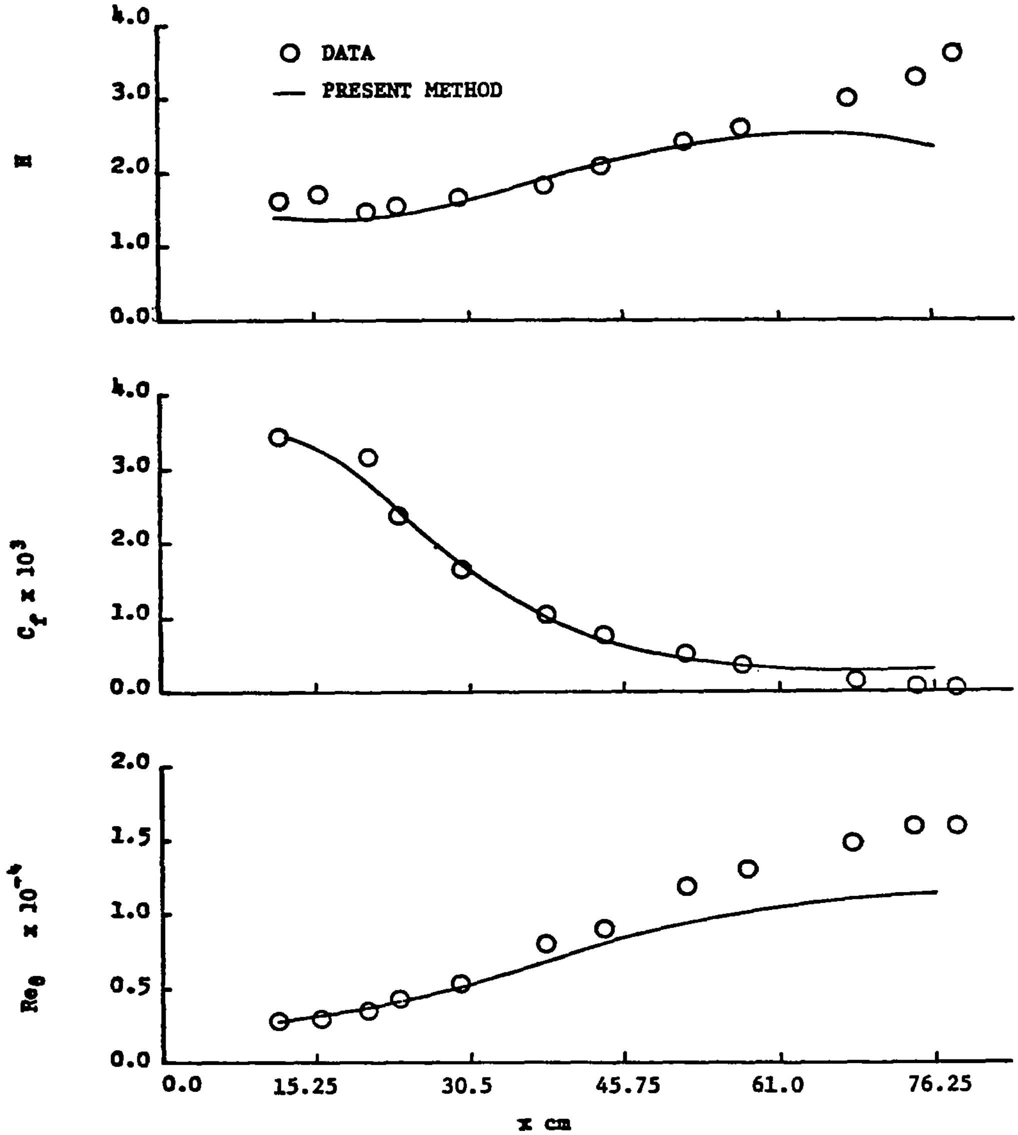


FIGURE 18. COMPARISON OF BOUNDARY LAYER PREDICTIONS OF BLGRN PROGRAM WITH DATA.

TABLE 1-A: PROGRAM LEAST

```
      PROGRAM  LEAST(INPUT,OUTPUT,TAPE 5=INPUT, TAPE 6=OUTPUT)
C
C
C     PROGRAM FOR LEAST SQUARES FIT OF WALL WAKE PROFILE
C
C   INPUT FORMAT 7F10.6 EXCEPT CARD 1
C
C   CARD(S) COLUMNS
C
C     1      TITLE,COLUMNS 1-72 HOLLERITH
C     2      1-10     AT     =0. NO TOTAL TEMPERATURE DISTRIBUTION INPUT
C                            =1. TOTAL TEMPERATURE DISTRIBUTION INPUT
C            11-20    AIP    =0. CONSTANT PRESSURE DISTRIBUTION
C                            =1. LINEAR PRESSURE DISTRIBUTION
C                            =2. POINTWISE PRESSURE INPUT
C            21-30    APT    =0. NO PITOT PRESSURE INPUT
C                            =1. PITOT PRESSURE DISTRIBUTION INPUT
C            31-40    AIM    =0. NO MACH NUMBER DISTRIBUTION INPUT
C                            =1. MACH NUMBER DISTRIBUTION INPUT
C            41-50    AIY    =0. EQUAL Y-INCREMENT
C                            =1. POINTWISE Y INPUT
C            51-60    AJB    =0. NO MORE JOB AFTER THIS INPUT
C                            =1. MORE JOB AFTER THIS INPUT
C     3      1-10     CA     =5.1
C            11-20    BK     =0.4
C            21-30    AID    =1.
C            31-40    AAK    =50.
C            41-50    UTFT   =0.04 FIRST ASSUMED VALUE FOR UT
C     4      1-10     GAMMA  =1.4 GAS CONSTANT
C            11-20    PT01   TOTAL PRESSURE OUTSIDE B.L. IN PSIA
C            21-30    TT01   TOTAL TEMPERATURE OUTSIDE B.L. IN R
C     5      1-10     AM     NUMBER OF PROFILES INPUT
C     6      1-10     PW     STATIC PRESSURE AT WALL
C            11-20    R      LOCAL RADIUS OF TUNNEL IN INCH
C            21-30    X      STATION DISTANCE
C            31-40    AN     NUMBER OF POINT INPUT
C            41-50    ANN    APPROXIMATE NUMBER OF POINTS TO BL EDGE
C            51-60    DY     SIZE OF Y-INCREMENT IN INCH
C     7      1-70     PT     PITOT PRESSURE,AN VALUES IN PSIA (APT=1.)
C     8      1-70     TT     TOTAL  TEMPERATURE AN VALUES IN R (AT=1.)
C     9      1-70     EM     MACH NUMBER AN VALUES (AIM=1.)
C    10      1-70     Y      Y INPUT IN I INCH,AN VALUE (AIY=1.)
C    11      1-70     P      STATIC PRESSURE INPUT (AIP=2.)
C
      DIMENSION PW(9),PEE(9),PTU(60,9),PTUE(9),PT(60,9),P(60,9),
     1          TT(60,9),T(60,9),TTE(9),EM(60,9),RHO(60,9),
     2          R(9),X(9),ANN(9),Y(60,9),ZZ(60)
      DIMENSION Z(60),UZ(60),YZ(60)
      DIMENSION TITLE(12),YY(60,9)
```

```
      DIMENSION ZP(60),ZM(60),ZT(60)
      DIMENSION ZS(60),ZH(60)
      COMMON AIC,BK,CA,GAMMA,GAM1,GAM2,GAM3,GAM4,GAM5,GAM6,EEM,
     1        AN(9),CFF(9),DEL(9),RHOE(9),UE(9),TE(9),
     2        U(60,9),AAK,UTFT
   90 READ(5,1010) (TITLE(J),J=1,12)
      READ(5,1000) AT,AIP,APT,AIM,AIY,AJB
      READ(5,1000) CA,BK,AID,AAK,UTFT
      READ(5,1000) GAMMA,PTO1,TTO1
      GAM1=GAMMA-1.
      GAM2=GAMMA+1.
      GAM3=GAMMA/GAM1
      GAM4=1./GAM3
      GAM5=1./GAMMA
      GAM6=GAM1/2.
      GAM7=1./GAM1
      READ(5,1000) AM
      M=AM
      DO 8 J=1,M
    1 READ(5,1000) PW(J),R(J),X(J),AN(J),ANN(J),DY
      AN1=AN(J)
      AN2=ANN(J)
      N=AN1
      N2=AN2
      L=1
      IF(APT.EQ.1.) READ(5,1000)(PT(I,J),I=1,N )
      IF(AT.EQ.1.) READ(5,1000)(TT(I,J),I=1,N)
      IF(AIM.EQ.1.) READ(5,1000)(EM(I,J),I=1,N)
      IF(AT.EQ.1.) GO TO 103
      DO 102 I=1,N
      TT(I,J)=TTO1
  102 CONTINUE
  103 IF(AIY.EQ.3.) GO TO 104
      READ(5,1000)(Y(I,J),I=1,N)
      GO TO 223
  104 Y(1,J)=0.
      DO 2 I=2,N
      Y(I,J)=Y(I-1,J)+DY
    2 CONTINUE
  223 IF(AIP.EQ.2.) READ(5,1000) (P(I,J),I=1,N)
      DEL(J)=Y(N2,J)
   11 DO 3 I=1,N
      YY(I,J)=Y(I,J)/DEL(J)
      Z(I)=Y(I,J)
      ZZ(I)=PT(I,J)
      ZP(I)=P(I,J)
      ZT(I)=TT(I,J)
      ZM(I)=EM(I,J)
    3 CONTINUE
      DLL=DEL(J)
      IF(AIM.EQ.1.) GO TO 14
      IF(AIP.EQ.2.) GO TO 15
C
C     COMPUTE EME BY PTO2/PTO1
C
      IF(L.EQ.1) PTO2=PT(N2,J)
      IF(L.GT.1) CALL INTP(Z,ZZ,DLL,PTO2,N)
```

```
      PT2PT1=PT02/PT01
      EMOLD=1.666*PT2PT1*PT2PT1-5.666*PT2PT1+5.
    4 AR1=(GAM2*EMOLD*EMOLD/( GAM1*EMOLD*EMOLD+2.))**GAMMA
      AR2=PT2PT1**GAM1
      AR3=(AR1*GAM2/AR2+GAM1)/(2.*GAMMA)
      EMNEW=SQRT(AR3)
      IF(ABS(EMOLD-EMNEW)-0.001) 10,10,20
   20 EMOLD=EMNEW
      GO TO 4
   14 IF(L.EQ.1) EMNEW=EM(N2,J)
      IF(L.GT.1) CALL INTP(Z,ZM,DLL,EMNEW,N)
   10 EME=EMNEW
C
C     COMPUTE PE BY PT01 AND EME
C
      AR4=(1.+GAM1*EME*EME/2.)**GAM3
      PE=PT01/AR4
      PEE(J)=PE
      IF(AIP.EQ.2.) GO TO 15
      DO 5  I=1,N
      P(I,J)=(PEE(J)-PW(J))*YY(I,J)*AIP+PW(J)
    5 CONTINUE
      IF(AIP.EQ.0.) PE=PW(J)
C
   15 IF(AIP.EQ.2.) CALL INTP(Z,ZP,DLL,PE,N)
      PEE(J)=PE
      TS=TT01
      IF(AT.EQ.1.)  CALL INTP(Z,ZT,DLL,TS,N)
      TTE(J)=TS
C
C     COMPUTE EM BY PT2/P
C
      IF(AIM.EQ.1.) GO TO 17
      TEST=(0.5*GAM2)**GAM3
      DO 6  I=1,N
      RATIO=PT(I,J)/P(I,J)
      IF(RATIO.LT.1.) GO TO 30
      IF(RATIO-TEST) 40,50,60
C
C     SUBSONIC
C
   40 EM(I,J)=SQRT(2.*(RATIO**GAM4-1.)/GAM1)
      GO TO 6
C
C     PT2 LESS THAN P
C
   30 EM(I,J)=0.
      GO TO 6
C
C     SONIC
C
   50 EM(I,J)=1.
      GO TO 6
C
C     SUPERSONIC
C
   60 EMOLD=1.05
```

```
   63 AR1=((2.*GAMMA*EMOLD*EMOLD-GAM1)/GAM2)**GAM5
      AR2=RATIO**GAM4
      EMNEW=SQRT(2.*AR1*AR2/GAM2)
      IF(ABS(EMOLD-EMNEW)-0.001) 61,61,62
   61 EM(I,J)=EMNEW
      GO TO 6
   62 EMOLD=EMNEW
      GO TO 63
    6 CONTINUE
C
C     COMPUTE UPSTREAM PROPERTIES
C
   17 DO 7 I=1,N
      PTU(I,J)=P(I,J)*(1.+GAM6*EM(I,J)*EM(I,J))**GAM3
      T(I,J)=TT(I,J)/(1.+GAM6*EM(I,J)*EM(I,J))
      RT=SQRT(T(I,J))
      U(I,J)=EM(I,J)*49.0*RT
      RHO(I,J)=P(I,J)*144.*32.2/(1716.*T(I,J))
    7 CONTINUE
      IF(APT.EQ.1.) GO TO 177
      DO 117 I=1,N
      PT(I,J)=PTU(I,J)
      IF(EM(I,J).GT.1.) PT(I,J)=P(I,J)*(0.5*GAM2*EM(I,J)*EM(I,J))
     1**GAM3/(2.*GAMMA*EM(I,J)*EM(I,J)/GAM2-GAM1/GAM2)**GAM7
  117 CONTINUE
  177 IF(AIM.EQ.1.) GO TO 18
C
C  COMPUTE EDGE CONDITION
C
      TEST=(0.5*GAM2)**GAM3
      RATIO=PT02/PEE(J)
      IF(RATIO.LT.1.) GO TO 39
      IF(RATIO-TEST) 49,59,69
C
C SUBSONIC
C
   49 EME    =SQRT(2.*(RATIO**GAM4-1.)/GAM1)
      GO TO 96
C
C PT2 LESS THAN P
C
   39 EME=0.
      GO TO 96
C
C SONIC
C
   59 EME=1.
      GO TO 96
C
C SUPERSONIC
C
   69 EMOLD=1.05
  163 AR1=((2.*GAMMA*EMOLD*EMOLD-GAM1)/GAM2)**GAM5
      AR2=RATIO**GAM4
      EMNEW=SQRT(2.*AR1*AR2/GAM2)
      IF(ABS(EMOLD-EMNEW)-0.001) 161,161,162
  162 EMOLD=EMNEW
```

```
      GO TO 163
  161 EME=EMNEW
   96 CONTINUE
C
C  COMPUTE UPSTREAM PROPERTIES
   18 PTUE(J)=PEE(J)*(1.+GAM6*EME*EME)**GAM3
      TE(J)=TTE(J)/(1.+GAM6*EME*EME)
      RT=SQRT(TE(J))
      UE(J)=EME*49.*RT
      RHOE(J)=PEE(J)*144.*32.2/(1716.*TE(J))
      EEM=EME
      TWTO=TT(1,J)/TTE(J)
      CALL LWLW(J,Z,SNN,NO,L,TWTO)
      IF(ABS(SNN).LE.0.00000001) GO TO 21
      IF(L.GT.1) GO TO 12
      L=L+1
      DE1=DEL(J)
      DEL(J)=0.9*DEL(J)
      SNN1=SNN
      GO TO 11
   12 L=L+1
      SLAPE=SNN1/(SNN-SNN1)
      DE2=DEL(J)
      DEL(J)=DE1+SLAPE*(DE1-DE2)
      DE1=DE2
      SNN1=SNN
      GO TO 11
   21 WRITE(6,2010)(TITLE(I),I=1,12)
      WRITE(6,2003) X(J),PT01,TT01
      WRITE(6,2004)
      DO 210 I=1,N
      WRITE(6,2005) I,Y(I,J),P(I,J),PT(I,J),EM(I,J),TT(I,J)
  210 CONTINUE
      WRITE(6,2010) (TITLE(I),I=1,12)
      WRITE(6,2000) X(J),R(J),PW(J),DEL(J),CFF(J),UE(J),RHOE(J)
      WRITE(6,2001)
      DO 211 I=1,NO
      TREF=T(I,J)+198.5
      TRRF=T(I,J)**1.5
      VIS=2.27*TRRF/TREF/10.**8.
      B=      U(I,J)*RHO(I,J)/32.2/VIS/10.**6.
      UR=U(I,J)/UE(J)
      PR=P(I,J)/PW(J)
      RR=RHO(I,J)/RHOE(J)
      PTR=PTU(I,J)/PT01
      TTR=TT(I,J)/TT01
      UU=UR*UE(J)
      PO=RR*RHOE(J)
      RRO=RO/32.2
      ZS(I)=(1.-UR*RR)*(R(J)-Y(I,J))
      ZH(I)=(1.-UR)*UR*RR*(R(J)-Y(I,J))
      WRITE(6,2002) I,Y(I,J),YY(I,J),B,EM(I,J),UR,RR,PR,TTR,PTR
  211 CONTINUE
      SUD=0.
      SUT=0.
      DO 212 I=2,NO
      IS=I-1
```

```
      SUD=SUD+0.5*(Y(I,J)-Y(IS,J))*(ZS(I)+ZS(IS))
      SUT=SUT+0.5*(Y(I,J)-Y(IS,J))*(ZH(I)+ZH(IS))
  212 CONTINUE
      NO=NO+1
      TREF=TE(J)+198.5
      TRRF=TE(J)**1.5
      VIS=2.27*TRRF/TREF/10.**8.
      B=UE(J)*RHOE(J)/32.2/VIS/10.**6.
      YZY=1.
      UR=1.
      PR=PEE(J)/PW(J)
      RR=RHOE(J)/RHOE(J)
      TTR=TTE(J)/TT01
      PTR=PTUE(J)/PT01
      WRITE(6,2002) NO,DLL,YZY,B,EEM,UR,RR,PR,TTR,PTR
      SUD=SUD+0.5*(DLL-Y(NO,J))*ZS(NO)
      SUT=SUT+0.5*(DLL-Y(NO,J))*ZH(NO)
      SQD=R(J)*R(J)-2.*SUD
      SQT=R(J)*R(J)-2.*SUT
      SRD=SQRT(SQD)
      SRT=SQRT(SQT)
      DELSTA=R(J)-SRD
      THETA=R(J)-SRT
      WRITE(6,2007) DELSTA,THETA
      WRITE(6,2010) (TITLE(I),I=1,12)
      WRITE(6,2000) X(J),R(J),PW(J),DEL(J),CFF(J),UE(J),RHOE(J)
      WRITE(6,2006)
      WRITE(6,2001)
      DO 311 I=1,N
      Z(I)=Y(I,J)
      ZZ(I)=P(I,J)
  311 CONTINUE
      CALL PRFL(J,TWTO,UZ,YZ,NO,UTSA)
      DO 312 I=1,NO
      T(I,J)=(TWTO+(1.-TWTO)*UZ(I)-GAM6*EEM*EEM*UZ(I)*UZ(I)/(1.
     1+GAM6*EEM*EEM))*TTE(J)
      TE1=TE(J)/T(I,J)
      TER=SQRT(TE1)
      EM(I,J)=EEM*UZ(I)*TER
      Y(I,J)= DEL(J)*YZ(I)
      TT(I,J)=T(I,J)*(1.+GAM6*EM(I,J)*EM(I,J))
      YQ=Y(I,J)
      CALL INTP(Z,ZZ,YQ,PQ,N)
      P(I,J)=PQ
      PTU(I,J)=P(I,J)*(1.+GAM6*EM(I,J)*EM(I,J))**GAM3
      TREF=T(I,J)+198.5
      TRRF=T(I,J)**1.5
      VIS=2.27*TRRF/TREF/10.**8.
      RHO(I,J)=P(I,J)*144.*32.2/(1716.*T(I,J))
      B=UZ(I)*UE(J)*RHO(I,J)/32.2/VIS/10.**6.
      PR=P(I,J)/PW(J)
      RR=RHO(I,J)/RHOE(J)
      PTR=PTU(I,J)/PT01
      TTR=TT(I,J)/TT01
      ZS(I)=(1.-UZ(I)*RR)*(R(J)-Y(I,J))
      ZH(I)=(1.-UZ(I))*UZ(I)*RR*(R(J)-Y(I,J))
      WRITE(6,2002)I,Y(I,J),YZ(I),B,EM(I,J),UZ(I),RR,PR,TTR,PTR
```

```
 312 CONTINUE
     SUD=0.
     SUT=0.
     DO 313 I=2,NO
     IS=I-1
     SUD=SUD+0.5*(Y(I,J)-Y(IS,J))*(ZS(I)+ZS(IS))
     SUT=SUT+0.5*(Y(I,J)-Y(IS,J))*(ZH(I)+ZH(IS))
 313 CONTINUE
     SQD=R(J)*R(J)-2.*SUD
     SQT=R(J)*R(J)-2.*SUT
     SRD=SQRT(SQD)
     SRT=SQRT(SQT)
     DELSTA=R(J)-SRD
     THETA=R(J)-SRT
     WRITE(6,2008) DELSTA,THETA,UTSA
   8 CONTINUE
     IF(AJB.EQ.1.) GO TO 90
1000 FORMAT(7F10.6)
1010 FORMAT(12A6)
2010 FORMAT(1H1,30X,12A6)
2000 FORMAT(/8X,10HSTATION X=,F10.6,3H IN,3X,2HR=,F10.3,3H IN,3X,
    16HPWALL=,F10.6,5H PSIA,3X,4HDEL=,F10.6,3H IN,3X,3HCF=,F10.6,
    1 2X,3HUE=,F7.2,2X,5HRHOE=,F9.6/)
2001 FORMAT(1H ,4X,1HI,9X,1HY,9X,2HYY,8X,6HRE(FT),7X,2HME,9X,
    14HU/UE,8X,8HRHO/RHOE,4X,4HP/PW,8X,6HTT/TTE,6X,6HPTU/PT/)
2002 FORMAT(2X,I3,2X, 9F12.6)
2003 FORMAT(/8X,10HSTATION X= ,F10.6,3H IN ,3X,4HPTO=,F10.5,3X,
    14HTTO=,F10.5/)
2004 FORMAT(/12X,1HI,12X,1HY,12X,1HP,12X,2HPT,12X,1HM,12X,2HTT  /)
2005 FORMAT(10X,I3,2X,5F14.6)
2006 FORMAT(/40X,28H WALL-WAKE VELOCITY PROFILE          /)
2007 FORMAT(20X,7HDELTA*=,F10.6,4H IN.,4X,6HTHETA=,F10.6, 4H IN. )
2008 FORMAT(20X,7HDELTA*=,F10.6,4H IN.,4X,6HTHETA=,F10.6, 4H IN.,
    14X,7HUT/UE*=,F10.6)
     END


     SUBROUTINE LWLW(J,Z,SNN,NO,L,TWTO)
     DIMENSION URAT(100),Y(100),UT(100),PXA(100)
     DIMENSION Z(60)
     COMMON AID,BK,CA,GAMMA,GAM1,GAM2,GAM3,GAM4,GAM5,GAM6,EEM,
    1       AN(9),CFF(9),DEL(9),RHOE(9),UE(9),TE(9),
    2       U(60,9),AAK,UTFT
     AN1=AN(J)
     N=AN1
     TRRF=TE(J)**1.5
     TREF=TE(J)+198.5
     VIS=2.27*TRRF/TREF/10.**8.
     REDEL=UE(J)*RHOE(J)*DEL(J)/12./32.2/VIS
     SIGMA=GAM6*EEM**2./(1.+GAM6*EEM**2.)/TWTO
     SIGMB=1./TWTO-1.
     SA=SQRT(SIGMA)
     SAB=SIGMB**2.+4.*SIGMA
     ASB=SQRT(SAB)
     BAS=(2.*SIGMA-SIGMB)/ASB
     DO 2 I=1,N
```

```
      IF(Z(I)-DEL(J))2,3,4
    2 CONTINUE
    3 NO=I
      GO TO 30
    4 NO=I-1
   30 DO 1 I=1,NO
      URAT(I)=U(I,J)/UE(J)
      Y(I)=Z(I)/DEL(J)
    1 CONTINUE
      K=1
      CIAA=CA-0.614/(BK*AID)
      SIG2=2.*SIGMA/ASB
      SIG3=ASIN(BAS)
      FSIG=SIG3/SA
      UT(K)=UTFT
      VWVE=(1./TWTO-SIGMA)**1.76
      AAE=REDEL*FSIG*VWVE
    6 IF(UT(K)) 5,7,5
    7 PXA(K)=0.5
      SMM=0.
      SNN=0.
      GO TO 9
    5 PXA(K)=0.5*(1.-UT(K)*((1./BK)*ALOG(REDEL*ABS(UT(K))*FSIG*VWVE)
     1+CIAA))
      SMM=0.
      SNN=0.
    9 DO 10 I=2,NO
      ACS=1.+COS(3.14*Y(I))
      YAA=SQRT(1.-Y(I)**AID)
      ALG=ALOG(Y(I))+2.*(YAA-ALOG(1.+YAA))/AID
      ACT=1.+UT(K)*ALG/BK-PXA(K)*ACS
      AFF=SIN(SIG3*ACT)/SIG2+SIGMB/2./SIGMA
      ACD=(ALG+0.5*ACS*(ALOG(ABS(UT(K)))+ALOG(AAE)+BK*CIAA+1.))/BK
      SUN=(URAT(I)-AFF)*FSIG*COS(SIG3*ACT)*ACD
      SMM=SMM+SUN
      ADD=ACS*UT(K)/(2.*BK*DEL(J))-YAA*UT(K)/(BK*DEL(J))-PXA(K)*Y(I)*
     13.14*SIN(3.14*Y(I))/DEL(J)
      SUU=(URAT(I)-AFF)*COS(SIG3*ACT)*FSIG*ADD
      SNN=SNN+SUU
   10 CONTINUE
      CFF(J)=2.*UT(K)*FSIG*FSIG*(1./TWTO-SIGMA)*UT(K)
      IF(ABS(SMM).LE.0.00000001) GO TO 20
      IF(K.GT.1) GO TO 11
      K=K+1
      UT(K)=0.8*UT(K-1)
      SMM1=SMM
      GO TO 6
   11 K=K+1
      SLOPE=SMM1/(SMM-SMM1)
      UT(K)=UT(K-2)+SLOPE*(UT(K-2)-UT(K-1))
      SMM1=SMM
      GO TO 6
   20 RETURN
      END
```

```
      SUBROUTINE PRFL(J,TWTO,URT,Y,KAA,UT1)
      DIMENSION URT(60),Y(60)
      COMMON AID,BK,CA,GAMMA,GAM1,GAM2,GAM3,GAM4,GAM5,GAM6,EEM,
     1        AN(9),CFF(9),DEL(9),RHOE(9),UE(9),TE(9),
     2        U(60,9),AAK,UTFT
      TRRF=TE(J)**1.5
      TREF=TE(J)+198.5
      VIS=2.27*TRRF/TREF/10.**8.
      REDEL=UE(J)*RHOE(J)*DEL(J)/12./32.2/VIS
      SIGMA=GAM6*EEM**2./(1.+GAM6*EEM**2.)/TWTO
      SIGMB=1./TWTO-1.
      SA=SQRT(SIGMA)
      SAB=SIGMB**2.+4.*SIGMA
      ASB=SQRT(SAB)
      BAS=(2.*SIGMA-SIGMB)/ASB
      CIAA=CA-0.614/(BK*AID)
      SIG2=2.*SIGMA/ASB
      SIG3=ASIN(BAS)
      FSIG=SIG3/SA
      UT2=CFF(J)/(2.*FSIG*FSIG*(1./TWTO-SIGMA))
      UT1=SQRT(ABS(UT2))
      VWVE=(1./TWTO-SIGMA)**1.76
      IF(UT1.GT.0.) GO TO 2
      PXA=0.5
      GO TO 1
    2 PXA=0.5*(1.-UT1*((1./BK)*ALOG(REDEL*ABS(UT1)*FSIG*VWVE)+CIAA))
    1 AN1=AAK+1.
      KAA=AN1
      Y(1)=0.
      URT(1)=0.
      DO 10 I=2,KAA
      AI=I-1
      Y(I)=AI/AAK
      YAA=SQRT(1.-Y(I)**AID)
      ALG=ALOG(Y(I))+2.*(YAA-ALOG(1.+YAA))/AID
      ACS=1.+COS(3.14*Y(I))
      ACT=1.+UT1*ALG/BK-PXA*ACS
      URT(I)=SIN(SIG3*ACT)/SIG2+SIGMB/2./SIGMA
   10 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE INTP(X,Y,XOT,YOT,NO)
      DIMENSION X(60),Y(60),V(60),VV(60)
      DO 11 I=1,NO
      IF(X(I)-XOT) 11,12,12
   11 CONTINUE
   12 NM=I
      NU=NM+2
      NL=NM-2
      IF(NL.LT.1) NL=1
      IF(NU.GT.NO) NU=NO
      NW=NU-NL+1
      DO 13 J=1,NW
      L=NL+J-1
```

```
      V(J)=X(L)
      VV(J)=Y(L)
   13 CONTINUE
      CALL LAGRAN(V,VV,XOT,YOT,NW)
      RETURN
      END


      SUBROUTINE LAGRAN(X,Y,XOT,YOT,N)
      DIMENSION X(60),Y(60)
      YOT=0.
      DO 1 I=1,N
      AL=1.
      DO 2 J=1,N
      IF(J.EQ.I) GO TO 2
      AL=AL*(XOT-X(J))/(X(I)-X(J))
    2 CONTINUE
    1 YOT=YOT+AL*Y(I)
      RETURN
      END
```

TABLE 1-B: INPUT TO PROGRAM LEAST

TEETER DATA

0.0	0.	1.	0.	0.	0.	0.
5.1	0.4	1.	50.	0.04		
1.4	34.130	539.6				
1.						
1.22485	1.02	1.9	40.	36.	0.005	
1.224	3.445	4.072	4.679	5.122	5.542	5.928
6.243	6.605	6.922	7.337	7.606	7.959	8.350
8.715	9.143	9.483	9.778	10.176	10.592	10.91
11.215	11.571	11.851	12.055	12.280	12.462	12.60
12.74	12.844	12.925	12.979	13.022	13.055	13.06
13.065	13.065	13.065	13.065	13.065	13.065	

TABLE 2-A: PROGRAM CONE

```
      PROGRAM CONE (INPUT,OUTPUT,PUNCH,TAPE 5=INPUT,TAPE 6=OUTPUT,TAPE 7
     1=PUNCH)
C
C   INPUT FORMAT 7F10.6
C
C   CARD(S) COLMNS
C     1      1-10    GAMMA       =1.4 SPECIFIC HEAT RATIO OF AIR
C            11-20   EM1         FREE STREAM MACH NUMBER
C            21-30   PHIC        HALF ANGLE OF CONE TIP IN DEGREE
C            31-40   XL          STATION OF OUTPUT DESIRED
C    THIS PROGRAM COMPUTES THE CONICAL FLOW PROPERTIES GIVEN
C    THE SHOCK ANGLE AND THE SURFACE MACH NUMBER
      DIMENSION EMINF(12),PHC(6)
      DIMENSION PH25(12),PH50(12),PH75(12),PH100(12),PH125(12),PH150(12)
      DIMENSION EM25(12),EM50(12),EM75(12),EM100(12),EM125(12),EM150(12)
      DIMENSION PC(6),Q(6)
      DIMENSION SAVE1(300),SAVE2(300),SAVE3(300),SAVE4(300),SAVE5(300)
     1,SAVE6(300),SAVE7(300)
      DIMENSION SAVE8(300)
      TT=2000.
      R=53.3
C
C    THE FOLLOWING CARDS READ IN THE DATA AS TAKEN FROM THE
C    CONICAL FLOW TABLES BY SIMS
C
      DATAEMINF/1.5,1.75,2.0,2.5,3.0,3.5,4.0,4.5,5.0,6.0,7.0,8.0/
      DATA PHC/.043633,.087266,.13090,.17453,.21817,.26180/
      DATA PH25/.72980,.60832,.52370,.41169,.34011,.29017,.25329,.22495,
     1.20252,.16937,.14623,.12931/
      DATA PH50/.73708,.60953,.52525,.41425,.34410,.29592,.26104,
     1.23484,.21458,.18565,.16628,.15262/
      DATA PH75/.73490,.61445,.53140,.42358,.35701,.31239,.28078,
     1.25747,.23973,.21481,.19846,.18712/
      DATA PH100/.74466,.62564,.54465,.44136,.37900,.33790,.30918,
     1.28822,.27242,.25049,.23633,.22664/
      DATA PH125/.76158,.64399,.56518,.46631,.40760,.36939,.34296,
     1.32383,.30953,.28990,.27740,.26895/
      DATA PH150/.78592,.66900,.59192,.49663,.44085,.40494,.38032,
     1.36266,.34955,.33174,.32052,.31301/
      DATA EM25/1.48669,1.73403,1.98086,2.47295,2.96276,3.45009,
     13.93477,4.41662,4.89553,5.84407,6.77969,7.70188/
      DATA EM50/1.45793,1.70046,1.94152,2.41940,2.89138,3.35716,
     13.81645,4.26906,4.71481,5.58525,6.42692,7.23908/
      DATA EM75/1.41973,1.65680,1.89123,2.35286,2.80480,3.24675,
     13.67839,4.09946,4.50971,5.29688,6.03849,6.73371/
      DATA EM100/1.37486,1.60645,1.83404,2.27888,2.7101,3.12751,
     13.53057,3.91891,4.29218,4.99278,5.63180,6.21039/
      DATA EM125/1.32490,1.55133,1.77219,2.20016,2.61039,3.00266,
     13.376145,3.73078,4.06627,4.68017,5.22045,5.69227/
```

```
      DATA EM150/1.27074,1.49255,1.70688,2.11794,2.50675,2.87312,
     13.21670,3.53743,3.83559,4.36681,4.81780,5.19815/
    1 READ (5,1010) GAMMA,EM1,PHIC,XL
      WRITE(6,2000) GAMMA,EM1,PHIC,XL
      PHIC=PHIC/57.2957795
      KKK=1
      GAMM1=GAMMA-1.0
      GAMP1=GAMMA+1.0
C
C    THE NEXT PART OF  THE PROGRAM INTERPOLATES TO FIND THE
C    SHOCK ANGLE AND THE SURFACE MACH NUMBER
C
      DMON=0.0
      CALL TAINT (EMINF,PH25,EM1,PC(1),12,2,NER,DMON)
      CALL TAINT (EMINF,PH50,EM1,PC(2),12,2,NER,DMON)
      CALL TAINT (EMINF,PH75,EM1,PC(3),12,2,NER,DMON)
      CALL TAINT (EMINF,PH100,EM1,PC(4),12,2,NER,DMON)
      CALL TAINT (EMINF,PH125,EM1,PC(5),12,2,NER,DMOM)
      CALL TAINT (EMINF,PH150,EM1,PC(6),12,2,NER,DMON)
      AMON=0.0
      CALL TAINT (PHC,PC,PHIC,PHIW,6,2,NER,AMON)
      DMON=0.0
      CALL TAINT (EMINF,EM25,EM1,Q(1),12,2,NER,DMON)
      CALL TAINT (EMINF,EM50,EM1,Q(2),12,2,NER,DMON)
      CALL TAINT (EMINF,EM75,EM1,Q(3),12,2,NER,DMON)
      CALL TAINT (EMINF,EM100,EM1,Q(4),12,2,NER,DMON)
      CALL TAINT (EMINF,EM125,EM1,Q(5),12,2,NER,DMON)
      CALL TAINT (EMINF,EM150,EM1,Q(6),12,2,NER,DMON)
      BMON=0.0
      CALL TAINT (PHC,Q,PHIC,EMC,6,2,NER,BMON)
C
C    CALCUTATE THE MAXIMUM VELOCITY
C
   20 VM=SQRT(2.0/GAMM1)*SQRT(GAMMA*R*TT*32.2)
C
C    INITIALIZE THE VELOCITY IN THE ANGULAR DIRECTION
C
   30 PSIO=0.0
C
C    CALCULATE THE VELOCITY ON THE CONE
C
   40 VROU=(EMC**2)*(VM**2)*(GAMM1/2.0)
      VROD=1.0+(EMC**2)*(GAMM1/2.0)
      VRO=SQRT(VROU/VROD)
      PHICC=PHIC
C    CALCULATE THE ENTROPY FUNCTION
      D1=ALOG(((7.0)*(EM1**2)*(SIN(PHIW)**2)-1.0)/6.0)
      D2=((6.0)*(EM1**2)*(SIN(PHIW)**2))
      D3=((EM1**2)*(SIN(PHIW)**2)+5.0)
      DS=(D1-(1.4)*ALOG(D2/D3))/0.4
      DP=EXP(-DS)
      SAVE1(KKK)=XL
      SAVE2(KKK)=XL*SIN(PHIC)/COS(PHIC)
      SAVE3(KKK)=PHIC*57.2957795
      SAVE4(KKK)=EMC
      SAVE5(KKK)=DP
      SAVE6(KKK)=PHIC*57.2957795
```

```
      EMX=EMC
      A1=1.+0.5*GAMM1*EM1**2.
      A11=ALOG(A1)
      B1=A11*GAMMA/GAMM1
      B11=EXP(B1)
      A2=1.+0.5*GAMM1*EMX**2.
      A21=ALOG(A2)
      B2=A21*GAMMA/GAMM1
      B21=EXP(B2)
      SAVE7(KKK)=DP*B11/B21
      KKK=2
C   SET THE INCREMENTAL VALUE OF THE ANGLE TO BY USED
   50 DELPHI=(PHIW-PHIC)/117.0
      WRITE (6,2050)
   60 DO 200 K=1,117
      STEP=K
      X=STEP*DELPHI
      PHI=PHICC+X
      FUZZ=STEP-1.0
      IF(FUZZ) 68,68,70
C   CALCULATE THE VELOCITY IN THE ANGUALR DIRECTION
   68 P3=(GAMM1)*(VRO)*((VM**2)-(VRO**2))
      D=-(GAMM1/2.0)*((VM**2)-(VRO**2))
      PSIX=PSIO+(DELPHI*P3)/D
      GO TO 80
   70 P1=-(GAMM1/2.0)*(PSIO**3)*(COS(PHIC)/SIN(PHIC))
      P2=(GAMM1/2.0)*((VM**2)-(VRO**2))*(PSIO)*(COS(PHIC)/SIN(PHIC))
      P3=(GAMM1)*(VRO)*((VM**2)-(VRO**2))
      P4=-(GAMMA)*(VRO)*(PSIO**2)
      D=(GAMP1/2.0)*(PSIO**2)-(GAMM1/2.0)*((VM**2)-(VRO**2))
      PSIX=PSIO+((DELPHI)*(P1+P2+P3+P4))/D
C   CALCULATE THE VELOCITY IN THE RADIAL DIRECTION
   80 VRX=PSIO*DELPHI+VRO
C   CALCULATE THE FLOW ANGLE
  100 THETAX=PHI+ATAN(PSIX/VRX)
  110 VX=SQRT(VRX**2+PSIX**2)
  120 AX=SQRT((GAMM1/2.0)*(VM**2-VX**2))
C   CALCULZTE THE MACH NUMBER
  130 EMX=VX/AX
      EM1U=(EMX**2)*(GAMP1/2.0)
      EM1D=1.0+(EMX**2)*(GAMM1/2.0)
      EM1ST=SQRT(EM1U/EM1D)
  140 YL=XL*(SIN(PHI)/COS(PHI))
      BURP=PHI*57.2957795
      WRITE (6,2100) VRX,PSIX,BURP,AX
      WRITE (6,2110) XL,YL,THETAX,EM1ST,DP
      SAVE1(KKK)=XL
      SAVE2(KKK)=YL
      SAVE3(KKK)=THETAX*57.2957795
      SAVE4(KKK)=EMX
      SAVE5(KKK)=DP
      SAVE6(KKK)=BURP
      A1=1.+0.5*GAMM1*EM1**2.
      A11=ALOG(A1)
      B1=A11*GAMMA/GAMM1
      B11=EXP(B1)
      A2=1.+0.5*GAMM1*EMX**2.
```

```
      A21=ALOG(A2)
      B2=A21*GAMMA/GAMM1
      B21=EXP(B2)
      SAVE7(KKK)=DP*B11/B21
      SAVE8(KKK)=1.02-SAVE2(KKK)
      PSIO=PSIX
      VRO=VRX
      PHIC=PHI
      KKK=KKK+1
  200 EMC=EMX
      WRITE(6,3000)
      WRITE(6,3001) (SAVE1(KKK),SAVE2(KKK),SAVE3(KKK),SAVE4(KKK),SAVE5(K
     1KK),SAVE6(KKK),SAVE7(KKK),KKK=1,118,2)
      WRITE(7,3002)(SAVE6(KKK),SAVE3(KKK),SAVE4(KKK),SAVE7(KKK),KKK=1,
     1118,2)
      WRITE(7,3003)(SAVE1(KKK),SAVE2(KKK),SAVE3(KKK),SAVE4(KKK),
     1SAVE5(KKK), KKK=1,118,2 )
      GO TO 1
 3000 FORMAT(1H1,12X,1HX,14X,1HY,14X,3HDEL,13X,1HM,15X,8HPT/PTINF,10X,
     15HTHETA,12X,4HP/P1)
 3001 FORMAT(2X,7F15.6)
 3002 FORMAT(4F10.6)
 3003 FORMAT(5F10.6)
 1000 FORMAT (2F10.3)
 1010 FORMAT (4F10.6)
 2000 FORMAT (1H1,7HGAMMA =,F15.6,10X,4HMC =,F15.6,10X,6HPHIC =,
     1F15.6,10X,3HX =,F15.6)
 2050 FORMAT (1H1,45X,7HRESULTS)
 2100 FORMAT (1H0,4HVR =,F15.6,10X,5HPSI =,F15.6,10X,
     16HPHI  =,F15.6,10X,3HA =,F15.6)
 2110 FORMAT (1H0,3HX =,F10.5,8X,3HY =,F10.5,8X,8HTHETAX =,F10.5,8X,
     16HMSTR =,F10.5,8X,10HPT/PTINF =,F10.5)
      END


      SUBROUTINE TAINT(XTAB,FTAB,X,FX,N,K,NER, MON)
      DIMENSION XTAB(1),FTAB(1),T(10),C(10)
CPS0400  TAINT SUBROUTINE- IN FORTRAN II.
      IF (N - K) 1,1,2
    1 NER=2
      RETURN
    2 IF (K-9) 3,3,1
    3 IF ( MON) 4,4,5
    5 IF ( MON-2) 6,7,4
    4 J=0
      NM1=N-1
      DO 8 I=1,NM1
      IF (XTAB(I)-XTAB(I+1)) 9,11,10
   11 NER=3
      RETURN
    9 J=J-1
      GO TO 8
   10 J=J+1
    8 CONTINUE
      MON=1
      IF (J) 12,6,6
```

```
12 MON=2
 7 DO 13 I=1,N
   IF (X-XTAB(I)) 14,14,13
14 J=I
   GO TO 18
13 CONTINUE
   GO TO 15
 6 DO 16 I=1,N
   IF (X-XTAB(I)) 16,17,17
17 J=I
   GO TO 18
16 CONTINUE
15 J=N
18 J=J-(K+1)/2
   IF (J) 19,19,20
19 J=1
20 M=J+K
   IF (M-N) 21,21,22
22 J=J-1
   GO TO 20
21 KP1=K+1
   JSAVE=J
26 DO 23 L=1,KP1
   C(L)=X-XTAB(J)
   T(L)=FTAB(J)
23 J=J+1
   DO 24 J=1,K
   I=J+1
25 T(I)=(C(J)*T(I)-C(I)*T(J))/(C(J)-C(I))
   I=I+1
   IF (I-KP1) 25,25 ,24
24 CONTINUE
   FX=T(KP1)
   NER=1
   RETURN
   END
```

TABLE 2-B: INPUT TO PROGRAM CONE

```
1.4        2.82       10.        1.835
```

TABLE 3-A: PROGRAM ANAL

```
      PROGRAM ANAL (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C         ANA
C  TWO-DIMENSIONAL AND AXIALLY SYMMETRIC SHOCK WAVE-BOUNDARY LAYER
C  INTERACTION
C
C
C                                PROGRAM INPUT
C  INPUT FORMAT 7F10.6 EXCEPT CARDS 1 AND 2
C  CARD(S)
C  1 AND 2 TITLES,COLUMNS 1-72, HOLLERITH
C  3        COL.1-10 EME1    UPSTREAM MACH NO.
C              11-20 UTUES1  UPSTREAM DIMENSIONLESS FRICTION VELOCITY
C                            =UE/UE*
C              21-30 REDEL1  UPSTREAM REYNOLDS NO. (DELTA)
C              31-40 AINPT   1.0 INPUT THETA1
C                            2.0 INPUT ALPHA1
C              41-50 RECFAC  RECOVERY FACTOR
C              51-60 AXI     0.0 OR 1.0 2-D CASE
C                            2.0 AXI CASE    CONE FLOW OR CENTERBODY
C              61-70 SHORT   0.0 LONG OUTPUT
C                            1.0 SHORT OUTPUT
C  4        COL.1-10 BLEED1  SUCTION RATE
C              11-20 BLEED2  ENTRAINMENT RATE
C              21-30 AIB     0.0 NO BLEED
C                            1.0 POROUS SUCTION
C                            2.0 SLOT SUCTION
C                            3.0 SCOOP SUCTION
C              31-40 BK      CONSTANT IN WALL-WAKE PROFILES(USUALLY 0.4)
C              41-50 C       CONSTANT IN WALL-WAKE PROFILES(USUALLY 5.1)
C              51-60 STCOEF  0. IF NO SHEAR FORCE IS DESIRED
C                            0.5 IF AVERAGE SHEAR STRESS IS USED
C              61-70 AIDD    PARAMETER IN (1.-(Y/DELTA)**AIDD) (=1. IS
C                            RECOMMENDED AT THIS TIME)
C  5        COL.1-10 TH1D    THETA1 WHEN AINPT=1.0
C                    ALP1D   ALPH1 WHEN AINPT=2.0
C              11-20 TH1ZZ   THETA1 WHEN AINPT=2.0
C  FOLLOWING FOR AXIALLY SYMMETRIC CASES ONLY (AXI=2.0)
C  6        COL.1-10 DEL1R   DELTA1/R
C              11-20 AIE2    1.0 B.L. EDGE STREAMLINE DATA INPUT
C                            2.0 CONICAL FLOW DATA INPUT
C                            3.0 INTERNAL FLOW FIELD INPUT DATA
C                            4.0 CONSTANT PRESSURE BOUNDARY
C              21-30 FLDIR3  FLOW DIRECTION ONSTREAM OF AXISYM. INTERACTNS
C  7        COL.1-10 AKK     NO. POINTS OF INPUT DATA
C  FOLLOWING FOR B.L. EDGE STREAMLINE INPUT(AIE2=1.0)
C  8        COL.1-10 XXO     X/XO
C              11-20 RRO     R/RO
C              21-30 EME2S   MACH NUMBER
C              31-40 PE2P1   P/P1
```

```
C              41-50 ALPHA  FLOW DIRECTION
C   CARD 8 IS REPEATED AKK TIMES IN ORDER FROM SHOCK TO CONE
C   FOLLOWING FOR CONICAL FLOW INPUT(AIE2=2.0)
C   8       COL.1-10 PHI   CONICAL RAY ANGLE
C              11-20 ALPHA  FLOW DIRECTION
C              21-30 EME2S  MACH NUMBER
C              31-40 PE2P1  P/P1
C   CARD 8 IS REPEATED AKK TIMES IN ORDER FROM SHOCK TO CONE
C   FOR SUCTION WITH NO SHOCK USE INPUT CARDS 1-6 WITH
C   AINPT=2.0, ALP1D=0.0
C
C
      DIMENSION TTRAT(200),PTRAT(200),PTRNS(200),URAT(200),EM(200)
      DIMENSION YY(200), UTUE3(100), E(100), WR(200), PHIR(200)
      DIMENSION REDEL3(100)
      COMMON  TTRAT    , PTRAT    , PTRNS    , URAT     ,
     1        EM       , WR       , PHIR     ,
     2        SHORT    , BLEED1   , BLEED2   , BLEED    ,
     3        AIB      , TWTTE    , GAMMA    , TH1D     ,
     4        BLMN     , BLMON    , BLMI     , BLMOI    ,
     5        DSD      , DDSD     , BK       , EME1     , SHFAC    ,
     6        SIG1     , SIGMA1   , SIGS1    , FSIG1    , VWVE1    ,
     7        CFWW1    , C        , STCOEF
      COMMON /UWU/AIDD
      COMMON /WUW/AINPT,TH1ZZ
C
C   READ DATA CARDS 1 AND 2
C
    1 CALL PRIN(ILINE,1)
C
C   READ DATA CARDS 3 AND 4
C
      READ(5,1000) EME1,UTUES1,REDEL1,AINPT,RECFAC,AXI,SHORT
      READ(5,1000) BLEED1,BLEED2,AIB,BK,C,STCOEF,AIDD
      C=C-0.614/(BK*AIDD)
      INPT=AINPT
      BLEED=BLEED1+BLEED2
      GAMMA=1.4
      G1=EME1*EME1
      TWTTE=RECFAC+(1.-RECFAC)/(1.+(GAMMA-1.)*G1/2.)
      SIG1=0.2*EME1*EME1
      SIGMA1=SIG1/(1.+SIG1)
      SIGS1=SQRT(SIGMA1)
      FSIG1=(ASIN(SIGS1))/SIGS1
      VWVE1=(TWTTE*(1.+SIG1))**1.76
      FUTUE1=UTUES1*FSIG1
      CFWW1=2.*FUTUE1*FUTUE1/(TWTTE*(1.+SIG1))
      TAU1P1=0.7*CFWW1*EME1*EME1
      PX1=.5*(1.-UTUES1*((1./BK)*ALOG(REDEL1*ABS(UTUES1)
     1*FSIG1/VWVE1)+C))
C
C   VARIABLES WHICH MUST BE INITIALIZED
C
      IZ=0
      YS=0.
      WRITE(6,1024)
      GO TO (10,20),INPT
```

```
C
C   INPUT PARAMETER IS THETA1
C   READ DATA CARD 5
C
   10 READ(5,1000) TH1D
      WRITE(6,1010) UTUES1,REDEL1,PX1,TH1D,EME1,RECFAC,TWTTE
      ILINE=ILINE+3
      TH1=TH1D*.01745329
      Z=SIN(TH1)**2.
      ANUM=2.*(G1*Z-1.)
      DNOM=(2.+G1*(GAMMA+1.-2.*Z))*TAN(TH1)
      ALP1=ATAN(ANUM/DNOM)
      ALP1D=ALP1/.01745329
C
C   FIND PRESSURE RATIO ACROSS SHOCK AND DOWNSTREAM MACH NO.
C
      CALL SHOCK(2,ALP1,TH1,EME1,EME2,P2P1)
      GO TO 30
C
C   INPUT PARAMETER IS ALPHA1
C   READ DATA CARD 5
C
   20 READ(5,1000) ALP1D,TH1ZZ
      WRITE(6,1011) UTUES1,REDEL1,PX1,ALP1D,EME1,RECFAC,TWTTE
      ILINE=ILINE+3
      ALP1=ALP1D*.01745329
      IF(ALP1D.EQ.0.) GO TO 30
C
C   FIND SHOCK WAVE ANGLE, PRESSURE RATIO ACROSS SHOCK AND DOWNSTREAM
C   MACH NO.
C
      CALL SHOCK(1,ALP1,TH1,EME1,EME2,P2P1)
      TH1D=TH1/.01745329
      ROOT=SIN(TH1)
C
C   ERROR EXIT IF SIN(THETA) GREATER THAN 1.0
C
      IF(ROOT.GT.1.)GO TO 1
C
C   EQUATE ALPHA1 AND ALPHA2
C
   30 ALP2=ALP1
      ALP2D=ALP1D
      L=1
      WRITE(6,1025) L,BLEED1
      L=2
      WRITE(6,1025) L,BLEED2
C
C   FIND SHOCK WAVE ANGLE, PRESSURE RATIO ACROSS SHOCK AND DOWNSTREAM
C   MACH NO.
C
      IF(ALP1D.EQ.0.) GO TO 310
      CALL SHOCK(1,ALP2,TH2,EME2,EME3,P3P2)
      ROOT=SIN(TH2)
C
C   ERROR EXIT IF SIN(THETA) GREATER THAN 1.0
C
```

```
      IF(ROOT.GT.1.)GO TO 1
      TH2D=TH2/.01745329
  310 IF(ALP1D.GT.0.) GO TO 311
C
C  PARAMETERS FOR NO SHOCK
C
      EME2=EME1
      EME3=EME1
      P2P1=1.
      P3P2=1.
      P3P1=1.
      GO TO 312
  311 P3P1=P3P2*P2P1
      WRITE(6,1012) P2P1,P3P2,P3P1,EME1,EME2,EME3
      ILINE=ILINE+6
      WRITE(6,1013) ALP1D,TH1D,ALP2D,TH2D
      ILINE=ILINE+6
C
C  DETERMINE UPSTREAM BOUNDARY LAYER PROFILE PROPERTIES
C
  312 CALL PRFL(UTUES1,PX1,EME1,1.0,2,YY)
      IF(SHORT.EQ.0.) CALL PRIN(ILINE,3)
      II=1
      WRITE(6,1014) II
      ILINE=ILINE+4
      IF(SHORT.EQ.1.) GO TO 4000
      WRITE(6,1028)
      DO 40 I=1,101
      WRITE(6,1015) I,YY(I),EM(I),URAT(I),PTRAT(I),PTRNS(I),TTRAT(I)
      ILINE=ILINE+1
      CALL PRIN(ILINE,2)
      IF(ILINE-2) 31,31,40
   31 WRITE(6,1014) II
      WRITE(6,1028)
      ILINE=ILINE+4
   40 CONTINUE
 4000 DUM=0.
C
C  DETERMINE UPSTREAM BOUNDARY LAYER INTEGRAL PROPERTIES
C
      CALL FLUX(101,YY,1,EME1,DUM)
      HI1=(SHFAC-SIG1)/(TWTTE*(1.+SIG1))
      RETH1=REDEL1*DDSD
      PRANDL=.72
      PR13=PRANDL**(1./3.)
      TBARTO=.5*TWTTE+.22*PR13+(.5-.22*PR13)/(1.+SIG1)
      CFLT1=.246*EXP(-1.561*HI1)*(RETH1**(-.268))/
     1((TBARTO*(1.+SIG1))**0.7963)
      WRITE(6,1016) DSD,DDSD,BLMN,BLMON,SHFAC,HI1,CFWW1,CFLT1
      DSD1=DSD
      DDSD1=DDSD
      ILINE =ILINE+6
C
C CONSTANTS FOR MASS AND MOMENTUM BALANCES
C
      H1=1.+(GAMMA-1.)/2.*EME3*EME3
      H2=SQRT(H1)
```

```
      H3=1.+(GAMMA-1.)/2.*G1
      H4=SQRT(H3)
      H5=1.-DSD-DDSD
      IF(AIB.EQ.1.) GO TO 410
      IF(BLEED1.EQ.0.) GO TO 410
      WS=ABS(BLEED1)*BLMN
      CALL INTRP(WR,YY,WS,YS,101)
      CALL INTRP(YY,PHIR,YS,PHIS,101)
      WRITE(6,1027) WS,YS,PHIS
C
C  AIB=1  POROUS PLATE SUCTION
C  AIB=2  SLOT SUCTION
C  AIB=3  SCOOP SUCTION
C
C
C  ITERATION TO FIND SOLUTION  TO CONTINUITY AND MOMENTUM EQUATIONS
C
C
  410 IF(AIB.LE.1.) BLMOM1=0.
      IF(AIB.GE.2.) BLMOM1=-GAMMA*EME1*EME1*PHIS
      KB=1
      WRITE(6,1026) KB,BLMOM1
      BLMOM2=BLEED2              *(1.-DSD)*GAMMA*EME1*EME2*COS(ALP1)
     1*H4/SQRT(1.+(GAMMA-1.)/2.*EME2*EME2)
      KB=2
      WRITE(6,1026) KB,BLMOM2
      BLMOMF=BLMOM1+BLMOM2
      KB=3
      WRITE(6,1026) KB,BLMOMF
C
C FOR APPROXIMATE SOLUTION ASSUME THAT TAU/P1=2.*STCOEF*TAU1/P1
C
      TAUP1=2.*STCOEF*TAU1P1
      H6=P2P1-1.-GAMMA*G1*H5-BLMOMF+TAUP1/TAN(ALP1)
      IF(AIB.EQ.3.) H6=H6-(P2P1-1.)*YS
      IF(SHORT.EQ.0.) WRITE(6,1022) H1,H2,H3,H4,H5,H6,TAUP1
      A1=P3P1*EME3/EME1*H2/H4/(1.-DSD)/(1.+BLEED)
      A2=(P2P1-P3P1)/H6
      A3=-GAMMA*P3P1*EME3*EME3/H6
      A4=TAUP1/TAN(ALP1)/H6
      IF(SHORT.EQ.0.) WRITE(6,1017) A1,A2,A3,A4
      IF(SHORT.EQ.0.) CALL PRIN(ILINE,3)
      IF(SHORT.EQ.0.) WRITE(6,1018)
      ILINE=ILINE+2
C
C APPROXIMATE 2-D SOLUTION (ASSUME REDEL3=REDEL1 AND TAU=TAU1)
C
      M=1
      REDEL3(1)=REDEL1
      SIG3=.2*EME3*EME3
      SIGMA3=SIG3/(1.+SIG3)
      SIGS3=SQRT(SIGMA3)
      FSIG3=(ASIN(SIGS3))/SIGS3
      VWVE3=(TWTTE*(1.+SIG3))**1.76
      UTUE3(1)=1.5*UTUES1
      IF(AIB.GE.1.) UTUE3(1)=3.*UTUES1
      PX3=.5*(1.-UTUE3(1)*((1./BK)*ALOG(REDEL3(M)*ABS(UTUE3(1))
```

```
     1*FSIG3/VWVE3)+C))
      J=1
      GO TO 43
   41 J=J+1
      IF(J.EQ.80) GO TO 50
      UTUE3(J)=UTUE3(J-1)-.01
      PX3=.5*(1.-UTUE3(J)*((1./BK)*ALOG(REDEL3(M)*ABS(UTUE3(J))
     1*FSIG3/VWVE3)+C))
   43 CALL PRFL(UTUE3(J),PX3,EME3,P3P1,1,YY)
      CALL FLUX(101,YY,1,EME3,DUM)
      E(J)=A2+A3-A1+(A1-A3)*DSD-A3*DDSD+A4
      IF(SHORT.EQ.1.) GO TO 440
      WRITE(6,1019) J,UTUE3(J),E(J)
      ILINE=ILINE+3
      CALL PRIN(ILINE,2)
      IF(ILINE-2) 430,430,440
  430 WRITE(6,1018)
      ILINE=ILINE+2
  440 TEST=ABS(E(J))
      IF(TEST.LE.0.00001) GO TO 60
      IF(E(J).LT.0.) GO TO 45
      IF(J.LT.9) GO TO 41
   45 SLOPE=(E(J-1)-E(J))/(UTUE3(J-1)-UTUE3(J))
      UTUE3(J+1)=UTUE3(J)-E(J)/SLOPE
   47 J=J+1
      PX3=.5*(1.-UTUE3(J)*((1./BK)*ALOG(REDEL3(M)*ABS(UTUE3(J))
     1*FSIG3/VWVE3)+C))
      IF(J.EQ.80) GO TO 50
      GO TO 43
   50 WRITE(6,1020)
      IZ=1
      GO TO 80
C
C
C  SOLUTION OBTAINED (APPROXIMATE)
C
C
C  DETERMINE DOWNSTREAM BOUNDARY LAYER PROFILE PROPERTIES
C
   60 CALL PRFL(UTUE3(J),PX3,EME3,P3P1,2,YY)
      IF(SHORT.EQ.0.) CALL PRIN(ILINE,3)
      II=3
      WRITE(6,1014) II
      WRITE(6,1033) UTUE3(J), REDEL3(M),PX3
      ILINE=ILINE+6
      IF(SHORT.EQ.1.) GO TO 7000
      WRITE(6,1028)
      DO 70 I=1,101
      WRITE(6,1015) I,YY(I),EM(I),URAT(I),PTRAT(I),PTRNS(I),TTRAT(I)
      ILINE=ILINE+1
      CALL PRIN(ILINE,2)
      IF(ILINE-2) 61,61,70
   61 WRITE(6,1014) II
      WRITE(6,1028)
      ILINE=ILINE+4
   70 CONTINUE
C
```

```
C  DETERMINE DOWNSTREAM BOUNDARY LAYER INTEGRAL PROPERTIES
C
 7000 CALL FLUX(101,YY,1,EME3,DUM)
      FUTUE3=UTUE3(J)*FSIG3
      CFWW3=2.*FUTUE3*FUTUE3/(TWTTE*(1.+SIG3))
      FM1=1.+SIG1
      FM3=1.+SIG3
      HI3=(SHFAC-SIG3)/(TWTTE*FM3)
      RETH3=REDEL3(M)*DDSD
      TBARTO=.5*TWTTE+.22*PR13+(.5-.22*PR13)/(1.+SIG3)
      CFLT3=.246*EXP(-1.561*HI3)*(RETH3**(-.268))/
     1((TBARTO*(1.+SIG3))**0.7963)
      WRITE(6,1016) DSD,DDSD,BLMN,BLMON,SHFAC,HI3,CFWW3,CFLT3
      D13=A1*(1.-DSD)
      D31=1./D13
      DS31=DSD*D31/DSD1
      DDS 31=DDSD*D31/DDSD1
      IF(ALP1D.EQ.0.) GO TO 79
C
C  INTERACTION LENGTH
C
      ELD1=(1.-D31)/TAN(ALP1)
      IF(AIB.EQ.3.) ELD1=(1.-D31-YS)/TAN(ALP1)
   79 IF(ALP1D.EQ.0.) ELD1=0.
      WRITE(6,1021) D31,DS31,DDS31,ELD1
C
C  TWO-DIMENSIONAL EXACT SOLUTION (ONLY FOR 2-D CASES)
C
      IF(M.GT.1) GO TO 80
      IF(AXI.EQ.2.) GO TO 80
      IF(D31.LT.0.) WRITE (6,1034)
      IF(D31.LT.0.) GO TO 1
      CALL PRIN(ILINE,3)
      WRITE(6,1029)
      IF (SHORT.EQ.1.) GO TO 500
      WRITE (6,1030)
      WRITE(6,1031) M,REDEL3(M)
      ILINE=ILINE+4
  500 M=M+1
      IF (M.EQ.11) GO TO 530
      REDEL3(M)=REDEL1*D31*P3P1*(EME3/EME1)*(FM3/FM1)**1.26
      FUTUE3=UTUE3(J)*FSIG3
      CFWW3=2.*FUTUE3*FUTUE3/(TWTTE*(1.+SIG3))
      TAU3P1=0.7*CFWW3*EME3*EME3*P3P1
      TAUP1=STCOEF*(TAU1P1+TAU3P1)
      IF(SHORT.EQ.1.) GO TO 650
      WRITE(6,1031) M,REDEL3(M)
      ILINE=ILINE+2
      CALL PRIN(ILINE,2)
      IF(ILINE-2) 600,600,650
  600 WRITE(6,1030)
      ILINE=ILINE+2
  650 TESTR=ABS((REDEL3(M-1)-REDEL3(M))/REDEL3(M-1))
      IF(TESTR.LE..001) GO TO 60
      UTUE3(1)=1.5*UTUES1
      IF(AIB.GE.1.) UTUE3(1)=3.*UTUES1
      PX3=.5*(1.-UTUE3(1)*((1./BK)*ALOG(REDEL3(M)*ABS(UTUE3(1))
```

```
     1*FSIG3/VWVE3)+C))
      J=1
      GO TO 503
  501 J=J+1
      IF(J.EQ.80) GO TO 50
      UTUE3(J)=UTUE3(J-1)-.01
      PX3=.5*(1.-UTUE3(J)*((1./BK)*ALOG(REDEL3(M)*ABS(UTUE3(J))
     1*FSIG3/VWVE3)+C))
  503 CALL PRFL(UTUE3(J),PX3,EME3,P3P1,1,YY)
      CALL FLUX(101,YY,1,EME3,DUM)
      H6=P2P1-1.-GAMMA*G1*H5-BLMOMF+TAUP1/TAN(ALP1)
      IF(AIB.EQ.3.) H6=H6-(P2P1-1.)*YS
      IF(SHORT.EQ.0.) WRITE(6,1022) H1,H2,H3,H4,H5,H6,TAUP1
      A2=(P2P1-P3P1)/H6
      A3=-GAMMA*P3P1*EME3*EME3/H6
C
C  A4 IS THE SHEAR TERM IN THE MOMENTUM EQUATION
C
      A4=TAUP1/TAN(ALP1)/H6
      IF(SHORT.EQ.0.) WRITE(6,1017) A1,A2,A3,A4
      E(J)=A2+A3-A1+(A1-A3)*DSD-A3*DDSD+A4
      TEST=ABS(E(J))
      IF(TEST.LE.0.00001) GO TO 520
      IF(J.LT.3) GO TO 501
  505 SLOPE=(E(J-1)-E(J))/(UTUE3(J-1)-UTUE3(J))
      UTUE3(J+1)=UTUE3(J)-E(J)/SLOPE
      J=J+1
      PX3=.5*(1.-UTUE3(J)*((1./BK)*ALOG(REDEL3(M)*ABS(UTUE3(J))
     1*FSIG3/VWVE3)+C))
      IF(J.EQ.80) GO TO 50
      GO TO 503
  520 D13=A1*(1.-DSD)
      D31=1./D13
      GO TO 500
  530 WRITE(6,1032)
      IZ=1
      GO TO 80
   80 IF(AXI.LT.2.) GO TO 1
      IF(ALP1.GT.0.) CALL AXIS(ELD1,UTUES1,UTUE3(J),
     1REDEL1,PX1,ALP1,EME1,IZ)
      IF(ALP1.EQ.0.) CALL ANOS(UTUES1,UTUE3(J),REDEL1,PX1,
     1D31,EME1,IZ)
      GO TO 1
 1000 FORMAT(7F10.6)
 1010 FORMAT(1H0, 9X,21HOPTION 1 INPUT THETA1/10X,9HUTUES1 = ,F10.6,
     15X,24HREYNOLDS NO. (DELTA1) = ,E14.6,5X,6HPX1 = ,F10.6/5X,
     25X,9HTHETA1 = ,F10.6,8H DEGREES,5X,5HM1 = ,F10.6/
     310X,18HRECOVERY FACTOR = ,F10.6,5X,9HTW/TTE = ,F10.6)
 1011 FORMAT(1H0, 9X,21HOPTION 2 INPUT ALPHA1/10X,9HUTUES1 = ,F10.6,
     15X,24HREYNOLDS NO. (DELTA1) = ,E14.6,5X,6HPX1 = ,F10.6/5X,
     25X,9HALPHA1 = ,F10.6,8H DEGREES,5X,5HM1 = ,F10.6/
     310X,18HRECOVERY FACTOR = ,F10.6,5X,9HTW/TTE = ,F10.6)
 1012 FORMAT(1H0/10X,30HBOUNDARY LAYER EDGE CONDITIONS//
     110X,8HP2/P1 = ,F10.6,5X,8HP3/P2 = ,F10.6,5X,8HP3/P1 = ,F10.6/
     210X,5HM1 = ,F10.6,8X,5HM2 = ,F10.6,8X,5HM3 = ,F10.6)
 1013 FORMAT(1H0/10X,32HSHOCK AND FLOW DEFLECTION ANGLES//10X,
     115HINCIDENT SHOCK ,5X,8HALPHA = ,F10.6,8H DEGREES,5X,
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    28HTHETA = ,F10.6,8H DEGREES/10X,15HREFLECTED SHOCK,5X,8HALPHA = ,
    3F10.6,8H DEGREES,5X,8HTHETA = ,F10.6,8H DEGREES)
1014 FORMAT(1H0, 9X,35HBOUNDARY LAYER PROFILE DATA STATION,I3)
1015 FORMAT(1H ,6X,I3,6F14.6)
1016 FORMAT(1H0/10X,14HDELSTAR/DEL = ,F14.6,4X,10HMOM/DEL = ,
    1F14.6/10X,28HNON-DIMENSIONAL MASS FLUX = ,F10.6/
    210X,32HNON-DIMENSIONAL MOMENTUM FLUX = ,F10.6/10X,
    315HSHAPE FACTOR = ,F10.6,5X,30HINCOMPRESSIBLE SHAPE FACTOR = ,
    4 F10.6/10X,16HCF(WALL-WAKE) = ,F10.6,5X,22HCF(LUDWEIG TILLMAN) = ,
    5F10.6)
1017 FORMAT(1H0,10X,5HA1 = ,F10.6,5X,5HA2 = ,F10.6,5X,5HA3 = ,F10.6,
    1 5X,5HA4 = ,F10.6)
1018 FORMAT(1H0/10X,32HRESULTS OF ITERATIONS FOR UTUE*3//)
1019 FORMAT(1H0,10X,4HJ = ,I3,5X,9HUTUE*3 = ,F10.6,5X,4HE = ,F10.6)
1020 FORMAT(1H0, 6X,25HNO CONVERGENCE FOR UTUE*3)
1021 FORMAT(1H0/10X,12HDEL3/DEL1 = ,F10.6/10X,
    120HDELSTAR3/DELSTAR1 = ,F10.6/10X,12HMOM3/MOM1 = ,F10.6//10X,
    29HL/DEL1 = ,F10.6)
1022 FORMAT(1H0/10X,5HH1 = ,F10.6,2X,5HH2 = ,F10.6,2X,5HH3 = ,F10.6,
    12X,5HH4 = ,F10.6,2X,5HH5 = ,F10.6,2X,5HH6 = ,F10.6/
    2 10X,9HTAU/P1 = ,F10.6)
1024 FORMAT(1H0/10X,54HTWO-DIMENSIONAL APPROXIMATE SOLUTION (REDEL3 = R
    1EDEL1))
1025 FORMAT(1H0, 9X,8H(M)BLEED,I1,11H/(M)B.L. = ,F10.6,
    120H (BLEED POSITIVE IN))
1026 FORMAT(1H0, 9X,40HMOMENTUM FLUX ASSOCIATED WITH B.L. BLEED,I1,
    13H = ,F14.6,14H (POSITIVE IN))
1027 FORMAT(1H0/10X,5HWS = ,F10.6,5X,5HYS = ,F10.6, 5X,7HPHIS = ,F10.6)
1028 FORMAT(1H0,
    1 9X,1HI,8X,1HY,14X,1HM,12X,4HU/UE, 9X,6HPT/PT1, 6X,10HPT(NS)/PT1,
    2 6X,6HTT/TT1//)
1029 FORMAT(1H0,7X,30HTWO-DIMENSIONAL EXACT SOLUTION)
1030 FORMAT(1H0/10X,31HRESULTS OF ITERATION FOR REDEL3)
1031 FORMAT(1H0,10X,4HM = ,I3,5X,22HREYNOLDS NO.(DELTA) = ,E14.6)
1032 FORMAT(1H0,6X,25HNO CONVERGENCE FOR REDEL3)
1033 FORMAT(1H0,10X,9HUTUE*3 = ,F10.6,5X,9HREDEL3 = ,E14.6,5X,
    16HPX3 = ,F10.6)
1034 FORMAT (1H0,6X,28HDEL3/DEL1 NEG. (NO SOLUTION))
     END


     SUBROUTINE AXIS(ELD1,UTUES1,UTUE3,REDEL1,PX1,ALP1,EME,IZ)
C   AXIALLY SYMMETRIC FLOW ANALYSIS
     DIMENSION TTRAT(200),PTRAT(200),PTRNS(200),URAT(200),EM(200)
     DIMENSION E1(100), E2(100),ELD1A(100), UTUE3A(100),YY(200)
     DIMENSION XXO( 50), RRO( 50),EME2S( 50), PE2P1( 50)
     DIMENSION PHI( 50), ALPHA( 50), RR( 50), DEL3OR( 50)
     DIMENSION EI2( 50), ELD2( 50),XR( 50),WR(200), PHIR(200)
     COMMON  TTRAT   , PTRAT   , PTRNS   , URAT    ,
    1        EM      , WR      , PHIR    ,
    2        SHORT   , BLEED1  , BLEED2  , BLEED   ,
    3        AIB     , THTTE   , GAMMA   , TH1D    ,
    4        BLMN    , BLMON   , BLMI    , BLMOI   ,
    5        DSD     , DDSD    , BK      , EME1    , SHFAC   ,
    6        SIG1    , SIGMA1  , SIGS1   , FSIG1   , VWVE1   ,
    7        CFWW1   , C       , STCOEF
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```
      COMMON /WUW/AINPT,TH1ZZ
C
C  READ DATA CARD 6
C
      PEAD(5,1000) DEL1R,AIE2,FLDIR3
      CALL FRFL(UTUES1,PX1,EME1,1.0,2,YY)
      CALL FLUX(101,YY,2,EME1,DEL1R)
      SN1=(1.-DSD)/DDSD
      SN2=SN1-3.0
      SN3=ALOG(SN2)
      SN4=-0.6169*SN3
      SN5=EXP(SN4)
      FEN=0.0299*SN5
      FENT=FEN*ELD1/BLMN
      FEMT=FENT*BLMI/BLMOI
      ROO=1.-DEL1R
      ROO1=ROO*ROO-2.*BLMI*FENT
      ROR1=SQRT(ROO1)
      IE2=AIE2
      ALP1D=ALP1/.01745329
      CALL PRIN(ILINE,3)
      WRITE(6,1011)
      GO TO (10,20,35),IE2
C
C  BOUNDARY LAYER EDGE STREAMLINE DATA ARE INPUT
C
C  READ DATA CARD 7
C
   10 READ(5,1000) AKK
      KK=AKK
      DO 11 I=1,KK
C
C  READ DATA CARDS 8
C
      READ(5,1000) XXO(I),RRO(I),EME2S(I),PE2P1(I),ALPHA(I)
   11 CONTINUE
      WRITE( 6,1025)
      ILINE=ILINE+5
      DO 12 I=1,KK
      WRITE(6,1026) I,XXO(I),RRC(I),EME2S(I),PE2P1(I),ALPHA(I)
      ILINE=ILINE+1
      CALL PRIN(ILINE,2)
      IF(ILINE-2) 13,13,12
   13 WRITE(6,1025)
      ILINE=ILINE+5
   12 CONTINUE
      GO TO 25
C
C  PROGRAM CALCULATES CONICAL FLOW STREAMLINE FROM INPUT DATA FROM
C  CONICAL FLOW PROGRAM
C  ARRAYS IN ORDER SHOCK TO CONE
C
   20 READ(5,1000) AKK
      KK=AKK
      DO 21 I=1,KK
C
C  PHI IS IN DEGREES
```

```
C  ALPHA IS IN DEGREES
C
      READ(5,1000) PHI(I), ALPHA(I), EME2S(I), PE2P1(I)
   21 CONTINUE
      IF(SHORT.EQ.0.) WRITE(6,1027)
      ILINE=ILINE+5
      DO 822 I=1,KK
      PHI(I)=PHI(I)*.01745329
      ALPHA(I)=ALPHA(I)*.01745329
C
C  PHI IS IN RADIANS
C  ALPHA IS IN RADIANS
C
      IF(SHORT.EQ.1.) GO TO 822
      WRITE(6,1028) I,PHI(I),ALPHA(I),EME2S(I),PE2P1(I)
      ILINE=ILINE+1
      CALL PRIN(ILINE,2)
      IF(ILINE-2) 821,821,822
  821 WRITE(6,1027)
      ILINE=ILINE+5
  822 CONTINUE
C
C  CONICAL FLOW STREAMLINE CALCULATION
C
      TERM1=0.
      TERM2=0.
      XXO(1)=1.
      RRO(1)=1.
      TP1=TAN(PHI(1))
      DO 22 K=2,KK
      PHIBAR=(PHI(K-1)+PHI(K))/2.
      ALPBAR=(ALPHA(K-1)+ALPHA(K))/2.
      TPB=TAN(PHIBAR)
      TAB=TAN(ALPBAR)
      TERM1=TERM1+(1.+TPB*TPB)*(PHI(K)-PHI(K-1))/(TAB-TPB)
      XXO(K)=EXP(TERM1)
      TERM2=TERM2+TAB*(XXO(K)-XXO(K-1))
      RRO(K)=1.+TERM2/TP1
      IF(XXO(K).GT.20.) GO TO 922
   22 CONTINUE
  922 IF(SHORT.EQ.0.) WRITE(6,1025)
      ILINE=ILINE+5
      DO 24 I=1,KK
      ALPHA(I)=ALPHA(I)/.01745329
C
C  ALPHA IS IN DEGREES
C
      IF(SHORT.EQ.1.) GO TO 24
      WRITE(6,1026) I, XXO(I), RRO(I), EME2S(I), PE2P1(I),ALPHA(I)
      ILINE=ILINE+1
      CALL PRIN(ILINE,2)
      IF(ILINE-2) 23,23,24
   23 WRITE(6,1025)
      ILINE=ILINE+5
   24 CONTINUE
C
C  CONVERSION OF STREAMLINE COORDINATES TO RS/R AND L/DEL1
```

```
C
   25 ROR=1.-DEL1R
      ROR=ROR1
      TH11=TH1D*0.01745329
      IF(AINPT.EQ.2.) TH11=TH1ZZ*0.01745329
      TP1=TAN(TH11)
      XOR=1.*ROR/TP1
      DO 26 K=1,KK
      RR(K)=RRO(K)*ROR
      XR(K)=XXO(K)*ROR/TP1
      ELD2(K)=(XR(K)-XOR)/DEL1R
      DEL3OR(K)=1.-RR(K)
   26 CONTINUE
      IF(SHORT.EQ.1.) GO TO 2800
      WRITE(6,1029)
      ILINE=ILINE+5
      DO 28 I=1,KK
      WRITE(6,1033) I,XXO(I),RRO(I),RR(I),ELD2(I),DEL3OR(I),XR(I)
      ILINE=ILINE+1
      CALL PRIN(ILINE,2)
      IF(ILINE-2) 27,27,28
   27 WRITE(6,1029)
      ILINE=ILINE+5
   28 CONTINUE
C
C  CALCULATION OF FORCE ALONG BOUNDARY OF CONTROL VOLUME ADJOINING
C  REGION 2
C
 2800 EI2(1)=0.
      DO 280 K=2,KK
      RRBAR=(RR(K-1)+RR(K))/2.
      PE2P1B=(PE2P1(K-1)+PE2P1(K))/2.
      EI2(K)=EI2(K-1)-PE2P1B*RRBAR*(RR(K-1)-RR(K))
  280 CONTINUE
      IF(SHORT.EQ.1.) GO TO 3000
      WRITE(6,1030)
      ILINE=ILINE+5
      DO 30 I=1,KK
      WRITE(6,1031) I,XXO(I),RRO(I),RR(I),ELD2(I),DEL3OR(I),EME2S(I)
     1,PE2P1(I), EI2(I),ALPHA(I)
      ILINE=ILINE+1
      CALL PRIN(ILINE,2)
      IF(ILINE-2) 29,29,30
   29 WRITE(6,1030)
      ILINE=ILINE+5
   30 CONTINUE
 3000 GO TO 37
C
C  CONSTANT PRESSURE BOUNDARY
C  FIND SHOCK WAVE ANGLE, PRESSURE RATIO ACROSS SHOCK AND DOWNSTREAM
C  MACH NO.
C
   35 CALL SHOCK(1,ALP1,TH1,EME1,EME2,P2P1)
      ALP1D=ALP1/.01745329
      ALP2=ALP1
      ALP2D=ALP1D
C
```

```
C   FIND SHOCK WAVE ANGLE, PRESSURE RATIO ACROSS SHOCK AND DOWNSTREAM
C   MACH NO.
C
      CALL SHOCK(1,ALP2,TH2,EME2,EME3,P3P2)
      TH2D=TH2/.01745329
      P3P1=P3P2*P2P1
      WRITE(6,1034)
      WRITE(6,1012) P2P1,P3P2,P3P1,EME1,EME2,EME3
      ILINE=ILINE+6
      WRITE(6,1013) ALP1D,TH1D,ALP2D,TH2D
      ILINE=ILINE+6
C
C   DETERMINE UPSTREAM BOUNDARY LAYER PROFILE PROPERTIES
C
   37 CALL PRFL(UTUES1,PX1,EME1,1.0,2,YY)
      IF(SHORT.EQ.0.) CALL PRIN(ILINE,3)
      II=1
      WRITE(6,1014) II
      ILINE=ILINE+4
      IF(SHORT.EQ.1.) GO TO 4000
      WRITE(6,1039)
      DO 40 I=1,101
      WRITE(6,1015) I,YY(I),EM(I),URAT(I),PTRAT(I),PTRNS(I),TTRAT(I)
      ILINE=ILINE+1
      CALL PRIN(ILINE,2)
      IF(ILINE-2) 38,38,40
   38 WRITE(6,1014) II
      ILINE=ILINE+4
      WRITE(6,1039)
   40 CONTINUE
C
C   DETERMINE UPSTREAM BOUNDARY LAYER INTEGRAL PROPERTIES
C
 4000 CALL FLUX(101,YY,2,EME1,DEL1R)
      HI1=(SHFAC-SIG1)/(TWTTE*(1.+SIG1))
      RETH1=REDEL1*DDSD
      PRANDL=.72
      PR13=PRANDL**(1./3.)
      TBARTO=.5*TWTTE+.22*PR13+(.5-.22*PR13)/(1.+SIG1)
      CFLT1=.246*EXP(-1.561*HI1)*(RETH1**(-.268))/
     1((TBARTO*(1.+SIG1))**0.7963)
      WRITE(6,1016) DSD,DDSD,BLMN,BLMON,SHFAC,HI1,CFWH1,CFLT1
      ILINE =ILINE+6
      DSD1=DSD
      DDSD1=DDSD
      WRITE(6,1017) DEL1R,BLMI,BLMOI
      ILINE=ILINE+3
      I=1
      UTUE3A(I)=UTUE3
      FM1=BLMI
      FMO1=BLMOI
      FMO1=FMO1*(1.+FEMT)
      FM1=FM1*(1.+FENT)
      J=1
      ELD1A(J)=ELD1
      R3=BLEED*2.*FM1
      L=1
```

```
      WRITE(6,1036) L,BLEED1
      L=2
      WRITE(6,1036) L,BLEED2
      WRITE(6,1035) BLEED,R3
      IF(IZ.EQ.1) RETURN
      IF(ELD1.LT.0.) RETURN
      YRS=0.
      IF(AIB.EQ.1.) GO TO 500
      IF(BLEED1.EQ.0.) GO TO 500
      WSA=ABS(BLEED1)*2.*FM1
      CALL INTRP(WR,YY,WSA,YYS,101)
      CALL INTRP(YY,PHIR,YYS,PHISA,101)
      YRS=YYS*DEL1R
      WRITE(6,1037) WSA,YRS,PHISA
      R3R=1.
      IF(AIB.EQ.3.) R3R=1.-YRS
C
C  AIB=1  POROUS PLATE SUCTION
C  AIB=2  SLOT SUCTION
C  AIB=3  SCOOP SUCTION
C
  500 IF(AIB.LE.1.) BLMOM1=0.
      IF(AIB.LE.3.) R3R=1.
      IF(AIB.GE.2.) BLMOM1=-PHISA
      KB=1
      WRITE(6,1038) KB,BLMOM1
      IF(SHORT.EQ.1.) GO TO 50
      CALL PRIN(ILINE,3)
      WRITE(6,1018)
      ILINE=ILINE+2
   50 GO TO (51,51,51,55), IE2
C
C  ITERATION PROCEDURE FOR SOLUTION OF CONTINUITY EQUATION
C
   51 CALL INTRP(ELD2,EME2S,ELD1A(J),EME2,KK)
      CALL INTRP(ELD2,PE2P1,ELD1A(J),P2P1,KK)
      CALL INTRP(ELD2,ALPHA,ELD1A(J),ALP2D,KK)
      ALP2=ALP2D*.01745329
C
C  ALLOW FOR NON-ZERO FLOW ANGLE DOWNSTREAM, FLDIR3
C
      ALP2=ALP2-FLDIR3*.01745329
      ALP2D=ALP2/.01745329
C
C  DETERMINE SHOCK WAVE ANGLE, PRESSURE RATIO ACROSS SHOCK AND
C  DOWNSTREAM MACH NO.
C
      CALL SHOCK(1,ALP2,TH2,EME2,EME3,P3P2)
      P3P1=P3P2*P2P1
      TH2D=TH2/.01745329
      IF(SHORT.EQ.1.) GO TO 55
      WRITE(6,1012) P2P1,P3P2,P3P1,EME1,EME2,EME3
      ILINE=ILINE+6
      WRITE(6,1013) ALP1D,TH1D,ALP2D,TH2D
      ILINE=ILINE+6
   55 R1=2.
      GAM1=(GAMMA-1.)/2.
```

```
      R1A=1.+GAM1*EME3*EME3
      R1B=1.+GAM1*EME1*EME1
      R2=-2.*P3P1*EME3*SQRT(R1A/R1B)/EME1
      IF(AIB.EQ.3.) R2=R2*R3R*R3R
      R3=BLEED*2.*FM1
      IF(IE2.EQ.3) D31P=1.-ELD1A(J)*TAN(ALP1)
      IF(IE2.EQ.3.AND.AIB.EQ.3.) D31P=1.-YYS-ELD1A(J)*TAN(ALP1)
      IF(IE2.LT.3) CALL INTRP(ELD2,DEL3OR,ELD1A(J),DEL3RP,KK)
      IF(IE2.LT.3.AND.AIB.EQ.3.) DEL3RP=DEL3RP-YRS
      IF(IE2.LT.3) D31P=DEL3RP/DEL1R
      REDEL3=REDEL1*D31P*P3P1*(EME3/EME1)*(R1A/R1B)**1.26
      SIG3=GAM1*EME3*EME3
      SIGMA3=SIG3/R1A
      SIGS3=SQRT(SIGMA3)
      FSIG3=(ASIN(SIGS3))/SIGS3
      VWVE3=(TWTTE*R1A)**1.76
      IF(REDEL3.LE.0.) RETURN
      PX3=.5*(1.-UTUE3A(I)*((1./BK)*ALOG(REDEL3*ABS(UTUE3A(I))
     1*FSIG3/VWVE3)+C))
   60 CALL PRFL(UTUE3A(I),PX3,EME3,P3P1,1,YY)
      GO TO (61,61,61,62), IE2
   61 CALL INTRP(ELD2,EI2,ELD1A(J),EI2PR,KK)
      CALL INTRP(ELD2,DEL3OR,ELD1A(J),DEL3R,KK)
      IF(SHORT.EQ.1.) GO TO 63
      WRITE(6,1032) ELD1A(J),EI2PR,DEL3R
      ILINE=ILINE+1
      CALL PRIN(ILINE,2)
      IF(ILINE-2) 610,610,620
  610 WRITE(6,1018)
      ILINE=ILINE+2
  620 GO TO 63
   62 D31=1.-ELD1A(J)*TAN(ALP1)
      DEL3R=D31*DEL1R
   63 CON=DEL3R
      D3PR3=(DEL3R-YRS)/R3R
      IF(AIB.EQ.3.) DEL3R=D3PR3
      IF(SHORT.EQ.0.) WRITE(6,1040) R3R,D3PR3
      ILINE=ILINE+2
      CALL FLUX(101,YY,2,EME3,DEL3R)
      DEL3R=CON
      FM3=BLMI
      FMO3=BLMOI
      E1(J)=R1*FM1+R2*FM3+R3
      IF(SHORT.EQ.1.) GO TO 65
      WRITE(6,1019) R1,R2,R3,FM1,FMO1,FM3,FMO3
      WRITE(6,1020) I,UTUE3A(I),E2(I),J,ELD1A(J),E1(J)
      ILINE=ILINE+6
      CALL PRIN(ILINE,2)
      IF(ILINE-2) 64,64,65
   64 WRITE(6,1018)
      ILINE=ILINE+2
   65 TEST=ABS(E1(J))
      IF(TEST.LE.0.00001) GO TO 80
      IF(J.GE.2) GO TO 70
      J=2
      ELD1A(J)=1.1*ELD1A(1)
      GO TO 50
```

```
   70 SLOPE1=(E1(J-1)-E1(J))/(ELD1A(J-1)-ELD1A(J))
      ELD1A(J+1)=ELD1A(J)-E1(J)/SLOPE1
      DEFG=ELD1A(J+1)
      EFG=ELD1A(1)*1.6
      IF(DEFG.GT.EFG) ELD1A(J+1)=1.1*ELD1A(J)
      J=J+1
      IF(J.EQ.51) GO TO 71
      IF(ELD1A(J)) 72,72,50
C
C  STOP CASE NO CONVERGENCE ON J
C
   71 WRITE(6,1021)
      RETURN
C
C  STOP CASE L/DEL1 LESS THAN 0.
C
   72 WRITE(6,1042) J,ELD1A(J),I
      RETURN
C
C  ITERATION PROCEDURE FOR SOLUTION OF MOMENTUM EQUATION
C
   80 S1=1.
      S2=-1.
      S3=-2.
      S4= 2.*GAMMA*EME1*EME1
      S5=2.*GAMMA*EME3*EME3*P3P1*(-1.)
      S6=GAMMA*EME1*EME1*BLMOM1
      S7=-1.
      TAU1P1=0.7*CFWW1*EME1*EME1
      FUTUE3=UTUE3A(I)*FSIG3
      CFWW3=2.*FUTUE3*FUTUE3/(TWTTE*(1.+SIG3))
      TAU3P1=0.7*CFWW3*EME3*EME3*P3P1
      TAUP1=STCOEF*(TAU1P1+TAU3P1)
C
C  S8 IS THE SHEAR TERM IN THE MOMENTUM EQUATION
C
      S8=2.*TAUP1*DEL1R*ELD1A(J)
      R1C=1.+GAM1*EME2*EME2
C
C  S9 IS THE ENTRAINMENT TERM IN THE MOMENTUM EQUATION
C
      S9=2.*BLEED2*FM1*COS(ALP1)*EME1*EME2*GAMMA*SQRT(R1B/R1C)
      T1=2.*DEL1R-DEL1R*DEL1R
      T2=2.*DEL3R-DEL3R*DEL3R
      IF (IE2.EQ.3.) T1=2.*DEL1R+DEL1R*DEL1R
      IF (IE2.EQ.3.) T2=2.*DEL3R+DEL3R*DEL3R
      T3=P2P1*(T1-T2)/2.
      T4=0.
      IF(AIB.EQ.3.) T2=(2.*D3PR3-D3PR3*D3PR3)*R3R*R3R
      IF(AIB.EQ.3.) T4=2.*YRS-YRS*YRS
      IF(AIB.EQ.3.) S5=S5*R3R*R3R
      IF(IE2.LT.4) T3=EI2PR
      E2(I)=S1*T1+S2*T2*P3P1+S3*T3+S4*FMO1+S5*FMO3+S6+S7*T4-S8+S9
      IF(SHORT.EQ.1.) GO TO 82
      WRITE(6,1022) S4,S5,S8,T1,T2,T3,T4
      WRITE(6,1020) I,UTUE3A(I),E2(I),J,ELD1A(J),E1(J)
      ILINE=ILINE+6
```

```
      CALL PRIN(ILINE,2)
      IF(ILINE-2) 81,81,82
   81 WRITE(6,1018)
      ILINE=ILINE+2
   82 TEST =ABS(E2(I))
      IF(TEST.LE.0.00001) GO TO 110
      IF(I.GE.2) GO TO 90
      I=2
      UTUE3A(I)=0.9*UTUE3
      IF(EME1.LT.2.5.AND.ALP1D.LT.3.5) UTUE3A(I)=1.1*UTUE3
      GO TO 100
   90 SLOPE2=(E2(I-1)-E2(I))/(UTUE3A(I-1)-UTUE3A(I))
      UTUE3A(I+1)=UTUE3A(I)-E2(I)/SLOPE2
      I=I+1
      IF(I.EQ.51) WRITE(6,1023)
      IF(I.EQ.51) RETURN
  100 ELD1A(1)=ELD1A(J)
      J=1
      GO TO 50
C
C  SOLUTION TO CONTINUITY AND MOMENTUM EQUATIONS HAS BEEN DETERMINED
C
  110 UTUE3=UTUE3A(I)
      ELD1F=ELD1A(J)
C
C  DETERMINE DOWNSTREAM BOUNDARY LAYER PROFILE PROPERTIES
C
      CALL PRFL(UTUE3,PX3,EME3,P3P1,2,YY)
      IF(SHORT.EQ.0.) CALL PRIN(ILINE,3)
      IF(SHORT.EQ.0.) WRITE (6,1018)
      IF(ALP1D.EQ.0.) GO TO 1100
      WRITE(6,1012) P2P1,P3P2,P3P1,EME1,EME2,EME3
      WRITE(6,1013) ALP1D,TH1D,ALP2D,TH2D
 1100 IF(SHORT.EQ.0.) CALL PRIN(ILINE,3)
      II=3
      WRITE(6,1014) II
      WRITE(6,1043)UTUE3,REDEL3,PX3
      ILINE=ILINE+6
      IF(SHORT.EQ.1.) GO TO 1200
      WRITE(6,1039)
      DO 120 I=1,101
      WRITE(6,1015) I,YY(I),EM(I),URAT(I),PTRAT(I),PTRNS(I),TTRAT(I)
      ILINE=ILINE+1
      CALL PRIN(ILINE,2)
      IF(ILINE-2) 111,111,120
  111 WRITE(6,1014) II
      ILINE=ILINE+4
      WRITE(6,1039)
  120 CONTINUE
C
C  DETERMINE DOWNSTREAM BOUNDARY LAYER INTEGRAL PROPERTIES
C
 1200 IF(AIB.EQ.3.) DEL3R=D3PR3
      CALL FLUX(101,YY,2,EME3,DEL3R)
      FUTUE3=UTUE3*FSIG3
      CFWW3=2.*FUTUE3*FUTUE3/(TWTTE*(1.+SIG3))
      HI3=(SHFAC-SIG3)/(TWTTE*(1.+SIG3))
```

```
      RETH3=REDEL3*DDSD
      TBARTO=.5*TWTTE+.22*PR13+(.5-.22*PR13)/(1.+SIG3)
      CFLT3=.246*EXP(-1.561*HI3)*(RETH3**(-.268))/
     1((TBARTO*(1.+SIG3))**0.7963)
      WRITE(6,1016) DSD,DDSD,BLMN,BLMON,SHFAC,HI3,CFWW3,CFLT3
      IF(AIB.EQ.3.) DEL3R=D3PR3*R3R
      WRITE(6,1017) DEL3R,BLMI,BLMOI
      ILINE=ILINE+3
      D31=DEL3R/DEL1R
      DS31=DSD*D31/DSD1
      DDS 31=DDSD*D31/DDSD1
      WRITE(6,1024) D31,DS31,DDS31,ELD1F
      IF(AIB.EQ.3.) WRITE(6,1041) YRS,D3PR3,R3R
      RETURN
 1000 FORMAT(7F10.6)
 1011 FORMAT(1H0/10X,35HSOLUTION FOR AXIALLY SYMMETRIC FLOW)
 1012 FORMAT(1H /10X,30HBOUNDARY LAYER EDGE CONDITIONS//
     110X,8HP2/P1 = ,F10.6,5X,8HP3/P2 = ,F10.6,5X,8HP3/P1 = ,F10.6/
     210X,5HM1 = ,F10.6,8X,5HM2 = ,F10.6,8X,5HM3 = ,F10.6)
 1013 FORMAT(1H0/10X,32HSHOCK AND FLOW DEFLECTION ANGLES//10X,
     115HINCIDENT SHOCK ,5X,8HALPHA = ,F10.6,8H DEGREES,5X,
     28HTHETA = ,F10.6,8H DEGREES/10X,15HREFLECTED SHOCK,5X,8HALPHA = ,
     3F10.6,8H DEGREES,5X,8HTHETA = ,F10.6,8H DEGREES)
 1014 FORMAT(1H0, 9X,35HBOUNDARY LAYER PROFILE DATA STATION,I3)
 1015 FORMAT(1H ,6X,I3,6F14.6)
 1016 FORMAT(1H0/10X,14HDELSTAR/DEL = ,F14.6,4X,10HMOM/DEL = ,
     1F14.6/10X,28HNON-DIMENSIONAL MASS FLUX = ,F10.6/
     210X,32HNON-DIMENSIONAL MOMENTUM FLUX = ,F10.6/10X,
     315HSHAPE FACTOR = ,F10.6,5X,30HINCOMPRESSIBLE SHAPE FACTOR = ,
     4 F10.6/10X,16HCF(WALL-WAKE) = ,F10.6,5X,22HCF(LUDWEIG TILLMAN) = ,
     5F10.6)
 1017 FORMAT(1H , 9X,8HDEL/R = ,F10.6/10X,21HB.L. MASS INTEGRAL = ,
     1F10.6/10X,25HB.L. MOMENTUM INTEGRAL = ,F10.6/)
 1018 FORMAT(1H0, 9X,42HRESULTS OF ITERATION FOR UTUE*3 AND L/DEL1)
 1019 FORMAT(1H0, 9X,5HR1 = ,F10.6,6X,5HR2 = ,F10.6,5X,5HR3 = ,F10.6/
     110X,6HFM1 = ,F10.6,5X,7HFMO1 = ,F10.6/10X,6HFM3 = ,F10.6,5X,
     27HFMO3 = ,F10.6)
 1020 FORMAT(1H , 9X,4HI = ,I3,3X,9HUTUE*3 = ,F10.6,5X,5HE2 = ,F10.6/
     110X,3HJ =,I4,5X,7HL/D1 = ,F10.6,5X,5HE1 = ,F10.6)
 1021 FORMAT(1H0, 6X,19HNO CONVERGENCE ON J)
 1022 FORMAT(1H0, 9X,5HS4 = ,F10.6,5X,5HS5 = ,F10.6,5X,5HS8 = ,F10.6/
     110X,5HT1 = ,F10.6,5X,5HT2 = ,F10.6,5X,5HT3 = ,F10.6,5X,5HT4 = ,
     2 F10.6)
 1023 FORMAT(1H0, 6X,19HNO CONVERGENCE ON I)
 1024 FORMAT(1H0/10X,12HDEL3/DEL1 = ,F10.6/10X,
     120HDELSTAR3/DELSTAR1 = ,F10.6/10X,12HMOM3/MOM1 = ,F10.6//10X,
     29HL/DEL1 = ,F10.6)
 1025 FORMAT(1H0/10X,35HBOUNDARY LAYER EDGE STREAMLINE DATA//
     1 9X,1HK, 8X,4HX/XO,10X,4HR/RO,11X,3HM2E,10X,5HPE2P1,
     2 9X,5HALPHA//)
 1026 FORMAT(1H ,6X,I3,5F14.6)
 1027 FORMAT(1H0/10X,34HCONICAL FLOW STREAMLINE INPUT DATA//
     1 9X,1HK,9X,3HPHI,10X,5HALPHA, 9X,3HM2E, 8X,5HPE2P1//)
 1028 FORMAT(1H ,6X,I3,4F14.6)
 1029 FORMAT(1H0/10X,25HCONVERTED STREAMLINE DATA//
     1 9X,1HK,8X,4HX/XO,10X,4HR/RO,10X,4HRS/R, 9X,6HL/DEL1, 8X,6HDEL3/R
     2,10X,3HX/R//)
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 1030 FORMAT(1H0/10X,31HSUMMARY OF EDGE STREAMLINE DATA//
     1 9X,1HK,4X,4HX/XO,10X,4HR/RO, 8X,4HRS/R, 7X,
     26HL/DEL1, 7X,6HDEL3/R, 8X,3HM2E, 7X,5HPE2P1, 7X,
     35H(I)E2, 7X,5HALPHA//)
 1031 FORMAT( 1H ,6X,I3,9F12.6)
 1032 FORMAT(1H ,10X,9HL/DEL1 = ,F14.6,5X,8H(I)E2 = ,F14.6,5X,
     18HDEL3R = ,F14.6)
 1033 FORMAT(1H ,6X,I3,6F14.6)
 1034 FORMAT(1H0/10X,38HCONSTANT PRESSURE BOUNDARY IN REGION 2)
 1035 FORMAT(1H , 9X,19H(M)BLEED/(M)B.L. = ,F10.6/
     110X,19H(M)BLEED/(M)DUCT = ,F10.6)
 1036 FORMAT(1H , 9X,8H(M)BLEED,I1,11H/(M)B.L. = ,F10.6,
     120H (BLEED POSITIVE IN))
 1037 FORMAT(1H0/10X,6HWSA = ,F10.6,5X,6HYRS = ,F10.6,5X,8HPHISA = ,
     1F10.6)
 1038 FORMAT(1H0, 9X,40HMOMENTUM FLUX ASSOCIATED WITH B.L. BLEED,I1,
     13H = ,F14.6,14H (POSITIVE IN))
 1039 FORMAT(1H0,
     1 9X,1HI,8X,1HY,14X,1HM,12X,4HU/UE, 9X,6HPT/PT1, 6X,10HPT(NS)/PT1,
     2 6X,6HTT/TT1//)
 1040 FORMAT(1H0,10X,7HR3/R = ,F10.6,5X,12HDEL3PR/R3 = ,F10.6)
 1041 FORMAT(1H0, 8X,28HSCOOP CASE,SCOOP HEIGHT/R = ,F10.6,5X,
     112HDEL3PR/R3 = ,F10.6,5X,7HR3/R = ,F10.6)
 1042 FORMAT(1H0/ 6X,17HSTOP CASE L/DEL1(,I3,4H) = ,F10.6,5X,4HI = ,I3)
 1043 FORMAT(1H0,10X,9HUTUE*3 = ,F10.6,5X,9HREDEL3 = ,E14.6,5X,
     16HPX3 = ,F10.6)
      END


      SUBROUTINE ANOS(UTUES1,UTUE3,REDEL1,PX1,D312D,EME,IZ)
C   AXIALLY SYMMETRIC FLOW ANALYSIS  BLEED WITH NO SHOCK WAVE
      DIMENSION TTRAT(200),PTRAT(200),PTRNS(200),URAT(200),EM(200)
      DIMENSION E1(100), E2(100),DEL3OR(100), UTUE3A(100),  YY(200)
      DIMENSION WR(200), PHIR(200)
      COMMON  TTRAT    , PTRAT    , PTRNS    , URAT     ,
     1        EM       , WR       , PHIR     ,
     2        SHORT    , BLEED1   , BLEED2   , BLEED    ,
     3        AIB      , TWITE    , GAMMA    , TH10     ,
     4        BLMN     , BLMON    , BLMI     , BLMOI    ,
     5        DSD      , DDSD     , BK       , EME1     , SHFAC    ,
     6        SIG1     , SIGMA1   , SIGS1    , FSIG1    , VWVE1    ,
     7        CFWW1    , C        , STCOEF
C
C   READ DATA CARD 6
C
      READ(5,1000) DEL1R
      CALL PRIN(ILINE,3)
      WRITE(6,1011)
C
C   DETERMINE UPSTREAM BOUNDARY LAYER PROFILE PROPERTIES
C
   37 CALL PRFL(UTUES1,PX1,EME1,1.0,2,YY)
C
C   PARAMETERS FOR NO SHOCK
C
      EME3=EME1
```

```
      EME2=EME1
      P2P1=1.
      P3P2=1.
      P3P1=1.
      II=1
      WRITE(6,1014) II
      ILINE=ILINE+4
      IF(SHORT.EQ.1.) GO TO 4000
      WRITE(6,1039)
      DO 40 I=1,101
      WRITE(6,1015) I,YY(I),EM(I),URAT(I),PTRAT(I),PTRNS(I),TTRAT(I)
      ILINE=ILINE+1
      CALL FRIN(ILINE,2)
      IF(ILINE-2) 38,38,40
   38 WRITE(6,1014) II
      ILINE=ILINE+4
      WRITE(6,1039)
   40 CONTINUE
C
C  DETERMINE UPSTREAM BOUNDARY LAYER INTEGRAL PROPERTIES
C
 4000 CALL FLUX(101,YY,2,EME1,DEL1R)
      HI1=(SHFAC-SIG1)/(TWTTE*(1.+SIG1))
      RETH1=REDEL1*DDSD
      PRANDL=.72
      PR13=PRANDL**(1./3.)
      TBARTO=.5*TWTTE+.22*PR13+(.5-.22*PR13)/(1.+SIG1)
      CFLT1=.246*EXP(-1.561*HI1)*(RETH1**(-.268))/
     1((TBARTO*(1.+SIG1))**0.7963)
      WRITE(6,1016) DSD,DDSD,BLMN,BLMON,SHFAC,HI1,CFWW1,CFLT1
      ILINE =ILINE+6
      DSD1=DSD
      DDSD1=DDSD
      WRITE(6,1017) DEL1R,BLMI,BLMOI
      ILINE=ILINE+3
      I=1
      UTUE3A(I)=UTUE3
      FM1=BLMI
      FMO1=BLMOI
      J=1
      DEL3OR(J)=D312D*DEL1R
      R3=BLEED*2.*FM1
      L=1
      WRITE(6,1036) L,BLEED1
      L=2
      WRITE(6,1036) L,BLEED2
      WRITE(6,1035) BLEED,R3
      IF(IZ.EQ.1) RETURN
      YRS=0.
      IF(AIB.EQ.1.) GO TO 500
      IF(BLEED1.EQ.0.) GO TO 500
      WSA=AES(BLEED1)*2.*FM1
      CALL INTRP(WR,YY,WSA,YYS,101)
      CALL INTRP(YY,PHIR,YYS,PHISA,101)
      YRS=YYS*DEL1R
      WRITE(6,1037) WSA,YRS,PHISA
      R3R=1.
```

```
      IF(AIB.EQ.3.) R3R=1.-YRS
C
C   AIB=1  POROUS PLATE SUCTION
C   AIB=2  SLOT SUCTION
C   AIB=3  SCOOP SUCTION
C
  500 IF(AIB.LE.1.) BLMOM1=0.
      IF(AIB.GE.2.) BLMOM1=-PHISA
      KB=1
      WRITE(6,1038) KB,BLMOM1
      IF(SHORT.EQ.1.) GO TO 50
      CALL PRIN(ILINE,3)
      WRITE(6,1018)
      ILINE=ILINE+2
C
C   ITERATION PROCEDURE FOR SOLUTION OF CONTINUITY EQUATION
C
   50 R1=2.
      GAM1=(GAMMA-1.)/2.
      R2=-2.
      IF(AIB.EQ.3.) R2=R2*R3R*R3R
      P3=BLEED*2.*FM1
   60 DEL3RP=DEL3OR(J)
      IF(AIB.EQ.3.) DEL3RP=DEL3RP-YRS
      D31P=DEL3RP/DEL1R
      REDEL3=REDEL1*D31P
      SIG3=GAM1*EME3*EME3
      SIGMA3=SIG3/(1.+SIG3)
      SIGS3=SQRT(SIGMA3)
      FSIG3=(ASIN(SIGS3))/SIGS3
      VWVE3=(TWTTE*(1.+SIG3))**1.76
      PX3=.5*(1.-UTUE3A(I)*((1./BK)*ALOG(REDEL3*ABS(UTUE3A(I))
     1*FSIG3/VWVE3)+C))
      CALL PRFL(UTUE3A(I),PX3,EME3,P3P1,1,YY)
      DEL3R=DEL3OR(J)
      CON=DEL3R
      D3PR3=(DEL3R-YRS)/R3R
      IF(AIB.EQ.3.) DEL3R=D3PR3
      IF(SHORT.EQ.0.) WRITE(6,1040) R3R,D3PR3
      ILINE=ILINE+2
      CALL FLUX(101,YY,2,EME3,DEL3R)
      DEL3R=CON
      FM3=BLMI
      FMO3=BLMOI
      E1(J)=R1*FM1+R2*FM3+R3
      IF(SHORT.EQ.1.) GO TO 65
      WRITE(6,1019) R1,R2,R3,FM1,FMO1,FM3,FMO3
      WRITE(6,1020) I,UTUE3A(I),E2(I),J,DEL3OR(J),E1(J)
      ILINE=ILINE+6
      CALL PRIN(ILINE,2)
      IF(ILINE-2) 64,64,65
   64 WRITE(6,1018)
      ILINE=ILINE+2
   65 TEST=ABS(E1(J))
      IF(TEST.LE.0.00001) GO TO 80
      IF(J.GE.2) GO TO 70
      J=2
```

```
      DEL3OR(J)=0.9*DEL3OR(1)
      GO TO 60
   70 SLOPE1=(E1(J-1)-E1(J))/(DEL3OR(J-1)-DEL3OR(J))
      DEL3OR(J+1)=DEL3OR(J)-E1(J)/SLOPE1
      J=J+1
      IF(J.EQ.51) GO TO 71
      GO TO 60
C
C  STOP CASE NO CONVERGENCE ON J
C
   71 WRITE(6,1021)
      RETURN
C
C  ITERATION PROCEDURE FOR SOLUTION OF MOMENTUM EQUATION
C
   80 S1=0.
      S2=0.
      S3=0.
      S4=2.
      S5=-2.
      S6=BLMOM1
      S7=0.
      T1=0.
      T2=0.
      T3=0.
      T4=0.
      IF(AIB.EQ.3.) S5=S5*R3R*R3R
      E2(I)=S1*T1+S2*T2*P3P1+S3*T3+S4*FMO1+S5*FMO3+S6+S7*T4
      IF(SHORT.EQ.1.) GO TO 82
      WRITE(6,1022) S4,S5,T1,T2,T3,T4
      WRITE(6,1020) I,UTUE3A(I),E2(I),J,DEL3OR(J),E1(J)
      ILINE=ILINE+6
      CALL PRIN(ILINE,2)
      IF(ILINE-2) 81,81,82
   81 WRITE(6,1018)
      ILINE=ILINE+2
   82 TEST =ABS(E2(I))
      IF(TEST.LE.0.00001) GO TO 110
      IF(I.GE.2) GO TO 90
      I=2
      UTUE3A(I)=0.9*UTUE3
      GO TO 100
   90 SLOPE2=(E2(I-1)-E2(I))/(UTUE3A(I-1)-UTUE3A(I))
      UTUE3A(I+1)=UTUE3A(I)-E2(I)/SLOPE2
      I=I+1
      IF(I.EQ.51) WRITE(6,1023)
      IF(I.EQ.51) RETURN
  100 DEL3OR(1)=DEL3OR(J)
      J=1
      GO TO 60
C
C  SOLUTION TO CONTINUITY AND MOMENTUM EQUATIONS HAS BEEN DETERMINED
C
  110 UTUE3=UTUE3A(I)
C
C  DETERMINE DOWNSTREAM BOUNDARY LAYER PROFILE PROPERTIES
C
```

```
      CALL PRFL(UTUE3,PX3,EME3,P3P1,2,YY)
      IF(SHORT.EQ.0.) CALL PRIN(ILINE,3)
      WRITE(6,1018)
 1100 II=3
      WRITE(6,1014) II
      WRITE(6,1043)UTUE3,REDEL3,PX3
      ILINE=ILINE+6
      IF(SHORT.EQ.1.) GO TO 1200
      WRITE(6,1039)
      DO 120 I=1,101
      WRITE(6,1015) I,YY(I),EM(I),URAT(I),PTRAT(I),PTRNS(I),TTRAT(I)
      ILINE=ILINE+1
      CALL PRIN(ILINE,2)
      IF(ILINE-2) 111,111,120
  111 WRITE(6,1014) II
      ILINE=ILINE+4
      WRITE(6,1039)
  120 CONTINUE
C
C  DETERMINE DOWNSTREAM BOUNDARY LAYER INTEGRAL PROPERTIES
C
 1200 IF(AIB.EQ.3.) DEL3R=D3PR3
      CALL FLUX(101,YY,2,EME3,DEL3R)
      FUTUE3=UTUE3*FSIG3
      CFWW3=2.*FUTUE3*FUTUE3/(TWTTE*(1.+SIG3))
      HI3=(SHFAC-SIG3)/(TWTTE*(1.+SIG3))
      RETH3=REDEL3*DDSD
      TBARTO=.5*TWTTE+.22*PR13+(.5-.22*PR13)/(1.+SIG3)
      CFLT3=.246*EXP(-1.561*HI3)*(RETH3**(-.268))/
     1((TBARTO*(1.+SIG3))**0.7963)
      WRITE(6,1016) DSD,DDSD,BLMN,BLMON,SHFAC,HI3,CFWW3,CFLT3
      IF(AIB.EQ.3.) DEL3R=D3PR3*R3R
      WRITE(6,1017) DEL3R,BLMI,BLMOI
      ILINE=ILINE+3
      D31=DEL3R/DEL1R
      DS31=DSD*D31/DSD1
      DDS 31=DDSD*D31/DDSD1
      WRITE(6,1024) D31,DS31,DDS31
      IF(AIB.EQ.3.) WRITE(6,1041) YRS,D3PR3,R3R
      RETURN
 1000 FORMAT(7F10.6)
 1011 FORMAT(1H0/10X,35HSOLUTION FOR AXIALLY SYMMETRIC FLOW)
 1014 FORMAT(1H0, 9X,35HBOUNDARY LAYER PROFILE DATA STATION,I3)
 1015 FORMAT(1H ,6X,I3,6F14.6)
 1016 FORMAT(1H0/10X,14HDELSTAR/DEL = ,F14.6,4X,10HMOM/DEL = ,
     1F14.6/10X,28HNON-DIMENSIONAL MASS FLUX = ,F10.6/
     210X,32HNON-DIMENSIONAL MOMENTUM FLUX = ,F10.6/10X,
     315HSHAPE FACTOR = ,F10.6,5X,30HINCOMPRESSIBLE SHAPE FACTOR = ,
     4 F10.6/10X,16HCF(WALL-WAKE) = ,F10.6,5X,22HCF(LUDWEIG TILLMAN) = ,
     5F10.6)
 1017 FORMAT(1H , 9X,8HDEL/R = ,F10.6/10X,21HB.L. MASS INTEGRAL = ,
     1F10.6/10X,25HB.L. MOMENTUM INTEGRAL = ,F10.6)
 1018 FORMAT(1H0, 9X,42HRESULTS OF ITERATION FOR UTUE*3 AND DEL3/R)
 1019 FORMAT(1H0, 9X,5HR1 = ,F10.6,6X,5HR2 = ,F10.6,5X,5HR3 = ,F10.6/
     110X,6HFM1 = ,F10.6,5X,7HFMO1 = ,F10.6/10X,6HFM3 = ,F10.6,5X,
     27HFMO3 = ,F10.6)
 1020 FORMAT(1H , 9X,4HI = ,I3,3X,9HUTUE*3 = ,F10.6,5X,5HE2 = ,F10.6/
```

```
     110X,3HJ =,I4,5X,9HDEL3/R = ,F10.6,5X,5HE1 = ,F10.6)
1021 FORMAT(1H0, 6X,19HNO CONVERGENCE ON J)
1022 FORMAT(1H0, 9X,5HS4 = ,F10.6,5X,5HS5 = ,F10.6/10X,
     15HT1 = ,F10.6,5X,5HT2 = ,F10.6,5X,5HT3 = ,F10.6,5X,5HT4 = ,F10.6)
1023 FORMAT(1H0, 6X,19HNO CONVERGENCE ON I)
1024 FORMAT(1H0/10X,12HDEL3/DEL1 = ,F10.6/10X,
     120HDELSTAR3/DELSTAR1 = ,F10.6/10X,12HMOM3/MOM1 = ,F10.6)
1035 FORMAT(1H0, 9X,19H(M)BLEED/(M)B.L. = ,F10.6/
     110X,19H(M)BLEED/(M)DUCT = ,F10.6)
1036 FORMAT(1H0, 9X,8H(M)BLEED,I1,11H/(M)B.L. = ,F10.6,
     120H (BLEED POSITIVE IN))
1037 FORMAT(1H0/10X,6HWSA = ,F10.6,5X,6HYRS = ,F10.6,5X,8HPHISA = ,
     1F10.6)
1038 FORMAT(1H0, 9X,40HMOMENTUM FLUX ASSOCIATED WITH B.L. BLEED,I1,
     13H = ,F14.6,14H (POSITIVE IN))
1039 FORMAT(1H0,
     1 9X,1HI,8X,1HY,14X,1HM,12X,4HU/UE, 9X,6HPT/PT1, 6X,10HPT(NS)/PT1,
     2 6X,6HTT/TT1//)
1040 FORMAT(1H0,10X,7HR3/R = ,F10.6,5X,12HDEL3PR/R3 = ,F10.6)
1041 FORMAT(1H0, 8X,28HSCOOP CASE,SCOOP HEIGHT/R = ,F10.6,5X,
     112HDEL3PR/R3 = ,F10.6,5X,7HR3/R = ,F10.6)
1043 FORMAT(1H0,10X,9HUTUE*3 = ,F10.6,5X,9HREDEL3 = ,E14.6,5X,
     16HPX3 = ,F10.6)
      END


      SUBROUTINE SHOCK(ISH,ALP,TH,EMX,EMY,PRAT)
C  SUBROUTINE TO CALCULATE CHANGES IN PROPERTIES ACROSS AN OBLIQUE
C  SHOCK WAVE
      DIMENSION TTRAT(200),PTRAT(200),PTRNS(200),URAT(200),EM(200) .
      DIMENSION AC(4), WR(200), PHIR(200)
      COMMON  TTRAT   , PTRAT    , PTRNS    , URAT     ,
     1        EM      , WR       , PHIR     ,
     2        SHORT   , BLEED1   , BLEED2   , BLEED    ,
     3        AIB     , TWTTE    , GAMMA    , TH1D     ,
     4        BLMN    , BLMON    , BLMI     , BLMOI    ,
     5        DSD     , DDSD     , BK       , EME1     , SHFAC    ,
     6        SIG1    , SIGMA1   , SIGS1    , FSIG1    , VWVE1    ,
     7        CFWW1   , C        , STCOEF
      G1=EMX*EMX
      G2=G1*G1
      IF(ISH-1) 10,10,20
C
C  DETERMINE SHOCK WAVE ANGLE
C
   10 G3=(G1+2.)/G1
      G4=(2.*G1+1.)/G2
      G5=(GAMMA+1.)*(GAMMA+1.)/4.+(GAMMA-1.)/G1
      SDS=SIN(ALP)**2.
      AC(1)=(SDS-1.)/G2
      AC(2)=G4+G5*SDS
      AC(3)=-G3-GAMMA*SDS
      AC(4)=1.
C
C  FIND ROOTS OF CUBIC EQUATION IN (SIN(THETA))**2
C
```

```
      CALL CUBIC(AC,Z)
      ROOT=SQRT(Z)
      IF(ROOT-1.) 12,12,11
C
C  ERROR EXIT IF SIN(THETA) GREATER THAN 1.0
C
   11 WRITE(6,1010) ROOT
      TH=ASIN(ROOT)
      RETURN
   12 TH=ASIN(ROOT)
C
C  DETERMINE PRESSURE RATIO ACROSS SHOCK AND DOWNSTREAM MACH NO.
C
   20 GAM1=GAMMA+1.
      GAM2=GAMMA-1.
      GAM3=GAM1*GAM1
      Z=SIN(TH)**2.
      PRAT=(2.*GAMMA*G1*Z-GAM2)/GAM1
      ANUM=GAM3*G2*Z-4.*(G1*Z-1.)*(GAMMA*G1*Z+1.)
      DENO=(2.*GAMMA*G1*Z-GAM2)*(GAM2*G1*Z+2.)
      EMY=SQRT(ANUM/DENO)
      RETURN
 1010 FORMAT(1H0,10X,10HSIN(TH) = ,F10.6)
      END


      SUBROUTINE FLUX(K,Y,INDIC,EME,DELR)
C  SUBROUTINE TO CALCULATE MASS AND MOMENTUM FLUX OF B.L.
C  ALSO CALCULATES DISPLACEMENT AND MOMENTUM THICKNESSES
C     INDIC=1  TWO-DIMENSIONAL FLOW
C          =2  AXIALLY SYMMETRIC FLOW ON COWL
C          =3  AXIALLY SYMMETRIC FLOW ON CENTERBODY
      DIMENSION TTRAT(200),PTRAT(200),PTRNS(200),URAT(200),EM(200)
      DIMENSION Y(200),YY(200),BLMR(200),BLMOR(200),BLMIR(200)
      DIMENSION BMOIR(200),YR(200),WR(200), PHIR(200)
      COMMON  TTRAT    , PTRAT    , PTRNS    , URAT     ,
     1        EM       , WR       , PHIR     ,
     2        SHORT    , BLEED1   , BLEED2   , BLEED    ,
     3        AIB      , TWTTE    , GAMMA    , TH1D     ,
     4        BLMN     , BLMON    , BLMI     , BLMOI    ,
     5        DSD      , DDSD     , BK       , EME1     , SHFAC    ,
     6        SIG1     , SIGMA1   , SIGS1    , FSIG1    , VWVE1    ,
     7        CFWH1    , C        , STCOEF
      DO 100 I = 1,K
      PRAT=1.
      TTOT=1.+(GAMMA-1.)*EM(I)*EM(I)/2.
      TTOTE=1.+(GAMMA-1.)*EME*EME/2.
      TOTE=TTOTE*TTRAT(I)/TTOT
      RHRAT=PRAT/TOTE
      GO TO (10,20,30),INDIC
C
C  TWO-DIMENSIONAL FLOW
C
   10 BLMR(I)=RHRAT*URAT(I)
      BLMOR(I)=BLMR(I)*URAT(I)
      IF(URAT(I).LE.0.) BLMOR(I)=-BLMOR(I)
```

```
      YY(I)=Y(I)
      GO TO 100
C
C  AXIALLY SYMMETRIC FLOW ON COWL
C
   20 BLMR(I)=RHRAT*URAT(I)
      BLMOR(I)=BLMR(I)*URAT(I)
      IF(URAT(I).LE.0.) BLMOR(I)=-BLMOR(I)
      YY(I)=Y(I)
      YR(I)=YY(I)*DELR
      BLMIR(I)=BLMR(I)*(1.-YR(I))
      BMOIR(I)=BLMOR(I)*(1.-YR(I))
      GO TO 100
C
C  AXIALLY SYMMETRIC FLOW ON CENTERBODY
C
   30 GO TO 100
  100 CONTINUE
      GO TO (110,120,130),INDIC
C
C  TWO-DIMENSIONAL FLOW
C
  110 DO 115 I=1,K
      CALL INTEG(I,YY,BLMR,AREA1)
      CALL INTEG(I,YY,BLMOR,AREA2)
      WR(I)=AREA1
      PHIR(I)=AREA2
  115 CONTINUE
      BLMN=AREA1
      BLMON=AREA2
      DSD=1.-BLMN
      DDSD=BLMN-BLMON
      SHFAC=DSD/DDSD
      RETURN
C
C  AXIALLY SYMMETRIC FLOW ON COWL
C
  120 DO 125 I=1,K
      CALL INTEG(I,YR,BLMIR,AREA5)
      CALL INTEG(I,YR,BMOIR,AREA6)
      WR(I)=AREA5*2.
      PHIR(I)=AREA6*2.
  125 CONTINUE
      BLMI=AREA5
      BLMOI=AREA6
      BLMN=2.*BLMI/(2.*DELR -DELR*DELR)
      BLMON=2.*BLMOI/(2.*DELR -DELR*DELR)
      DSD=(1.-SQRT(1.-2.*DEL R+DELR*DELR  +2.*BLMI))/DELR
      DDSD=(1.-SQRT(1.-2.*BLMI+2.*BLMOI))/DELR
      SHFAC=DSD/DDSD
  130 RETURN
      END


      SUBROUTINE PRFL(UTUEST,PX,EME,PKP1,IOPT,YY)
C  SUBROUTINE TO CALCULATE DISTRIBUTIONS OF PROPERTIES
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```
C   FOR BOUNDARY LAYER WITH WALL-WAKE VELOCITY PROFILE
      DIMENSION TTRAT(200),PTRAT(200),PTRNS(200),URAT(200),EM(200)
      DIMENSION YY(200),WR(200), PHIR(200)
      COMMON  TTRAT   , PTRAT    , PTRNS    , URAT     ,
     1        EM      , WR       , PHIR     ,
     2        SHORT   , BLEED1   , BLEED2   , BLEED    ,
     3        AIB     , TWTTE    , GAMMA    , TH1D     ,
     4        BLMN    , BLMON    , BLMI     , BLMOI    ,
     5        DSD     , DDSD     , BK       , EME1     , SHFAC    ,
     6        SIG1    , SIGMA1   , SIGS1    , FSIG1    , VWVE1    ,
     7        CFWW1   , C        , STCOEF
      COMMON /UWU/AIDD
      PI=3.1415927
      EXP2=GAMMA/(GAMMA-1.)
      EXP3=1./(GAMMA-1.)
      GAM1=(GAMMA-1.)/2.
      GAM2=GAMMA+1.
      GAM3=GAMMA-1.
      G1=EME*EME
      SIGMA=GAM1*G1/(1.+GAM1*G1)
      SIGG1=SQRT(SIGMA)
      SIGG2=1./SIGG1
      SIGG3=ASIN(SIGG1)
      URAT(1)=0.
      TTRAT(1)=TWTTE
      EM(1)=0.
      YY(1)=0.
      PTRAT(1)=(1./(1.+GAM1*EME1*EME1))**EXP2*PKP1
      PTRNS(1)=PTRAT(1)
      DO 100 I=2,101
      AI=I-1
      YY(I)=AI/100.
      YAA=SQRT(1.-YY(I)**AIDD)
      ALG=ALOG(YY(I))+2.*(YAA-ALOG(1.+YAA))/AIDD
      URAT(I)=SIGG2*SIN(SIGG3-SIGG3*PX*(1.+COS(PI*YY(I)))+
     1(1./BK)*UTUEST*SIGG3*ALG)
      TTRAT(I)=TWTTE+(1.-TWTTE)*ABS(URAT(I))
      U2=URAT(I)*URAT(I)
      EM(I)=SQRT(U2/((1./G1+GAM1)*TTRAT(I)-GAM1*U2))
      IF(URAT(I).LE.0.) EM(I)=-1.*EM(I)
      IF(IOPT-1) 100,100,20
C
C   CALCULATION OF TOTAL PRESSURE DOWNSTREAM OF NORMAL SHOCK
C
   20 PTRAT(I)=((1.+GAM1*EM(I)*EM(I))/(1.+GAM1*EME1*EME1))**EXP2*PKP1
      IF(EM(I)-1.) 40,40,50
   40 PTRNS(I)=PTRAT(I)
      GO TO 100
   50 PTRNS(I)=(GAM2*EM(I)*EM(I)/2./(1.+GAM1*EME1*EME1))**EXP2*(GAM2/
     1(2.*GAMMA*EM(I)*EM(I)-GAM3))**EXP3*PKP1
  100 CONTINUE
      RETURN
      END


      SUBROUTINE INTRP(X,Y,XX,YY,N)
```

```
C  LINEAR INTERPOLATION
      DIMENSION X(200),Y(200)
      DC 30 I=1,N
      IF(XX-X(I)) 10,20,30
   10 K=I-1
      YY=Y(K)+(Y(I   )-Y(K))*(XX-X(K))/(X(I   )-X(K))
      RETURN
   20 YY=Y(I)
      RETURN
   30 CONTINUE
      RETURN
      END


      SUBROUTINE CUBIC(C,Z)
C  SUBROUTINE TO DETERMINE ROOTS OF A CUBIC EQUATION
C     NASA, AMES RESEARCH CENTER, MOFFETT FIELD, CALIF.
      DIMENSION C(4),VLST( 7)
      ACOS(X)=ATAN(SQRT(1.0-X**2)/X)
      P=-C(3)**2/3.0 + C(2)
      Q=2.0*C(3)**3/27.0 - C(2)*C(3)/3.0 + C(1)
      RSQ =     -C.5*Q/ SQRT(-P**3/27.0)
       IF (ABS(RSQ) .GT. 1.0) RSQ=SIGN(1.0,RSQ)
      PHI=ACOS( RSQ)
      TEM=2.0*SQRT(-P/3.0)
      X1= TEM*COS(PHI/3.0)
      X2= TEM*COS(PHI/3.0 + 2.09439510)
      X3= TEM*COS(PHI/3.0 + 4.18879020)
      IF (X2-X3) 150,150,160
  150 Y1=AMAX1(X1,X2)
      Y1=AMIN1(Y1,X3)
      GO TO 175
  160 Y1=AMIN1(X1,X2)
      Y1=AMAX1(Y1,X3)
  175 Y1=Y1-C(3)/3.0
    8 Z=Y1
      RETURN
      END


      SUBROUTINE INTEG(K,Y,Z,AREA)
C  INTEGRATION USING SIMPSON≠S RULE
      DIMENSION Y(200), Z(200)
      IF(K.GE.5) GO TO 1
      IF(K.EQ.1) GO TO 21
      IF(K.EQ.2) GO TO 22
      IF(K.EQ.3) GO TO 23
      IF(K.EQ.4) GO TO 24
    1 AK=K
      BK=AK/2.
      KK=BK
      CK=KK
      IF(BK-CK) 4,2,4
C
C     K IS EVEN
```

```
C
    2 N=K-1
      GO TO 5
C
C     K IS ODD
C
    4 N=K
    5 ODD=0.
      EVEN = 0.
      J=N-3
      DO 10 I=2,J ,2
      EVEN = EVEN + Z(I)
      ODD = ODD + Z(I+1)
   10 CONTINUE
      AREA = (Y(2)-Y(1))/3.*(Z(1)+Z(N)+4.*(EVEN+Z(N-1))+2.*ODD)
      IF(BK-CK) 14,12,14
C
C     K IS EVEN
C
   12 AREA = AREA + (Y(K)-Y(K-1))*(Z(K)+Z(K-1))/2.
      RETURN
C
C     K IS ODD
C
   14 RETURN
   21 AREA=0.
      RETURN
   22 AREA=(Y(2)-Y(1))*(Z(2)+Z(1))/2.
      RETURN
   23 AREA=(Y(2)-Y(1))*(Z(3) +4.*Z(2)+Z(1))/3.
      RETURN
   24 AREA=(Y(2)-Y(1))*((Z(4)+Z(3))/2.+(Z(3)+4.*Z(2)+Z(1))/3.)
      RETURN
      END


      SUBROUTINE PRIN(ILINE,IND)
C   SUBROUTINE TO COUNT LINES OF OUTPUT ON PAGE, CHANGE PAGE WHEN
C   NECESSARY AND WRITE TITLE ON EACH PAGE
      DIMENSION TITLE(12),TITL1(12)
      GO TO (10,20,30),IND
C
C     FIRST PAGE TITLE
C
   10 READ(5,1000)(TITLE(J),J=1,12)
      READ(5,1000)(TITL1(J),J=1,12)
      ILINE=2
      WRITE(6,1010)(TITLE(J),J=1,12)
      WRITE(6,1012)(TITL1(J),J=1,12)
      IPAGE=1
      WRITE(6,1011) IPAGE
      RETURN
C
C     TEST FOR END OF PAGE
C
   20 IF(ILINE-48)21,22,22
```

```
   21 RETURN
C
C     CHANGES PAGE
C
   22 ILINE=2
      IPAGE=IPAGE+1
C
C     PAGE TITLE
C
      WRITE(6,1010)(TITLE(J),J=1,12)
      WRITE(6,1012)(TITL1(J),J=1,12)
      WRITE(6,1011) IPAGE
      RETURN
C
C     PROGRAMMED PAGE CHANGE
C
   30 IPAGE=IPAGE+1
      WRITE(6,1010)(TITLE(J),J=1,12)
      WRITE(6,1012)(TITL1(J),J=1,12)
      WRITE(6,1011) IPAGE
      ILINE=2
      RETURN
 1000 FORMAT(12A6)
 1010 FORMAT(1H1,30X,12A6)
 1011 FORMAT(1H ,100X,5HPAGE ,I3)
 1012 FORMAT(1H ,30X,12A6)
      END
```

TABLE 3-B: INPUT TO PROGRAM ANAL

```
    10 DEGREE CONE NC ALPHA=1.
    CHEN CHIH SUN
2.82      0.0446    71200.     1.        1.        2.          0.0
0.0       0.0        0.0       0.4       5.1       1.0
22.7
0.15      2.0        0.0
50.
 22.751213  2.902980  2.684648  1.229258
 22.311516  3.182413  2.673301  1.250928
 22.091668  3.306284  2.668448  1.260316
 21.871819  3.423220  2.663971  1.269043
 21.651971  3.534813  2.659794  1.277243
```

21.432122	3.642199	2.655863	1.285010
21.212274	3.746224	2.652139	1.292413
20.992425	3.847539	2.648592	1.299505
20.772577	3.946660	2.645198	1.306328
20.552728	4.044005	2.641939	1.312916
20.113031	4.234706	2.635768	1.325487
19.893183	4.328607	2.632832	1.331511
19.673334	4.421846	2.629984	1.337382
19.453486	4.514618	2.627216	1.343113
19.233637	4.607097	2.624522	1.348717
18.793940	4.791800	2.619333	1.359576
18.574092	4.884306	2.616830	1.364847
18.354243	4.977087	2.614383	1.370022
18.134395	5.070264	2.611988	1.375105
17.914546	5.163953	2.609643	1.380101
17.474849	5.353313	2.605093	1.389849
17.255001	5.449201	2.602885	1.394607
17.035152	5.546036	2.600718	1.399290
16.815304	5.643924	2.598592	1.403901
16.595455	5.742972	2.596506	1.408441
16.155758	5.944979	2.592451	1.417312
15.935910	6.048160	2.590480	1.421644
15.716061	6.152942	2.588546	1.425907
15.496213	6.259446	2.586650	1.430100
15.276364	6.367793	2.584792	1.434222
14.836667	6.590529	2.581190	1.442248
14.616819	6.705188	2.579447	1.446148
14.396970	6.822235	2.577744	1.449969
14.177122	6.941821	2.576082	1.453707
13.957273	7.064109	2.574463	1.457359
13.517576	7.317486	2.571360	1.464386
13.297728	7.448952	2.569879	1.467751
13.077879	7.583874	2.568450	1.471007
12.858031	7.722475	2.567074	1.474147
12.638182	7.864991	2.565756	1.477164
12.198485	8.162819	2.563306	1.482786
11.978637	8.318704	2.562184	1.485369
11.758788	8.479660	2.561137	1.487782
11.538940	8.646040	2.560173	1.490010
11.319091	8.818227	2.559297	1.492035
10.879394	9.181742	2.557845	1.495400
10.659546	9.374038	2.557288	1.496691
10.439697	9.574088	2.556860	1.497685
10.219849	9.782512	2.556574	1.498350
10.000000	10.000000	2.556446	1.498649

TABLE 4: INPUT TO METHOD OF CHARACTERISTICS PROGRAM

```
   MACH 2.82  10 DEGREE CONE
2.05
    0    47     1     0     0     0
2.82        1.4         23.9999    22.78       2.5         1.          1.0
0.000001    0.001       0.00001    .01
3.5         0.001       0.001      0.0         5.0
2.          2.
0.0         5.0
0.0
10.         10.
1.0         5.0
0.99
0.0         0.0
0.0         1.          2.82
    2     3     2     1     2    22
  1.8350000   .9900000 0.00000   2.82        1.0
  1.8350000   .9800000 0.000000  2.82        1.00
  1.8350000   .9700000 0.0000    2.82        1.00
  1.8350000   .9600000 0.00000   2.82        1.00
  1.8350000   .9500000 0.000000  2.82        1.00
  1.8350000   .9400000 0.00000   2.82        1.00
  1.8350000   .9300000 0.000000002.82        1.
  1.8350000   .9200000 0.00000   2.82        1.00
  1.8350000   .9100000 0.00000   2.82        1.00
  1.8350000   .9000000 0.00000   2.82        1.00
  1.8350000   .8900000 0.00000   2.82        1.00
  1.8350000   .8800000 0.00000   2.82        1.00
  1.8350000   .8700000 0.00000   2.82        1.00
  1.8350000   .8600000 0.000000  2.82        1.00
  1.8350000   .8500000 0.0000    1.82        1.00
  1.8350000   .8400000 0.00000   2.82        1.00
  1.8350000   .8300000 0.00000   2.82        1.00
  1.8350000   .8200000 0.0000    2.82        1.00
  1.8350000   .8100000 0.000000  2.82        1.00
  1.8350000   .8000000 0.0000000  2.8200000  1.0000000
  1.8350000   .7900000 0.0000000  2.8200000  1.0000000
  1.8350000   .7800000 0.0000000  2.8200000  1.0000000
    1     3     3     1     1    27
   1.835000    .323560 10.000000   2.556446    .999057
   1.835000    .345365  9.374038   2.557288    .999057
   1.835000    .367305  8.818227   2.559297    .999057
   1.835000    .389326  8.318704   2.562184    .999057
   1.835000    .411455  7.864991   2.565756    .999057
   1.835000    .433699  7.448952   2.569879    .999057
   1.835000    .456064  7.064109   2.574463    .999057
   1.835000    .478557  6.705188   2.579447    .999057
   1.835000    .501186  6.367793   2.584792    .999057
   1.835000    .523957  6.048160   2.590480    .999057
   1.835000    .546879  5.742972   2.596506    .999057
```

1.835000	.569958	5.449201	2.602885	.999057
1.835000	.593203	5.163953	2.609643	.999057
1.835000	.616622	4.884306	2.616830	.999057
1.835000	.628399	4.745611	2.620607	.999057
1.835000	.640223	4.607097	2.624522	.999057
1.835000	.652094	4.468279	2.628590	.999057
1.835000	.664014	4.328607	2.632832	.999057
1.835000	.675983	4.187440	2.637271	.999057
1.835000	.688004	4.044005	2.641939	.999057
1.835000	.700076	3.897346	2.646877	.999057
1.835000	.712202	3.746224	2.652139	.999057
1.835000	.724382	3.588973	2.657800	.999057
1.835000	.736617	3.423220	2.663971	.999057
1.835000	.748909	3.245340	2.670822	.999057
1.835000	.761259	3.049241	2.678641	.999057
1.835000	.773668	2.823021	2.687994	.999057

TABLE 5-A: PROGRAM BLGRN

```
      PROGRAM BLGRN(INPUT,TAPE 5=INPUT.OUTPUT,TAPE6=OUTPUT)
C   INPUT FORMAT 10F7.0 EXCEPT CARD 1
C   CARD(S)
C   1 TITLE, COLUMNS 1-72, HOLLERITH
C   2    COL.1-7  AJ     AJ=0. FOR 2-D FLOW
C                        AJ=1. FOR AXISYMMETRIC FLOW
C            8-14 TO     TOTAL TEMPERATURE (R)
C           15-21 TW     WALL TEMPERATURE (R)
C           22-28 REYNOF FREE STREAM REYNOLDS NO. PER FT /100000.
C           29-35 SIGMA  PRANDTL NUMBER (=.72)
C           36-42 CF     COEFFICIENT OF SKIN FRICTION
C           43-49 DEL    BOUNDARY LAYER THICKNESS (IN.)
C   3   COL. 1-7  XO     VALUE OF X FOR STARTING POINT (MAY EQUAL TO ZERO)
C            8-14 DXMN   MINIMUN PERMISSIBLE STEP SIZE (IN.)
C           15-21 DXMX   MAXIMUM PERMISSIBLE STEP SIZE (IN.)
C           22-28 ANP    FREQUENCY OF PRINTOUT AS MULTIPLE OE STEP SIZE
C           29-35 ANXP   NUMBER OF POINTS AT WHICH EXTRA PRINT IS REQUIRED
C   4    COL.1-7  XEND   VALUE OF X FOR ENDUNG POINT
C            8-14 ASEA   PARAMETER IN (1.-(Y/DEL)**ASEA) (=1. IS RECOMMENDE
C   5    COL.1-7  ANME   NUMBER OF VALUES GIVEN IN MACH NUMBER ARRAY(BETWEE
C                        4. AND 200.)
C            8-14 ANSME  NUMBER OF SMOOTHING PASSES ON MACH NO. DATA   .
C   6    COL.1-70 AME    VALUES OF MACH NUMBER ARE INPUT, MORE THAN ONE CAR
C                        CAN BE USED IF NECESSARY
C   7    COL.1-70 X      CENTERLINE DISTANCE(IN.) AT WHICH MACH NUMBERS
C                        ARE INPUT
C   8    COL.1-7  ANR    NUMBER OF VALUES GIVEN IN RADIUS ARRAY (AT LEAST 4
C            8-14 ANSR   NUMBER OF SMOOTHING PASSES ON INPUT DATA
C   9    COL.1-70 R      VALUES OF R ARE INPUT.  MORE THAN ONE CARD CAN BE
C                        USED IF NECESSARY
C   10   COL.1-70 X      CENTERLINE DISTANCE (IN) AT WHICH R VALUE
C                        ARE INPUT
      COMMON/XCHGE/SIGN1,P,FF,TORR
      COMMON/HONE/H1,H2
      COMMON/ANS/THTA,DELSTA,GASCT,BMU,GAM21
      COMMON/ARRR/KR,NR,XIR(200),AIR(200),DIR(200),XCR(200)
      COMMON/BBDD/AJ,AAME(200),AAR(200)
      COMMON/CONST/R,S,G,PI,GW,TOW,B,E91,E92,H,AME,DME,PT3,REY3,TE,IRY
      COMMON/INTEG/CF,DEL,DCF,DDL,DX,DXMN,DXMX,X,XEND,MEND
      COMMON/REIN/TO,TW,SIGMA,GAMMA,REYNO,ASEA
      COMMON/ARRME/KME,NME,XIME(200),AIME(200),DIME(200),XCME(200)
  925 FORMAT(10F7.0)
  904 FORMAT(1X,13F10.6)
  903 FORMAT(//7X,1HX,7X,5HTHETA,5X,8HDISP.TH.,3H  H,9X,2HH2,8X,1HP,9X,1
     1HF,7X,9HR*TH/1000,3X,2HME,8X,5HDELTA,5X,2HCF,6X,7HDDEL/DX,4X,6HDCF
     2/DX//)
  902 FORMAT(//17H  INITIAL DELTA =,F9.6,7H INCHES,5X,13H INITIAL CF =,F
     19.6)
  901 FORMAT(*  TO =        *,F7.2/
```

```
     1        *  TW =          *,F7.2/
     2        *  SIGMA =        *,F6.3/
     3        *  GAMMA =        *,F6.3/
     4        *  PSIA =        *,F7.3/
     4        *  REYNO =       *,F9.2//
     5        *  XO =          *,F7.2/
     6        *  DXMIN =       *,F7.4/
     7        *  DXMAX =       *,F7.4/
     8        *  XEND =        *,F7.2/
     9        *  NPRINT =         *,I3)
   40 FORMAT(8A10)
   41 FORMAT( //,8A10//)
   49 FORMAT(1H1)
12344 FORMAT(16H PROGRAM RAN AT I2,1H.,I2,3H.   ,2A10///)

  200 FORMAT(1H115X,100HTEM235 - A COMPUTER PROGRAM TO PREDICT THE DEVEL
     1OPMENT OF A COMPRESSIBLE TURBULENT BOUNDARY LAYER     )
      DIMENSION TITLE(8)
      CALL CLOCK(IHR,MIN,ISEC)
      CALL DATE(A7,B7)
      WRITE(6,200)
      WRITE(6,12344)IHR,MIN,A7,B7
    5 CONTINUE
C     READ HEADING
      READ(5,40)(TITLE(I),I=1,8)
      IF(EOF,5)6,7
    6 CALL EXIT
    7 CONTINUE
      READ(5,925) AJ,TO,TW,REYNOF,SIGMA,CF,DEL
      IRY=0
      TOLRER=.00008
      TORR=.0000005
      GAMMA=1.4
      REYNO=REYNOF/12.
      REYNO=REYNO*100000.
      READ(5,925)XO,DXMN,DXMX,ANP,ANXP
      NPRINT=ANP+0.1
C NXP IS NUMBER OF POINT AT WHICH EXTRA OUTPUY IS REQUIRED.
      NXP=ANXP+0.1
      READ(5,925) XEND,ASEA
      NME = 0
      WRITE(6,41)(TITLE(I),I=1,8)
C READ AND PRINT MACH NUMBER DISTRIBUTION
      KME=NME+1
      READ(5,925) ANME,ANSME
      NME=KME+IFIX(ANME-0.9)
      IF(ANSME)230,225,225
  225 NSME=ANSME+0.1
      READ(5,925)(AIME(I),I=KME,NME)
      READ (5,925)(XIME(I),I=KME,NME)
      DO 3388 I=KME,NME
 3388 AAME(I)=AIME(I)
C CHECK THAT X IS INCREASING
      KP=KME+1
      DO 228 I=KP,NME
      IF (XIME(I)-XIME(I-1)) 226,226,228
  226 WRITE (6,934) XIME(I-1),XIME(I)
```

```
      IE=-1
  228 CONTINUE
      CALL SMOOTH(NSME,KME,NME,XIME,AIME,DIME)
      NR=0
C READ AND PRINT CONTOUR
  400 KR=NR+1
      READ (5,925) ANR,ANSR
      NR=KR+IFIX(ANR-0.9)
      IF(ANSR) 410,420,420
  420 NSR=ANSR+0.1
      READ(5,925)(AIR(I),I=KR,NR)
      DO 3399 I=KR,NR
 3399 AAR(I)=AIR(I)
      READ (5,925)(XIR(I),I=KR,NR)
C     K THAT X IS INCREASING
      KP=KR+1
      DO 422 I=KP,NR
      IF (XIR(I)-XIR(I-1)) 421,421,422
  421 WRITE (6,934) XIR(I-1),XIR(I)
      IE=-1
  422 CONTINUE
C SMOOTH RADII AND PRINT SMOOTHED VALUES
      CALL  SMOOTH(NSR,KR,NR,XIR,AIR,DIR)
      IF(KR.NE.1) GO TO 425
      XCR(1)=XIR(1)
      KR=KR+1
  425 DO 430 I=KR,NR
      XCR(I)=XCR(I-1)+SQRT((XIR(I)-XIR(I-1))**2+(AIR(I)-AIR(I-1))**2)
  430 CONTINUE
C OBTAIN ME AS A FUNCTION OF ARC LENGTH
      DO 440 I=KME,NME
      CALL PI(KR,NR,XIR,XCR,XIME(I),XCME(I))
  440 CONTINUE
      CALL PI(KR,NR,XIR,XCR,XO,X)
C     CONSTANT
C      SQRT(2.)=1.414214
      R=53.35
      G=32.174
      S=0.5*GAMMA-0.5
      PI=3.141592
      GW=TW/TO
      TOW=TO/TW
      B=TOW-1.
      E91 =1./0.915
      E92=E91-1.
      CV=4290.
      TO15=2.27*TO**1.5
      BMU=TO15*1.E-8/(TO+198.6)
      GASQ3= GAMMA/(2.*S*CV*TO)
      GASQT=SQRT(GASQ3)
      GAM21=(GAMMA-2.)/(GAMMA-1.)
      DX=DXMN
      MEND=0
      NPC=1
      CALL DERIV
      PT3=REYNO*12./(REY3*AME)
      PTT=PT3/144.
```

```
      RRRT=REYNO*THTA/1000.
      WRITE(6,901) TO,TW,SIGMA,GAMMA,PTT,REYNO,XO,DXMN,DXMX,XEND,NPRINT
      WRITE(6,902)DEL,CF
      WRITE(6,935) ANME,ANSME
  935 FORMAT (*ONME=*,F7.2,* NSME = *,F7.2)
      WRITE(6,936)
  936 FORMAT (* ME VALUES*)
      WRITE(6,937)(AAME(I),I=KME,NME)
  937 FORMAT (1X,10F10.3)
      WRITE(6,938)
  938 FORMAT(* CORRESPONDING X VALUES*)
      WRITE(6,937)(XIME(I),I=KME,NME)
  934 FORMAT(*OTWO SUCCESSIVE X FOUND WHICH ARE NOT INCREASING *,
     1   2F12.4)
C SMOOTH MACH NUMBER AND PRINY SMOOTH VALUEW
  230 WRITE (6,939)
  939 FORMAT (* SMOOTHED MACH NUMBERS*/
     1          *      X            ME          DME*)
      WRITE (6,940)((XIME(I),AIME(I),DIME(I)),I=KME,NME)
  940 FORMAT (1X,3F10.3)
C
      WRITE(6,955) ANR,ANSR
  955 FORMAT (*ONR =*,F7.2,* NSR = *,F7.2)
      WRITE(6,956)
  956 FORMAT(* R VALUES*)
      WRITE (6,937) (AAR(I),I=KR,NR)
      WRITE(6,938)
      WRITE (6,937)(XIR(I),I=KR,NR)
  410 WRITE (6,959)
  959  FORMAT (* SMOOTHED RADII*/
     1          *      X           R            DR*)
      WRITE (6,940)((XIR(I),AIR(I),DIR(I)),I=KR,NR)
      WRITE(6,903)
C
      WRITE(6,904)X,THTA,DELSTA,H,H2,P,FF,RRRT,AME,DEL,CF,DDL,DCF
      IRY=2
   42 CONTINUE
   10 CALL MERSON
   11 IF (MEND.EQ.1) GO TO 16
      IF (NPC.EQ.NPRINT) GO TO 16
      NPC=NPC+1
      GO TO 10
C RESET COUNTER
   16 NPC=1
C
      RRRT=REYNO*THTA/1000.
      WRITE(6,904)X,THTA,DELSTA,H,H2,P,FF,RRRT,AME,DEL,CF,DDL,DCF
      IF((CF.GT.0.).AND.(CF.LT.TOLRER)) GO TO 43
      IF((CF.LT.0.).AND.(DX.LT..000065)) GO TO 43
      IF (MEND.EQ.0) GO TO 10
      GO TO 88
   43 CF=-CF
      DXABS=2.*ABS(CF)/ABS(DCF)
      X=X+DXABS
      DEL=DEL+DDL*DXABS
      TOLRER=ABS(CF)
      CALL DERIV
```

```
      RRRT=REYNO*THTA/1000.
      WRITE(6,904)X,THTA,DELSTA,H,H2,P,FF,RRRT,AME,DEL,CF,DDL,DCF
      GO TO 42
   88 CONTINUE
      WRITE(6,49)
      GO TO 5
      END


      SUBROUTINE MERSON
C MERSON INTEGPATION
C V IS THE VARIABLE ARRAY (BOTH INPUT AND OUTPUT), D IS THE DERIVATIVE
C ARRAY.
C DX IS CURRENT STEP LENGTH, DXMN AND DXMX MINIMUM AND MAXIMUM VALUES OF
C DX. X IS INDEPENDENT VARIABLE, AND XEND ITS UPPER LIMIT.
C
      COMMON/CONST/R,S,G,PI,GW,TOW,B,E91,E92,H,AME,DME,PT3,REY3,TE,IRY
      COMMON /INTEG/V(2),D(2),DX,DXMN,DXMX,X,XEND,MEND
      DIMENSION U(2),VE(2),DA(2),DC(2),DD(2),DE(2)
C BU,BL ARE UPPER AND LOWER BOUNDS ON TRUNCATION ERROR.
      DATA BU,BL/0.0005,0.00005/
C
C MARK IS SET NON-ZERO TO PREVENT INCREASING THE STEP LENGTH IF EITHER
C XEND IS REACHED, OR THE STEP LENGTH HAS JUST BEEN DECREASED.
      MARK=0
      IF (X+DX-XEND) 5,7,7
C PREVENT OVERSHOOTING X END.
    7 MARK=1
      DX=XEND-X
      MEND=1
C SAVE POINT A.
    5 DO 10 I=1,2
   10 U(I)=V(I)
C
   15 DX2=DX/2.
      DX3=DX/3.
      DX6=DX/6.
      DX8=DX/8.
C FIND POINT B.
      CALL DERIV
      DO 20 I=1,2
      DA(I)=D(I)
   20 V(I)=U(I)+D(I)*DX3
C FIND POINT C.
      X=X+DX3
      CALL DERIV
      V(1)=(D(1)+DA(1))*DX6+U(1)
      V(2)=(D(2)+DA(2))*DX6+U(2)
C FIND POINT D.
      CALL DERIV
      X=X+DX6
      DO 40 I=1,2
      DC(I)=D(I)
   40 V(I)=U(I)+DX8*(DA(I)+3.*D(I))
C FIND POINT E.
      CALL DERIV
```

```
      X=X+DX2
      DO 50 I=1,2
      DD(I)=D(I)
      V(I)=U(I)+DX2*(DA(I)-3.*DC(I)+4.*D(I))
   50 VE(I)=V(I)
C FIND POINT F.
      CALL DERIV
      MINC=0
      MDEC=0
      DO 60 I=1,2
      V(I)=U(I)+DX6*(DA(I)+4.*DD(I)+D(I))
      IF (VE(I)) 51,60,51
C TRUNC IS A MEASURE OF THE TRUNCATION ERROR.
   51 TRUNC=ABS(1.-V(I)/VE(I))
      IF (TRUNC-BU) 54.54,52
   52 MDEC=MDEC+1
   54 IF (TRUNC-BL) 56,56,60
   56 MINC=MINC+1
   60 CONTINUE
      IF (MDEC.GT.0) GO TO 70
      IF (MINC.EQ.2.AND.MARK.EQ.0) GO TO 80
   65 RETURN
C IF EITHER TRUNCATION ERROR IS ABOVE THE UPPER BOUND, DECREASE STEP LEN
   70 MARK=1
      IF (DX-DXMN) 65,65,71
   71 X=X-DX
C HALVE STEP LENGTH.
      DX=AMAX1(DX2,DXMN)
C IN CASE MEND HAS BEEN SET, RESET IT.
      MEND=0
      GO TO 15
C IF BOTH TRUNCATION ERRORS ARE BELOW THE LOWER BOUND, INCREASE STEP LEN
   80 IF (DX-DXMX) 81,65,65
   81 X=X-DX
C DOUBLE STEP LENGTH.
      DX=AMIN1(DX*2.,DXMX)
      GO TO 15
      END



      SUBROUTINE PI(K,N,X,V,X1,V1)
C INTERPOLATES BY POLYNOMIAL FITTING.
C GIVEN V(K),V(K+1),...,V(N) AT X(K),X(K+1),...,X(N), FITS A SECOND
C ORDER POLYNOMIAL TO THE THREE POINTS NEAREST X1 AND RETURNS A VALUE V1
C AT X1. FAILS IF ANY TWO OF THE X ARE EQUAL. IF N-K EQUALS ZERO OR ONE
C THE SUBROUTINE ALSO RETURNS A RESULT.
C
      DIMENSION X(1),V(1)
C
C CHECK IF ONLY ONE OR TWO POINTS IN ARRAY.
C
      IF (N-K-1) 2,4,6
C RETURN CONSTANT VALUE IF N=K
    2 V1=V(K)
      GO TO 100
C INTERPOLATE LINEARLY IF N=K+1
```

```
    4 V1=V(K)+(V(N)-V(K))/(X(N)-X(K))*(X1-X(K))
      GO TO 100
C
C LAGRANGIAN INTERPOLATION.
C
C FIND NEAREST THREE POINTS.
    6 DO 10 J=K,N
      IF (X1-X(J)) 15,10,10
   15 I=J
      GO TO 17
   10 CONTINUE
      I=N
   17 IF (I.GT.K+1) GO TO 20
C USE FIRST THREE POINTS.
      I=K-1
      GO TO 25
   20 IF (I.NE.N) GO TO 22
C USE LAST THREE POINTS.
      I=N-3
      GO TO 25
C USE TWO POINTS WHICH STRADDLE X1 AND SELECT THE THIRD.
   22 IF (X(I-2)+X(I+1)-2.*X1) 23,23,24
   23 I=I-2
      GO TO 25
   24 I=I-3
C INTERPOLATE USING LAGRANGES FORMULA.
   25 S=0.
      DO 40 J=1,3
      P=1.
      DO 30 L=1,3
      IF (J.EQ.L) GO TO 30
      P=P*(X1-X(I+L))/(X(I+J)-X(I+L))
   30 CONTINUE
   40 S=S+V(I+J)*P
      V1=S
  100 RETURN
      END


      SUBROUTINE SMOOTH(K,L,M,X,Y,DY)
C INPUT   Y(I) AS A FUNCTION OF X(I) FOR I=L,L+1,...,M.
C         SMOOTH IN K PASSES.
C OUTPUT  Y(I) SMOOTHED AND THE DERIVATIVES DY(I).
C ROUTINE FAILS IF ANY TWO X EQUAL
      DIMENSION X(1),Y(1),DY(1)
C N IS THE NUMBER OF POINTS TO BE SMOOTHED.
      N=M-L+1
C DO NOT SMOOTH IF LESS THAN FOUR POINTS.
      IF (K.EQ.0.OR.N.LT.4) GO TO 50
C
C SMOOTH
C
      M3=M-3
      DO 40 J=1,K
C SMOOTH SUCCESSIVE SETS OF FOUR POINTS.
      DO 40 I=L,M3
```

```
      A=(Y(I+2)-Y(I))/(X(I+2)-X(I))
      C=(Y(I+3)-Y(I+1))/(X(I+3)-X(I+1))
      B=Y(I)-A*X(I)
      D=Y(I+1)-C*X(I+1)
C DO NOT SMOOTH IF THE FOUR POINTS ARE COLINEAR.
      IF (A-C) 10,12,10
   12 IF (B-D) 14,40,14
C XINT IS INTERSECTION OF LINES JOINING ALTERNATE POINTS
   10 XINT=(B-D)/(C-A)
      IF (XINT.GE.X(I+1).AND.XINT.LE.X(I+2)) GO TO 40
   14 Y(I+1)=0.5*(Y(I+1)+A*X(I+1)+B)
      Y(I+2)=0.5*(Y(I+2)+C*X(I+2)+D)
   40 CONTINUE
C
C CALCULATE DERIVATIVES
C
   50 IF (N.EQ.1) GO TO 70
      IF (N.EQ.2) GO TO 80
C AT FIRST POINT.
      D1=X(L+1)-X(L)
      D2=X(L+2)-X(L)
      S1=(Y(L+1)-Y(L))/D1
      S2=(Y(L+2)-Y(L))/D2
      DY(L)=(D2*S1-D1*S2)/(D2-D1)
C AT INTERMEDIATE POINTS.
      L1=L+1
      M1=M-1
      DO 60 I=L1,M1
      D1=X(I)-X(I-1)
      D2=X(I+1)-X(I)
      S1=(Y(I)-Y(I-1))/D1
      S2=(Y(I+1)-Y(I))/D2
   60 DY(I)=(D1*S2+D2*S1)/(D1+D2)
C AT LAST POINT.
      D1=X(M)-X(M-1)
      D2=X(M)-X(M-2)
      S1=(Y(M)-Y(M-1))/D1
      S2=(Y(M)-Y(M-2))/D2
      DY(M)=(D2*S1-D1*S2)/(D2-D1)
   66 RETURN
C
C ONLY ONE POINT GIVEN.
   70 DY(L)=0.
      GO TO 66
C ONLY TWO POINTS GIVEN.
   80 DY(L)=(Y(M)-Y(L))/(X(M)-X(L))
      DY(M)=DY(L)
      GO TO 66
      END


      SUBROUTINE DERIV
      COMMON/XCHGE/SIGN1,P,FF,TORR
      COMMON/HONE/H1,H2
      COMMON/ARRR/KR,NR,XIR(200),AIR(200),DIR(200),XCR(200)
      COMMON/BBDD/AJ,AAME(200),AAR(200)
```

```
      COMMON/ARRME/KME,NME,XIME(200),AIME(200),DIME(200),XCME(200)
      COMMON/ANS/THTA,DELSTA,GASQT,BMU,GAM21
      COMMON/REIN/TO,TW,SIGMA,GAMMA,REYNO,ASEA
      COMMON/CONST/R,S,G,PI,GW,TOW,B,E91,E92,H,AME,DME,PT3,REY3,TE,IRY
      COMMON/INTEG/CF,DEL,DCF,DDL,DX,DXMN,DXMX,X,XEND,MEND
      CALL PI(KME,NME,XCME,AIME,X,AME)
      CALL PI(KME,NME,XCME,DIME,X,DME)
      CALL PI(KR,NR,XCR,AIR,X,RR)
      CALL PI(KR,NR,XCR,DIR,X,DR)
      SIGN1=-1.
      IF(CF.GT.0.) SIGN1=1.
      SIGN=1.
      C51=5.1-0.614/(0.4*ASEA)
      C52=5.1
      G1K=0.
      G2K=0.
      HG1K=0.
      HG2K=0.
      G1=0.
      G2=0.
      HG1=0.
      HG2=0.
      DG1CF=0.
      DG2CF=0.
      DG1DL=0.
      DG2DL=0.
      DG1ME=0.
      DG2ME=C.
      HDG1CF=0.
      HDG2CF=0.
      HDG1DL=0.
      HDG2DL=0.
      HDG1ME=0.
      HDG2ME=0.
      AME2=AME*AME
      S1=1.+S*AME2
      C11=GW*S1
      C22=S1-S1*GW
      C33=-S*AME2
      TE=TC/S1
      TOTT=(TC/TE)**GAM21
      TE198=(TE+198.6)/(TO+198.6)
      REY3=GASQT*TOTT*TE198/BMU
      IF(IRY .LT.1) GO TO 40
      REYNO=PT3*AME*REY3/12.
   40 CONTINUE
      ASQ=S*AME2*TOW/S1
      A=SQRT(ASQ)
      ASB=2.*ASQ-B
      XYZ1=2.*S*AME
      STWE=SQRT(0.5*TW/TE)
      B24=B*B+4.*ASQ
      SQBA=SQRT(B24)
      SARC=ASIN(ASB/SQBA)
      USTT=A/SARC
      USTA=STWE*USTT
      CF3=ABS(CF)
```

```
      CF2=SQRT(CF3)
      IF(CF.LT.0.) SIGN=-1.
      SCF=SIGN*CF2
      R1=SCF*USTA
      Q1=0.5*SQBA/ASQ
      Q2=0.5*B/ASQ
      TETW=TE/TW
      TAT=REYNO*STWE*TETW**1.76
      TATD=TAT*CF2
      TATDC=TATD*DEL
      IF(CF3.LT.TORR) GO TO 83
      R2=2.5*ALOG(TATDC)+C51
      P=0.5-0.5*R1*R2
      GO TO 84
   83 CONTINUE
      P=0.5
   84 CONTINUE
      UU=SQRT(GAMMA*R*TE)*AME*12.*SQRT(G)
      SIG3=S*AME2*SIGMA**0.333333+1.
      TR=TO*SIG3/S1
      GAM1=(GAMMA-1.)*AME
C DIFFERENTIATE WITH RESPECT TO ME
      DTEME=-TO*2.*S*AME/(S1*S1)
      DAME=SQRT(TOW*S/S1)*(1.-S*AME2/S1)
      DASQME=2.*A*DAME
      DT17ME=1.76*(TETW)**0.76*DTEME/TW
      DBAME=-0.5*B*DASQME/(ASQ*ASQ)
      DSQBME=DASQME/(ASQ*SQBA)-0.5*SQBA*DASQME/(ASQ*ASQ)
      DA2BME=(2.*DASQME-(2.*ASQ-B)*2.*DASQME/B24)/SQBA
      TIN=1.-(ASB*ASB/B24)
      TINSQ=SQRT(TIN)
      DARCME=DA2BME/TINSQ
      DSQTME=-0.5*STWE*DTEME/TE
      DAARME=DAME/SARC-A*DARCME/(SARC*SARC)
      IF(CF3.LT.TORR) GO TO 85
      DR1ME=SCF*(DSQTME*USTT+STWE*DAARME)
      DR2ME=2.5*DT17ME/TETW**1.76+2.5*DSQTME/STWE
      DPME=-0.5*R2*DR1ME-0.5*R1*DR2ME
      DR1CF=0.5*R1/CF3
      DR2CF=1.25/CF3
      DPCF=-0.5*DR1CF*R2-0.5*DR2CF*R1
      DR2DL=2.5/DEL
      DPDL=-0.5*2.5*R1/DEL
      GO TO 86
   85 CONTINUE
      DPME=0.
      DPCF=0.
      DPDL=0.
   86 CONTINUE
      E605=EXP((10.-C52)/2.5)
      DEL10=DEL/10.
      Y1=E605/TATD
      IF(Y1.GT.DEL10) Y1=DEL10
      DY=(DEL-Y1)/50.
      M=1
      N=1
   77 DO 1 I=M,N
```

```
      Y=Y1+(51-I)*DY
      YD=Y/DEL
      PYD=PI*YD
      YDDC=YD**ASEA
      YDD1=1.-YDDC
      YDSQ=SQRT(YDD1)
      YDS1=YDSQ+1.
      ALGY=ALOG(YD)+2.*(YDSQ-ALOG(YDS1))/ASEA
      UUEST=1.+2.5*R1*ALGY    -P-P*COS(PYD)
      UUE=Q1*SIN(UUEST*SARC)+Q2
      UUE2=UUE*UUE
      Z=C11+C22*UUE+C33*UUE2
      Z1=1./Z
      Z2=Z1/Z
      B70=UUEST*SARC
      DUSTME=2.5*SCF*ALGY    *(DSQTME*USTT+STWE*DAARME)-DPME*(1.+COS(P
     1YD))
      DSINME=COS(B70)*(SARC*DUSTME+UUEST*DARCME)
      DUUEME=DSQBME*SIN(B70)+Q1*DSINME+DBAME
      DZM=(GAMMA-1.)*AME
      DZME=DZM*GW+DZM*(1.-GW)*UUE+DUUEME*C22-DZM*UUE2+2.*C33*UUE*DUU
     1EME
      DUESTU=Q1*COS(B70)*SARC
      DZUUE=C22+2.*C33*UUE
      DUSTCF=2.5*USTA*0.5*ALGY    /SCF-DPCF*(1.+COS(PYD))
      DUUECF=DUESTU*DUSTCF
      DZCF=DZUUE*DUUECF
      RPI=YDSQ/DEL
      DUSTDL=-2.5*USTA*SCF*RPI-DPDL*(1.+COS(PYD))-P*SIN(PYD)*PYD/DEL
      DUUEDL=DUESTU*DUSTDL
      DZDL=DZUUE*DUUEDL
      G1KP=UUE
      G2KP=UUE2
      G1P=UUE*Z1
      G2P=UUE2*Z1
      DG1CFP=Z1*DUUECF-Z2*UUE*DZCF
      DG2CFP=2.*UUE*DUUECF*Z1-UUE2*DZCF*Z2
      DG1DLP=Z1*DUUEDL-Z2*UUE*DZDL
      DG2DLP=2.*UUE*DUUEDL*Z1-UUE2*DZDL*Z2
      DG1MEP=Z1*DUUEME-Z2*UUE*DZME
      DG2MEP=2.*UUE*DUUEME*Z1-UUE2*DZME*Z2
      G1K=G1K+G1KP
      G2K=G2K+G2KP
      G1=G1+G1P
      G2=G2+G2P
      DG1CF=DG1CF+DG1CFP
      DG2CF=DG2CF+DG2CFP
      DG1DL=DG1DL+DG1DLP
      DG2DL=DG2DL+DG2DLP
      DG1ME=DG1ME+DG1MEP
      DG2ME=DG2ME+DG2MEP
    1 CONTINUE
      HG1K=HG1K+G1KP
      HG2K=HG2K+G2KP
      HG1=HG1+G1P
      HG2=HG2+G2P
      HDG1CF=HDG1CF+DG1CFP
```

```
      HDG2CF=HDG2CF+DG2CFP
      HDG1DL=HDG1DL+DG1DLP
      HDG2DL=HDG2DL+DG2DLP
      HDG1ME=HDG1ME+DG1MEP
      HDG2ME=HDG2ME+DG2MEP
      IF(M.NE.1) GO TO 11
      M=2
      N=51
      GO TO 77
   11 CONTINUE
      G1I=(G1-0.5*HG1)*DY+0.5*Y1*G1P
      G2I=(G2-0.5*HG2)*DY+0.5*Y1*G2P
      G1KI=(G1K-0.5*HG1K)*DY+0.5*Y1*G1KP
      G2KI=(G2K-0.5*HG2K)*DY+0.5*Y1*G2KP
      THTA=G1I-G2I
      DELSTA=DEL-G1I
      DG1CFI=(DG1CF-0.5*HDG1CF)*DY+0.5*Y1*DG1CFP
      DG2CFI=(DG2CF-0.5*HDG2CF)*DY+0.5*Y1*DG2CFP
      DG1DLI=(DG1DL-0.5*HDG1DL)*DY+0.5*Y1*DG1DLP
      DG2DLI=(DG2DL-0.5*HDG2DL)*DY+0.5*Y1*DG2DLP
      DG1MEI=(DG1ME-0.5*HDG1ME)*DY+0.5*Y1*DG1MEP
      DG2MEI=(DG2ME-0.5*HDG2ME)*DY+0.5*Y1*DG2MEP
      DTHCF=DG1CFI-DG2CFI
      DTHDL=DG1DLI-DG2DLI
      DTHME=DG1MEI-DG2MEI
      DDSCF=-DG1CFI
      DDSME=-DG1MEI
      DDSDL=-DG1DLI
      H=DELSTA/THTA
      A8=((H+1.-TR/TE)*TETW-1.)/1.12
      IF(A8.LT.0.) WRITE(6,700) A8,H
  700 FORMAT(5X,3HA8=,F10.6,12X,2HH=,F10.6)
      IF(A8.LT.0.) WRITE(6,701) G1I,G2I,DEL,DELSTA,CF,DX
  701 FORMAT(5X,4HG1I=,F10.6,5X,4HG2I=,F10.6,5X,4HDEL=,F10.6,5X,
     17HDELSTA=,F10.6,3X,3HCF=,F10.6,3X,3HDX=,F10.6)
      AA=A8**E91+2.
      A1=E91*A8**E92   /1.12
      DTRDX=DME*GAM1*TO*(SIGMA**.333333-TR/TO)/S1
      FRAC=(4.-2.*AA)*(4.-2.*AA)/(2.-8.*AA+2.*AA*AA)
      H1=(1.-AA*AA)/(4.-2.*AA)
      H2=DEL/THTA-H
      H2K=G1KI/(G1KI-G2KI)
      IF(CF.GT.0.) GO TO 50
C
C
C
C
C
      FF=(H2+4.2)*.0067
      GO TO 51
   50 CONTINUE
C
      FF=0.0306*(H2K-3.0)**-0.653
   51 CONTINUE
      DUDX1=12.*SQRT(G*GAMMA*R)
      TES2=TO*AME2*(GAMMA-1.)/(2.*SQRT(TE)*S1*S1)
      DUDX=DUDX1*(SQRT(TE)-TES2)*DME
```

```
      DUDXU=THTA*DUDX/UU
C
      DH2DX=(FF-H2*CF/2.)/THTA+H2*(H+1.)*DUDX/UU
      DTHDX=CF/2.-(H+2.-AME2)*DUDXU
      IF(AJ.NE.0.)DTHDX=DTHDX-THTA*DR/RR
      DTEDX=-T0*2.*S*AME*DME/(S1*S1)
      T15=(DTRDX-DTEDX)*THTA/TE
      DDSD1=DDSDL-1.
      DETERM=DTHCF*DDSD1-DTHDL*DDSCF
      THME=DTHDX-DME*DTHME
      DDSDC=-THTA*DH2DX-H2*DTHDX
      DSME=DDSDC-DME*DDSME
      DCF=(DDSD1*THME-DTHDL*DSME)/DETERM
      DDL=(DTHCF*DSME-DDSCF*THME)/DETERM
      DDSDX=DDL+DDSDC
   30 RETURN
      END
```

TABLE 5-B: INPUT TO PROGRAM BLGRN

```
   2.82 10 + 13 TEETER
0.      536.6  536.6  73.     0.72    .00169 0.126
2.65    0.0001 0.01   1.      1.
3.1     1.
7.      4.
2.4514  2.4427 2.4187 2.403   2.3896  2.3802 2.3648
2.65    2.708  2.814  2.886   2.9542  3.0018 3.08
7.      4.

2.65    2.708  2.814  2.886   2.9542  3.0018 3.08
```

TABLE 6: INPUT TO METHOD OF CHARACTERISTICS PROGRAM

```
   10+13 FROM 2.4
2.85
    0    47    1     0     0     0
2.82        1.4         24.         25.31       4.1         1.          1.
0.0000001   0.001       0.00001      0.001
3.00        0.001       0.001       0.0         5.
4.          3.
1.942       3.235       3.25        5.
0.342375
13.         13.         -10.         -10.
2.02        3.02        5.0
1.02
0.          0.          0.
6.335       0.999       2.584
    2     3     2     1     2    26
2.40        1.02        0.0         2.53637     0.99835
2.40        1.01        0.0         2.53637     0.99835
2.40        1.00        0.0         2.53637     0.99835
2.40        0.99        0.6         2.53637     0.99835
2.40        0.9797      1.2         2.5369      0.99835
2.40        0.971827    1.8         2.538211    0.99835
2.40        0.9617      2.4         2.66272     0.999
2.40        0.9516      3.0         2.6588      0.999
2.40        0.9416      3.631       2.655       0.999
2.40        0.9315      3.7305      2.6515      0.999
2.40        0.921477    3.8277      2.6482      0.999
2.40        0.91144     3.923       2.645       0.999
2.40        0.9014      4.0164      2.6418      0.999
2.40        0.881519    4.19945     2.6359      0.999
2.40        0.86174     4.3785      2.63035     0.999
2.40        0.84213     4.555       2.62511     0.999
2.40        0.8227      4.72992     2.620       0.999
2.40        0.80348     4.904       2.6154      0.999
2.40        0.78445     5.078366    2.6109      0.999
2.40        0.765465    5.25314     2.60662     0.999
2.40        0.7471      5.4289      2.6025      0.999
2.40        0.728777    5.6062      2.598       0.999
2.40        0.7107      5.7853      2.5948      0.999
2.40        0.69297     5.96648     2.5912      0.999
2.40        0.67553     6.15        2.58775     0.999
2.40        0.6584      6.3367      2.58447     0.999
    1     3     3     1     1     9
2.40        0.44812     13.0        2.42914     0.998
2.40        0.46601     12.33       2.4298      0.998
2.40        0.50812     11.2254     2.43212     0.998
2.40        0.51993     10.9846     2.43446     0.998
2.40        0.581397    9.8785      2.447921    0.998
2.40        0.60356     9.5647      2.451       0.998
2.40        0.616255     9.44656     2.4505     0.998
2.4         0.624544    9.375146    2.4500      0.998
2.4012      0.63984     9.24714     2.4495      0.998
```

TABLE 7-A: PROGRAM MFLX

```
      PROGRAM   MFLX(INPUT,OUTPUT,TAPE 5=INPUT, TAPE 6=OUTPUT)
C
C
C  PROGRAM FOR COMPUTATION OF MASS AND MOMENTUM FLUX
C
C  INPUT FORMAT 7F10.6 EXCEPT CARD 1
C
  CARD(S)  COLUMNS
C   1       TITLE, COLUMNS 1-72 HOLLERITH
C   2      1-10   TO  TOTAL TEMPERATURE DEGREE R
C          11-20  CR  GAS CONSTANT(=53.3)
C          21-30  AN  NO. OF POINTS INPUT
C          31-40  DY  AVERAGE INCREMENT (INCH)
C          41-50  RC  RADIUS OF LOCAL CONE SURFACE(INCH)
C          51-60  AIN =0.  NO MORE JOB AFTER THIS INPUT
C                     =1.  MORE JOB AFTER THIS INPUT
C   3      1-70   R   RADIUS AN VALUES (INCH)
C   4      1-70   EM  MACH NUMBER AN VALUES
C   5      1-70   P   STATIC PRESSURE AN VALUES (PSIA)
      DIMENSION EM(200),R(200),ROU(200),ROUU(200)
      DIMENSION P(200)
      DIMENSION TITLE(12)
    1 READ(5,1000) (TITLE(J),J=1,12)
      WRITE(6,2000)(TITLE(J),J=1,12)
      READ(5,100) TO,CR,AN,DY,RC,AIN
      WRITE(6,400) TO,RC
      N=AN
      READ(5,100) (R(I),I=1,N)
      READ(5,100) (EM(I),I=1,N)
      READ(5,100) (P(I),I=1,N)
      WRITE(6,300)
      SUM=0.
      BU=0.
      BUU=0.
      SUN=0.
      DO 2 I=1,N
      AI=I
      A=SQRT(TO)
      TOT=1.+0.2*EM(I)*EM(I)
      AB=SQRT(TOT)
      ROU(I)=49.*144.*P(I)*EM(I)*AB/(CR*A)
      U=49.*EM(I)*A/AB
      ROUU(I)=ROU(I)*U
      IF(I.EQ.1) GO TO 20
      RIU=0.5*(ROU(I-1)+ROU(I))
      RIUU=0.5*(ROUU(I-1)+ROUU(I))
      ARE=3.1416*(R(I)*R(I)-R(I-1)*R(I-1))/144.
      BU=RIU*ARE
      BUU=RIUU*ARE
```

```
   20 SUM=SUM+BU
      SUN=SUN+BUU
      WRITE(6,200) R(I),EM(I),P(I),SUM,SUN
    2 CONTINUE
 1000 FORMAT(12A6)
 2000 FORMAT(1H1,10X,12A6//)
  100 FORMAT (7F10.6)
  200 FORMAT( 10X,F10.6,5X,F10.6,5X,F10.6,5X,F10.6,5X,F15.6)
  300 FORMAT(/15X,1HR,15X,1HM,15X,1HP,10X,9HMASS FLUX,10X,8HMOM FLUX//)
  400 FORMAT(/20X,3HTO=,F6.2,9H DEGREE R   ,5X,4H RC= ,F8.4,4H IN./)
      IF(AIN.EQ.1.) GO TO 1
      END
```

TABLE 7-B: INPUT TO PROGRAM MFLX

M=2.82	X=2.85	MASS FLUX	CHECK			
536.6	53.3	70.	0.005	0.55145	1.	
0.55145	0.555	0.560	0.565	0.570	0.575	0.580
0.585	0.590	0.595	0.600	0.605	0.610	0.615
0.620	0.625	0.630	0.635	0.640	0.645	0.650
0.655	0.660	0.665	0.670	0.675	0.680	0.685
0.690	0.695	0.700	0.705	0.710	0.715	0.720
0.725	0.730	0.735	0.740	0.745	0.750	0.755
0.760	0.765	0.770	0.775	0.780	0.785	0.790
0.795	0.800	0.805	0.810	0.815	0.820	0.825
0.830	0.835	0.840	0.845	0.850	0.855	0.860
0.865	0.870	0.875	0.880	0.885	0.890	0.895
2.434	2.434	2.434	2.434	2.434	2.434	2.434
2.434	2.434	2.434	2.434	2.434	2.434	2.434
2.434	2.434	2.434	2.434	2.434	2.434	2.434
2.440	2.440	2.440	2.440	2.440	2.440	2.440
2.440	2.440	2.450	2.450	2.450	2.450	2.450
2.450	2.450	2.450	2.450	2.450	2.450	2.460
2.460	2.460	2.460	2.460	2.460	2.460	2.460
2.460	2.460	2.460	2.460	2.460	2.400	2.335
2.335	2.335	2.335	2.335	2.325	2.325	2.320
2.310	2.310	2.311	2.340	2.347	2.345	2.345
1.810	1.810	1.810	1.810	1.810	1.810	1.810
1.809	1.810	1.810	1.805	1.805	1.805	1.805
1.805	1.805	1.800	1.800	1.800	1.800	1.800
1.795	1.795	1.795	1.795	1.790	1.790	1.790
1.785	1.785	1.780	1.780	1.770	1.775	1.775

1.770	1.770	1.765	1.760	1.755	1.754	1.750
1.750	1.740	1.734	1.723	1.720	1.720	1.720
1.725	1.725	1.735	1.740	1.830	2.110	2.120
2.150	2.160	2.170	2.170	2.170	2.170	2.170
2.170	2.170	2.150	2.130	2.125	2.090	2.080

X=2.988 MASS CHECK

536.6	53.3	69.	0.005	0.58331	1.	
0.58331	0.585	0.590	0.595	0.600	0.605	0.610
0.615	0.620	0.625	0.630	0.635	0.640	0.645
0.650	0.655	0.660	0.665	0.670	0.675	0.680
0.685	0.690	0.695	0.700	0.705	0.710	0.715
0.720	0.725	0.730	0.735	0.740	0.745	0.750
0.755	0.760	0.765	0.770	0.775	0.780	0.785
0.790	0.795	0.800	0.805	0.810	0.815	0.820
0.825	0.830	0.835	0.840	0.845	0.850	0.855
0.860	0.865	0.870	0.875	0.880	0.885	0.890
0.895	0.900	0.905	0.910	0.915	0.920	
2.444	2.444	2.444	2.444	2.444	2.444	2.444
2.444	2.444	2.444	2.444	2.444	2.444	2.444
2.444	2.444	2.444	2.444	2.444	2.444	2.444
2.444	2.444	2.444	2.444	2.444	2.444	2.444
2.444	2.444	2.444	2.444	2.444	2.444	2.444
2.444	2.444	2.444	2.444	2.444	2.307	2.307
2.307	2.307	2.307	2.307	2.307	2.307	2.307
2.307	2.307	2.307	2.307	2.307	2.307	2.307
2.307	2.307	2.307	2.307	2.307	2.307	2.307
2.307	2.307	2.307	2.307	2.307	2.307	
1.784	1.784	1.784	1.784	1.784	1.784	1.784
1.784	1.784	1.784	1.784	1.784	1.784	1.784
1.784	1.784	1.784	1.784	1.784	1.784	1.784
1.784	1.784	1.784	1.784	1.784	1.784	1.784
1.785	1.785	1.785	1.785	1.795	1.795	1.795
1.795	1.796	1.796	1.798	2.220	2.215	2.215
2.215	2.215	2.215	2.215	2.215	2.215	2.215
2.215	2.215	2.215	2.215	2.220	2.220	2.220
2.220	2.220	2.220	2.220	2.220	2.220	2.220
2.220	2.220	2.220	2.220	2.220	2.220	2.220

X=3.205 MASS FLUX CHECK

536.6	53.3	63.	0.005	0.6334		
0.633417	0.635	0.640	0.645	0.650	0.655	0.660
0.665	0.670	0.675	0.680	0.685	0.690	0.695
0.700	0.705	0.710	0.715	0.720	0.725	0.730
0.735	0.740	0.745	0.750	0.755	0.760	0.765
0.770	0.775	0.780	0.785	0.790	0.795	0.800
0.805	0.810	0.815	0.820	0.825	0.830	0.835
0.840	0.845	0.850	0.855	0.860	0.865	0.870
0.875	0.880	0.885	0.890	0.895	0.900	0.905
0.910	0.915	0.920	0.925	0.930	0.935	0.940
2.445	2.445	2.445	2.445	2.445	2.445	2.445
2.445	2.445	2.445	2.445	2.445	2.445	2.350
2.295	2.280	2.265	2.250	2.240	2.245	2.250

2.255	2.260	2.270	2.283	2.300	2.310	2.315
2.315	2.310	2.305	2.300	2.309	2.380	2.380
2.375	2.370	2.265	2.262	2.260	2.260	2.260
2.258	2.255	2.252	2.252	2.252	2.252	2.252
2.252	2.252	2.252	2.252	2.252	2.252	2.252
2.252	2.252	2.252	2.252	2.252	2.252	2.252
1.775	1.775	1.775	1.775	1.775	1.775	1.775
1.775	1.775	1.775	1.775	1.775	1.775	2.000
2.247	2.250	2.260	2.275	2.298	2.290	2.280
2.270	2.260	2.250	2.240	2.230	2.220	2.220
2.182	2.192	2.210	2.230	2.250	2.270	2.290
2.310	2.335	2.350	2.365	2.370	2.375	2.380
2.384	2.390	2.395	2.400	2.401	2.401	2.401
2.401	2.401	2.401	2.401	2.401	2.401	2.410
2.410	2.410	2.415	2.415	2.415	2.415	2.415

TABLE 8: INPUT TO PROGRAM ANAL

SECOND SHOCK M=2.82 10+13
SLOT BLEED=0.028

2.411	0.037747	77599.4	2.	1.	2.	0.
-0.028	0.	2.	0.4	5.1	0.5	1.
4.5	33.					
0.1225	1.0	0.5				
13.						
1.00	1.00	2.3447	1.156	4.52		
1.03627	1.005586	2.322	1.1987	4.02		
1.072559	1.009497	2.32	1.2014	3.998		
1.10013	1.013407	2.2993	1.24084	3.954		
1.12697	1.01676	2.293	1.25415	3.90		
1.18140	1.0229	2.269	1.3007	4.00		
1.21767	1.027933	2.259	1.32075	4.010		
1.25758	1.0305	2.248	1.3457	4.018		
1.27935	1.03575	2.244	1.35682	4.02		
1.29749	1.038	2.24	1.3667	4.04		
1.36279	1.0447	2.234	1.40843	4.08		
1.39907	1.05027	2.230	1.44133	4.12		
1.43535	1.05586	2.227	1.48133	4.16		

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