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DONBOL: A Computer Program for Predicting Axisymmetric Nozzle Afterbody Pressure Distributions and Drag at Subsonic Speeds

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National Aeronautics
and Space Administration

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SUMMARY

A Neumann solution for inviscid external flow has been coupled to a modified Reshotko-Tucker integral boundary-layer technique, the control volume method of Presz for calculating flow in the separated region, and an inviscid one-dimensional solution for the jet exhaust flow in order to predict axisymmetric nozzle afterbody pressure distributions and drag. The viscous and inviscid flows are solved iteratively until convergence is obtained. A computer algorithm of this procedure has been written and is called DONBOL. This paper provides a description of the computer program and a guide to its use. Comparisons of the predictions of this method with experiment show that the method accurately predicts the pressure distributions of boattail afterbodies which have the jet exhaust flow simulated by solid bodies. For nozzle configurations which have the jet exhaust simulated by high-pressure air, the present method significantly underpredicts the magnitude of nozzle pressure drag. This deficiency results because the method neglects the effects of jet plume entrainment. This method is limited to subsonic free-stream Mach numbers below that for which the flow over the body of revolution becomes sonic.

INTRODUCTION

The drag-producing components of the airplane propulsion system are usually installed in areas where the flow field is extremely complex. High body slopes and long boundary-layer runs, especially in the afterbody nozzle region, result in strong viscous effects on boattail drag. Furthermore, the viscous nature of the jet exhaust plume complicates the flow in this region. Because of these strong viscous interactions, current methods used for predicting the installed propulsion system drag are usually limited to empirical techniques. Recently, however, investigators have achieved some success in predicting uninstalled drag of axisymmetric nozzles with what is usually called the patched viscous-inviscid technique. (See refs. 1 to 7, for example.) In reference 1, Reubush and Putnam combine iteratively a conventional boundary-layer technique with a linearized potential-flow computation to account for the viscous-inviscid interaction. For boattail nozzles on which boundary-layer separation occurs, Reubush and Putnam employ the discriminating streamline concept of Presz (refs. 8 and 9) to separate the reverse flow region from the outer flow. The patched viscous-inviscid interaction methods have been successful in predicting the qualitative trends in boattail pressure drag with Mach number, Reynolds number, and nozzle geometry in spite of the complexity of the flow even for isolated boattails. (See ref. 1, for example.) In general, however, these techniques substantially underpredict the absolute levels of pressure drag on boattail nozzles at subsonic speeds.

Recently, an improved analytical model of the flow in the separated region has been developed by Presz (refs. 10 and 11). With this analytical model, the effects of axial-pressure gradients, surface skin friction, and jet plume entrainment on the shape of the discriminating streamline are computed. Predictions made using this new technique (refs. 10 and 11) are in substantially better agreement with experiment than the predictions of the previous methods (refs. 1 to 7). This improved model of the separated flow region, therefore, has been combined iteratively with the inviscid linearized potential-flow solution described in reference 1.

The present paper describes the various components of the resulting computer algorithm called DONBOL. Also, this paper illustrates the prediction capabilities of the method by comparison with experimental data. A user's guide to the computer program is presented. The computer program may be obtained from COSMIC, Suite 112, Barrow Hall, University of Georgia, Athens, GA 30602.

SYMBOLS

The symbols used in the computer printouts are given in a separate column.

A	SREF	maximum cross-sectional area of body of revolution
B		compressibility correction factor (see eq. (6))
C_D		boattail pressure drag coefficient, $\text{Drag}/q_\infty A$
	CDF	skin-friction drag coefficient
	CDP	pressure drag coefficient
	CDT	total drag coefficient
C_p	CP	static pressure coefficient
c_f	CF	local skin-friction coefficient
D	D	maximum diameter of body of revolution
d_b	DB	base diameter
H	H	boundary-layer shape factor, δ^*/θ
L		length of body of revolution
	L	reference length
l		length of nozzle or boattail
M	MO	Mach number
NPR		ratio of jet total pressure to free-stream static pressure, $p_{t,jet}/p_\infty$
N_{Re}		Reynolds number based on distance from nose of model to start of boattail

p		static pressure
p_t	PT	total pressure
q_∞		free-stream dynamic pressure
R		gas constant
	RC	body radius corrected for δ^* and discriminating streamline
r	R	radial coordinate of cylindrical coordinate system with origin at nose of body of revolution
	RDS	radius of the discriminating streamline
r^*		radius of stream tube for Mach number of 1
T_t	TT	total temperature
V_r	VR	ratio of radial velocity to free-stream velocity
	VT	ratio of local velocity to free-stream velocity
V_x	VX	ratio of axial velocity to free-stream velocity
x	X	axial coordinate of cylindrical coordinate system with origin at nose of body of revolution
Δx		axial distance downstream of start of boattail
β		$= \sqrt{1 - M_\infty^2}$
γ		ratio of specific heats
	DEL	boundary-layer thickness
δ^*	DEL*	boundary-layer displacement thickness
	ETA	local flow angle
θ	THETA	boundary-layer momentum thickness

Subscripts:

a	analogous configuration (see eqs. (1) to (6))
des	design conditions of nozzle
e	exit
exp	experiment

jet	jet
p	predicted
s	separation
∞	free stream

DESCRIPTION OF METHOD

The present analytical method has been developed to calculate the flow over axisymmetric boattail bodies at subsonic speeds. It is assumed that the flow is composed of a viscous layer near the body, an inviscid external flow, and, if present, an inviscid jet exhaust flow. (See fig. 1.) The effect of the viscous layer is accounted for by modifying the body shape with an appropriate displacement thickness. In the framework of this representation, any boundary-layer separation on the boattail or nozzle surface is accounted for by modifying the afterbody geometry and plume boundary.

Inviscid External Flow Solution

The Neumann solution of reference 12 for incompressible flow over bodies of revolution was used to calculate the inviscid external flow. Since this is a solution for incompressible flow, the compressibility correction of reference 13 was used to correct for Mach number effects. The incompressible flow field considered is that for an "analogous" configuration obtained by means of the affine coordinate transformation given by the following equations:

$$x_a = \frac{x}{\beta} \tag{1}$$

$$r_a = r \tag{2}$$

where

$$\beta = \sqrt{1 - M_\infty^2} \tag{3}$$

The calculated flow velocities of the analogous configuration are then corrected using the following equations:

$$V_x = \frac{V_{x,a}}{B^2} \tag{4}$$

$$V_r = \frac{\beta V_{r,a}}{B^2} \tag{5}$$

where

$$B = \sqrt{1 - M_\infty^2(1 + V_{x,a})} \tag{6}$$

The pressure coefficients are obtained from the corrected velocities by using the compressible Bernoulli equation and the isentropic flow relations. Experience to date indicates that this compressibility correction provides better agreement with experimental results for flow over boattails than the classic Goethert compressibility correction.

Because the inviscid outer flow solution is based on incompressible flow theory with a compressibility correction, the present method is limited to freestream Mach numbers for which the flow is subsonic everywhere.

Inviscid Jet Exhaust Flow

To calculate the inviscid boundary of the jet exhaust flow, a procedure based on one-dimensional isentropic flow theory has been developed and is used in the present computer program, DONBOL. The procedure for calculating the radius of the inviscid jet plume at any axial location downstream of the nozzle exit is as follows. Initially, a shape for the jet plume boundary is assumed. Next, the pressure distribution along this boundary is calculated. Then, a new value of the radius at each axial location is ascertained by calculating the cross-sectional area required to expand isentropically from the flow conditions at the nozzle exit to the pressure on the boundary at that location. This new boundary is used in the next iteration as the guess. The equations used to compute the inviscid jet plume boundary from the flow conditions at the nozzle exit and the pressure distribution along the boundary are as follows:

$$\left(\frac{p_t}{p}\right)_{des} = \left(1 + \frac{\gamma - 1}{2} M_{des}^2\right)^{\gamma/(\gamma-1)} \tag{7}$$

$$p_e = q_\infty C_{p,e} + p_\infty \tag{8}$$

If

$$\frac{p_{t,jet}}{p_e} > \left(\frac{p_t}{p}\right)_{des}$$

then

$$M_{jet} = M_{des} \tag{9}$$

If

$$\frac{p_{t,jet}}{p_e} \leqq \left(\frac{p_t}{p}\right)_{des}$$

then the static pressure across the exit is assumed equal to the external static pressure at the exit and

$$M_{jet} = \sqrt{\frac{2}{\gamma - 1}\left[\left(\frac{p_{t,jet}}{p_e}\right)^{(\gamma-1)/\gamma} - 1\right]} \tag{10}$$

Then

$$\frac{r^*}{r_e} = \sqrt{M_{jet}\left(\frac{\gamma + 1}{2}\right)^{(\gamma+1)/2(\gamma-1)}\left(1 + \frac{\gamma - 1}{2} M_{jet}^2\right)^{-(\gamma+1)/2(\gamma-1)}} \tag{11}$$

Now at any given x-location downstream of nozzle exit since C_p is a function of x,

$$p = q_\infty C_p + p_\infty \tag{12}$$

$$M = \sqrt{\frac{2}{\gamma - 1}\left[\left(\frac{p_{t,jet}}{p}\right)^{(\gamma-1)/\gamma} - 1\right]} \tag{13}$$

and

$$\frac{r^*}{r} = \sqrt{M\left(\frac{\gamma + 1}{2}\right)^{(\gamma+1)/2(\gamma-1)}\left(1 + \frac{\gamma - 1}{2} M^2\right)^{-(\gamma+1)/2(\gamma-1)}} \tag{14}$$

Then

$$\frac{r}{r_e} = \frac{r^*/r_e}{r^*/r} \tag{15}$$

Also

$$V_{x,jet} = M\sqrt{\frac{\gamma R T_{t,jet}}{1 + \frac{\gamma - 1}{2} M^2}} \tag{16}$$

This procedure has been used to calculate the shape of the inviscid jet plume for the exhaust flow from a convergent nozzle at two nozzle pressure ratios. The procedure is compared in figure 2 with the predictions of the method of Salas (ref. 14) modified to account for pressure variation along the jet boundary. The identical longitudinal pressure distribution along the boundary of the jet was assumed with each method. However, slightly different pressure distributions were assumed for each nozzle pressure ratio. At NPR = 2.90, the shapes of the jet exhaust plume boundary predicted by the two methods are in very good agreement. At NPR = 5.03, the one-dimensional method does not agree as well with the method of Salas. As will be shown later, however, the one-dimensional method does provide a reasonable estimate of the effects of NPR on nozzle drag.

Viscous Flow

The properties of the viscous boundary layer (both attached and separated) and the location of any separation on the nozzle boattail are calculated using the methods and computer algorithm developed by Presz, King, and Buteau and described in reference 10. Presz, King, and Buteau computed the turbulent boundary-layer displacement-thickness distribution along the body with the method described in reference 15. This method is a modified version of the Reshotko-Tucker integral boundary-layer solution (ref. 16). A comparison of the predictions of this technique with the experimental measurements of Winter, Rotta, and Smith (ref. 17) at $M_\infty = 0.6$ and a Reynolds number, based on body length, of 9.85×10^6 is presented in figure 3.

If boundary-layer separation occurs on the boattail, the boundary-layer equations become singular at the separation point. To overcome this difficulty, Presz uses the concept of a discriminating streamline to separate the reverse flow region from the outer boundary-layer flow. This method, described in reference 10, accounts for the effects of axial-pressure gradients, surface skin friction, and viscous mixing in the jet exhaust flow on the shape of this discriminating streamline. Note that the present method does not account for the effects of viscous mixing downstream of the reattachment point.

The use of Presz's model of the separated region requires that some method be available for predicting the location of separation. Several methods are available. They include Presz's control volume technique (ref. 8), Goldschmied's criterion (ref. 18), a modified Page criterion (ref. 19), and Stratford's criterion (ref. 20). A discussion of the accuracy of the various separation location criteria is given in reference 21 by Abeyounis. Any of these methods can be used in the current computer program.

Viscous-Inviscid Interaction

Since the boundary-layer displacement thickness, the discriminating streamline shape, and the inviscid jet boundary are functions of the pressure distribution along the body and the jet boundary, the final converged solution must be obtained by iteration between the inviscid outer flow solution, the inviscid jet plume solution, and the viscous boundary-layer solution. The iteration algorithm used in the present method is shown in figure 4 and is as follows:

(1) Calculate the inviscid pressure distribution on the body of revolution.

(2) Calculate the inviscid jet plume boundary.

(3) Calculate the boundary-layer displacement thickness.

(4) Calculate the location of boundary-layer separation on the boattail. The separation location is calculated using the criteria selected by the user and is based on the pressure distribution and, in some cases, boundary-layer characteristics of the flow over the body. For the first iteration, a separation location will always be predicted. Ideally, the separation location should move aft with increasing number of iterations, and the separation region should essentially disappear as the solution approaches convergence for nozzles and flow conditions where no boundary-layer separation would occur. Unfortunately, with the available separation criteria, this separation region does not always disappear. It is suggested that a solution first be attempted assuming attached flow for nozzles when there is a question about whether or not separation occurs. If the solution diverges, the user can then assume that the flow is not attached, and the calculation must be repeated assuming that the flow is separated.

(5) If a separated flow calculation is required, calculate the shape of the discriminating streamline. To speed convergence and to eliminate some initial numerical stability problems, the present method assumes that for the first four iterations, axial-pressure gradients do not affect the shape of the discriminating streamline. After nine iterations, the shape of the discriminating streamline is frozen.

will it converge if not frozen?

(6) Correct the body geometry for boundary-layer displacement effects by adding an effective displacement thickness to the original body. The effective displacement thickness includes the discriminating streamline in the separation region. A relaxation procedure described in reference 8 is used to expedite convergence and to eliminate instabilities in the iteration procedure.

(7) Repeat steps (1) to (6) for the desired number of iterations. In the present algorithm, no convergence criteria are specified. Convergence is assumed to occur when two successive iterations plotted to a reasonable scale give essentially the same results. To obtain this result, most configurations require about 15 iterations.

COMPARISONS OF PREDICTIONS AND EXPERIMENT

The predictions of program DONBOL for an $l/D = 1.768$, $d_b/D = 0.51$ circular-arc afterbody with a solid cylindrical jet plume simulator and with attached boundary-layer flow are compared with the experimental data of reference 22 in figure 5. At both free-stream Mach numbers shown, the agreement between the predicted and experimental pressure distributions is excellent. The boattail pressure drag of the configuration is underpredicted. However, the differences between theory and experimental drag are within the accuracy of the experimental measurements. These results are typical of all attached-flow cases computed to date with DONBOL.

factor of two different

For boattail nozzles and afterbodies on which the boundary layer separates, the agreement between the predictions of the present method and experiment depends on the chosen separation criterion. In reference 21 Abeyounis showed that a criterion predicts significantly different locations for separation depending on whether the theoretical inviscid pressure distribution or the experimental pressure distribution is used. This result suggests that the predicted separation location may also be a function of the iteration algorithm used in a patched viscous-inviscid interaction procedure such as DONBOL. Therefore, the accuracy of a given separation criterion should be assessed using the total prediction algorithm for which it is to be incorporated. Predictions of the separation location criteria incorporated in DONBOL are compared with the experimental data of Abeyounis (ref. 21) in figure 6(a). The large differences shown in predicted separation location can affect predicted afterbody pressure distributions and drag significantly, as illustrated in figure 6(b). Based on these limited results and because it more accurately predicts the location of separation on the steep, highly separated $l/D = 0.8$ boattail configuration, the method of Presz is recommended and is used for all further calculations presented in this paper.

An illustration of the capabilities of the present method for predicting the effects of free-stream Mach number on the pressure distribution and drag of an afterbody with separated boundary layer is shown in figure 7. The experimental data from references 22 and 23 shown in this figure are for the same $l/D = 0.8$, $d_b/D = 0.51$ circular-arc afterbody with solid cylindrical plume simulator for which separation location data are presented in figure 6(a). At a Mach number of 0.4 where the separation location is accurately predicted using the Presz criterion, the agreement between experimental and predicted pressure distributions is very good. As the difference in predicted and actual separation location increases with increasing free-stream Mach number, the agreement in pressure distributions between theory and experiment deviates somewhat. However, as shown in figure 7(b) the agreement between predicted and actual boattail pressure drag improves with increasing Mach number. This agreement is essentially within experimental accuracy throughout the range of Mach numbers for which the theory is applicable.

as assumption gets worse, results get better?

says it doesn't matter anyhow

At a given free-stream Mach number, the agreement between theory and experiment is a function of boattail geometry. The comparisons between the theory and experiment of reference 23 shown in figure 8 indicate that for boattails with less closure than the configuration of figure 7, substantially better agreement between theory and experiment can result.

The capabilities of the present method for predicting the effects of Reynolds number on boattail pressure distributions and drag are illustrated in figure 9. The agreement between theory and experiment is a function of Reynolds number and boattail geometry. However, the predicted variation of the boattail-pressure drag coefficient with Reynolds number is in relatively good agreement with the experimental results (fig. 9(c)).

A comparison of the experimental (refs. 22 to 24) and predicted effects of the ratio of nozzle total pressure to free-stream static pressure NPR on the pressure distribution and drag of a $l/D = 0.8$, $d_b/D = 0.51$ circular-arc nozzle is shown in figure 10. In general, the present method reasonably predicts the variation of the pressure distributions with NPR. However, at both $M_\infty = 0.6$ and 0.8 (figs. 10(a) and 10(b)) DONBOL generally predicts more positive pressures than actually exist on the nozzle. As a result, the magnitude of the boattail drag is substantially underpredicted (fig. 10(c)). These deficiencies probably result because the present method does not account for the effects of jet entrainment. Note that the present method does account for the effects of jet entrainment on the shape of the separation discriminating streamline, but does not account for jet plume entrainment in any manner downstream of the reattachment of the separated boundary layer. Jet entrainment downstream of reattachment should reduce the pressures on the nozzle and thereby increase the nozzle drag. As shown in figure 10(c), the present method accurately predicts the nozzle drag when the jet exhaust flow is simulated experimentally by a solid cylindrical sting. This solid sting, of course, does not simulate the effects of jet plume entrainment, but does simulate the effects of jet plume blockage on the flow over the nozzle. Even though the present method does not accurately predict the magnitude of nozzle drag, it does predict the decrease in drag at the higher nozzle total-pressure ratios. The present method does not, however, predict the increase in drag at the lower pressure ratios. Further illustrations of the capabilities of the present method for predicting pressure distributions and drag for nozzles with jet exhaust flow are shown in figure 11. Here the program DONBOL was used to calculate the flow over the equivalent bodies of reference 25 with the nozzles operating at an NPR of approximately 2.5. For these configurations, the predictions generally agree better with experiment than for the configuration shown in figure 10.

DESCRIPTION OF COMPUTER PROGRAM

A flow chart of program DONBOL is presented in figure 12 and a listing of the program is provided in the appendix. This program is written in overlay form and consists of the main overlay and four primary overlays. Primary overlays 1 to 3 are used to calculate the inviscid external flow, and overlay (5,0) is used to calculate the inviscid jet exhaust flow, the boundary-layer flow, and the "effective" body geometry for further iterations. The program uses nine disk files during computation. Input data are obtained from TAPE5 and the results are written on TAPE6 which is set equal to OUTPUT. A restart output file is written on TAPE7. The remaining disk files are used internally by the program. DONBOL requires about 125 000 octal storage locations on the Control Data CYBER 175 computer system and executes 15 iterations in approximately 3 minutes.

A brief description of the various routines in the program is given in the following list:

DONBOL	This routine reads the input data, stores the x- and r-coordinates on TAPE13, and controls the iteration procedure. All primary overlays are called from this routine.
ONE	This routine prints certain control parameter information and calls subroutines BASIC1 and MATRIX.
BASIC1	This subroutine makes the compressibility correction transformations to the x- and r-coordinates, calculates coordinates of the midpoint of each body panel, and calculates the slope of each body panel.
MATRIX	The influence coefficient matrix and the boundary condition matrix are set up in this subroutine. MATRIX calls subroutine XYZ.
XYZ	The influence coefficients are calculatd by this subroutine. A constant source of unit strength is assumed to act on each panel. The influence coefficient is the integral of the effect of the constant strength source. The subroutine calls XYZ1 and XYZ2.
XYZ1	This subroutine performs the integration of the effects of the constant strength source for points within a specified radius of the singularity.
XYZ2	This subroutine performs the integration using Simpson's rule to determine the influence of the unit source panel at all distances greater than the specified radius from the singularity. The routine calls subroutine ELIP.
ELIP	This subroutine is used to calculate the value of various elliptical integrals.
TWO	This routine initializes parameters for call to MISNA2.
MISNA2	This subroutine calculates the strengths of the source panels by solving the matrix equation using a Seidel iteration procedure.
THREE	This routine initializes various parameters and then calls subroutine AXIS. The pressure coefficients computed by AXIS are then written on TAPE13.
AXIS	This subroutine calculates velocity components of the flow and surface-pressure coefficients. The velocity components are corrected for compressibility effects using either the Goethert or Labrujere method, before computing the pressure coefficient.
FIVE	This routine is the interface between the inviscid external flow calculation and the viscous flow calculations. The body geometry and pressure coefficients are read from TAPE13. The inviscid jet plume

exhaust flow boundary and velocity are calculated. The viscous subroutine package is called to obtain boundary-layer parameters and the corrected effective body contour. See reference 8 for details of the subroutines in the viscous package. Routine FIVE also computes the drag coefficient. The results are printed and the final solution put on TAPE7 for further iteration if necessary.

IUNI	This is a Langley Research Center computer system library subroutine. The subroutine uses first- or second-order Lagrangian interpolation to estimate the value of a set of functions at a specified value of the independent value.

Description of Input Data Cards

Sample input data required for program DONBOL are presented in figure 13. This figure presents the input data required to compute the flow over a boattail nozzle configuration with jet exhaust flow. This test case also illustrates the input data required to compute flow conditions at points off the body. Specifically, the input data required are as follows:

Card 1: identification.- Card 1 contains any desired identifying information in columns 1 to 80.

Card 2: control integers.- Card 2 contains 13 integers, each punched right justified in a five-column field. An identification of the card columns, the name used by the source program, and a description of each integer is given in the following table:

Columns	FORTRAN name	Description
1 to 5	ISWITCH	Calculation Option Code: If ISWITCH = 1, potential-flow solution only. If ISWITCH = 2, boundary-layer effects on pressure distribution are included in solution using an iteration scheme. If ISWITCH = 3, boundary-layer solution only.
6 to 10	IPRINT	Iteration number to start printing results.
11 to 15	IPUNCH	Punch option code: If IPUNCH greater than 0, last iteration is written on TAPE7 in format necessary for a restart of solution. CP for last iteration also written on TAPE7.
16 to 20	ITERA	Iteration number for first calculation of this submittal. For initial submittal of any calculation, ITERA must be 0.

Columns	FORTRAN name	Description
21 to 25	ITERMAX	Maximum number of iterations (less than or equal to 20).
26 to 30	IMACH	Compressibility correction code: If IMACH = 1, Goethert compressibility correction used. If IMACH = 2, Labrujere compressibility correction used.
31 to 35	ISEP	Separation location criteria code: If ISEP = 0, no separation model used. If ISEP = 1, separation location specified by user. ! If ISEP = 2, Presz control volume criterion used. If ISEP = 3, Goldschmied criterion used. If ISEP = 4, modified Page criterion used. If ISEP = 5, Stratford criterion used.
41 to 45	INT(3)	X-array location to start search for separation.
46 to 50	INT(4)	X-array location to end search for separation.
51 to 55	INT(5)	Jet plume and entrainment option: If INT(5) = 0, omit jet plume and entrainment calculations. If INT(5) = 1, include jet plume and entrainment calculations.
56 to 60	INT(6)	X-array location of nozzle exit.
61 to 65	INT(7)	Smoothing parameter: If INT(7) = 0, no smoothing. If INT(7) = 1, aerodynamic body contour and pressure distribution are smoothed. INT(7) = 1 should be used. !
66 to 70	IFLAG5	An integer which if greater than 0 specifies that off-body points are to be calculated.

Card 3: free-stream conditions and reference dimensions.- Card 3 contains quantities used to define the free-stream flow and dimensional information required to convert body coordinate inputs to meters. If the separation location is to be input by the user, it is given on this card. Identification of the card columns, names used in the source program, and a description of each variable is given in the following table:

Columns	FORTRAN name	Description
1 to 10	MO	Free-stream Mach number.
11 to 20	PT	Free-stream total pressure, Pa.
21 to 30	TT	Free-stream total temperature, K.
31 to 40	REFL	Reference length - factor required to convert input values of x and r to meters.
41 to 50	SREF	Reference area, meters^2.
51 to 60	XSEPND	The x-coordinate of the separation location. Required if ISEP = 1.

Card 4: jet exhaust conditions.- This card contains quantities used to define the jet exhaust flow. If there is no jet exhaust flow (INT(5) = 0) this card may be blank, but it must be input. The card contains the following information:

Columns	FORTRAN name	Description
1 to 10	XMJET	Mach number of jet at nozzle exit.
11 to 20	PTJET	Jet total pressure, Pa.
21 to 30	TTJET	Jet total temperature, K.
31 to 40	RJET	Radius of nozzle exit.

Cards 5, 6, . . .: remaining data input cards.- The remaining data cards provide a description of the body geometry, the location of any off-body points at which the flow is to be calculated, and the surface pressure coefficients if the boundary-layer solution only is to be computed. Unless otherwise noted, each card contains up to six values with each value punched in a ten-column field with a decimal.

Body geometry cards: The first body geometry data card gives the number of coordinates, NN. The integer, NN is punched in columns 1 to 5 right justified. The number of body coordinates may not be greater than 200. The next group of body geometry data cards contains the axial location at which the body radius is to be specified. There are exactly NN locations with up to six values per card. The next group of body geometry data cards contains the radius of the body at the specified axial locations. Again there are NN values of the body radius specified. Note that if the jet exhaust flow option is selected, an initial guess of the shape of the jet plume boundary must be included in the description of the body geometry.

Off-body points: If the flow is to be calculated at any off-body points *and IFLAG5 > 0, then the following cards must be input. First the number of* off-body points must be specified on a data card. The number of off-body points is punched in columns 1 to 5 right justified. (Note that the sum of the points on the body of revolution and the off-body points may not be greater than 200.) Then a group of data cards giving the location of the x-coordinates at which the flow is to be calculated is input. This group of cards is followed by a group of cards on which the r-coordinates of the off-body points are specified.

Pressure coefficients cards: This group of cards is input only if the program is to be restarted or if ISWITCH = 3, that is, when the boundary-layer solution only is to be calculated. The pressure coefficient at each body x-coordinate location is input with six values per card.

Description of Output

Program output consists of printed output and a disk file TAPE7 written in the form necessary for a restart of the program. An example of the printed output is presented in figure 14 for the test case presented in figure 13.

The first page of output includes the program title, case identification, list of control options selected, free-stream conditions, and, if requested, jet exhaust flow conditions. On the second page, several diagnostic messages from various routines in the program are written.

Following these pages, the results of the calculation are output. Case identification and free-stream conditions are again specified. The iteration number, the reference length L, the reference area SREF, and the axial location of boundary-layer separation and reattachment are given. Following this information, tabulated listings of the body axial coordinate X/L, the body radial coordinate R/L, the body radius corrected for the discriminating streamline RDS/L, and the body radius corrected for boundary-layer displacement thickness and the discriminating streamline RC/L are printed. Also listed are values of pressure coefficient CP, local skin-friction coefficient CF, boundary-layer thickness DEL/L, boundary-layer displacement thickness DEL*X/L, boundary-layer momentum thickness THETA/L, and boundary-layer shape factor H. In addition, listings of the pressure drag coefficient CDP, skin-friction drag coefficient CDF, and total drag coefficient CDT are given. The drag values listed are based on the reference area SREF and are the integrals of the pressure forces and/or skin-friction forces from the nose of the body to the specified X/L location. To obtain the nozzle boattail pressure drag coefficient, for example, it is necessary to subtract the value of the pressure drag coefficient at the start of the boattail from the value of the pressure drag coefficient at the nozzle exit or end of the boattail. This information is repeated for each iteration as specified in the input data.

If flow conditions at off-body points are calculated, the axial location X/L and radial location R/L of the off-body points are tabulated on the next page together with the ratio of axial velocity to free-stream velocity VX, the ratio of radial velocity to free-stream velocity VR, and the ratio of local velocity to free-stream velocity VT. Also tabulated are the local flow angle ETA in radians, the local Mach number ML, and the local pressure coefficient CP.

CONCLUDING REMARKS

A computer program has been written to compute the flow over axisymmetric nozzle configurations at subsonic speeds with and without separated flow. The computer algorithm is based on a patched viscous-inviscid interaction procedure. That is, solutions for the various regions of the flow are coupled together and solved iteratively to obtain a converged solution. The results of the present alogrithm called DONBOL are in good agreement with experimental pressure distribution results for flow over nozzles with the jet exhaust simulated with solid bodies. The method substantially underpredicts the magnitude of the boattail drag when the jet exhaust flow is simulated with high-pressure air. This deficiency results because the present technique does not account for the effects of jet plume entrainment downstream of reattachment of the separated boundary layer on the flow over the nozzle. The method is limited to free-stream Mach numbers below that for which flow on the body of revolution reaches sonic speeds.

Langley Research Center
National Aeronautics and Space Administration
Hampton, VA 23665
April 11, 1979

APPENDIX

TABULATED LISTING OF COMPUTER PROGRAM

APPENDIX

```
      OVERLAY(LINK,0,0)
      PROGRAM DONBOL(INPUT=201,OUTPUT=201,TAPE5,TAPE6=OUTPUT,TAPE3=1001,
     1TAPE4=1001,TAPE9=1001,TAPE11=1001,TAPE12=1001,TAPE13=1001,TAPE7=10
     201)
C
C
C     ******************************************************************
C                                                                      *
C             INPUT DATA DESCRIPTION FOR PROGRAM DONBOL                *
C             -------------------------------------                    *
C                                                                      *
C     CARD    COL       NAME                  DESCRIPTION              *
C                                                                      *
C       1     1-80      HEDR        CASE DESCRIPTION                   *
C                                                                      *
C       2     1-5      ISWITCH      CALCULATION OPTION CODE -          *
C                                   IF ISWITCH=1 POTENTIAL FLOW SOLUTION *
C                                     ONLY.                            *
C                                   IF ISWITCH=2 BOUNDARY LAYER EFFECTS ON*
C                                     PRESSURE DISTRIBUTION ARE INCLUDED *
C                                     IN SOLUTION USING AN ITERATION   *
C                                     SCHEME.                          *
C                                   IF ISWITCH=3 BOUNDARY LAYER SOLUTION *
C                                     ONLY.                            *
C                                                                      *
C       2     6-10      IPRINT      ITERATION NUMBER TO START PRINTING *
C                                   RESULTS.                           *
C                                                                      *
C       2    11-15      IPUNCH      PUNCH OPTION CODE - IF IPUNCH GREATER *
C                                   THAN 0 LAST ITERATION ON TAPE 7 IN *
C                                   FORMAT NECESSARY FOR A RESTART OF  *
C                                   SOLUTION.  CP FOR LAST ITERATION ALSO *
C                                   WRITTEN ON TAPE 7.                 *
C                                                                      *
C       2    16-20      ITERA       ITERATION NUMBER FOR FIRST CALCULATION*
C                                   OF THIS SUBMITTAL                  *
C                                                                      *
C       2    21-25     ITERMAX      MAXIMUM NUMBER OF ITERATIONS (LESS *
C                                   THAN OR EQUAL TO 20)               *
C                                                                      *
C                                                                      *
C                                                                      *
C     CARD    COL       NAME                  DESCRIPTION              *
C                                                                      *
C       2    26-30      IMACH       COMPRESSIBILITY CORRECTION CODE -  *
C                                   IF IMACH=1 GOETHERT COMPRESSIBILITY *
C                                     CORRECTION USED.                 *
C                                   IF IMACH=2 LABRUJERE COMPRESSIBILITY *
C                                     CORRECTION USED.                 *
C                                                                      *
C       2    31-35      ISEP        SEPARATION LOCATION CRITERIA CODE - *
C                                   IF ISEP=0 NO SEPARATION MODEL USED. *
C                                   IF ISEP=1 SEPARATION LOCATION      *
C                                     SPECIFIED BY USER.               *
C                                   IF ISEP=2 PRESZ CONTROL VOLUME     *
C                                     CRITERIA USED.                   *
C                                   IF ISEP=3 GOLDSCHMIED CRITERIA USED. *
C                                   IF ISEP=4 MODIFIED PAGE CRITERIA USED.*
C                                   IF ISEP=5 STRATFORD CRITERIA USED. *
C                                                                      *
C       2    36-40                  NOT USED.                          *
C                                                                      *
C       2    41-45      INT(3)      X-ARRAY LOCATION TO START SEARCH FOR *
C                                   SEPARATION.                        *
C                                                                      *
C       2    46-50      INT(4)      X-ARRAY LOCATION TO END SEARCH FOR *
```

```
C                                       SEPARATION.                            *DON  66
C                                                                              *DON  67
C     2    51-55      INT(5)            JET PLUME AND ENTRAINMENT OPTION -     *DON  68
C                                       IF INT(5)=0 OMIT JET PLUME AND         *DON  69
C                                         ENTRAINMENT CALCULATIONS.            *DON  70
C                                       IF INT(5)=1 INCLUDE JET PLUME AND      *DON  71
C                                         ENTRAINMENT CALCULATIONS.            *DON  72
C                                                                              *DON  73
C     2    56-60      INT(6)            X-ARRAY LOCATION OF NOZZLE EXIT.       *DON  74
C                                                                              *DON  75
C     2    61-65      INT(7)            SMOOTHING PARAMETER -                  *DON  76
C                                       IF INT(7)=0 NO SMOOTHING.              *DON  77
C                                       IF INT(7)=1 AERODYNAMIC BODY CONTOUR   *DON  78
C                                       AND PRESSURE DISTRIBUTION ARE SMOOTHED*DON  79
C                                                                              *DON  80
C     2    66-70      IFLAGS            AN INTEGER WHICH IF GREATER THAN 0     *DON  81
C                                       SPECIFIES THAT OFF BODY POINTS ARE TO *DON  82
C                                       BE CALCULATED.                         *DON  83
C                                                                              *DON  84
C   CARD    COL        NAME                         DESCRIPTION                *DON  85
C                                                                              *DON  86
C     3     1-10        MN              FREE STREAM MACH NUMBER.               *DON  87
C                                                                              *DON  88
C     3    11-20        PT              FREE STREAM TOTAL PRESSURE, PASCALS    *DON  89
C                                                                              *DON  90
C                                                                              *DON  92
C     3    21-30        TT              FREE STREAM TOTAL TEMPERATURE, KELVIN *DON  91
C     3    31-40       REFL             REFERENCE LENGTH - FACTOR REQUIRED TO *DON  93
C                                       CONVERT INPUT VALUES OF X AND R TO     *DON  94
C                                       METERS.                                *DON  94A
C                                                                              *DON  95
C     3    41-50       SREF             REFERENCE AREA, SQ METERS              *DON  96
C                                                                              *DON  97
C     3    51-60      XSEPND            THE X-COORDINATE OF THE SEPARATION     *DON  98
C                                       LOCATION.  REQUIRED IF ISEP=1.         *DON  99
C                                                                              *DON 100
C     4     1-10      XMJET             MACH NUMBER OF JET AT NOZZLE EXIT.     *DON 101
C                                                                              *DON 102
C     4    11-20      PTJET             JET TOTAL PRESSURE, PASCALS            *DON 103
C                                                                              *DON 104
C     4    21-30      TTJET             JET TOTAL TEMPERATURE, KELVIN          *DON 105
C                                                                              *DON 106
C     4    31-40       RJET             RADIUS OF NOZZLE EXIT                  *DON 107
C                                                                              *DON 108
C     5     1-5         NN              NUMBER OF COORDINATES FOR BODY         *DON 109
C                                                                              *DON 110
C     6     1-60   X(I),I=1,NN          THE X-COORDINATES OF THE POINTS DEFIN-*DON 111
C                                       ING THE BODY.  DATA IS INPUT WITH A    *DON 112
C                                       FORMAT OF 6F10.6.  MAY BE MORE THAN    *DON 113
C                                       ONE CARD                               *DON 114
C                                                                              *DON 115
C     7     1-60   R(I),I=1,NN          THE R-COORDINATES OF THE POINTS DEFIN-*DON 116
C                                       ING THE BODY.  DATA IS INPUT WITH A    *DON 117
C                                       FORMAT OF 6F10.6.  MAY BE MORE THAN    *DON 118
C                                       ONE CARD                               *DON 119
C                                                                              *DON 120
C                                                                              *DON 121
C                                                                              *DON 122
C                                                                              *DON 123
C   IF IFLAGS GREATER THAN 0 THE FOLLOWING CARDS MUST BE INPUT                 *DON 124
C                                                                              *DON 125
C   CARD    COL        NAME                         DESCRIPTION                *DON 126
C                                                                              *DON 127
C     8     1-5         NN              NUMBER OF OFF BODY POINTS              *DON 128
C                                                                              *DON 129
C     9     1-60   X(I),I=1,NN          THE X-COORDINATES OF THE OFF BODY      *DON 130
```

```
C                                POINTS.  DATA IS INPUT WITH A FORMAT  *
C                                OF 6F10.6.  MAY BE MORE THAN ONE CARD.*
C                                                                      *
C      10    1-60  R(I),I=1,NN   THE R-COORDINATES OF THE OFF BODY     *
C                                POINTS.  DATA IS INPUT WITH A FORMAT  *
C                                OF 6F10.6.  MAY BE MORE THAN ONE CARD.*
C                                                                      *
C     IF ISWITCH IS EQUAL TO 3 THE FOLLOWING CARD MUST BE INPUT        *
C                                                                      *
C     CARD   COL        NAME                  DESCRIPTION              *
C                                                                      *
C      11    1-60  CP(I),I=1,NN  PRESSURE COEFFICIENT AT EACH X-       *
C                                COORDINATE ON BODY.  DATA IS INPUT    *
C                                WITH A FORMAT OF 6F10.6.  MAY BE MORE *
C                                THAN ONE CARD.                        *
C                                                                      *
C     *****************************************************************
C
C
      COMMON HEDR(8),ISWITCH,IPUNCH,ITERA,ITERMAX,IMACH,ISEP,INT(8),IFLA
     1G5,FLG05,MN,APT,ATT,REFL,SREF,XSEPND,NN,BDN,ND(2),NT,NSIGA,IPRINT,
     2AMJET,PTJET,TTJET,RJET,RSTAR
      COMMON /SAVE/ VDUM(951)
      DIMENSION X(200), R(200), CP(200)
      INTEGER FLG05,BDN
      REAL MN
C
      LINK=4LLINK
      BDN=1
      DO 10 I=1,200
10    CP(I)=0.0
20    READ (5,70) HEDR
      IF (EOF(5)) 60,30
30    READ (5,80) ISWITCH,IPRINT,IPUNCH,ITERA,ITERMAX,IMACH,ISEP,(INT(I)
     1,I=2,7),IFLAG5
      READ (5,90) MN,APT,ATT,REFL,SREF,XSEPND,AMJET,PTJET,TTJET,RJET
      READ (5,80) NN
      READ (5,90) (X(I),I=1,NN)
      DO 40 IZ=1,2
      IF (IZ.EQ.1.OR.ITERA.GT.0) READ (5,90) (R(I),I=1,NN)
      WRITE (13) NN,(X(I),I=1,200)
      WRITE (13) NN,(R(I),I=1,200)
40    CONTINUE
      IF ((ISWITCH.EQ.3).OR.(ITERA.GT.0)) READ (5,90) (CP(I),I=1,NN)
      WRITE (13) (CP(I),I=1,200)
      IF (ISWITCH.EQ.3) CALL OVERLAY (LINK,5,0)
      IF ((ISWITCH.EQ.1).OR.(ISWITCH.EQ.2)) GO TO 50
      GO TO 20
50    IF (ITERA.GT.ITERMAX.AND.IFLAG5.EQ.0) GO TO 20
      REWIND 3
      REWIND 4
      REWIND 9
      REWIND 11
      REWIND 12
      REWIND 13
      CALL OVERLAY (LINK,1,0)
      CALL OVERLAY (LINK,2,0)
      CALL OVERLAY (LINK,3,0)
      IF (IFLAG5.GT.0.AND.ITERA.GE.(ITERMAX+1)) GO TO 20
      CALL OVERLAY (LINK,5,0)
      ITERA=ITERA+1
      GO TO 50
60    CONTINUE
      STOP
C
C
```

```
70    FORMAT (8A10)                                                     DON 197
80    FORMAT (16I5)                                                     DON 198
90    FORMAT (6F10.6)                                                   DON 199
      END                                                               DON 200-
      OVERLAY(LINK,1,0)
      PROGRAM ONE                                                       ONE   1
C                                                                       ONE   2
C             *CONTROL FOR BASIC DATA AND FORM MATRIX                   ONE   3
C                                                                       ONE   4
      COMMON HEDR(8),ISWITCH,IPUNCH,ITERA,ITERMAX,IMACH,ISEP,INT(8),IFLAONE   5
     1G5,FLG05,MN,APT,ATT,REFL,SREF,XSEPND,NN,BDN,ND(2),NT,NSIGA,IPRINT,ONE   6
     2AMJET,PTJET,TTJET,RJET,RSTAR                                      ONE   7
      COMMON /CL/ X1(200),Y1(200),X2(200),Y2(200),DELS(200),SINA(200),COONE   8
     1SA(200),XP(200),YP(200)                                           ONE   9
      COMMON /TL/ TX1(200),TY1(200),NG(200),TG(200),ALFA(200),RSDS(200),ONE  10
     1DALF(200),TEMP(1017)                                              ONE  11
      INTEGER FLG05,BDN                                                 ONE  12
      REAL MN,NG                                                        ONE  13
C                                                                       ONE  14
C        OUTPUT CASE CONTROL DATA                                       ONE  15
C                                                                       ONE  16
      FLG05=0                                                           ONE  17
      IF (ITERA.GT.0) GO TO 10                                          ONE  18
      WRITE (6,250)                                                     ONE  19
      WRITE (6,20) HEDR                                                 ONE  20
      IF (IFLAG5.GT.0) WRITE (6,30)                                     ONE  21
      IF (IMACH.EQ.1) WRITE (6,40)                                      ONE  22
      IF (IMACH.EQ.2) WRITE (6,50)                                      ONE  23
      WRITE (6,60)                                                      ONE  24
      IF (ISEP.EQ.0) WRITE (6,70)                                       ONE  25
      IF (ISEP.GT.0) WRITE (6,80)                                       ONE  26
      IF (ISEP.EQ.1) WRITE (6,90) XSEPND                                ONE  27
      IF (ISEP.EQ.2) WRITE (6,100)                                      ONE  28
      IF (ISEP.EQ.3) WRITE (6,110)                                      ONE  29
      IF (ISEP.EQ.4) WRITE (6,120)                                      ONE  30
      IF (ISEP.EQ.5) WRITE (6,130)                                      ONE  31
      IF (ISEP.GE.2) WRITE (6,140) INT(3)                               ONE  32
      IF (ISEP.GE.2) WRITE (6,150) INT(4)                               ONE  33
      IF (INT(5).GT.0) WRITE (6,160)                                    ONE  34
      WRITE (6,170) INT(6)                                              ONE  35
      IF (INT(7).GT.0) WRITE (6,180)                                    ONE  36
      WRITE (6,190)                                                     ONE  37
      G=1.4                                                             ONE  38
      G1=(G-1.)/2.                                                      ONE  39
      G2=G/(G-1)                                                        ONE  40
      RG=286.96                                                         ONE  41
      PO=APT/(1.+G1*MN**2)**G2                                          ONE  42
      TO=ATT/(1.+G1*MN**2)                                              ONE  43
      RHO=PO/(TO*RG)                                                    ONE  44
      XMU=1.458/10**6*TO**1.5/(TO+110.33)                               ONE  45
      RN=RHO*MN*SQRT(G*RG*TO)/XMU                                       ONE  46
      RN=RN/10.**6                                                      ONE  47
      WRITE (6,200)                                                     ONE  48
      WRITE (6,210) MN,APT,ATT                                          ONE  49
      WRITE (6,220) RN                                                  ONE  50
      IF (INT(5).GT.0) WRITE (6,240)                                    ONE  51
      IF (INT(5).GT.0) WRITE (6,210) AMJET,PTJET,TTJET                  ONE  52
      XNPR=PTJET/PO                                                     ONE  53
      IF (INT(5).GT.0) WRITE (6,230) XNPR                               ONE  54
      IF (IPRINT.GT.0) WRITE (6,250)                                    ONE  55
C                                                                       ONE  56
C        SETUP FOR UNIFORM FLOW                                         ONE  57
C                                                                       ONE  58
10    CALL BASIC1                                                       ONE  59
      NSIGA=1                                                           ONE  60
      REWIND 4                                                          ONE  61
```

```
      CALL MATRIX
C
C
C
20    FORMAT (10X,64HDONBOL --- AN AXISYMMETRIC INVISCID/VISCID INTERA
     1CTION PROGRAM//16X,52HBY LAWRENCE E. PUTNAM, NASA, LANGLEY RESEARC
     2H CENTER//2X,13HCASE TITLE = ,8A10//13X,29H***** CASE CONTROL DATA
     3 *****//)
30    FORMAT (13X,15HOFF-BODY POINTS)
40    FORMAT (13X,35HGOETHERT COMPRESSIBILITY CORRECTION)
50    FORMAT (13X,36HLABRUJERE COMPRESSIBILITY CORRECTION)
60    FORMAT (13X,48HMODIFIED RESHOTKO TUCKER BOUNDARY LAYER SOLUTION)
70    FORMAT (13X,29HSEPARATED FLOW MODEL NOT USED)
80    FORMAT (13X,64HPRESZ MODIFIED CONTROL VOLUME DISCRIMINATING STREAM
     1LINE SOLUTION)
90    FORMAT (13X,46HSEPARATION LOCATION SPECIFIED BY USER AT X/L =,F10.
     16)
100   FORMAT (13X,49HPRESZ CONTROL VOLUME SEPARATION LOCATION CRITERIA)
110   FORMAT (13X,40HGOLDSCHMIED SEPARATION LOCATION CRITERIA)
120   FORMAT (13X,42HMODIFIED PAGE SEPARATION LOCATION CRITERIA)
130   FORMAT (13X,38HSTRATFORD SEPARATION LOCATION CRITERIA)
140   FORMAT (13X,34HSTART SEARCH FOR SEPARATION AT I =,I4)
150   FORMAT (13X,32HEND SEARCH FOR SEPARATION AT I =,I4)
160   FORMAT (13X,29HJET EXHAUST PLUME CALCULATION)
170   FORMAT (13X,18HNOZZLE EXIT AT I =,I4)
180   FORMAT (13X,26HSMOOTH AERODYNAMIC CONTOUR)
190   FORMAT (13X,28HSMOOTH PRESSURE DISTRIBUTION)
200   FORMAT (1H0,12X,22HFREE STREAM CONDITIONS)
210   FORMAT (20X,20HMACH NUMBER        =,F12.3/20X,20HTOTAL PRESSURE
     1  =,F12.3,8H PASCALS/20X,20HTOTAL TEMPERATURE  =,F12.3,7H KELVIN)
220   FORMAT (20X,20HREYNOLDS NUMBER    =,F12.3,18H MILLION PER METER)
230   FORMAT (20X,20HNPR                =,F12.3)
240   FORMAT (1H0,12X,37HJET EXHAUST CONDITIONS AT NOZZLE EXIT)
250   FORMAT (1H1)
      END
      SUBROUTINE BASIC1
C
C           * READ DATA AND SETUP FOR UNIFORM FLOW
C
      COMMON HEDR(8),ISWITCH,IPUNCH,ITERA,ITERMAX,IMACH,ISEP,INT(8),IFLA
     1G5,FLG05,MN,APT,ATT,REFL,SREF,XSEPND,NN,BDN,ND(2),NT,NSIGA,IPRINT,
     2AMJET,PTJET,TTJET,RJET,RSTAR
      COMMON /CL/ X1(200),Y1(200),X2(200),Y2(200),DELS(200),SINA(200),CO
     1SA(200),XP(200),YP(200)
      COMMON /TL/ TX1(200),TY1(200),NG(200),TG(200),ALFA(200),RSDS(200),
     1DALF(200),TEMP(1017)
      INTEGER FLG05,BDN
      REAL MN,NG
C
      REWIND 13
      NT=0
      K=0
      K2=1
      IF (ITERA.GT.ITERMAX) FLG05=IFLAG5
      IF (FLG05.NE.0) K2=2
C
C           * MAJOR LOOP * NO. OF BODIES + OFF BODY POINTS
C
      DO 130 L=1,K2
      IF (FLG05.GT.0.AND.L.GT.1) GO TO 10
      ND(L)=NN
      M=NN-1
      READ (13) BLANK
      READ (13) BLANK
      READ (13) NN,(TX1(I),I=1,NN)
      READ (13) NN,(TY1(I),I=1,NN)
```

APPENDIX

```
      GO TO 20                                                          BAS  32
10    CONTINUE                                                          BAS  33
C                                                                       BAS  34
C               * BASIC DATA CALC. AND PRINT (UNTRANSFORMED COORDINATES) BAS  35
C                                                                       BAS  36
      BDN=0                                                             BAS  37
      READ (5,150) ND(2)                                                BAS  38
      NN=ND(2)                                                          BAS  39
      READ (5,160) (TX1(I),I=1,NN)                                      BAS  40
      READ (5,160) (TY1(I),I=1,NN)                                      BAS  41
      GO TO 50                                                          BAS  42
20    SUMS=0.0                                                          BAS  43
      DO 30 I=1,M                                                       BAS  44
      T1=TX1(I+1)-TX1(I)                                                BAS  45
      T2=TY1(I+1)-TY1(I)                                                BAS  46
      X2(I)=(TX1(I+1)+TX1(I))/2.                                        BAS  47
      Y2(I)=(TY1(I+1)+TY1(I))/2.                                        BAS  48
      DELS(I)=SQRT(T1*T1+T2*T2)                                         BAS  49
      SUMS=SUMS+DELS(I)                                                 BAS  50
      RSDS(I)=SUMS                                                      BAS  51
30    ALFA(I)=ATAN2(T2,T1)                                              BAS  52
      MA=M-1                                                            BAS  53
      DO 40 I=1,MA                                                      BAS  54
40    DALF(I)=(ALFA(I+1)-ALFA(I))*57.2957795                            BAS  55
50    CONTINUE                                                          BAS  56
      IF (MN) 60,80,60                                                  BAS  57
60    SRM=SQRT(1.-MN*MN)                                                BAS  58
      DO 70 I=1,NN                                                      BAS  59
70    TX1(I)=TX1(I)/SRM                                                 BAS  60
C                                                                       BAS  61
C               * SHIFT X1 AND Y1 TO COMMON /CL/                        BAS  62
C                                                                       BAS  63
80    IF (BDN) 110,90,110                                               BAS  64
90    DO 100 I=1,NN                                                     BAS  65
      XP(I)=TX1(I)                                                      BAS  66
100   YP(I)=TY1(I)                                                      BAS  67
      WRITE (12) (XP(I),I=1,NN),(YP(I),I=1,NN)                          BAS  68
      GO TO 130                                                         BAS  69
110   DO 120 I=1,NN                                                     BAS  70
      K=K+1                                                             BAS  71
      X1(K)=TX1(I)                                                      BAS  72
120   Y1(K)=TY1(I)                                                      BAS  73
      NT=NT+M                                                           BAS  74
130   CONTINUE                                                          BAS  75
      REWIND 13                                                         BAS  76
C                                                                       BAS  77
C               * CALC. PARAMETERS WITH TRANSFORMED COORDINATES AND     BAS  78
C                 MACH NO. ADJUSTMENT                                   BAS  79
C                                                                       BAS  80
      J1=0                                                              BAS  81
      N1=ND(1)-1                                                        BAS  82
      DO 140 J=1,N1                                                     BAS  83
      J1=J1+1                                                           BAS  84
      T1=X1(J1+1)-X1(J1)                                                BAS  85
      T2=Y1(J1+1)-Y1(J1)                                                BAS  86
      X2(J)=(X1(J1+1)+X1(J1))/2.                                        BAS  87
      Y2(J)=(Y1(J1+1)+Y1(J1))/2.                                        BAS  88
      DELS(J)=SQRT(T1*T1+T2*T2)                                         BAS  89
      COSA(J)=T1/DELS(J)                                                BAS  90
140   SINA(J)=T2/DELS(J)                                                BAS  91
      J1=J1+1                                                           BAS  92
C                                                                       BAS  93
C               * SAVE PARAMETERS                                       BAS  94
C                                                                       BAS  95
      WRITE (12) (X1(I),I=1,J1),(Y1(I),I=1,J1),(X2(I),I=1,NT),(Y2(I),I=1BAS  96
     1,NT),(DELS(I),I=1,NT)                                             BAS  97
```

```
      REWIND 12
C
C               * SAVE SINA AND COSA ON TAPE 4 FOR CALC, OF MATRIX
C                 SOLUTION (RIGHT HAND MATRIX)
      WRITE (4) (SINA(I),I=1,NT),(COSA(I),I=1,NT)
      RETURN
C
C
150   FORMAT (2I5)
160   FORMAT (6F10,0)
      END
      SUBROUTINE MATRIX
C
C               * COMPUTE MATRIX A,B,Z OR X,Y,Z
C
      COMMON HEDR(8),ISWITCH,IPUNCH,ITERA,ITERMAX,IMACH,ISEP,INT(8),IFLA
     1G5,FLG05,MN,APT,ATT,REFL,SREF,XSEPND,NN,BDN,ND(2),NT,NSIGA,IPRINT,
     2AMJET,PTJET,TTJET,RJET,RSTAR
      COMMON /CL/ X1(200),Y1(200),X2(200),Y2(200),DELS(200),SINA(200),CO
     1SA(200),XP(200),YP(200)
      COMMON /TL/ A(200),B(200),AX(200),AY(200),AZ(200),CX(200),CY(200),
     1CZ(200),AXV(200),AYV(200),VN(200,1),VT(200,1),BON,YZERO,IAC,II,JJ,
     2J1,SJ,DS,DX,DY,NI,XJ,YJ,XK,EEK,EKK,KK
      INTEGER FLG05,BDN
      REAL MN
C
C               * INITIALIZE
      L1=NT
      BON=0,0
      YZERO=0,0
      IAC=1
10    DO 20 I=1,NT
      J=1
      VN(I,J)=0,
20    VT(I,J)=0,
C
C               *  I MIDPOINT LOOP
C
      DO 70 I=1,L1
      II=I
C
C                  J1 IS THE COORDINATE COUNTER
C
      J1=0
      N1=ND(1)-1
      KK=1
      DO 30 J=1,N1
      JJ=J
      J1=J1+1
C
C               * COMPUTE X,Y,Z MATRICES
C
      CALL XYZ
30    CONTINUE
      J1=J1+1
      IF (BON) 40,50,40
C
C               * SAVE X,Y,Z ON TAPE *OFF BODY POINTS
C
40    WRITE (9) (AX(J),J=1,NT),(AY(J),J=1,NT),(AZ(J),J=1,NT)
      GO TO 70
C
C               * SAVE A,B,Z ON TAPE *ON BODY
C
50    DO 60 J=1,NT
      A(J)=-AX(J)*SINA(I)+AY(J)*COSA(I)
```

```
60    B(J)=AX(J)*COSA(I)+AY(J)*SINA(I)                                  MAT   56
      WRITE (9) (A(J),J=1,NT),(B(J),J=1,NT),(AZ(J),J=1,NT)              MAT   57
70    CONTINUE                                                          MAT   58
C                                                                       MAT   59
C               * TEST IF OFF BODY COMPLETED                            MAT   60
C               * TEST IF OFF BODY                                      MAT   61
C                                                                       MAT   62
      IF (FLG05.EQ.0.OR.BON.NE.0.) GO TO 90                             MAT   63
C                                                                       MAT   64
C               * INITIAL FOR OFF BODY * THEN RE-ENTER I,J LOOPS        MAT   65
C                                                                       MAT   66
      BON=1.                                                            MAT   67
      L1=ND(2)                                                          MAT   68
      DO 80 I=1,L1                                                      MAT   69
      X2(I)=XP(I)                                                       MAT   70
80    Y2(I)=YP(I)                                                       MAT   71
      GO TO 10                                                          MAT   72
90    REWIND 9                                                          MAT   73
      REWIND 4                                                          MAT   74
      RETURN                                                            MAT   75
      END                                                               MAT   76-
      SUBROUTINE XYZ                                                    XYZ    1
C                                                                       XYZ    2
C               * CONTROL FOR X,Y,Z MATRICES COMPUTATION                XYZ    3
C                                                                       XYZ    4
      COMMON HEDR(8),ISWITCH,IPUNCH,ITERA,ITERMAX,IMACH,ISEP,INT(8),IFLAXYZ    5
     1G5,FLG05,MN,APT,ATT,REFL,SREF,XSEPND,NN,BON,ND(2),NT,NSIGA,IPRINT,XYZ    6
     2AMJET,PTJET,TTJET,RJET,RSTAR                                      XYZ    7
      COMMON /CL/ X1(200),Y1(200),X2(200),Y2(200),DELS(200),SINA(200),COXYZ    8
     1SA(200),XP(200),YP(200)                                           XYZ    9
      COMMON /TL/ A(200),B(200),AX(200),AY(200),AZ(200),CX(200),CY(200),XYZ   10
     1CZ(200),AXV(200),AYV(200),VN(200,1),VT(200,1),BON,YZERO,IAC,I,J,J1XYZ   11
     2,SJ,DS,DX,DY,NI,XJ,YJ,XK,EEK,EKK,K                                XYZ   12
      INTEGER FLG05,BDN                                                 XYZ   13
      REAL MN                                                           XYZ   14
C                                                                       XYZ   15
      IF (BON) 50,10,50                                                 XYZ   16
10    IF (J-I) 60,20,60                                                 XYZ   17
C                                                                       XYZ   18
C               * J EQUAL I PATH                                        XYZ   19
C                                                                       XYZ   20
20    T1=.5*DELS(J)                                                     XYZ   21
      SJ=T1/Y2(J)                                                       XYZ   22
      IF (SJ-.08) 30,30,40                                              XYZ   23
30    CALL XYZ1                                                         XYZ   24
      GO TO 190                                                         XYZ   25
40    SJ=.08                                                            XYZ   26
      CALL XYZ1                                                         XYZ   27
      NI=33                                                             XYZ   28
      T2=.08*Y2(J)                                                      XYZ   29
      DS=(T1-T2)/32.                                                    XYZ   30
      DX=DS*COSA(J)                                                     XYZ   31
      DY=DS*SINA(J)                                                     XYZ   32
      XJ=X2(J)+T2*COSA(J)-DX                                            XYZ   33
      YJ=Y2(J)+T2*SINA(J)-DY                                            XYZ   34
      CALL XYZ2                                                         XYZ   35
      GO TO 180                                                         XYZ   36
C                                                                       XYZ   37
C               * INITIAL Y COORDINATE MID-POINT FOR ZERO TEST          XYZ   38
C                                                                       XYZ   39
50    YZERO=Y2(I)-.000001                                               XYZ   40
C                                                                       XYZ   41
C               * J NOT EQUAL I PATH                                    XYZ   42
C               * COMPUTE MINIMUM DISTANCE TO I MIDPOINT                XYZ   43
C                                                                       XYZ   44
60    D1=(X2(I)-X1(J1))**2+(Y2(I)-Y1(J1))**2                            XYZ   45
```

```
      D2=(X2(I)-X2(J))**2+(Y2(I)-Y2(J))**2
      D3=(X2(I)-X1(J1+1))**2+(Y2(I)-Y1(J1+1))**2
      IF (D1-D2) 80,80,70
70    IF (D2-D3) 100,100,90
80    IF (D1-D3) 110,110,90
90    DM=SQRT(D3)
      GO TO 120
100   DM=SQRT(D2)
      GO TO 120
110   DM=SQRT(D1)
C
C                 * COMPUTE NO. OF INTERVALS(NI) AND DELTA S (DS)
C                   FOR SIMPSON RULE INTEGRATION
C
120   IF (DM.EQ.0.0) GO TO 150
      NI=8.*DELS(J)/DM+0.9
      IF (NI) 130,130,140
130   NI=3
      DS=DELS(J)/2.
      GO TO 170
140   NI=NI+NI
      IF (NI-128) 160,150,150
150   NI=129
      DS=DELS(J)/128.
      GO TO 170
160   XNI=NI
      DS=DELS(J)/XNI
      NI=NI+1
170   DX=DS*COSA(J)
      DY=DS*SINA(J)
180   XJ=X1(J1)-DX
      YJ=Y1(J1)-DY
      CALL XYZ2
190   RETURN
      END
      SUBROUTINE XYZ1
C
C                 * COMPUTE X,Y,Z MATRICES FOR SJ LESS THAN OR EQUAL .08
C
      COMMON HEDR(8),ISWITCH,IPUNCH,ITERA,ITERMAX,IMACH,ISEP,INT(8),IFLA
     1G5,FLG05,MN,APT,ATT,REFL,SREF,XSEPND,NN,BDN,ND(2),NT,NSIGA,IPRINT,
     2AMJET,PTJET,TTJET,RJET,RSTAR
      COMMON /CL/ X1(200),Y1(200),X2(200),Y2(200),DELS(200),SINA(200),CO
     1SA(200),XP(200),YP(200)
      COMMON /TL/ A(200),B(200),AX(200),AY(200),AZ(200),CX(200),CY(200),
     1CZ(200),AXV(200),AYV(200),VN(200,1),VT(200,1),BON,YZERO,IAC,I,J,J1
     2,SJ,DS,DX,DY,NI,XJ,YJ,XK,EEK,EKK,K
      INTEGER FLG05,BDN
      REAL MN
C
C                 * INITIALIZE
C
      T1=SJ*SJ
      T2=ALOG(SJ/8.)
      T3=SINA(J)*SINA(J)
      T4=T2+T3
      T5=.666666667*T3
      T6=T5*T3
      T7=SJ+SJ
      T8=T7+T7
      T9=6.2831853*COSA(J)
      T10=6.2831853*SINA(J)
      T11=T1*SJ
C
C                 * AXIS FLOW
C
```

```
10    AX(J)=T10+SINA(J)*COSA(J)*(T7+(T4+2.16666667)*T11/12.)
      AX(J)=T10+SINA(J)*COSA(J)*(T7+(T4+2.16666667)*T11/12.)
      AY(J)=T7*T4-T9-(1.+T2-T3-T6)*T11/8.
      T12=T1+T1
      AZ(J)=Y2(J)*T8*(1.-T2+T1*(2.-T12+3.*T2*(1.+T12))/144.)
      RETURN
      END
      SUBROUTINE XYZ2
C
C                * COMPUTE X,Y,Z MATRICES USING SIMPSON RULE INTEGRATION
C
      COMMON HEDR(8),ISWITCH,IPUNCH,ITERA,ITERMAX,IMACH,ISEP,INT(8),IFLA
     1G5,FLG05,MN,APT,ATT,REFL,SREF,XSEPND,NN,BDN,ND(2),NT,NSIGA,IPRINT,
     2AMJET,PTJET,TTJET,RJET,RSTAR
      COMMON /CL/ X1(200),Y1(200),X2(200),Y2(200),DELS(200),SINA(200),CO
     1SA(200),XP(200),YP(200)
      COMMON /TL/ A(200),B(200),AX(200),AY(200),AZ(200),CX(200),CY(200),
     1CZ(200),AXV(200),AYV(200),VN(200,1),VT(200,1),BON,YZERO,IAC,I,J,J1
     2,SJ,DS,DX,DY,NI,XJ,YJ,XK,EEK,EKK,K
      INTEGER FLG05,BDN
      REAL MN
C
C                * INITIALIZE
C
10    S2=.666666667*DS
      S4=S2+S2
      T1=Y2(I)*Y2(I)
C
C                * NO. OF INTERVAL LOOP
C
      DO 130 IS=1,NI
      XJ=XJ+DX
      YJ=YJ+DY
      T2=YJ*YJ
      T3=X2(I)-XJ
      T4=T3*T3
      T5=(Y2(I)+YJ)**2
      T6=T4+T5
      T7=SQRT(T6)
      T8=T2+T4
      T9=(Y2(I)-YJ)**2
      T10=T9+T4
C
C                * COMPUTE ELLIPIC INTEGRAL
C
      XK=4.*YJ*Y2(I)/T6
      CALL ELIP
C
C                * AXIS FLOW
C
      T11=YJ/T7
      IF (Y2(I).EQ.0.) GO TO 20
      T12=YJ/Y2(I)
      FV2=(EKK+EEK*(T1-T8)/T10)/T7
      FV3=Y2(I)/T10*T3/T7*EEK
      F1=FV3*T12
      F2=FV2*T12
      FV4=FV2*T3/Y2(I)
      GO TO 30
20    FV2=0.
      FV3=0.
      FV4=0.
      F2=0.
      F1=T11/T10*T3*EEK
30    F3=T11*EKK
C
```

```
C                * SIMPSON RULE INTEGRATION
C
      IF (IS-1) 40,40,50
C
C                * FIRST PASS
C
40    AXS=F1
      AYS=F2
      AZS=F3
      IA=0
      GO TO 120
50    IF (IS-NI) 60,90,60
60    IF (IA) 80,70,80
C
C                * EVEN PASS
C
70    AXS=AXS+4.*F1
      AYS=AYS+4.*F2
      AZS=AZS+4.*F3
      IA=1
      GO TO 120
C
C                * ODD PASS
C
80    AXS=AXS+F1+F1
      AYS=AYS+F2+F2
      AZS=AZS+F3+F3
      IA=0
      GO TO 120
C
C                * LAST PASS
C
90    IF (J-I) 110,100,110
100   IF (BON.NE.0.0) GO TO 110
      AX(J)=AX(J)-S4*(AXS+F1)
      AY(J)=AY(J)-S2*(AYS+F2)
      AZ(J)=AZ(J)+S4*(AZS+F3)
      GO TO 120
110   AX(J)=-S4*(AXS+F1)
      AY(J)=-S2*(AYS+F2)
      AZ(J)=S4*(AZS+F3)
120   CONTINUE
130   CONTINUE
      RETURN
      END
      SUBROUTINE ELIP
C
C                * HASTINGS APPROXIMATION FOR ELLIPTIC INTEGRALS
C
      COMMON /TL/ A(200),B(200),AX(200),AY(200),AZ(200),CX(200),CY(200),
     1CZ(200),AXV(200),AYV(200),VN(200,1),VT(200,1),BON,YZERO,IAC,I,J,J1
     2,SJ,DS,DX,DY,NI,XJ,YJ,XK,EEK,EKK,K
C
10    ETA=1.-XK
      IF (ETA) 20,20,30
20    WRITE (6,40) ETA
      CALL EXIT
30    ELN=ALOG(ETA)
      EKK=1.38629436112+ETA*(0.09666344259+ETA*(0.03590092383+ETA*(0.037
     114256371 3+ETA*0.01451196212)))-ELN*(0.5+ETA*(0.12498593597+ETA*(0.0
     226880248576+ETA*(0.03328355346+ETA*0.00441787012))))
      EEK=1.+ETA*(0.44325141463+ETA*(0.06260601220+ETA*(0.04757383546+ET
     1A*0.01736506451)))-ELN*(ETA*(0.24998368310+ETA*(0.09200180037+ETA*
     2(0.04069697526+ETA*0.00526449639))))
      RETURN
C
```

```
40    FORMAT (1H136H,27H* ERROR IN SUBROUTINE ELIP ,ETA=F15.8)
      END
      OVERLAY(LINK,2,0)
      PROGRAM TWO
C
C              * COMPUTE SOURCE DENSITY SIGMA BY SIEDEL ITERATION
C
      COMMON HEDR(8),ISWITCH,IPUNCH,ITERA,ITERMAX,IMACH,ISEP,INT(8),IFLA
     1G5,FLG05,MN,APT,ATT,REFL,SREF,XSEPND,NN,BDN,ND(2),NT,NSIGA,IPRINT,
     2AMJET,PTJET,TTJET,RJET,RSTAR
      COMMON /C2/ A(200),R(200),NSIG,IT
      DIMENSION ASIG(200,1)
      INTEGER FLG05,BDN
      REAL MN
C
C              * AXIS FLOW
C
      READ (4) (R(I),I=1,NT)
10    REWIND 4
      IT=9
      NSIG=NSIGA
C
C              * SOLVE SIMULTANEOUS EQUATIONS FOR SIGMAS
C
      CALL MISNA2 (ASIG)
      REWIND 9
C
C              * WRITE SIGMAS ON TAPE 3
C
      WRITE (3) (ASIG(I,1),I=1,NT)
      END
      SUBROUTINE MISNA2 (SIG)
C
C              * SOLVE LINEAR SIMULTANEOUS EQUATIONS BY SEIDEL ITERATION
C
      COMMON HEDR(8),ISWITCH,IPUNCH,ITERA,ITERMAX,IMACH,ISEP,INT(8),IFLA
     1G5,FLG05,MN,APT,ATT,REFL,SREF,XSEPND,NN,BDN,ND(2),NT,NSIGA,IPRINT,
     2AMJET,PTJET,TTJET,RJET,RSTAR
      COMMON /C2/ A(200),R(200),NSIG,IT
      DIMENSION SIG(200,1), KFLAG(1), DSIG1(1), DSIG(200,1)
      INTEGER FLG05,BDN
      REAL MN
C
C              * INITIALIZE
C
10    NTU=0
      ITER=0
      NCONV=0
      DO 20 J=1,NSIG
      KFLAG(J)=0
      DO 20 I=1,NT
20    SIG(I,J)=0.0
30    DO 40 I=1,NSIG
40    DSIG1(I)=0.0
C
C              * COMPUTE SIGMA AND DELTA SIGMA
C
      DO 100 I=1,NT
      IF (NTU-3) 50,60,70
C
C              * PLACE A IN LEFT SIDE MATRIX
C
50    READ (9) (A(L),L=1,NT)
C
C              * SAVE LEFT SIDE MATRIX
C
```

```
      WRITE (3) (A(L),L=1,NT)
      WRITE (11) (A(L),L=1,NT)
      GO TO 80
C
C              * READ LEFT SIDE MATRIX
C
60    READ (3) (A(L),L=1,NT)
      GO TO 80
70    READ (11) (A(L),L=1,NT)
80    DO 100 J=1,NSIG
      IF (KFLAG(J).NE.0) GO TO 100
      SUM=0.0
      DO 90 L=1,NT
90    SUM=SUM+A(L)*SIG(L,J)
      DSIG(I,J)=(R(I)-SUM)/A(I)
      SIG(I,J)=SIG(I,J)+DSIG(I,J)
      IF (ABS(DSIG(I,J)).GT.DSIG1(J)) DSIG1(J)=ABS(DSIG(I,J))
100   CONTINUE
C
C              * TEST FOR SOLUTION
C
      REWIND 3
      REWIND 11
      ITER=ITER+1
      DO 110 J=1,NSIG
      IF (KFLAG(J).NE.0) GO TO 110
      IF (DSIG1(J).GE.1.E-6) GO TO 110
      KFLAG(J)=ITER
      NCONV=NCONV+1
      IF (NCONV.EQ.NSIG) GO TO 130
110   CONTINUE
      IF (ITER.EQ.100) GO TO 130
      IF (NTU.EQ.3) GO TO 120
      NTU=3
      GO TO 30
120   NTU=11
      GO TO 30
C
C              * PRINT NO. OF ITERATIONS
C
130   DO 150 J=1,NSIG
      IF (KFLAG(J).NE.0) GO TO 140
      WRITE (6,160) ITERA
      GO TO 150
140   WRITE (6,170) ITERA,KFLAG(J)
150   CONTINUE
      RETURN
C
C
160   FORMAT (1H0,10HFOR ITERA=,I3,46H NO CONVERGENCE IN MISNA2 AFTER 10
     10 ITERATIONS)
170   FORMAT (1H0,10HFOR ITERA=,I3,I5,46H ITERATIONS REQUIRED FOR CONVER
     1GENCE IN MISNA2)
      END
      OVERLAY(LINK,3,0)
      PROGRAM THREE
C
C              * COMPUTE VELOCITY COMPONENTS AND PRINT
C
      COMMON HEDR(8),ISWITCH,IPUNCH,ITERA,ITERMAX,IMACH,ISEP,INT(8),IFLA
     1GS,FLGOS,MN,APT,ATT,REFL,SREF,XSEPND,NN,BDN,ND(2),NT,NSIGA,IPRINT,
     2AMJET,PTJET,TTJET,RJET,RSTAR
      COMMON /C4/ X1(200),Y1(200),X2(200),Y2(200),DELS(200),SINA(200),CO
     1SA(200),XP(200),YP(200)
      COMMON /TC/ RB(200,2),SIG(200,1),A(200),B(200),Z(200),PHI(200,1),X
     1N(200,1),T(200,1),TS(200,1),NSIG,NP,NI,SUMV,SUMM(4)
```

```
      INTEGER FLG05,BDN
      REAL MN
C
      REWIND 3
      IF (FLG05.EQ.0) GO TO 10
C
C              * READ OFF-BODY XP,YP
C
      NP=ND(2)
      READ (12) (XP(I),I=1,NP),(YP(I),I=1,NP)
C
C              * READ X1,Y1,X2,Y2,DELS WITH MACH NO. ADJUSTMENT IF ANY
C
10    NI=NT+1
      READ (12) (X1(I),I=1,NI),(Y1(I),I=1,NI),(X2(I),I=1,NT),(Y2(I),I=1,
     1NT),(DELS(I),I=1,NT)
C
C              * READ SINA,COSA,NO,TO,..
C
      READ (4) (A(I),I=1,NT),(B(I),I=1,NT)
      SUMV=0.0
      DO 20 I=1,NT
      SINA(I)=A(I)
      COSA(I)=B(I)
20    SUMV=SUMV+B(I)*DELS(I)*Y2(I)**2
      SUMV=SUMV*3.14159265
      L=1
      DO 30 I=1,NT
      RB(I,L)=A(I)
30    RB(I,L+1)=B(I)
      REWIND 4
      NSIG=NSIGA
      CALL AXIS
      REWIND 13
      BLANK=0.0
      READ (13) DUMMY
      READ (13) DUMMY
      WRITE (13) NN,BLANK,(X2(I),I=1,199)
      WRITE (13) NN,BLANK,(Y2(I),I=1,199)
      WRITE (13) BLANK,(T3(I,1),I=1,199)
      END
      SUBROUTINE AXIS
C
C              * COMPUTE AXISYMMETRIC VELOCITY COMPONENTS AND PRINT
C
      COMMON HEDR(8),ISWITCH,IPUNCH,ITERA,ITERMAX,IMACH,ISEP,INT(8),IFLA
     1G5,FLG05,MN,APT,ATT,REFL,SREF,XSEPND,NN,BDN,ND(2),NT,NSIGA,IPRINT,
     2AMJET,PTJET,TTJET,RJET,RSTAR
      COMMON /C4/ X1(200),Y1(200),X2(200),Y2(200),DELS(200),SINA(200),CO
     1SA(200),XP(200),YP(200)
      COMMON /TC/ RB(200,2),SIG(200,1),A(200),B(200),Z(200),PHI(200,1),X
     1N(200,1),T(200,1),T3(200,1),INSIG,INP,NI,SUMV,SUMM(4)
      DIMENSION VX(200,1), VY(200,1), VT(200,1), TH(200,1), CP(200,1), S
     1UMTDS(4)
      EQUIVALENCE (VX,XN), (VY,T), (VT,T3), (TH,SIG), (CP,T3)
      REAL MN
      INTEGER FLG05,BDN
C
      NC=NT
      N=1
      NP=INP
C
C              * READ AXIS SIGMAS
C
      SUMM(N)=0.0
      SUMTDS(N)=0.0
```

```
      READ (3) (SIG(I,N),I=1,NC)
C
C              * NO. OF MIDPOINTS LOOP
C
      DO 20 I=1,NT
C
C              * READ MATRICES A,B,Z
C
      READ (9) (A(J),J=1,NT),(B(J),J=1,NT),(Z(J),J=1,NT)
C
C              * NO. OF FLOWS LOOP
C
      N1=0
      N1=N1+2
      SN=0.0
      ST=0.0
      SP=0.0
C
C              * NO. OF ELEMENTS LOOP
C
      DO 10 J=1,NT
      SN=SN+A(J)*SIG(J,N)
      ST=ST+B(J)*SIG(J,N)
10    SP=SP+Z(J)*SIG(J,N)
      XN(I,N)=SN-RB(I,N1-1)
      PHI(I,N)=SP
      T(I,N)=ST+RB(I,N1)
      SUMM(N)=SUMM(N)+PHI(I,N)*Y2(I)*RB(I,N1-1)*DELS(I)
      CP(I,N)=1.-T(I,N)**2
20    CONTINUE
      IF (MN.EQ.0.0) GO TO 60
C
C              * MACH NO. ADJUSTMENT
C
      D1=MN*MN
      D2=1.-D1
      D3=SQRT(D2)
      D4=.7*D1
      D5=.2*D1
      DO 30 I=1,NT
      IF (IMACH.LT.2) BB=D2
      IF (IMACH.GE.2) BB=1.-MN**2*T(I,N)*COSA(I)
      IF (BB.LE.0.0) GO TO 160
      TX=(T(I,N)*COSA(I)-1.)/BB+1.
      TY=T(I,N)*SINA(I)*D3/BB
      T(I,N)=SQRT(TX*TX+TY*TY)
      CP(I,N)=((1.+D5*(1.-T(I,N)**2))**3.5-1.)/D4
30    CONTINUE
      D2=1.-D1
      D3=SQRT(D2)
C
C              * ELIMINATE MACH NO EFFECT FOR PRINTOUT
C
      DO 40 I=1,NI
40    X1(I)=X1(I)*D3
      J1=0
      M=ND(1)-1
      DO 50 J=1,M
      J1=J1+1
      T1=X1(J1+1)-X1(J1)
      T2=Y1(J1+1)-Y1(J1)
      X2(J)=(X1(J1+1)+X1(J1))/2.
      DELS(J)=SQRT(T1*T1+T2*T2)
      COSA(J)=T1/DELS(J)
50    SINA(J)=T2/DELS(J)
      J1=J1+1
```

```
60    CONTINUE
      IF (FLGOS.EQ.0) RETURN
C
C              * OFF-BODY POINT
C
      DO 80 I=1,NP
C
C              * READ MATRICES X,Y,Z
C
      READ (9) (A(J),J=1,NT),(B(J),J=1,NT),(Z(J),J=1,NT)
C
C              * NO. OF FLOW
C
      SX=0.0
      SY=0.0
      SP=0.0
C
C              * NO. OF ELEMENTS LOOP
C
      DO 70 J=1,NT
      SX=SX+A(J)*SIG(J,N)
      SY=SY+B(J)*SIG(J,N)
70    SP=SP+Z(J)*SIG(J,N)
      PHI(I,N)=SP
      VX(I,N)=SX+1.
      VY(I,N)=SY
80    CONTINUE
      IF (MN.EQ.0.0) GO TO 110
C              * MACH NO. ADJUSTMENT
      DO 90 I=1,NP
      BB=D2
C
C       LABRUJERE COMPRESSIBILITY CORRECTION
C
      IF (IMACH.GE.2) BB=1.-MN**2*VX(I,N)
      VY(I,N)=VY(I,N)*D3/BB
      VX(I,N)=(VX(I,N)-1.)/BB+1.
90    CONTINUE
      DO 100 I=1,NP
100   XP(I)=XP(I)*D3
C
C              * COMPUTE VT AND THETA
C
110   CONTINUE
      DO 120 I=1,NP
      VT(I,N)=SQRT(VX(I,N)**2+VY(I,N)**2)
120   TH(I,N)=ATAN2(VY(I,N),VX(I,N))*57.2957795
C
C              * PRINT AXIS FLOW (OFF-BODY) OUTPUT
C
      L=1
      I=1
      LCTR=45
130   WRITE (6,170) HEDR
      WRITE (6,180)
      WRITE (6,190)
140   CONTINUE
      CP2=((1.+D5*(1.-VT(I,L)**2))**3.5-1.)/D4
      XM2=VT(I,L)*MN/SQRT(1.-D5*(VT(I,L)**2-1.))
      WRITE (6,210) I,XP(I),YP(I),VX(I,L),VY(I,L),VT(I,L),TH(I,L),XM2,CP
     12
      I=I+1
      IF (I.GT.NP) GO TO 150
      IF (I.LE.LCTR) GO TO 140
      LCTR=LCTR+45
      GO TO 130
```

```
150   CONTINUE
      RETURN
160   WRITE (6,200)
      STOP
C
C
C
170   FORMAT (1H1,25X,23HPOTENTIAL FLOW SOLUTION///6X,8A10//)
180   FORMAT (1X,35H OFF-BODY UNIFORM AXISYMMETRIC FLOW)
190   FORMAT (1X//10X,3HX/L,9X,3HR/L,10X,2HVX,10X,2HVR,10X,2HVT,9X,3HETA
     1,10X,2HML,10X,2HCP//)
200   FORMAT (1X////1X,73HFREESTREAM MACH NUMBER TOO LARGE FOR LABRUJERE
     1 COMPRESSIBILITY CORRECTION/1X,62HRESUBMIT USING IMACH=1 FOR GOETH
     2ERT COMPRESSIBILITY CORRECTION)
210   FORMAT (1X,I3,8F12.6)
      END
      OVERLAY(LINK,5,0)
      PROGRAM FIVE
C
C     VISCOUS FLOW/POTENTIAL FLOW INTERFACE PROGRAM
C
      COMMON HEDR(8),ISWITCH,IPUNCH,ITERA,ITERMAX,IMACH,ISEP,INT(8),IFLA
     1G5,FLG05,MO,APT,ATT,REFL,SREF,XSEPND,NN,BDN,ND(2),NT,NSIGA,IPRINT,
     2AMJET,PTJET,TTJET,RJET,RSTAR
      COMMON /SAVE/ VDUM(402),RDS(201),XIN,VDUM2(347)
      DIMENSION X(200), R(200), CP(200), ME(200), THETA(200), CAPH(200),
     1 CF(200), CAPHI(200), CDF(200), CDP(200), CDT(200), RCPUNCH(200),
     2XO(200), RO(200), CS(200), RI(200), UI(200), DELI(200), RET(200),
     3TAW51(200), PTPT(200), FNN(200), DELTA(200), FLOT(15), FLOTO(7)
      INTEGER FLG05,BDN
      REAL MO,ME
C
C     INITIALIZE
C
      G=1.4
      G1=(G-1.)/2.
      G2=G/(G-1.)
      G3=1./(G-1.)
      G4=(G+1.)/2.
      G5=G4*G3
      G6=G4/G1
      TT=ATT
      PT=APT
      ME(1)=0.0
      THETA(1)=0.0
      CAPH(1)=1.3
      CAPHI(1)=1.3
      CF(1)=0.0
C
C     READ XO,RO,X,R,AND CP FROM TAPE13
C
      REWIND 13
      READ (13) NXO,(XO(I),I=1,NXO)
      READ (13) NXO,(RO(I),I=1,NXO)
      READ (13) NUM,(X(I),I=1,NUM)
      READ (13) NUM,(R(I),I=1,NUM)
      READ (13) CP
C
C     OBTAIN CP AND R AT ORIGINAL X
C
      NTAB=1
      IORDER=2
      IPT=-1
      DO 10 I=2,NUM
      CALL IUNI (200,NUM,X,NTAB,CP,IORDER,XO(I),CS(I),IPT,IERR)
10    CONTINUE
```

APPENDIX

```
      DO 20 I=2,NUM
      CP(I)=CS(I)
      R(I)=RO(I)
      X(I)=XO(I)
20    CONTINUE
      REWIND 13
      DO 30 J=1,NUM
      IF (ITERA.EQ.0) RDS(J)=R(J)
      X(J)=X(J)*REFL
      R(J)=R(J)*REFL
      RDS(J)=RDS(J)*REFL
30    CONTINUE
      DO 40 I=1,NXO
      XO(I)=XO(I)*REFL
      RO(I)=RO(I)*REFL
40    CONTINUE
C
C     CALCULATE FREE STREAM CONDITIONS
C
      PO=PT*(1.+G1*MO**2)**(-G2)
      QINF=G/2.*PO*MO**2
      RG=286.96
      PI=3.1415926
      CP(1)=(PT-PO)/(0.5*PO*G*MO**2)
C
C     CALCULATE PLUME BOUNDARY AND VELOCITY
C     USING ONE DIMENSIONAL METHOD
C
      DO 50 I=1,200
      UI(I)=0.0
      RI(I)=0.0
50    CONTINUE
      IT=INT(6)
      NJ=NUM-IT+1
      IF (INT(5).EQ.0) GO TO 90
      RJET=RJET*REFL
      K=0
      DO 80 I=IT,NUM
      K=K+1
      PE=QINF*CP(I)+PO
      PRAT=PTJET/PE
      IF (I.GT.IT) GO TO 70
      PCRIT=(1.0+G1*AMJET**2)**G2
      IF (PRAT.GT.PCRIT) GO TO 60
      RSTAR=PRAT**(-1./G)*SQRT(G4**G6/G1*(1.-PRAT**(-1./G2)))
      RSTAR=SQRT(RSTAR)*RJET
      GO TO 70
60    ASTAR=G4**G5*AMJET/(1.+G1*AMJET**2)**G5
      RSTAR=SQRT(ASTAR)*RJET
70    XME=SQRT((PRAT**(1./G2)-1.)/G1)
      ASOA=G4**G5*XME/(1.+G1*XME**2)**G5
      IF (I.GT.IT) R(I)=RSTAR/SQRT(ASOA)
      UI(K)=XME*SQRT(G*RG*TTJET/(1.+G1*XME**2))
      RI(K)=R(I)
80    CONTINUE
      RJET=RJET/REFL
90    CONTINUE
C
C     PREPARE INPUT TO SUBROUTINE VISCOUS
C
      INT(1)=NUM
      INT(2)=1
      INT(8)=ISEP-2
      FLOT(1)=12.
      FLOT(2)=0
      FLOT(3)=PT/FLOT(1)**2/47.880258
```

```
      FLOT(4)=TT*1.8
      FLOT(5)=MO
      FLOT(6)=ITERA+1
      FLOT(7)=G
      FLOT(8)=CAPHI(INT(2))
      FLOT(9)=THETA(INT(2))*FLOT(1)/.3048
      FLOT(10)=IPRINT
      FLOT(11)=UI(1)*FLOT(1)/.3048
      FLOT(12)=0.25
      FLOT(13)=0.0
      FLOT(14)=0.0
      FLOT(15)=XSEPND*REFL*FLOT(1)/.3048
      IF (ITERA.EQ.0) XIN=X(NUM)
      IF (INT(7).GT.0) CALL SMINT (X,CP,NUM,INT(3),NUM)
      XIN=XIN*FLOT(1)/.3048
      DO 100 I=1,NUM
      X(I)=X(I)*FLOT(1)/.3048
      R(I)=R(I)*FLOT(1)/.3048
      RDS(I)=RDS(I)*FLOT(1)/.3048
100   CONTINUE
      DO 110 K=1,NJ
      RI(K)=RI(K)*FLOT(1)/.3048
      UI(K)=UI(K)*FLOT(1)/.3048
110   CONTINUE
      CALL VISCUS (INT,FLOT,X,R,CP,RI,UI,FLOTO,RCPUNCH,ME,THETA,DELTA,CA
     1PH,CF,DELI,CAPHI,RET,TAW51,PTPT,FNN)
C
C     CHANGE OUTPUT FROM VISCOUS TMETERS
C
      FLOTO(7)=FLOTO(7)/FLOT(1)*.3048
      XIN=XIN/FLOT(1)*.3048
      DO 120 I=1,NUM
      X(I)=X(I)/FLOT(1)*.3048
      R(I)=R(I)/FLOT(1)*.3048
      RDS(I)=RDS(I)/FLOT(1)*.3048
      RCPUNCH(I)=RCPUNCH(I)/FLOT(1)*.3048
      THETA(I)=THETA(I)/FLOT(1)*.3048
      DELTA(I)=DELTA(I)/FLOT(1)*.3048
      DELI(I)=DELI(I)/FLOT(1)*.3048
120   CONTINUE
      DO 130 K=1,NJ
      UI(K)=UI(K)/FLOT(1)*.3048
130   CONTINUE
      QS=QINF*SREF
C
C     CALCULATION OF DRAG COEFFICIENTS
C
      CDF(1)=0.0
      CDP(1)=0.0
      CDT(1)=0.0
      ROLD=0.0
      QOLD=0.0
      DO 140 J=2,NUM
      PE=PO*(1.+G/2.*MO**2*CP(J))
      QNEW=G/2.*PE*ME(J)**2
      RNEW=RO(J)
      ANGLE=ATAN((RNEW-ROLD)/(X(J)-X(J-1)))
      SL=PI*(RNEW+ROLD)*SQRT((RNEW-ROLD)**2+(X(J)-X(J-1))**2)
      CDF(J)=(CF(J)+CF(J-1))*(QNEW+QOLD)*SL*COS(ANGLE)/QS/4.+CDF(J-1)
      CDP(J)=PI/SREF*(RNEW*CP(J)+ROLD*CP(J-1))*(RNEW-ROLD)+CDP(J-1)
      CDT(J)=CDP(J)+CDF(J)
      ROLD=RNEW
      QOLD=QNEW
140   CONTINUE
C
C     OUTPUT   DATA
```

```
C
      DO 150 N=1,NUM
      X(N)=X(N)/REFL
      R(N)=R(N)/REFL
      THETA(N)=THETA(N)/REFL
      DELTA(N)=DELTA(N)/REFL
      RCPUNCH(N)=RCPUNCH(N)/REFL
      RDS(N)=RDS(N)/REFL
      DELI(N)=DELI(N)/REFL
150   CONTINUE
      IF (ITERA.LT.IPRINT) GO TO 170
      FLOTO(7)=FLOTO(7)/REFL
      XINND=XIN/REFL
      N1=1
160   N2=N1+34
      IF (N2.GE.NUM) N2=NUM
      WRITE (6,200) HEDR,ITERA,MO,TT,PT,REFL,SREF
      PRINT 210, FLOTO(7),XINND
      WRITE (6,220)
      WRITE (6,230) (X(N),R(N),CP(N),CF(N),CDP(N),CDF(N),CDT(N),RDS(N),R
     1CPUNCH(N),DELTA(N),DELI(N),THETA(N),CAPH(N),N=N1,N2)
      IF (N2.GE.NUM) GO TO 170
      N1=N2+1
      GO TO 160
170   CONTINUE
      REWIND 13
      READ (13) BLANK
      READ (13) BLANK
      NN=NUM
      WRITE (13) NN,(X(I),I=1,NN)
      WRITE (13) NN,(RCPUNCH(I),I=1,NN)
      WRITE (13) CP
C
C     WRITE DATA ON TAPE 7 FOR RESTART
C
      IF (IPUNCH.LT.1) GO TO 190
      IF (ITERA.NE.ITERMAX) GO TO 190
      DO 180 I=1,NXO
      XO(I)=XO(I)/REFL
      RO(I)=RO(I)/REFL
180   CONTINUE
      IDM=ITERMAX+1
      REWIND 7
      WRITE (7,270) HEDR
      WRITE (7,240) ISWITCH,IPRINT,IPUNCH,IDM,IDM,IMACH,ISEP,(INT(I),I=2
     1,7),IFLAGS
      WRITE (7,280) MO,APT,ATT,REFL,SREF,XSEPND
      WRITE (7,280) AMJET,PTJET,TTJET,RJET
      WRITE (7,240) NN
      WRITE (7,290) (XO(I),I=1,NN)
      WRITE (7,300) (RO(I),I=1,NN)
      WRITE (7,250) (RCPUNCH(I),I=1,NN)
      WRITE (7,260) (CP(I),I=1,NN)
190   CONTINUE
C
C
200   FORMAT (1H1,8A10,5X,14HITERATION NO  ,I2//2X,4HMO =,F7.4,4X,4HTT =
     1,F7.2,7H KELVIN,4X,4HPT =,F10.1,8H PASCALS,4X,3HL =,F10.6,7H METER
     2S,4X,6HSREF =,F10.6,10H SQ METERS//)
210   FORMAT (4X,34HBOUNDARY LAYER SEPARATION AT X/L =,F10.6,12X,36HBOUN
     1DARY LAYER REATTACHMENT AT X/L =,F10.6,//)
220   FORMAT (5X,3HX/L,5X,3HR/L,5X,2HCP,6X,2HCF,6X,3HCDP,5X,3HCDF,5X,3HC
     1DT,4X,5HRDS/L,4X,4HRC/L,2X,6HDEL*/L,3X,5HDEL/L,2X,7HTHETA/L,3X,1HH
     2/)
230   FORMAT (1X,13F8.4)
240   FORMAT (16I5)
```

```
250   FORMAT (6F10.6,4X,2HRC)                                           FIV 248
260   FORMAT (6F10.6,4X,2HCP)                                           FIV 249
270   FORMAT (8A10)                                                     FIV 250
280   FORMAT (F10.6,F10.1,F10.2,3F10.6)                                 FIV 251
290   FORMAT (6F10.6,4X,2HXO)                                           FIV 252
300   FORMAT (6F10.6,4X,2HRO)                                           FIV 253
      END                                                               FIV 254-
      SUBROUTINE VISCUS (INT,FLOT,XA,RAD,CP,RI,UJ,FLOTO,RADO,A,THR,DEL51VIS   1
     1,H51,CFA,DEL1,H1,RET,TAW51,PTB51,FNN51)                           VIS   2
C                                                                       VIS   3
C           VISCOUS  FLOW  SUBROUTINE  PACKAGE                          VIS   4
C                                                                       VIS   5
      COMMON /SAVE/ SS(201),SC(201),Y(201),XIN,XSEPSV(20),DELSV(20),YOUTVIS   6
     1(201)                                                             VIS   7
      DIMENSION INT(8), FLOT(15), FLOTO(7), XA(201), RAD(201), U(201), RVIS   8
     1ADO(201), A(201), THR(201), DEL51(201), H51(201), CFA(201), DEL1(2VIS   9
     201), H1(201), RET(201), TAW51(201), PTB51(201), FNN51(201), CP(201VIS  10
     3), RI(201), UJ(201), VBLC(201), SS(201), S1(201), DSTAR(201), CSV(VIS  11
     4201), CPCV(4)                                                     VIS  12
C                                                                       VIS  13
      ANA=FLOT(6)                                                       VIS  14
      IAN=ANA                                                           VIS  15
      THR(1)=0.                                                         VIS  16
      DEL51(1)=0.                                                       VIS  17
      DEL1(1)=0.                                                        VIS  18
      H51(1)=0.                                                         VIS  19
      RET(1)=0.                                                         VIS  20
      TAW51(1)=0.                                                       VIS  21
      PTB51(1)=0.                                                       VIS  22
      FNN51(1)=0.                                                       VIS  23
      NN=INT(1)                                                         VIS  24
      NAZ=INT(2)                                                        VIS  25
      NMIN=INT(3)                                                       VIS  26
      NMAX=INT(4)                                                       VIS  27
      IJET=INT(5)                                                       VIS  28
      NEXT=INT(6)                                                       VIS  29
      ISMOD=INT(7)                                                      VIS  30
      IPRESS=INT(8)                                                     VIS  31
      Z=FLOT(1)                                                         VIS  32
      TWW=FLOT(2)                                                       VIS  33
      PT=FLOT(3)                                                        VIS  34
      TT=FLOT(4)                                                        VIS  35
      AMIN=FLOT(5)                                                      VIS  36
      GA=FLOT(7)                                                        VIS  37
      HIX=FLOT(8)                                                       VIS  38
      THRR=FLOT(9)                                                      VIS  39
      C=FLOT(12)                                                        VIS  40
      XSIN=FLOT(15)                                                     VIS  41
      IF (IAN.EQ.1) XIN=XA(NN)                                          VIS  42
      R=53.35                                                           VIS  43
      GC=32.174                                                         VIS  44
      PFREE=PT*(1.+(GA-1.)*.5*AMIN**2)**(GA/(1.-GA))                    VIS  45
      IF (ANA.GT.1) GO TO 20                                            VIS  46
      DO 10 I=1,NN                                                      VIS  47
10    Y(I)=RAD(I)                                                       VIS  48
      XSEP=0.                                                           VIS  49
20    CONTINUE                                                          VIS  50
      DO 30 I=1,NN                                                      VIS  51
30    SS(I)=3.1416*Y(I)**2                                              VIS  52
C                                                                       VIS  53
C           CALCULATE  VELOCITY  FROM  CP                               VIS  54
C                                                                       VIS  55
      DO 40 I=1,NN                                                      VIS  56
      PL=.5*GA*PFREE*AMIN**2*CP(I)+PFREE                                VIS  57
      AML2=2./(GA-1.)*((PL/PT)**((1.-GA)/GA)-1.)                        VIS  58
      IF(AML2.LE.0.0)  AML2=0.000000001                                 VIS  58A
```

```
      AML=SQRT(AML2)
      TL=TT/(1.+(GA-1.)*.5*AML**2)
40    U(I)=SQRT(2./(GA-1.)*GA*R*GC*(TT-TL))
C
C          SHAPEJ  CALCULATES  1ST  DERIVATIVE  OF  CONTOUR
C
      CALL SHAPEJ (SS,S1,XA,NN)
C
C          NEWBL  CONTROL  CALCULATION  OF  BOUNDARY  LAYER
C
      CALL NEWBL (VBLC,XA,Y,SS,NAZ,NN,TWW,Z,PT,TT,ANA,GA,U,S1,CFA,HIX,TH
     1RR,A,DEL1,RET,THR,DSTAR,DEL51,H51,TAW51,PTB51,FNN51,H1,DRAG)
      FLOTO(1)=DRAG
      IF (IPRESS.GE.0) GO TO 50
      IF (IPRESS.EQ.-1.AND.XSIN.NE.0.0) GO TO 90
      XSIN=XA(NEXT-1)
      GO TO 85
50    CONTINUE
C
C          FIX  DETERMINES  MIN.  CP.  THE  MIN  CP  IS  USED  AS  START
C               LOCATION  IN  SEARCH  FOR  SEPARATION
C
      CALL FIX (NMIN,NMAX,CP,MI)
      CPS=0
      CPCV(4)=1.00
C
C          SEPA  DETERMINES  SEPARATION  PROPERTIES
C
      IF (MI-NN) 60,170,170
60    CONTINUE
      MM=MI-NAZ
      CALL SEPA (XA,RAD,CP,AMIN,CFA(MI),DEL1(MM),THR(MM),RET(MM),CP(MI),
     1MI,NMAX,CPCV)
      CPS=CPCV(IPRESS+1)
      FLOTO(2)=CPCV(1)
      FLOTO(3)=CPCV(2)
      FLOTO(4)=CPCV(3)
      FLOTO(5)=CPCV(4)
      DO 80 I=MI,NMAX
      IF (CP(I)-CPS) 80,70,70
70    XSEP=((CPS-CP(I-1))/(CP(I)-CP(I-1)))*(XA(I)-XA(I-1))+XA(I-1)
      AML=A(I)
      GO TO 90
80    CONTINUE
      IF (IAN.EQ.1) GO TO 90
      IF (XSIN.NE.0.) GO TO 90
      IF (XSEPSV(IAN-1).EQ.0.) GO TO 90
85    XSEP=XA(NEXT-1)
      WRITE (6,220) XSEP
90    CONTINUE
C
C     CALCULATE SEPARATION POINT
C
      IF (ANA.EQ.1.) GO TO 160
      IF (ANA.GT.2.) GO TO 100
      DELSV(2)=ABS(XSEP-XSEPSV(1))
      XSEP=XSEPSV(1)
      GO TO 160
100   CONTINUE
      IF (ANA.EQ.3.) GO TO 140
      IF (ANA.GE.8.) GO TO 150
      AVEDEL=0.
      IAN1=IAN-1
      DO 110 IBJ=2,IAN1
110   AVEDEL=AVEDEL+DELSV(IBJ)
      AVEDEL=AVEDEL/IAN1
```

```
      IF (ABS(XSEP-XSEPSV(IAN-1)).LT.2.*AVEDEL) GO TO 140
      IF (XSEP-XSEPSV(IAN-1)) 120,120,130
120   XSEP=XSEPSV(IAN-1)-2.*AVEDEL
      GO TO 140
130   XSEP=XSEPSV(IAN-1)+2.*AVEDEL
140   DELSV(IAN)=ABS(XSEP-XSEPSV(IAN-1))
      XSEP=(XSEP+XSEPSV(IAN-1))*.5
      GO TO 160
150   CONTINUE
      XSEP=AMIN1(XSEPSV(7),XSEPSV(6),XSEPSV(5))
160   XSEPSV(IAN)=XSEP
170   CONTINUE
      DO 180 I=1,NN
180   CSV(I)=CP(I)
      IF (XSIN.NE.0.) XSEP=XSIN
      IF (ANA.GT.4) GO TO 200
C
C           ZERO   CP   FOR   THE   FIRST   4   ITERATIONS
C
      DO 190 I=1,NN
      RATIO=0.
190   CSV(I)=CP(I)*RATIO
C
C           SEP   CALCULATES   THE   AERODYNAMIC   CONTOUR
C
200   CALL SEP (NN,XA,RAD,CSV,XSEP,AMIN,GA,TT,PT,RADO,DSTAR,Y,ANA,IJET,N
     1EXT,RI,UJ,C)
      FLOTO(7)=XSEP
      IF (ISMOO.EQ.0) GO TO 210
      CALL SMINT (XA,RADO,NN,NMIN,NMAX)
C     WRITE (6,220) (I,XA(I),RADO(I),I=1,NN)
210   RETURN
C
C
C
220   FORMAT (54H DID NOT SEPARATE, USE NOZZLE EXIT AS SEPARATION POINT,
     1E12.4)
      END
      SUBROUTINE SHAPEJ (SS,S1,X,NN)
C
C     THIS SUBROUTINE SETS THE BOUNDARY CONDITIONS. THESE BOUNDARY
C          CONDITIONS ARE SET BY THE INITIAL AND FINAL SLOPES OF THE
C          CROSSECTIONAL AREA CURVES.
C
      DIMENSION C1SS(201), C2SS(201), C3SS(201), SS(1), S1(1), X(1)
C
      CALL POWER (X,NN)
      CALL SUMA (2,NN-1,3,X,SS,C1SS,C2SS,C3SS,S1,1)
      S1(1)=0.0
      S1(NN)=0.0
      RETURN
      END
      SUBROUTINE POWER (X,NN)
C
      DIMENSION X(1)
      COMMON /COEFF/ X2(201),X3(201),X4(201)
C
      DO 10 I=1,NN
      X2(I)=X(I)*X(I)
      X3(I)=X2(I)*X(I)
      X4(I)=X3(I)*X(I)
10    CONTINUE
      RETURN
      END
      SUBROUTINE SUMA (NX,NY,LZ,X,S,C1,C2,C3,S1,L)
C
```

APPENDIX

```
C     THIS SUBROUTINE CURVE FITS A PARABOLIC ARC THRU LEAST SQUARES
C
      COMMON /COEFF/ X2(201),X3(201),X4(201)
      DIMENSION X(1), S(1), S1(1), C1(1), C2(1), C3(1)
      DOUBLE PRECISION SUM1,SUM2,SUM3,SUM4,SUM5,SUM6,SUM7
C
      LN=LZ/2
      C1(NX-1)=0.0
      C2(NX-1)=0.0
      C3(NX-1)=0.0
      DO 30 J=NX,NY
      SUM1=0.0
      SUM2=0.0
      SUM3=0.0
      SUM4=0.0
      SUM5=0.0
      SUM6=0.0
      SUM7=0.0
      M=J-LN
      MM=J+LN
      DO 10 I=M,MM
      SUM1=SUM1+X(I)
      SUM2=SUM2+X2(I)
      SUM3=SUM3+X3(I)
      SUM4=SUM4+X4(I)
      SUM5=SUM5+(X(I)*S(I))
      SUM6=SUM6+(X2(I)*S(I))
      SUM7=SUM7+S(I)
10    CONTINUE
      AA=SUM7
      AB=SUM1
      AC=SUM2
      AD=SUM5/SUM1
      AE=SUM2/SUM1
      AF=SUM6/SUM2
      AG=SUM3/SUM1
      AH=SUM4/SUM2
      AI=SUM3/SUM2
      AAAR=AA/LZ
      A=AAAR-AD
      C=AAAR-AF
      ABAR=AB/LZ
      B=ABAR-AE
      D=ABAR-AI
      ACAR=AC/LZ
      E=ACAR-AG
      G=ACAR-AH
      B=B+.1D-10
      D=D+.1D-10
      EB=E/B
      AM=EB-G/D
      IF (ABS(AM).LE.0.1D-10) GO TO 20
      AOB=A/B
      C3(J)=(AOB-C/D)/AM
      C2(J)=AOB-EB*C3(J)
      C1(J)=AAAR-C2(J)*ABAR-C3(J)*ACAR
      GO TO 30
20    CONTINUE
      C3(J)=C3(J-1)
      C2(J)=C2(J-1)
      C1(J)=C1(J-1)
30    CONTINUE
      IF (L.EQ.0) RETURN
C
C     COMPUTE 1ST DERIV. OF X VS S CURVE.
C
```

```
      DO 40 J=NX,NY                                                     SUM  69
      S1(J)=C2(J)+2*C3(J)*X(J)                                          SUM  70
   40 CONTINUE                                                          SUM  71
      DO 50 J=1,LN                                                      SUM  72
      K=NX-LN+J-1                                                       SUM  73
      S1(K)=C2(NX)+2*C3(NX)*X(K)                                        SUM  74
      I=J+NY                                                            SUM  75
      S1(I)=C2(NY)+2*C3(NY)*X(I)                                        SUM  76
   50 CONTINUE                                                          SUM  77
      RETURN                                                            SUM  78
      END                                                               SUM  79-
      SUBROUTINE NEWBL (VBLC,X,YO,S,NAZ,NN,TWW,Z,PT,TT,ANA,GA,U,S1,CFA,HNBL   1
     1IX,THRR,AM,DEL1,RET,THR,DSTAR,DEL51,H51,TAW51,PTB51,FNN51,H1,DRAG)NBL   2
C                                                                       NBL   3
      DIMENSION H1(1), DSTAR(201), U(1), VBLC(1), X(1), YO(1), S(1), S1(NBL   4
     11), CFA(201), AM(1), THR(1), DEL1(1), RET(1), DEL51(1), H51(1), TANBL   5
     2W51(1), PTB51(1), FNN51(1), BC(201), CPB(201), YBAR(201)          NBL   6
      COMMON /SAVE/ SB(201),SC(201),Y(201),XIN                          NBL   7
C                                                                       NBL   8
      NBJ=NN-NAZ+1                                                      NBL   9
      DO 10 I=1,NN                                                      NBL  10
   10 VBLC(I)=U(I)                                                      NBL  11
      DO 20 KJ=1,NBJ                                                    NBL  12
      NJA=NAZ+KJ-1                                                      NBL  13
      CPB(KJ)=VBLC(NJA)                                                 NBL  14
      YBAR(KJ)=X(NJA)                                                   NBL  15
      BC(KJ)=YO(NJA)                                                    NBL  16
   20 CONTINUE                                                          NBL  17
      ABC=PT                                                            NBL  18
      CALL BLC (PT,TT,YBAR,BC,CPB,TWW,Z,NBJ,DSTAR,THRR,HIX,H1,CFA,AM,GA,NBL  19
     1DEL1,RET,THR,DEL51,H51,TAW51,PTB51,FNN51,DRAG)                    NBL  20
      PT=ABC                                                            NBL  21
      IF (NAZ) 60,60,30                                                 NBL  22
   30 DO 40 NJ=1,NBJ                                                    NBL  23
      NAJ=NAZ+NJ-1                                                      NBL  24
      CPB(NAJ)=CFA(NJ)                                                  NBL  25
      BC(NAJ)=AM(NJ)                                                    NBL  26
      YBAR(NAJ)=DSTAR(NJ)                                               NBL  27
   40 CONTINUE                                                          NBL  28
      DO 50 NJ=1,NAZ                                                    NBL  29
      YBAR(NJ)=DSTAR(2)                                                 NBL  30
      CPB(NJ)=CFA(2)                                                    NBL  31
      BC(NJ)=AM(1)                                                      NBL  32
   50 CONTINUE                                                          NBL  33
   60 CONTINUE                                                          NBL  34
      DO 100 I=1,NN                                                     NBL  35
      CFA(I)=CPB(I)                                                     NBL  36
      AM(I)=BC(I)                                                       NBL  37
      DSTAR(I)=YBAR(I)                                                  NBL  38
      IF (S(I)-.1E-8) 70,70,80                                          NBL  39
   70 RCO=0.0                                                           NBL  40
      GO TO 90                                                          NBL  41
   80 CONTINUE                                                          NBL  42
      RCO=S1(I)/(2.0*SQRT(3.1416*S(I)))                                 NBL  43
      RCO=ABS(RCO)                                                      NBL  44
   90 CONTINUE                                                          NBL  45
      DEV=RCO**2+1.0                                                    NBL  46
      SUQ=1.0/DEV                                                       NBL  47
      AMB=SQRT(SUQ)                                                     NBL  48
      DSTAR(I)=DSTAR(I)/AMB                                             NBL  49
  100 CONTINUE                                                          NBL  50
      IF (ANA.GT.1.) GO TO 120                                          NBL  51
      DO 110 I=1,NN                                                     NBL  52
      SC(I)=0.                                                          NBL  53
  110 SB(I)=0.                                                          NBL  54
  120 ABC=0.                                                            NBL  55
```

```
      DO 140 I=1,NN
      IF (ANA.LE.3.) GO TO 130
      DSTAR(I)=.25*DSTAR(I)+.5*SB(I)+.25*SC(I)
130   SC(I)=SB(I)
      SB(I)=DSTAR(I)
140   CONTINUE
      RETURN
      END
      SUBROUTINE BLC (PT,TT,XV,YV,V,TWW,Z,NN,DSTAR,THRR,HIX,HICH,CFA,AM,
     1GAM,DEL1,RET,THB,DEL51,H51,TAW51,PTB51,FNN51,DRAG)
C
      DIMENSION AM(1), XV(1), YV(1), V(1), DSTAR(1), HICH(1), DEL1(1), C
     1FA(201), DEL51(1), H51(1), TAW51(1), PTB51(1), FNN51(1), RET(1), T
     2HB(1), X(201), Y(201)
C
      TF(X)=1.+.2*X**2
      PF(X)=TF(X)**3.5
      TAWE(X)=1.+.178*X**2
      H2(X)=(X*(X+1.)**2)/2.
      H3(HI)=2.*HIF/(HI+1.)*(HI-1.)-.5*((HI+1.)*.3/4.3)
C
      G1=(GAM-1.)/2.
      G2=GAM/(1.-GAM)
      DSTAR(1)=HIX*THRR
      THR=THRR
      IF (THR.LT..00001) THR=.00001
      DO 10 I=1,NN
      X(I)=XV(I)/Z
      AM(I)=V(I)/49./SQRT(TT-V(I)**2/.48/778./32.17)
10    Y(I)=YV(I)/Z
      IF (AM(1).LE.0.00001) AM(1)=AM(2)
      PT=PT*Z*Z
      L=1
      HIF=1.3
      U=2.27E-08*TT**1.5/(TT+198.6)
      AU=SQRT(1.4/1716./TT)*PT/U
      M=NN-1
      THTR=THR/TF(AM(1))**3/Z
      HM=1.
      DRAG=0.0
      THT=0.
      HD=0.
      IF (HIX) 20,20,30
20    HI=1.3
      GO TO 40
30    HI=HIX
40    DO 230 I=1,M
      DM=AM(I+1)-AM(I)
      DY=Y(I+1)-Y(I)
      DX=X(I+1)-X(I)
      XXN=N
      DLM=ABS(DM/AM(I)+DM/AM(I+1))+.001*DX/THR*Z+XXN*HD
      IF (Y(I+1)) 50,60,50
50    DLM=DLM+ABS(DY/Y(I+1))
60    N=30.*DLM
      IF (N-10) 70,70,80
70    N=10
80    IF (30-N) 90,100,100
90    N=30
100   S=N
      DX=DX/S
      YY=Y(I)-DY/2./S
      DY=DY/S
      AA=AM(I)-DM/2./S
      DM=DM/S
      DL=SQRT(DX**2+DY**2)
```

```
      N=8                                                               BLC  59
      DO 220 J=1,N                                                      BLC  60
      YY=YY+DY                                                          BLC  61
      AA=AA+DM                                                          BLC  62
      TE=TT/TF(AA)                                                      BLC  63
      TAW=TE*TAWE(AA)                                                   BLC  64
      IF (TWW) 110,110,120                                              BLC  65
  110 TW=TAW                                                            BLC  66
      GO TO 130                                                         BLC  67
  120 TW=TWW                                                            BLC  68
  130 TR=(TAW+TE)/2.+.22*TE*(TAWE(AA)-1.)                               BLC  69
      TR=TR+(TW-TAW)/2.                                                 BLC  70
      THH=THTR                                                          BLC  71
      HH=HI                                                             BLC  72
      THTR=(THH+THT/2.)                                                 BLC  73
      HI=HD/2.+HH                                                       BLC  74
      AY=ABS(THTR)                                                      BLC  75
      A=.123*EXP(-1.561*HI)*(AA*AU*AY)**(-.268)*(TE/TR)**.732*(TE/TT)**3BLC  76
     1.268                                                              BLC  77
      A=A*(TT/TR)**.0645                                                BLC  78
      THT=+A*DL-THTR*DM/AA*(2.+HI+(TW/TT-1.)*HIF/HM)                    BLC  79
      THT=(THTR*(-DY/YY)+THT)                                           BLC  80
      THTR=(THH+THT/2.)                                                 BLC  81
      HD=-DM/AA*H2(HI)*(HI-1.+(TW/TT-1.)*H3(HI)/HM)                     BLC  82
      HF=(HI-(HI+1.)*.36*(EXP(2.9*(HI-1.))-1./HI))                      BLC  83
      HF=HF*(HI**2-1.+EXP(20.-20.*HI)*.1)                               BLC  84
      HD=HD+HF/THTR*A*DL                                                BLC  85
      IF (ABS(HD)/HI-.2) 150,150,140                                    BLC  86
  140 HD=.2*HD/ABS(HD)*HI                                               BLC  87
  150 HI=HH+HD                                                          BLC  88
      THTR=(THH+THT)                                                    BLC  89
      IF (HI) 160,160,170                                               BLC  90
  160 HI=.5                                                             BLC  91
      HD=0.                                                             BLC  92
      GO TO 190                                                         BLC  93
  170 CONT=2.0                                                          BLC  94
      IF (HI-CONT) 190,190,180                                          BLC  95
  180 HI=CONT                                                           BLC  96
      HH=CONT                                                           BLC  97
      HD=0.                                                             BLC  98
  190 TFA=TF(AA)                                                        BLC  99
      THR=THTR*TFA**3                                                   BLC 100
      CF=2.*A*TFA**3                                                    BLC 101
      IF (J+I-2) 200,200,210                                            BLC 102
  200 RV=PT/PF(AA)*SQRT(1.4/TE/1716.)*AA                                BLC 103
  210 HEAD=0.7*(AA*AA)*PT                                               BLC 104
      HEAD=HEAD/((1.0+(0.2*(AA*AA)))**3.5)                              BLC 105
      CFQ=CF*HEAD                                                       BLC 106
      DRAG=DRAG+(6.2832*CFQ*YY*DX)                                      BLC 107
      RV=PT/PF(AA)*SQRT(1.4/TE/1716.)*AA                                BLC 108
      HTR=HI+(TW/TT-1.)*HIF/HM                                          BLC 109
      H=HTR*TFA+.2*AA**2                                                BLC 110
      U=2.27E-08*TE**1.5/(TE+198.6)                                     BLC 111
      RE=RV*THR/U                                                       BLC 112
      THR=THR*Z                                                         BLC 113
      DEL=THR*H                                                         BLC 114
      DSTAR(I+1)=DEL                                                    BLC 115
  220 CONTINUE                                                          BLC 116
      FNN=2.0/(HI-1.)                                                   BLC 117
      FM1=1.+G1*(AM(I+1)**2)                                            BLC 118
      FM2=FM1-1.0                                                       BLC 119
      FM3=GAM*(AM(I+1)**2)/2.                                           BLC 120
      TTT=THR/FM1**3                                                    BLC 121
      DDD=TTT*(1.+FNN)*(2.+FNN)/FNN                                     BLC 122
      DSTA=DEL/FM1**3                                                   BLC 123
      AGB=TTT+DSTA-DDD                                                  BLC 124
```

APPENDIX

```
      DEL1(I+1)=DDD*(FM1**4)+AGB*FM2*(FM1**3)
      PTBAR=FM1**G2*(1.+FM3*(1.-(DEL+THR)/DEL1(I+1)))
      L=L+1
      DEL51(L)=DEL
      H51(L)=H
      TAW51(L)=TAW
      PTB51(L)=PTBAR
      FNN51(L)=FNN
      CFA(I+1)=CF
      HICH(I+1)=HI
      RET(I+1)=RE
      THB(I+1)=THR
230   CONTINUE
      CFA(1)=CFA(2)
      RETURN
      END
      SUBROUTINE FIX (NMIN,NN,CP,MI)
C
      DIMENSION CP(1)
C
      MI=NMIN
      PMIN=CP(NMIN)
      DO 20 I=NMIN,NN
      IF (CP(I)-PMIN) 10,20,20
10    PMIN=CP(I)
      MI=I
20    CONTINUE
      RETURN
      END
      SUBROUTINE SEPA (X,R,CP,EMI,CF1,DEL1,THETA1,RETH1,CP1,NSN,NEN,CPRT
     1)
C
      DIMENSION X(201), R(201), CP(201), CPD(201), C1(201), C2(201), C3(
     1201), CPRT(4), YY(201), PSP1(201), E(201)
      COMMON /COEFF/ X2(201),X3(201),X4(201)
      COMMON /BCB/ TTRAT(201),PTRAT(201),PTRNS(201),URAT(201),EM(201),WR
     1(201),PHIR(201),TWTTE,GAMMA,BLMN,BLMON,VWVE1,C,DSD,DDSD,BK,EME1,SH
     2FAC,SIG1,SIGMA1,SIGS1
C
      ASIN(X)=ATAN(X/SQRT(1-X*X))
C
      EM1=0.0
      BTAIL=0.0
      ELLBT=0.0
      ENTMAS=0.0
      ENPRES=3.0
      CFWCF1=1.0
      GAMMA=1.4
      GAM=GAMMA
      EM1=SQRT(5.*((1.+.2*EMI*EMI)*(1.+.7*EMI*EMI*CP1)**((1.-GAM)/GAM)-1
     1.))
      EME1=EM1
      EM1EMI=EM1/EMI
      CPSG=CP1+200.*CF1*(1.+(GAM/2.)*EMI*EMI*CP1)*EM1EMI*EM1EMI
C
C     CALCULATE CP(SEP) AND P(SEP)/PI USING GOLDSCHMEID METHOD
C
      PSPIG=1.+.5*GAM*CPSG*EMI*EMI
      PSP1G=PSPIG/(1.+.5*GAM*CP1*EMI*EMI)
C
C     STRATFORDS SEPARATION CALCULATION
C
      NX=NSN+2
      NY=NEN-2
      LZ=5
      L=1
```

```
      CALL SUMA (NX,NY,LZ,X,CP,C1,C2,C3,CPD,L)
      RE=RETH1*(X(NSN)/THETA1)
      SS=DEL1/(.37*RE**(-.2))
      RHS=.39*(10.**(-6.)*RE)**(+.1)
      DIF=0
      JK=0
      DO 100 I=NSN,NEN
      DX=X(I)-X(NSN)
      S=SS+DX
      IF (CPD(I)) 90,90,10
10    CONTINUE
      HLS=CP(I)*(S*CPD(I))**.5
      DIF=RHS-HLS
      IF (JK-1) 20,40,40
20    CONTINUE
      JK=1
      LNZ=0
      IF (DIF) 30,30,40
30    LNZ=1
40    CONTINUE
      IF (LNZ) 50,50,70
50    IF (DIF) 60,60,90
60    IA=I
      GO TO 110
70    IF (DIF) 90,80,80
80    IA=I
      GO TO 110
90    CONTINUE
100   CONTINUE
      GO TO 120
110   CONTINUE
      CPSS=CP(IA-1)
      CPRT(4)=CPSS
120   CONTINUE
C
C     CALCULATE CP(SEP) AND P(SEP)/PI USING MODIFIED PAGE METHOD
C
      CPSP=CP1+0.38*(1.+(GAM/2.)*EM1*EM1*CP1)*EM1EM1*EM1EM1
C
C     EVALUATE PROFILE PARAMETERS AT STATION 1
C
      BK=0.4
      C=5.1
      TWTTE=1.
      SIG1=0.2*EM1*EM1
      SIGMA1=SIG1/(1.+SIG1)
      SIGS1=SQRT(SIGMA1)
      FSIG1=(ASIN(SIGS1))/SIGS1
      VWVE1=(1.+SIG1)**1.76
      UTUES1=SQRT((CF1/2.)*(SIGMA1/(1.-SIGMA1)))/ASIN(SQRT(SIGMA1))
      REDEL1=RETH1*DEL1/THETA1
      PX1=.5*(1.-UTUES1*((1./BK)*ALOG(REDEL1*ABS(UTUES1)*FSIG1/VWVE1)+C)
     1)
C
C     DETERMINE B.L. PROFILE PROPERTIES AT STATION 1
C
      CALL PRFL (UTUES1,PX1,EM1,1.0,2,YY)
C
C     DETERMINE UPSTREAM BOUNDARY LAYER INTEGRAL PROPERTIES
C
      CALL FLUX (101,YY,EM1)
      RETH1=REDEL1*DDSD
      AMASS1=BLMN
      AMOM1=BLMON
C
C     START SOLUTION PROCEDURE, ASSUME PS/P1
```

```
      DOD=DSD                                                           SPA 104
      DDOD=DDSD                                                         SPA 105
      UTUESS=0.                                                         SPA 106
      PSP1(1)=PSP1G                                                     SPA 107
      P1PT=(1.+.2*EM1*EM1)**(GAM/(1.-GAM))                              SPA 108
      FEMS1=(PSP1(1)*P1PT)**((1.-GAM)/GAM)-1.                           SPA 109
      FEMS2=P1PT**((1.-GAM)/GAM)-1.                                     SPA 110
      EMS=EM1*SQRT(FEMS1/FEMS2)                                         SPA 111
      PXS=0.5                                                           SPA 112
      J=1                                                               SPA 113
      GO TO 140                                                         SPA 114
130   J=J+1                                                             SPA 115
      IF (J.EQ.80) GO TO 290                                            SPA 116
      PSP1(J)=PSP1(J-1)-0.1                                             SPA 117
      FEMS1=(PSP1(J)*P1PT)**((1.-GAM)/GAM)-1.                           SPA 118
      FEMS2=P1PT**((1.-GAM)/GAM)-1.                                     SPA 119
      EMS=EM1*SQRT(FEMS1/FEMS2)                                         SPA 120
      PXS=0.5                                                           SPA 121
C                                                                       SPA 122
C     ENTRAINMENT AND FRICTION CONSTANTS                                SPA 123
C                                                                       SPA 124
      IF (ENTMAS.GT.0.) GO TO 270                                       SPA 125
C                                                                       SPA 126
C     CALCULATE ENTRAINMENT FROM GREENS THEOREM                         SPA 127
C                                                                       SPA 128
140   ELDEL1=ELLBT*BTAIL/DEL1                                           SPA 129
      AP1PI=1.0+.7*EMI*EMI*CP1                                          SPA 130
      PGX=(1.0+.7*EMI*EMI*CP(NSN-1))/AP1PI                              SPA 131
      IJB=NEN                                                           SPA 132
      DO 230 II=NSN,NEN                                                 SPA 133
      PGX1=PGX                                                          SPA 134
      PGX=(1.0+.7*EMI*EMI*CP(II))/AP1PI                                 SPA 135
      IF (II-NSN) 150,150,160                                           SPA 136
150   PGX1=PGX                                                          SPA 137
      GO TO 230                                                         SPA 138
160   CONTINUE                                                          SPA 139
      DPG=PGX-PSP1(J)                                                   SPA 140
      IF (DPG) 190,170,170                                              SPA 141
170   IF (PGX1-PSP1(J)) 180,220,220                                     SPA 142
180   DBG=ABS(PSP1(J)-PGX1)                                             SPA 143
      DTG=ABS(PGX-PGX1)                                                 SPA 144
      GO TO 210                                                         SPA 145
190   IF (PGX1-PSP1(J)) 220,220,200                                     SPA 146
200   DBG=ABS(PSP1(J)-PGX1)                                             SPA 147
      DTG=ABS(PGX-PGX1)                                                 SPA 148
210   AL=X(II-1)-X(NSN)+(DBG/DTG)*(X(II)-X(II-1))                       SPA 149
      IJB=II-1                                                          SPA 150
      GO TO 240                                                         SPA 151
220   CONTINUE                                                          SPA 152
230   CONTINUE                                                          SPA 153
      AL=X(NEN)-X(NSN)                                                  SPA 154
240   ELDEL1=AL/DEL1                                                    SPA 155
      IF (J.LE.2) GO TO 260                                             SPA 156
      TOTAL=0.                                                          SPA 157
      DO 250 II=NSN,IJB                                                 SPA 158
250   TOTAL=TOTAL+CP(II)                                                SPA 159
      CPAVE=TOTAL/(IJB-NSN+1)                                           SPA 160
      CPCV=(PSP1(J)*(1.+.7*EMI*EMI*CP1)-1.)/(.7*EMI*EMI)                SPA 161
      ENPRES=(CPCV-CP1)/(CPAVE-CP1)                                     SPA 162
260   CONTINUE                                                          SPA 163
      FENT1=(1.-DOD)/DDOD-3.                                            SPA 164
      FENT2=FENT1**(-0.6169)                                            SPA 165
      FENT3=1.-DOD                                                      SPA 166
      AMEMBL=ELDEL1*.0299*FENT2/FENT3                                   SPA 167
      GO TO 280                                                         SPA 168
270   AMEMBL=ENTMAS                                                     SPA 169
```

```
280   CONTINUE
      CALL PRFL (UTUESS,PXS,EMS,PSP1(J),1,YY)
      CALL FLUX (101,YY,EMS)
      AMASSS=BLMN
      AMOMS=BLMON
      ALHS1=(1./PSP1(J))*(1.+AMEMBL)*EM1/EMS
      ALHS2=SQRT((1.+.2*EM1*EM1)/(1.+.2*EMS*EMS))
      ALHS3=AMASS1/AMASSS
      ALHS=ALHS1*ALHS2*ALHS3
      RHS1=(1./ENPRES)*(PSP1(J)-1.)
      RHS2=1.4*EM1*EM1*AMOM1
      RHS3=1.4*AMEMBL*EM1*EM1*AMASS1
      RHS4=.5*CF1*CFWCF1*.70*EM1*EM1*ELDEL1
      RHS5=1.+(1./ENPRES)*(PSP1(J)-1.)-PSP1(J)
      RHS6=PSP1(J)*1.4*EMS*EMS*AMOMS
      RHS=(RHS1-RHS2-RHS3+RHS4)/(RHS5-RHS6)
      E(J)=RHS-ALHS
      TEST=ABS(E(J))
      IF (TEST.LE.0.00001) GO TO 300
      IF (J.EQ.1) GO TO 130
      IF (ABS(E(J)-E(J-1)).LE..001*ABS((E(J)+E(J-1))*.5)) GO TO 300
      SLOPE=(E(J-1)-E(J))/(PSP1(J-1)-PSP1(J))
      PSP1(J+1)=PSP1(J)-E(J)/SLOPE
      IF (PSP1(J+1).LT.0.) GO TO 130
      FEMS1=(PSP1(J+1)*P1PT)**((1.-GAM)/GAM)-1.
      IF (FEMS1.LE.0.) GO TO 130
      EMS=EM1*SQRT(FEMS1/FEMS2)
      J=J+1
      IF (J.EQ.80) GO TO 290
      GO TO 140
290   CONTINUE
      GO TO 310
C
C     SOLUTION OBTAINED
C
C     DETERMINE B.L. PROPERTIES AT SEPARATION
300   CALL PRFL (UTUESS,PXS,EMS,PSP1(J),2,YY)
C
C     DETERMINE DOWNSTREAM B.L. INTEGRAL PROPERTIES
C
      CALL FLUX (101,YY,EMS)
C
C     DETERMINE DEL3/DEL1 AND SEPARATION PRESSURES
C
      PSP1F=PSP1(J)
      CPCV=(PSP1F*(1.+.7*EMI*EMI*CP1)-1.)/(.7*EMI*EMI)
C
C     RESULTS FROM CONTROL VOLUME APPROACH
C
      CPRT(1)=CPCV
C
C     RESULTS FROM GOLDSCHMEID
C
      CPRT(2)=CPSG
C
C     RESULTS FROM MODIFIED PAGE METHOD
C
      CPRT(3)=CPSP
310   CONTINUE
      RETURN
      END
      SUBROUTINE PRFL (UTUEST,PX,EME,PKP1,IOPT,YY)
C
C     SUBROUTINE TO CALCULATE DISTRIBUTIONS OF PROPERTIES
C
      DIMENSION YY(201)
```

APPENDIX

```
      COMMON /BCB/ TTRAT(201),PTRAT(201),PTRNS(201),URAT(201),EM(201),WR
     1(201),PHIR(201),TWTTE,GAMMA,BLMN,BLMON,VWVE1,C,DSD,DDSD,BK,EME1,SH
     2FAC,SIG1,SIGMA1,SIGS1
C
      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=ATAN(SIGG1/SQRT(1-SIGG1*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 40 I=2,101
      AI=I-1
      YY(I)=AI/100.
      URAT(I)=SIGG2*SIN(SIGG3-SIGG3*PX*(1.+COS(PI*YY(I)))+(1./BK)*UTUEST
     1*SIGG3*ALOG(YY(I)))
      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) 40,40,10
C
C     CALCULATION OF TOTAL PRESSURE DOWNSTREAM OF NORMAL SHOCK
C
10    PTRAT(I)=((1.+GAM1*EM(I)*EM(I))/(1.+GAM1*EME1*EME1))**EXP2*PKP1
      IF (EM(I)-1.) 20,20,30
20    PTRNS(I)=PTRAT(I)
      GO TO 40
30    PTRNS(I)=(GAM2*EM(I)*EM(I)/2./(1.+GAM1*EME1*EME1))**EXP2*(GAM2/(2.
     1*GAMMA*EM(I)*EM(I)-GAM3))**EXP3*PKP1
40    CONTINUE
      RETURN
      END
      SUBROUTINE FLUX (K,Y,EME)
C
C     SUBROUTINE TO CALCULATE MASS AND MOMENTUM FLUX OF B.L.
C     ALSO CALCULATES DISPLACEMENT AND MOMENTUM THICKNESSES
C
      DIMENSION Y(201), YY(201), BLMR(201), BLMOR(201)
      COMMON /BCB/ TTRAT(201),PTRAT(201),PTRNS(201),URAT(201),EM(201),WR
     1(201),PHIR(201),TWTTE,GAMMA,BLMN,BLMON,VWVE1,C,DSD,DDSD,BK,EME1,SH
     2FAC,SIG1,SIGMA1,SIGS1
C
      DO 10 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
      BLMR(I)=RHRAT*URAT(I)
      BLMOR(I)=BLMR(I)*URAT(I)
      IF (URAT(I).LE.0.) BLMOR(I)=-BLMOR(I)
      YY(I)=Y(I)
10    CONTINUE
      DO 20 I=1,K
      CALL INTEG (I,YY,BLMR,AREA1)
```

```
      CALL INTEG (I,YY,BLMOR,AREA2)                                     FLU  24
      WR(I)=AREA1                                                       FLU  25
      PHIR(I)=AREA2                                                     FLU  26
20    CONTINUE                                                          FLU  27
      BLMN=AREA1                                                        FLU  28
      BLMON=AREA2                                                       FLU  29
      DSD=1.-BLMN                                                       FLU  30
      DDSD=BLMN-BLMON                                                   FLU  31
      SHFAC=DSD/DDSD                                                    FLU  32
      RETURN                                                            FLU  33
      END                                                               FLU  34-
      SUBROUTINE INTEG (K,Y,Z,AREA)                                     INT   1
C                                                                       INT   2
C     INTEGRATION USING SIMPSON*S RULE                                  INT   3
C                                                                       INT   4
      DIMENSION Y(201), Z(201)                                          INT   5
C                                                                       INT   6
      IF (K.GE.5) GO TO 10                                              INT   7
      IF (K.EQ.1) GO TO 80                                              INT   8
      IF (K.EQ.2) GO TO 90                                              INT   9
      IF (K.EQ.3) GO TO 100                                             INT  10
      IF (K.EQ.4) GO TO 110                                             INT  11
10    AK=K                                                              INT  12
      BK=AK/2.                                                          INT  13
      KK=BK                                                             INT  14
      CK=KK                                                             INT  15
      IF (BK-CK) 30,20,30                                               INT  16
C                                                                       INT  17
C     K IS EVEN                                                         INT  18
C                                                                       INT  19
20    N=K-1                                                             INT  20
      GO TO 40                                                          INT  21
C                                                                       INT  22
C     K IS ODD                                                          INT  23
C                                                                       INT  24
30    N=K                                                               INT  25
40    ODD=0.                                                            INT  26
      EVEN=0.                                                           INT  27
      J=N-3                                                             INT  28
      DO 50 I=2,J,2                                                     INT  29
      EVEN=EVEN+Z(I)                                                    INT  30
      ODD=ODD+Z(I+1)                                                    INT  31
50    CONTINUE                                                          INT  32
      AREA=(Y(2)-Y(1))/3.*(Z(1)+Z(N)+4.*(EVEN+Z(N-1))+2.*ODD)           INT  33
      IF (BK-CK) 70,60,70                                               INT  34
C                                                                       INT  35
C     K IS EVEN                                                         INT  36
C                                                                       INT  37
60    AREA=AREA+(Y(K)-Y(K-1))*(Z(K)+Z(K-1))/2.                          INT  38
      RETURN                                                            INT  39
C                                                                       INT  40
C     K IS ODD                                                          INT  41
C                                                                       INT  42
70    RETURN                                                            INT  43
80    AREA=0.                                                           INT  44
      RETURN                                                            INT  45
90    AREA=(Y(2)-Y(1))*(Z(2)+Z(1))/2.                                   INT  46
      RETURN                                                            INT  47
100   AREA=(Y(2)-Y(1))*(Z(3)+4.*Z(2)+Z(1))/3.                           INT  48
      RETURN                                                            INT  49
110   AREA=(Y(2)-Y(1))*((Z(4)+Z(3))/2.+(Z(3)+4.*Z(2)+Z(1))/3.)          INT  50
      RETURN                                                            INT  51
      END                                                               INT  52-
      SUBROUTINE SEP (NN,XA,RAD,CP,XSEP,AMIN,GAMMA,TTO,PT,RADO,DSTAR,Y,ASEP   1
     1NA,IJET,NEXT,RI,UJ,C)                                             SEP   2
C                                                                       SEP   3
```

APPENDIX

```
      DIMENSION DSTAR(1), RADO(1), XA(1), RAD(1), CP(1), Y(1), X834(201)SEP    4
     1, Y834(201), RI(1), UJ(1)                                         SEP    5
      COMMON /SAVE/ SB(201),SC(201),YJB(201),XINS,XSEPSV(20),DELSV(20),YSEP    6
     1OUT(201)                                                          SEP    7
C                                                                       SEP    8
      DO 10 I=1,NN                                                      SEP    9
10    Y(I)=RAD(I)                                                       SEP   10
      IF (XSEP.GT.0.) GO TO 30                                          SEP   11
      DO 20 I=1,NN                                                      SEP   12
20    RADO(I)=Y(I)+DSTAR(I)                                             SEP   13
      GO TO 120                                                         SEP   14
30    CONTINUE                                                          SEP   15
      DO 40 I=1,NN                                                      SEP   16
      IS=I                                                              SEP   17
      IF (XSEP-XA(I)) 50,40,40                                          SEP   18
40    RADO(I)=Y(I)+DSTAR(I)                                             SEP   19
      GO TO 120                                                         SEP   20
50    RTAN=(Y(IS-1)-Y(IS))/(XA(IS)-XA(IS-1))                            SEP   21
      RTAN=ATAN(RTAN)                                                   SEP   22
      YSEP=Y(IS)+(XSEP-XA(IS))*((Y(IS-1)-Y(IS))/(XA(IS-1)-XA(IS)))      SEP   23
      IC=1                                                              SEP   24
      X834(1)=XSEP                                                      SEP   25
      Y834(1)=YSEP                                                      SEP   26
      DO 60 I=IS,NN                                                     SEP   27
      IC=IC+1                                                           SEP   28
      X834(IC)=XA(I)                                                    SEP   29
60    Y834(IC)=Y(I)                                                     SEP   30
      RADDEG=180./3.1415926                                             SEP   31
      RTAN=RTAN*RADDEG                                                  SEP   32
      NEIN=NEXT-IS+2                                                    SEP   33
      IJJB=0                                                            SEP   34
      IF (ANA.GE.1.) IJJB=IJET                                          SEP   35
      IF (ANA.GE.9.) GO TO 70                                           SEP   36
      CALL B834 (IC,AMIN,GAMMA,TTO,PT,RTAN,X834,Y834,CP(IS-1),YOUT,IJJB,SEP   37
     1NEIN,RI,UJ,C,ANA)                                                 SEP   38
70    CONTINUE                                                          SEP   39
      IF (ANA.EQ.1) GO TO 100                                           SEP   40
      JB=2                                                              SEP   41
      DO 90 I=IS,NN                                                     SEP   42
      Y(I)=YOUT(JB)                                                     SEP   43
      RADO(I)=YOUT(JB)+DSTAR(I)                                         SEP   44
      IF (Y(I).LT.Y(I-1)) GO TO 80                                      SEP   45
      IF (RADO(I).GT.RADO(I-1)+Y(I)-Y(I-1)) RADO(I)=RADO(I-1)+Y(I)-Y(I-1SEP   46
     1)                                                                 SEP   47
      GO TO 90                                                          SEP   48
80    IF (RADO(I).GT.RADO(I-1)) RADO(I)=RADO(I-1)                       SEP   49
90    JB=JB+1                                                           SEP   50
      GO TO 120                                                         SEP   51
100   CONTINUE                                                          SEP   52
      JB=2                                                              SEP   53
      API=2.*Y(IS)*DSTAR(IS)+DSTAR(IS)**2                               SEP   54
      DO 110 I=IS,NN                                                    SEP   55
      Y(I)=YOUT(JB)                                                     SEP   56
      ARGF=4.0*Y(I)**2+4.0*API                                          SEP   57
      DSTAR(I)=(-2.*Y(I)+SQRT(ARGF))/2.0                                SEP   58
      RADO(I)=YOUT(JB)+DSTAR(I)                                         SEP   59
      IF (RADO(I).GT.RADO(I-1)) RADO(I)=RADO(I-1)                       SEP   60
110   JB=JB+1                                                           SEP   61
120   CONTINUE                                                          SEP   62
C     WRITE (6,150) ANA                                                 SEP   63
C     WRITE (6,130) XSEP,YSEP                                           SEP   64
C     WRITE (6,140) (I,XA(I),RAD(I),Y(I),DSTAR(I),RADO(I),I=1,NN)       SEP   65
      RETURN                                                            SEP   66
C                                                                       SEP   67
C                                                                       SEP   68
      END                                                               SEP   69-
```

APPENDIX

```
      SUBROUTINE B834 (NST,FMS,GAMMA,TTO,PT,ABOD,XL,RAD,CPIN,YSTR,IJET,N
     1EXT,RI,UJ,C,ANA)
C
C     AXISYMMETRIC SEPARATION ANGLE PROGRAM
C
      COMMON /SAVE/ SB(201),SC(201),Y(201),XINS
      DIMENSION XSTR(201), YSTR(201), H1V(201), UEV(201), UBUEV(201), PS
     1IV(201), P1V(201), AME1V(201), XJET(201), CPIN(1), RI(1), UJ(1), X
     2L(201), RAD(201)
C
      NSEP=1
      NPT=101
      EPSLN=.00001
      DRJDX=-.05
      DUMDX=400.
      DELLOC=0.
      ILSV=0
      SLOPL=0.
      DO 10 I=1,20
   10 H1V(I)=0.
      DEGRAD=3.1415926/180.
      DO 20 I=1,NST
      XSTR(I)=XL(I)
   20 YSTR(I)=RAD(I)
      ABOD=ABOD*DEGRAD
      ABODSV=ABOD
      AT=SQRT(GAMMA*32.174*53.35*TTO)
      ISTOP=0
      PS=PT*(1.+(GAMMA-1.)*.5*FMS**2)**(GAMMA/(1.-GAMMA))
      IF (NSEP.LE.0) NSEP=1
      IL=NSEP-1
      IUE=0
      PSISV=0.
      DO 30 I=NSEP,NST
      P1V(I)=PS*(1.+GAMMA*.5*CPIN(I)*FMS**2)
      POWER=(1.-GAMMA)/GAMMA
      AME1V(I)=((P1V(I)/PT)**POWER-1.)*2./(GAMMA-1.)
      AME1V(I)=SQRT(AME1V(I))
   30 UEV(I)=AME1V(I)*AT/SQRT(1.+.5*(GAMMA-1.)*AME1V(I)**2)
   40 DELPSI=.05
C
C          ASSUME AN INITIAL SEPARATION ANGLE, PSIOLD; AND AN
C          INCREMENT , DELPSI
C
      IL=IL+1
      IUE=IUE+1
      P1=P1V(IL)
      P2=PS*(1.+GAMMA*.5*CPIN(IL+1)*FMS**2)
      POWER=(1.-GAMMA)/GAMMA
      AME1=AME1V(IL)
      AME2=((P2/PT)**POWER-1.)*2./(GAMMA-1.)
      AME2=SQRT(AME2)
      UE=UEV(IL)
      SIGMA=12.*(1.+.2298*AME1)
      IBAD=0
      I=0
      PSIOLD=.0
      IF (IL.GT.1) PSIOLD=PSIV(IL-1)-DELPSI
      PSIOLD=PSIOLD+DELPSI
   50 CONTINUE
      I=I+1
C
C     CALCULATE H1
C
      IF (IL.GT.1.OR.I.GT.1) GO TO 60
      XSTR(IL)=XL(IL)
```

```
      YSTR(IL)=RAD(IL)                                                  B83  67
60    CONTINUE                                                          B83  68
      IF (IL-2) 70,80,90                                                B83  69
70    H1=0.                                                             B83  70
      GO TO 90                                                          B83  71
80    ANGLE1=PSIV(1)                                                    B83  72
      H1=TAN(ANGLE1)*SQRT((XL(2)-XL(1))**2+(RAD(2)-RAD(1))**2)          B83  73
90    CONTINUE                                                          B83  74
      RHO0=1.                                                           B83  75
      RHO1=1.                                                           B83  76
      RHO2=1.                                                           B83  77
      IF (I.GE.100) GO TO 260                                           B83  78
      UBUE=0.                                                           B83  79
      ALPJ=(.2090+.0226*AME1+.308*UBUE)/SIGMA                           B83  80
      ALPHA=PSIOLD-ALPJ                                                 B83  81
      DELTA=PSIOLD/FLOAT(NPT-1)                                         B83  82
      ICNT=0                                                            B83  83
100   ICNT=ICNT+1                                                       B83  84
      UBUEO=UBUE                                                        B83  85
      SUM1=0.                                                           B83  86
      SUM2=0.                                                           B83  87
      INTJB=NPT-1                                                       B83  88
C                                                                       B83  89
C          USE SIMPSON*S RULE TO INTEGRATE THE CONTINUITY EQUATION      B83  90
C          FOR UB/UE                                                    B83  91
C                                                                       B83  92
      DO 120 J=2,INTJB,2                                                B83  93
      THET0=DELTA*(J-2)                                                 B83  94
      THET1=DELTA*(J-1)                                                 B83  95
      THET2=DELTA*(J-0)                                                 B83  96
      ARG0=SIGMA*(THET0-ALPHA)                                          B83  97
      ARG1=SIGMA*(THET1-ALPHA)                                          B83  98
      ARG2=SIGMA*(THET2-ALPHA)                                          B83  99
      XERF0=.5*(1.+ERT(ARG0))                                           B83 100
      XERF1=.5*(1.+ERT(ARG1))                                           B83 101
      XERF2=.5*(1.+ERT(ARG2))                                           B83 102
      IF (ICNT.EQ.1) GO TO 110                                          B83 103
      ANUM=1.-(GAMMA-1.)*.5*((1.+UBUE)*XERF0-UBUE)**2*(UE/AT)**2        B83 104
      POWER=1./(GAMMA-1.)                                               B83 105
      DEN=1.-(GAMMA-1.)*.5*(UE/AT)**2                                   B83 106
      RHO0=(ANUM/DEN)**POWER                                            B83 107
      ANUM=1.-(GAMMA-1.)*.5*((1.+UBUE)*XERF1-UBUE)**2*(UE/AT)**2        B83 108
      RHO1=(ANUM/DEN)**POWER                                            B83 109
      ANUM=1.-(GAMMA-1.)*.5*((1.+UBUE)*XERF2-UBUE)**2*(UE/AT)**2        B83 110
      RHO2=(ANUM/DEN)**POWER                                            B83 111
110   CONTINUE                                                          B83 112
      AX0=1.+H1*THET0/(RAD(IL)*PSIOLD)                                  B83 113
      AX1=1.+H1*THET1/(RAD(IL)*PSIOLD)                                  B83 114
      AX2=1.+H1*THET2/(RAD(IL)*PSIOLD)                                  B83 115
      SUM1=SUM1+(DELTA/3.)*(RHO0*XERF0*AX0+4.*RHO1*XERF1*AX1+RHO2*XERF2*B83 116
     1AX2)                                                              B83 117
      SUM2=SUM2+(DELTA/3.)*(RHO0*(XERF0-1.)*AX0+4.*RHO1*(XERF1-1.)*AX1+RB83 118
     1HO2*(XERF2-1.)*AX2)                                               B83 119
120   CONTINUE                                                          B83 120
      UBUE=-SUM1/SUM2                                                   B83 121
      IF (ICNT.GT.10) GO TO 130                                         B83 122
      IF (ABS(UBUEO-UBUE).GT.ABS(.001*(UBUEO+UBUE)*.5)) GO TO 100       B83 123
C                                                                       B83 124
C     THETA ITERATION                                                   B83 125
C                                                                       B83 126
130   THETA=0.                                                          B83 127
      IF (UBUE.GT.1.0) UBUE=1.0                                         B83 128
      ICNT=0                                                            B83 129
      DELTH=DELTA                                                       B83 130
      RIGHT=2.*UBUE/(1.+UBUE)-1.                                        B83 131
140   ARG=SIGMA*(THETA-ALPHA)                                           B83 132
```

```
      ALEFT=ERT(ARG)                                                    B83 133
      IF (ICNT.GE.100) GO TO 170                                        B83 134
      IF (ABS(ALEFT).GT.ABS(RIGHT)) GO TO 150                           B83 135
      IF (ABS(RIGHT-ALEFT).LE.ABS(.01*(RIGHT+ALEFT)*.5)) GO TO 160      B83 136
      THETA=THETA-DELTH                                                 B83 137
      DELTH=DELTH/10.                                                   B83 138
 150  THETA=THETA+DELTH                                                 B83 139
      ICNT=ICNT+1                                                       B83 140
      IF (THETA.GE.PSIOLD) GO TO 160                                    B83 141
      GO TO 140                                                         B83 142
 160  CONTINUE                                                          B83 143
      ICNT=THETA/PSIOLD*100                                             B83 144
      IF (ICNT/2*2.NE.ICNT) ICNT=ICNT+1                                 B83 145
 170  CONTINUE                                                          B83 146
      SUM3=0.                                                           B83 147
C                                                                       B83 148
C           USE SIMPSON*S RULE TO INTEGRATE THE MOMENTUM EQUATION       B83 149
C                                                                       B83 150
      DO 180 J=2,ICNT,2                                                 B83 151
      THETO=DELTA*(J-2)                                                 B83 152
      THET1=DELTA*(J-1)                                                 B83 153
      THET2=DELTA*(J-0)                                                 B83 154
      ARGO=SIGMA*(THETO-ALPHA)                                          B83 155
      ARG1=SIGMA*(THET1-ALPHA)                                          B83 156
      ARG2=SIGMA*(THET2-ALPHA)                                          B83 157
      XERFO=.5*(1.+ERT(ARGO))                                           B83 158
      XERF1=.5*(1.+ERT(ARG1))                                           B83 159
      XERF2=.5*(1.+ERT(ARG2))                                           B83 160
      ANUM=1.-(GAMMA-1.)*.5*((1.+UBUE)*XERFO-UBUE)**2*(UE/AT)**2        B83 161
      POWER=1./(GAMMA-1.)                                               B83 162
      DEN=1.-(GAMMA-1.)*.5*(UE/AT)**2                                   B83 163
      RHOO=(ANUM/DEN)**POWER                                            B83 164
      ANUM=1.-(GAMMA-1.)*.5*((1.+UBUE)*XERF1-UBUE)**2*(UE/AT)**2        B83 165
      RHO1=(ANUM/DEN)**POWER                                            B83 166
      ANUM=1.-(GAMMA-1.)*.5*((1.+UBUE)*XERF2-UBUE)**2*(UE/AT)**2        B83 167
      RHO2=(ANUM/DEN)**POWER                                            B83 168
      AXO=1.+(H1*THETO)/(RAD(IL)*PSIOLD)                                B83 169
      AX1=1.+(H1*THET1)/(RAD(IL)*PSIOLD)                                B83 170
      AX2=1.+(H1*THET2)/(RAD(IL)*PSIOLD)                                B83 171
      TEMP=(DELTA/3.)*(RHOO*COS(THETO)*((1.+UBUE)*XERFO-UBUE)**2*AXO+4.*B83 172
     1RHO1*COS(THET1)*((1.+UBUE)*XERF1-UBUE)**2*AX1+RHO2*COS(THET2)*((1.B83 173
     2+UBUE)*XERF2-UBUE)**2*AX2)                                        B83 174
      SUM3=SUM3+TEMP                                                    B83 175
 180  CONTINUE                                                          B83 176
      SUM4=0.                                                           B83 177
      IF (ICNT.GE.100) GO TO 200                                        B83 178
      ICNT=ICNT+2                                                       B83 179
      DO 190 J=ICNT,INTJB,2                                             B83 180
      THETO=DELTA*(J-2)                                                 B83 181
      THET1=DELTA*(J-1)                                                 B83 182
      THET2=DELTA*(J-0)                                                 B83 183
      ARGO=SIGMA*(THETO-ALPHA)                                          B83 184
      ARG1=SIGMA*(THET1-ALPHA)                                          B83 185
      ARG2=SIGMA*(THET2-ALPHA)                                          B83 186
      XERFO=.5*(1.+ERT(ARGO))                                           B83 187
      XERF1=.5*(1.+ERT(ARG1))                                           B83 188
      XERF2=.5*(1.+ERT(ARG2))                                           B83 189
      ANUM=1.-(GAMMA-1.)*.5*((1.+UBUE)*XERFO-UBUE)**2*(UE/AT)**2        B83 190
      POWER=1./(GAMMA-1.)                                               B83 191
      DEN=1.-(GAMMA-1.)*.5*(UE/AT)**2                                   B83 192
      RHOO=(ANUM/DEN)**POWER                                            B83 193
      ANUM=1.-(GAMMA-1.)*.5*((1.+UBUE)*XERF1-UBUE)**2*(UE/AT)**2        B83 194
      RHO1=(ANUM/DEN)**POWER                                            B83 195
      ANUM=1.-(GAMMA-1.)*.5*((1.+UBUE)*XERF2-UBUE)**2*(UE/AT)**2        B83 196
      RHO2=(ANUM/DEN)**POWER                                            B83 197
      AXO=1.+(H1*THETO)/(RAD(IL)*PSIOLD)                                B83 198
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      AX1=1.+(H1*THET1)/(RAD(IL)*PSIOLD)
      AX2=1.+(H1*THET2)/(RAD(IL)*PSIOLD)
      TEMP=(DELTA/3.)*(RHO0*COS(THET0)*((1.+UBUE)*XERF0-UBUE)**2*AX0+4.*
     1RHO1*COS(THET1)*((1.+UBUE)*XERF1-UBUE)**2*AX1+RHO2*COS(THET2)*((1.
     2+UBUE)*XERF2-UBUE)**2*AX2)
      SUM4=SUM4+TEMP
190   CONTINUE
200   CONTINUE
      SUM5=SUM3+SUM4
      ANUM=1.-(GAMMA-1.)*.5*(1.+UBUE)**2*(UE/AT)**2
      DEN=1.-(GAMMA-1.)*.5*(UE/AT)**2
      RHOT=.0005821*PT/TT0
      RHORT=(1.+(GAMMA-1.)*.5*AME1**2)**(1./(1.-GAMMA))
      RHOE=RHORT*RHOT
      ANUM=1.-(GAMMA-1.)*.5*UBUE**2*(UE/AT)**2
      RHOBT=(ANUM/DEN)**(1./(GAMMA-1.))
      AMACB=RHOBT*UBUE**2
C     CF
      IF (IJET.EQ.0) GO TO 210
      IF (IL.LT.NEXT) GO TO 210
      CF=0.
      GO TO 220
210   CONTINUE
      ENU=.56/3600.
      XX=1.
      REX=UBUE*UE/(ENU*XX)
      CF=1.328/SQRT(REX)
220   SKIN=CF*.5*AMACB
      DPDX=(P2-P1)/(XL(IL+1)-XL(IL))
      H2=H1
      HA=H1
      DIST=SQRT((XL(IL+1)-XL(IL))**2+(RAD(IL+1)-RAD(IL))**2)
      IF (IL.EQ.1) GO TO 230
      H2=H1*TAN(PSIOLD)/TAN(PSIV(IL-1))+DIST*TAN(PSIOLD)
C
C     AB  PERPENDICULAR DISTANCE FROM SEPARATION SLOPE LINE TO CONTOUR
C     DB DISTANCE ALONG SLOPE LINE AT SEPARATION
C
      DB=ABS(H2-H1)/TAN(PSIOLD)
      SLOPL=(RAD(IL)-RAD(IL+1))/(XL(IL+1)-XL(IL))
      SLOPL=ATAN(SLOPL)
      AMUS=SLOPL-ABODSV
      AB=DB*TAN(AMUS)
      HA=H1
230   PRESS=DPDX/(RHOE*UE**2)*(HA+HA**2/(2.*RAD(IL)))*COS(SLOPL)
      IF (PRESS.LT.0.) PRESS=0.
      SHEAR=(1.+HA/RAD(IL))*(.1481-.0478*AME1+.1278*UBUE-.1632*AME1*UBUE
     1+.399*UBUE**2-.0239*EXP(-5.0*AME1))/SIGMA
      SHEAR=SHEAR*COS(PSIOLD)
      SHRJT=0.
      OLDANS=SHEAR-PRESS-SKIN+SHRJT
C
C             COMPARE THE RIGHT AND LEFT SIDE OF MOMENTUM EQUATION
C
      AMULT=P2*AME2**2/(P1*AME1**2)
      SUM5NW=SUM5*AMULT
      IF (IL.EQ.1) GO TO 240
      X01=H1/PSIV(IL-1)
      X02=H2/PSIOLD
      RATIO=(1.+H1/RAD(IL))/(1.+H1V(IL-1)/RAD(IL-1))
      SUM5NW=(X02*AMULT*SUM5-X01*RATIO*SUMSV)/(X02-X01)
240   CONTINUE
      GLI=OLDANS-SUM5NW
      IF (IBAD.EQ.0) GO TO 250
      IJB=1
      GO TO 300
```

```
250   CALL NEWRAP (I,PSIOLD,GLI,EPSLN,PSINEW,IJB)
      IF (PSINEW.LT.0.) GO TO 260
      IF (PSINEW.GT.ABODSV) GO TO 260
      IF (I.GE.100) GO TO 260
      GO TO 300
C
C     ITERATION FAILED, USE ANGLE FROM PREVIOUS ITERATION
C
260   CONTINUE
      IF (AME1.LT..2) GO TO 280
      IF (AME1.LT..5) GO TO 270
      SLOPE=(8.4-15.625)/(1.-.5)
      PSINEW=15.625+SLOPE*(AME1-.5)
      GO TO 290
270   SLOPE=(15.625-17.5)/(.5-.2)
      PSINEW=17.5+SLOPE*(AME1-.2)
      GO TO 290
280   PSINEW=17.5
290   WRITE (6,370) PSINEW
      PSINEW=PSINEW*DEGRAD
      IF (PSINEW.GT.ABODSV) PSINEW=ABODSV
      PSIOLD=PSINEW
      IBAD=1
      IF (ANA.GE.8.) WRITE (6,380)
      GO TO 50
300   PSIOLD=PSINEW
      IF (IJB.EQ.0) GO TO 50
      DELOLD=DELLOC
      IF (IL.GT.1) DELLOC=ABS(H2-H1)/DB
      DELLOC=ATAN(DELLOC)
      IF (IL.EQ.1) DELLOC=PSIOLD
      IF (IL.EQ.1) DELOLD=0.
      ASTR=ABOD-(DELLOC-DELOLD)
C
C     CALCULATE DISCRIMINATING STREAMLINE
C
      XSTR(IL+1)=XL(IL+1)
      A=SQRT((XL(IL+1)-XL(IL))**2)
      B=TAN(ASTR)*A
      YSTR(IL+1)=YSTR(IL)-B
      H1P=YSTR(IL)-RAD(IL)
      XIN=XSTR(NST)*1.001
      IX=NST
      IF (YSTR(IL+1).GT.RAD(IL+1)) GO TO 320
      H2P=ABS(YSTR(IL+1)-RAD(IL+1))
      AX=(XL(IL+1)-XL(IL))/(1.+H2P/H1P)
      XSTR(IL+1)=XSTR(IL)+AX
      XIN=XSTR(IL+1)
      XINS=XIN
      CX=(RAD(IL)-RAD(IL+1))/(1.+H2P/H1P)
      YSTR(IL+1)=RAD(IL)-CX
      ISTOP=1
      IX=IL+1
      IF (IX.GT.NST) GO TO 320
      DO 310 JB=IX,NST
      XSTR(JB+1)=XL(JB)
310   YSTR(JB+1)=RAD(JB)
320   CONTINUE
      SUMSV=SUMS
      UBUEV(IL)=UBUE
      H1V(IL)=H1
      PSIV(IL)=PSIOLD
      ABOD=ASTR
      PSISV=PSIOLD
      IF (ISTOP.EQ.1) GO TO 360
      IF (IJET.EQ.0) GO TO 340
```

```
      IF (IL+1.LT.NEXT) GO TO 340                                       B83 331
C                                                                       B83 332
C     CALL JET ENTRAINMENT IF OPTION TURNED ON                          B83 333
C                                                                       B83 334
      RJ=RAD(IL+1)                                                      B83 335
      RD=YSTR(IL+1)                                                     B83 336
      NSIN=NST-NEXT+1                                                   B83 337
      DO 330 I=NEXT,NST                                                 B83 338
330   XJET(I)=XL(I)-XL(NEXT)                                            B83 339
      UM=-UBUEV(IL)*UE                                                  B83 340
      DRDDX0=(YSTR(NEXT)-YSTR(NEXT-1))/(XL(NEXT)-XL(NEXT-1))            B83 341
      CALL JET (RJ,UM,C,DRJDX,DUMDX,RD,NSIN,XJET(NEXT),UEV(NEXT),YSTR(NEB83 342
     1XT),RI,UJ,DRDDX0)                                                 B83 343
      GO TO 360                                                         B83 344
340   CONTINUE                                                          B83 345
C                                                                       B83 346
C     DETERMINE IF ITERATION COMPLETE                                   B83 347
C                                                                       B83 348
      IF (IL.EQ.1) GO TO 350                                            B83 349
      DB=ABS(H2-H1)/TAN(PSIOLD)                                         B83 350
      AMUS=SLOPL-ABODSV                                                 B83 351
      AB=DB*TAN(AMUS)                                                   B83 352
      H1=H2+AB                                                          B83 353
      IF (H1.GT.0.) GO TO 350                                           B83 354
      IF (ILSV.EQ.0) ILSV=IL                                            B83 355
      H1=H1V(ILSV)*.01                                                  B83 356
350   IF (IL+1.LT.NST) GO TO 40                                         B83 357
360   RETURN                                                            B83 358
C                                                                       B83 359
C                                                                       B83 360
370   FORMAT (1H ,6HPSINEW,F12.4)                                       B83 361
380   FORMAT (1H0,46HITERATION FOR DISCRIMINATING STREAMLINE ANGLE ,28HFB83 362
     1AILED, USING DEFAULT VALUE.,/17H  TRY DECREASING ,36HSTEP SIZE (MOB83 363
     2RE POINTS ON AFTERBODY))                                          B83 364
      END                                                               B83 365-
      FUNCTION ERT (X)                                                  ERT   1
C                                                                       ERT   2
C         THIS FUNCTION ROUTINE OBTAINS VALUE OF THE ERROR FUNCTION     ERT   3
C         WITH ARGUMENT X USING LIBRARY SUBROUTINE ERF                  ERT   4
C                                                                       ERT   5
      CALL ERF (X,Y)                                                    ERT   6
      ERT=Y                                                             ERT   7
      RETURN                                                            ERT   8
      END                                                               ERT   9-
      SUBROUTINE NEWRAP (ICNT,X,FUNC,TOLL,XZERO,IE)                     NEW   1
C                                                                       NEW   2
      IE=0                                                              NEW   3
      IF (ICNT.GT.100) STOP                                             NEW   4
      IF (ICNT-2) 10,20,30                                              NEW   5
10    FUN1=FUNC                                                         NEW   6
      X1=X                                                              NEW   7
      IF (X.EQ.0.) X=100.*TOLL                                          NEW   8
      XZERO=X+.1*X                                                      NEW   9
      GO TO 90                                                          NEW  10
20    CONTINUE                                                          NEW  11
      FUN2=FUNC                                                         NEW  12
      X2=X                                                              NEW  13
      GO TO 80                                                          NEW  14
30    CONTINUE                                                          NEW  15
      IF (FUN1*FUN2) 50,40,40                                           NEW  16
40    FUN1=FUN2                                                         NEW  17
      FUN2=FUNC                                                         NEW  18
      X1=X2                                                             NEW  19
      X2=X                                                              NEW  20
      GO TO 80                                                          NEW  21
50    CONTINUE                                                          NEW  22
```

```
      IF (FUNC*FUN2) 70,60,60
60    FUN2=FUNC
      X2=X
      GO TO 80
70    FUN1=FUNC
      X1=X
C
C     CALCULATE DERIVATIVE
C
80    DERV=(FUN2-FUN1)/(X2-X1)
      XZERO=X2-FUN2/DERV
      IF (ABS(XZERO-X).LT.ABS((XZERO+X2)*.5)*TOLL) IE=1
90    RETURN
      END
      SUBROUTINE JET (RJ,UM,C,DRJDX,DUMDX,RD,NSIN,XIN,UE,YSTR,RJA,UJA,DR
     1DDX0)
C
      DIMENSION XIN(201), YSTR(201), RJA(201), UJA(201), UE(201)
      REAL L0,L1,L2
C
      TOL=.001
      DRDDX=.1
      ICNT=0
      ISTA=1
      RDSV=RD
      X=XIN(ISTA)
      DL2DX=.25
      DRCDX=DRJDX+DL2DX
      DREDX=0.
      UE0=UE(1)
      R0=RJ
      A=(.5714*RD+.2286*R0)/(2.*(.2*RD+.05*R0))
      B=(RD+R0)*UM/(2.*(.2*RD+.05*R0)*(UE0-UM))
      XI=A-SQRT(A**2+B)
      ETA=XI**(1./1.5)
      ETA2=(1.-SQRT(UE0/(UE0-UM)))**(1./1.5)
      IF (ETA.LT.ETA2) ETA=ETA2
      L0=(RD-R0)/ETA
      RE=R0+L0
10    CONTINUE
      UE1=UE(ISTA)
      UJ=UJA(ISTA)
      DUEDX=(UE(ISTA+1)-UE(ISTA))/(XIN(ISTA+1)-XIN(ISTA))
      DUJDX=(UJA(ISTA+1)-UJA(ISTA))/(XIN(ISTA+1)-XIN(ISTA))
      ISTA=ISTA+1
      L2=.25*X
      RC=RJ+L2
      DELUE=UE1-UM
      L1=RE-RJ-L2
C
C     DUMDX  LOOP
C
      ICNT=0
20    CONTINUE
      ICNT=ICNT+1
      DL1DX=C
      DDUEDX=DUEDX-DUMDX
      DLEUJ=UJ-UM
      DDUJXX=DUJDX-DUMDX
      AJB=L2*(UM+.55*DLEUJ)+UJ*RJ
      BJB=(RJ*(UM+.55*DLEUJ)+.3572*DLEUJ*L2)*DL2DX+(RC*L2-.5*L2**2)*DUMD
     1X+(.55*RC*L2-.3714*L2**2)*DDUJXX
      DRJDX=(.043*UJ*RC-BJB)/AJB
      IF (ISTA.GT.2) GO TO 30
      DRDDX=DRDDX0
      TRM1=(RC*(UM+DELUE*(2.*ETA**1.5-ETA**3))+L1*ETA*(UM+DELUE*(2.*ETA*
```

```
     1*1.5-ETA**3)))*(DRDDX-DL2DX-ETA*DL1DX)+(RC*(UM*ETA+DELUE*(2./2.5*E
     2TA**2.5-1./4.*ETA**4))+2.*L1*(.5*UM*ETA**2+DELUE*(2./3.5*ETA**3.5-
     31./5.*ETA**5)))*DL1DX
      TRM2=L1*(UM*ETA+DELUE*(2./2.5*ETA**2.5-1./4.*ETA**4))*DL2DX+(RC*L1
     1*ETA+.5*L1**2*ETA**2)*DUMDX+(RC*L1*(2./2.5*ETA**2.5-1./4.*ETA**4)+
     2L1**2*(2./3.5*ETA**3.5-1./5.*ETA**5))*DDUEDX
      B=TRM1+TRM2
      A=L1*(UM*ETA+DELUE*(2./2.5*ETA**2.5-1./4.*ETA**4))-RC*(UM+DELUE*(2
     1.*ETA**1.5-ETA**3))-L1*ETA*(UM+DELUE*(2.*ETA**1.5-ETA**3))
      XZ=(BJB-(AJB*(BJB+B))/(AJB+A))/(UJ*RC)
30    CONTINUE
      DRJDX=(UJ*XZ*RC-BJB)/AJB
      DRCDX=DRJDX+DL2DX
      DDUEDX=DUEDX-DUMDX
      TRM1=(RC*(UM+.55*DLEUJ)-2.*L2*(.5*UM+.3714*DLEUJ))*DL2DX
      TRM2=L2*(UM+.55*DLEUJ)*DRCDX+(RC*L2-.5*L2**2)*DUMDX
      TRM3=(.55*RC*L2-.3714*L2**2)*DDUJXX
      UDR1X=TRM1+TRM2+TRM3
      DREDX=DRJDX+C+DL1DX
      IF (ISTA.GT.2) GO TO 40
      B1=L1*(UM+DELUE*(2./2.5*ETA**1.5-1./4.*ETA**3))*ETA*DRCDX+(RC*L1*E
     1TA+.5*L1**2*ETA**2)*DUMDX+(RC*L1*(2./2.5*ETA**2.5-1./4.*ETA**4)+L1
     2**2*(2./3.5*ETA**3.5-1./5.*ETA**5))*DDUEDX
      ZZZ=RC*L1*(UM+DELUE*(2.*ETA**1.5-ETA**3))+L1**2*ETA*(UM+DELUE*(2.*
     1ETA**1.5-ETA**3))
      Q1=-(UJ*RJ*DRJDX+UDR1X+B1)/ZZZ
      P1=-(RC*(UM*ETA+DELUE*(2./2.5*ETA**2.5-1./4.*ETA**4))+2.*L1*(.5*UM
     1*ETA**2+DELUE*(2./3.5*ETA**3.5-1./5.*ETA**5)))/ZZZ
      DL1DX=(DRDDX0-DRJDX-DL2DX-L1*Q1)/(ETA+P1*L1)
40    DREDX=DRJDX+C+DL1DX
      DL1DX=C
      DREDX=DRJDX+C+DL1DX
      IF (DRDDX.EQ.0.) ETA=(1.-SQRT(UE1/DELUE))**(1./1.5)
      TRM1=(RC*(UM*ETA+DELUE*(2./2.5*ETA**2.5-ETA**4/4.))+2.*L1*(.5*UM*E
     1TA**2+DELUE*(2./3.5*ETA**3.5-ETA**5/5.)))*DL1DX
      TRM2=L1*(UM+DELUE*(2./2.5*ETA**1.5-ETA**3/4.))*ETA*DRCDX+(RC*L1*ET
     1A+.5*L1**2*ETA**2)*DUMDX
      TRM3=(RC*L1*(2./2.5*ETA**2.5-ETA**4/4.)+L1**2*(2./3.5*ETA**3.5-ETA
     1**5/5.))*DDUEDX
      WWW=TRM1+TRM2+TRM3
      ZZZ=RC*L1*(UM+DELUE*(2.*ETA**1.5-ETA**3))+L1**2*ETA*(UM+DELUE*(2.*
     1ETA**1.5-ETA**3))
      DLEUJ=UJ-UM
      DDUJXX=DUJDX-DUMDX
      TRM1=(RC*(UM+.55*DLEUJ)-2.*L2*(.5*UM+.3714*DLEUJ))*DL2DX
      TRM2=L2*(UM+.55*DLEUJ)*DRCDX+(RC*L2-.5*L2**2)*DUMDX
      TRM3=(.55*RC*L2-.3714*L2**2)*DDUJXX
      UDR1X=TRM1+TRM2+TRM3
      UDR2X=(2.*L1*(.5*UM+.3714*DELUE)+RC*(UM+.55*DELUE))*DL1DX+L1*(UM+.
     155*DELUE)*DRCDX+(.5*L1**2+RC*L1)*DUMDX+(.3714*L1**2+.55*RC*L1)*DDU
     2EDX
      IF (DRDDX.EQ.0.) GO TO 50
      DEDX=-(XZ*UJ*RC+WWW)/ZZZ
      DRDDX=ETA*DREDX+(1.-ETA)*DRCDX+L1*DEDX
50    CONTINUE
      DLEUJ=UJ-UM
      DDUJXX=DUJDX-DUMDX
      TRM1=L2*(UM**2+1.1*UM*DLEUJ+.4156*DLEUJ**2)*DRCDX
      TRM2=(RC*(UM**2+1.1*UM*DLEUJ+.4156*DLEUJ**2)-2.*L2*(.5*UM**2+.7428
     1*UM*DLEUJ+.3096*DLEUJ**2))*DL2DX
      TRM3=(RC*L2*(2.*UM+1.1*DLEUJ)-L2**2*(UM+.7428*DLEUJ))*DUMDX
      TRM4=(RC*L2*(1.1*UM+.8312*DLEUJ)-L2**2*(.7428*UM+.6192*DLEUJ))*DDU
     1JXX
      U2DR1X=TRM1+TRM2+TRM3+TRM4
      TRM1=((UM**2+1.4856*UM*DELUE+.6192*DELUE**2)*L1+(UM**2+1.1*UM*DELU
     1E+.4156*DELUE**2)*RC)*DL1DX
```

```
      TRM2=L1*(UM**2+1.1*UM*DELUE+.4156*DELUE**2)*DRCDX+L1**2*(UM+.7428*
     1DELUE)*DUMDX
      TRM3=L1*RC*(2.*UM+1.1*DELUE)*DUMDX+L1**2*(.6192*DELUE+.7428*UM)*DD
     1UEDX+RC*L1*(.8312*DELUE+1.1*UM)*DDUEDX
      U2DR2X=TRM1+TRM2+TRM3
      AMRHO=UJ*RJ*DRJDX+(UDR1X+UDR2X)
      XMOMNT=UJ**2*RJ*DRJDX+(U2DR1X+U2DR2X)-RE**2*.5*UE1*DUEDX-UE1*AMRHO
      CALL NEWRAP (ICNT,DUMDX,XMOMNT,TOL,DUMDXN,IE)
      IF (ICNT.LE.30) GO TO 60
      ISTA=ISTA-1
      GO TO 130
60    CONTINUE
      IF (IE.NE.0) GO TO 70
      DUMDX=DUMDXN
      GO TO 20
70    CONTINUE
C
C     SOLVE  FOR  THE  RADIUS  OF  THE  DISCRIMINATING  STREAMLINE
C
      X=XIN(ISTA)
      DX=XIN(ISTA)-XIN(ISTA-1)
      L2=C*X
      IF (ETA.LE.ETA2) GO TO 80
      IF (DRDDX.EQ.0.) GO TO 80
      RD=DRDDX*DX+RD
      ETA=DEDX*DX+ETA
      DELUE=UE(ISTA)-(DUMDX*DX+UM)
      ETA2=(1.-SQRT(UE(ISTA)/DELUE))**(1./1.5)
      IF (ETA.LT.ETA2) GO TO 80
      GO TO 90
80    CONTINUE
      DRDDX=0.
90    UM=DUMDX*DX+UM
      IF (UM.GE.0.) GO TO 170
      RJ=RJ+DRJDX*DX
      DREDX=DRJDX+2.*C
      RE=RE+DREDX*DX
      IF (DRDDX.NE.0.) GO TO 100
      L1=RE-RJ-L2
      IF (L1.LE.0.) GO TO 170
      DELUE=UE(ISTA)-UM
      ETA=(1.-SQRT(UE(ISTA)/DELUE))**(1./1.5)
      RD=RJ+L2+ETA*L1
      IF (RD.GT.RDSV) GO TO 170
100   CONTINUE
      YSTR(ISTA)=RD+RJA(ISTA)-R0-L2
      RDSV=RD
      ICNT=0
      IF (RD.LE.R0) GO TO 110
      IF (YSTR(ISTA).LE.RJA(ISTA)) GO TO 110
      GO TO 190
110   ISRT=ISTA
      DO 120 I=ISRT,NSIN
120   YSTR(I)=RJA(I)
      GO TO 200
130   SLOPE=(YSTR(ISTA-1)-YSTR(ISTA-2))/DX
      IF (SLOPE.GT.0.) GO TO 150
      ISRT=ISTA
      DO 140 I=ISRT,NSIN
      YSTR(I)=SLOPE*(XIN(I)-XIN(I-1))+YSTR(I-1)
140   IF (YSTR(I).LT.RJA(I)) YSTR(I)=RJA(I)
      GO TO 200
150   DO 160 I=ISTA,NSIN
160   YSTR(I)=YSTR(I-1)
      GO TO 200
170   DO 180 I=ISTA,NSIN
```

```
      L2=C*XIN(I)
      YSTR(I)=RDSV+RJA(I)-R0-L2
180   IF (YSTR(I).LT.RJA(I)) YSTR(I)=RJA(I)
      GO TO 200
190   CONTINUE
      IF (ISTA.LT.NSIN) GO TO 10
200   RETURN
      END
      SUBROUTINE SMINT (XA,YA,NA,NMIN,NMAX)
C
C     INTERFACE ROUTINE FOR VISCOUS PACKAGE AND SMOOTHING ROUTINES
C
      COMMON /SAVE/ SB(201),SC(201),YJB(201),XIN
      DIMENSION X1(201), X2(201), Y1(201), Y2(201), XA(1), YA(1), S(201)
     1, S1(201), Y22(201), Y22S(201), Y(201), Z(201), DDY(201), DY(201),
     2 DZ(201), DDZ(201), Z1(201)
C
      NA1=NA-1
      DO 10 I=1,NA1
      X1(I)=XA(I)
      X2(I)=XA(I+1)
      Y1(I)=YA(I)
10    Y2(I)=YA(I+1)
      K9=1
      NSMTH1=NMIN-4
      IF (NSMTH1.LT.2) NSMTH1=2
      NSMTH2=NA-1
      DO 20 I=NMAX,NA
      IF (XIN.LT.XA(I)) GO TO 30
      NSMTH2=I+6
20    CONTINUE
30    IF (NSMTH2.GT.NA-1) NSMTH2=NA-1
      IVSM=0
      K11=10
      CALL SMOOTH (X1,X2,Y1,Y2,K9,K11,NSMTH1,NSMTH2,IVSM,NA,S,S1,Y22,Y22
     1S,Y,Z,DDY,DY,DZ,DDZ,Z1)
      DO 40 I=1,NA1
      XA(I)=X1(I)
40    YA(I)=Y1(I)
      RETURN
      END
      SUBROUTINE SMOOTH (X1,X2,Y1,Y2,K9,K11,NSMTH1,NSMTH2,IVSM,NA,S,S1,Y
     122,Y22S,Y,Z,DDY,DY,DZ,DDZ,Z1)
C
      DIMENSION X1(NA), Y1(NA), Y2(NA), S(NA), S1(NA), X2(NA), Y22(NA),
     1Y22S(NA), Y(NA), Z(NA), NSMTH1(5), NSMTH2(5), DDY(NA), DY(NA), DZ(
     2NA), DDZ(NA), Z1(NA)
C
      DO 170 I=1,K9
      N5=NSMTH1(I)
      N6=NSMTH2(I)
      I1=MIN0(N5,N6)
      I2=MAX0(N5,N6)
      S(I1-1)=0.0
      IF (IVSM.EQ.1) GO TO 20
      DO 10 J=I1,I2
10    S(J)=S(J-1)+SQRT((X2(J)-X1(J))**2+(Y2(J)-Y1(J))**2)
      GO TO 40
20    DO 30 J=I1,I2
30    S(J)=S(J-1)+SQRT((X1(J)-X1(J-1))**2+(X2(J)-X2(J-1))**2)
40    CONTINUE
      II=I2-I1+1
      DELS=S(I2)/II
      I3=I2-1
      S1(I1-1)=0.0
      DO 50 J=I1,I3
```

```
50    S1(J)=S1(J-1)+DELS                                                SMO  26
      S1(I2)=S(I2)                                                      SMO  27
      DO 90 J=I1,I3                                                     SMO  28
      DO 60 K=I1,I3                                                     SMO  29
      IF (S(K)-S1(J)) 60,70,70                                          SMO  30
60    CONTINUE                                                          SMO  31
70    IF (IVSM.EQ.1) GO TO 80                                           SMO  32
      Y22(J)=Y1(K)+(Y2(K)-Y1(K))*(S1(J)-S(K-1))/(S(K)-S(K-1))           SMO  33
      GO TO 90                                                          SMO  34
80    Y22(J)=Y1(K-1)+(Y1(K)-Y1(K-1))*(S1(J)-S(K-1))/(S(K)-S(K-1))       SMO  35
90    CONTINUE                                                          SMO  36
      Y22(I2)=Y2(I2)                                                    SMO  37
      IF (IVSM.EQ.1) Y22(I2)=Y1(I2)                                     SMO  38
      DO 100 J=1,II                                                     SMO  39
100   Y(J)=Y22(J+I1-1)                                                  SMO  40
      CALL MSMTH (Y,Z,II,K11,NA,DDY,DY,DZ,DDZ,Z1)                       SMO  41
      DO 110 J=I1,I2                                                    SMO  42
110   Y22S(J)=Z(J-I1+1)                                                 SMO  43
      Y22S(I1-1)=Y2(I1-1)                                               SMO  44
      IF (IVSM.EQ.1) Y22S(I1-1)=Y1(I1-1)                                SMO  45
      DO 160 J=I1,I3                                                    SMO  46
      DO 120 K=I1,I3                                                    SMO  47
      IF (S1(K)-S(J)) 120,130,130                                       SMO  48
120   CONTINUE                                                          SMO  49
130   IF (IVSM.EQ.1) GO TO 140                                          SMO  50
      Y2(J)=Y22S(K-1)+(Y22S(K)-Y22S(K-1))*(S(J)-S1(K-1))/(S1(K)-S1(K-1))SMO  51
      GO TO 150                                                         SMO  52
140   CONTINUE                                                          SMO  53
      Y1(J)=Y22S(K-1)+(Y22S(K)-Y22S(K-1))*(S(J)-S1(K-1))/(S1(K)-S1(K-1))SMO  54
150   CONTINUE                                                          SMO  55
      IF (IVSM.EQ.0) Y1(J)=Y2(J-1)                                      SMO  56
160   CONTINUE                                                          SMO  57
170   CONTINUE                                                          SMO  58
      RETURN                                                            SMO  59
      END                                                               SMO  60-
      SUBROUTINE MSMTH (Y,Z,N,K,NA,DDY,DY,DZ,DDZ,Z1)                    MSM   1
C                                                                       MSM   2
      DIMENSION Y(NA), Z(NA), DY(NA), DZ(NA), DDY(NA), DDZ(NA), Z1(NA)  MSM   3
C                                                                       MSM   4
      IF (N-5) 40,10,10                                                 MSM   5
10    CALL RSMTH (Y,N,K,Z,NA,Z1)                                        MSM   6
      NM1=N-1                                                           MSM   7
      NM2=N-2                                                           MSM   8
      DO 20 I=1,NM1                                                     MSM   9
      DY(I)=Y(I+1)-Y(I)                                                 MSM  10
      DZ(I)=Z(I+1)-Z(I)                                                 MSM  11
20    CONTINUE                                                          MSM  12
      DO 30 I=1,NM2                                                     MSM  13
      DDY(I)=DY(I+1)-DY(I)                                              MSM  14
      DDZ(I)=DZ(I+1)-DZ(I)                                              MSM  15
30    CONTINUE                                                          MSM  16
40    RETURN                                                            MSM  17
      END                                                               MSM  18-
      SUBROUTINE RSMTH (Y,N,K,Z,NA,Z1)                                  RSM   1
C                                                                       RSM   2
      DIMENSION Y(NA), Z(NA), Z1(NA)                                    RSM   3
C                                                                       RSM   4
      J=0                                                               RSM   5
      DO 10 I=1,N                                                       RSM   6
      Z1(I)=Y(I)                                                        RSM   7
10    CONTINUE                                                          RSM   8
      Z(1)=Y(1)                                                         RSM   9
      Z(N)=Y(N)                                                         RSM  10
20    J=J+1                                                             RSM  11
      CALL SMTH (Z1,N,U,Z,NA)                                           RSM  12
      IF (U) 60,60,30                                                   RSM  13
```

```
30    IF (J-K) 40,60,60                                                 RSM  14
40    DO 50 I=1,N                                                       RSM  15
      Z1(I)=Z(I)                                                        RSM  16
50    CONTINUE                                                          RSM  17
      GO TO 20                                                          RSM  18
60    RETURN                                                            RSM  19
      END                                                               RSM  20-
      SUBROUTINE SMTH (Y,N,U,Z,NA)                                      SMT   1
C                                                                       SMT   2
      DIMENSION Y(NA), Z(NA)                                            SMT   3
C                                                                       SMT   4
      F(ETA)=(1.0-ETA*ETA)**2                                           SMT   5
      G(ET)=0.5*ET*(1.0+ET)                                             SMT   6
C                                                                       SMT   7
      U=0.0                                                             SMT   8
      J=3                                                               SMT   9
10    A=ABS(Y(J-2)-2.0*Y(J-1)+2.0*Y(J+1)-Y(J+2))                        SMT  10
      D=-Y(J-2)-4.0*Y(J-1)+10.0*Y(J)-4.0*Y(J+1)-Y(J+2)                  SMT  11
      IF (A-ABS(D)) 20,40,40                                            SMT  12
20    FS=F(A/D)                                                         SMT  13
      A=ABS(-Y(J-2)+Y(J-1)+Y(J+1)-Y(J+2))                               SMT  14
      B=ABS(3.0*(Y(J-1)-2.0*Y(J)+Y(J+1)))                               SMT  15
      IF (A-B) 30,40,40                                                 SMT  16
30    GS=G(1.0-A/B)                                                     SMT  17
      Z(J)=Y(J)-0.1*FS*GS*D                                             SMT  18
      U=1.0                                                             SMT  19
      GO TO 50                                                          SMT  20
40    Z(J)=Y(J)                                                         SMT  21
50    J=J+1                                                             SMT  22
      IF (J-(N-2)) 10,10,60                                             SMT  23
60    A=0.4*ABS(Y(4)-Z(4))                                              SMT  24
      D=0.2*(-6.0*Y(1)+10.0*Y(2)-2.0*Y(3)-Y(4)-Z(4))                    SMT  25
      IF (A-ABS(D)) 70,80,80                                            SMT  26
70    FS=F(A/D)                                                         SMT  27
      GS=G(A/ABS(D))                                                    SMT  28
      Z(2)=Y(2)-0.5*FS*GS*D                                             SMT  29
      GO TO 90                                                          SMT  30
80    Z(2)=Y(2)                                                         SMT  31
90    A=.4*ABS(Y(N-3)-Z(N-3))                                           SMT  32
      D=.2*(-Y(N-3)-Z(N-3)-2.*Y(N-2)+10.0*Y(N-1)-6.*Y(N))               SMT  33
      IF (A-ABS(D)) 100,110,110                                         SMT  34
100   FS=F(A/D)                                                         SMT  35
      GS=G(A/ABS(D))                                                    SMT  36
      Z(N-1)=Y(N-1)-0.5*FS*GS*D                                         SMT  37
      GO TO 120                                                         SMT  38
110   Z(N-1)=Y(N-1)                                                     SMT  39
120   RETURN                                                            SMT  40
      END                                                               SMT  41-
      SUBROUTINE IUNI(NMAX,N,X,NTAB,Y,IORDER,X0,Y0,IPT,IERR)            IUNI0010
C***********************************************************************IUNI0020
C*                                                                     *IUNI0030
C*    PURPOSE:                                                         *IUNI0040
C*                SUBROUTINE IUNI USES FIRST OR SECOND ORDER           *IUNI0050
C*                LAGRANGIAN INTERPOLATION TO ESTIMATE THE VALUES      *IUNI0060
C*                OF A SET OF FUNCTIONS AT A POINT X0.  IUNI           *IUNI0070
C*                USES ONE INDEPENDENT VARIABLE TABLE AND A DEPENDENT  *IUNI0080
C*                VARIABLE TABLE FOR EACH FUNCTION TO BE EVALUATED.    *IUNI0090
C*                THE ROUTINE ACCEPTS THE INDEPENDENT VARIABLES SPACED *IUNI0100
C*                AT EQUAL OR UNEQUAL INTERVALS.  EACH DEPENDENT       *IUNI0110
C*                VARIABLE TABLE MUST CONTAIN FUNCTION VALUES CORRES-  *IUNI0120
C*                PONDING TO EACH X(I) IN THE INDEPENDENT VARIABLE     *IUNI0130
C*                TABLE.  THE ESTIMATED VALUES ARE RETURNED IN THE Y0  *IUNI0140
C*                ARRAY WITH THE N-TH VALUE OF THE ARRAY HOLDING THE   *IUNI0150
C*                VALUE OF THE N-TH FUNCTION VALUE EVALUATED AT X0.    *IUNI0160
C*                                                                     *IUNI0170
C*       USE:                                                          *IUNI0180
```

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C*                    CALL IUNI(NMAX,N,X,NTAB,Y,IORDER,X0,Y0,IPT,IERR)       *IUNI0190
C*                                                                            *IUNI0200
C* PARAMETERS:                                                                *IUNI0210
C*                                                                            *IUNI0220
C*          NMAX      THE MAXIMUM NUMBER OF POINTS IN THE INDEPENDENT         *IUNI0230
C*                    VARIABLE ARRAY.                                         *IUNI0240
C*                                                                            *IUNI0250
C*             N      THE ACTUAL NUMBER OF POINTS IN THE INDEPENDENT          *IUNI0260
C*                    ARRAY,WHERE N .LE. NMAX.                                *IUNI0270
C*                                                                            *IUNI0280
C*             X      A ONE-DIMENSIONAL ARRAY, DIMENSIONED (NMAX) IN THE      *IUNI0290
C*                    CALLING PROGRAM, WHICH CONTAINS THE INDEPENDENT         *IUNI0300
C*                    VARIABLES.  THESE VALUES MUST BE STRICTLY MONOTONIC.    *IUNI0310
C*                                                                            *IUNI0320
C*          NTAB      THE NUMBER OF DEPENDENT VARIABLE TABLES                 *IUNI0330
C*                                                                            *IUNI0340
C*             Y      A TWO-DIMENSIONAL ARRAY DIMENSIONED (NMAX,NTAB) IN      *IUNI0350
C*                    THE CALLING PROGRAM.  EACH COLUMN OF THE ARRAY          *IUNI0360
C*                    CONTAINS A DEPENDENT VARIABLE TABLE                     *IUNI0370
C*                                                                            *IUNI0380
C*        IORDER      INTERPOLATION PARAMETER SUPPLIED BY THE USER.           *IUNI0390
C*                                                                            *IUNI0400
C*                    =0  ZERO ORDER INTERPOLATION: THE FIRST FUNCTION        *IUNI0410
C*                        VALUE IN EACH DEPENDENT VARIABLE TABLE IS           *IUNI0420
C*                        ASSIGNED TO THE CORRESPONDING MEMBER OF THE Y0      *IUNI0430
C*                        ARRAY.  THE FUNCTIONAL VALUE IS ESTIMATED TO        *IUNI0440
C*                        REMAIN CONSTANT AND EQUAL TO THE NEAREST KNOWN      *IUNI0450
C*                        FUNCTION VALUE.                                     *IUNI0460
C*                                                                            *IUNI0470
C*            X0      THE INPUT POINT AT WHICH INTERPOLATION WILL BE          *IUNI0480
C*                    PERFORMED.                                              *IUNI0490
C*                                                                            *IUNI0500
C*            Y0      A ONE-DIMENSIONAL ARRAY DIMENSIONED (NTAB) IN THE       *IUNI0510
C*                    CALLING PEOGRAM.  UPON RETURN THE ARRAY CONTAINS THE    *IUNI0520
C*                    ESTIMATED VALUE OF EACH FUNCTION AT X0.                 *IUNI0530
C*                                                                            *IUNI0540
C*           IPT      ON THE FIRST CALL IPT MUST BE INITIALIZED TO -1 SO      *IUNI0550
C*                    THAT MONOTONICITY WILL BE CHECKED. UPON LEAVING THE     *IUNI0560
C*                    ROUTINE IPT EQUALS THE VALUE OF THE INDEX OF THE X      *IUNI0570
C*                    VALUE PRECEDING X0 UNLESS EXTRAPOLATION WAS             *IUNI0580
C*                    PERFORMED.  IN THAT CASE THE VALUE OF IPT IS            *IUNI0590
C*                    RETURNED AS:                                            *IUNI0600
C*                    =0  DENOTES X0 .LT. X(1) IF THE X ARRAY IS IN           *IUNI0610
C*                        INCREASING ORDER AND X(1) .GT. X0 IF THE X ARRAY    *IUNI0620
C*                        IS IN DECREASING ORDER.                             *IUNI0630
C*                    =N  DENOTES X0 .GT. X(N) IF THE X ARRAY IS IN           *IUNI0640
C*                        INCREASING ORDER AND X0 .LT. X(N) IF THE X ARRAY    *IUNI0650
C*                        IS IN DECREASING ORDER.                             *IUNI0660
C*                                                                            *IUNI0670
C*                    ON SUBSEQUENT CALLS, IPT IS USED AS A POINTER TO        *IUNI0680
C*                    BEGIN THE SEARCH FOR X0.                                *IUNI0690
C*                                                                            *IUNI0700
C*          IERR      ERROR PARAMETER GENERATED BY THE ROUTINE                *IUNI0710
C*                    =0  NORMAL RETURN                                       *IUNI0720
C*                    =J  THE J-TH ELEMENT OF THE X ARRAY IS OUT OF ORDER     *IUNI0730
C*                    =-1 ZERO ORDER INTERPOLATION PERFORMED BECAUSE          *IUNI0740
C*                        IORDER =0.                                          *IUNI0750
C*                    =-2 ZERO ORDER INTERPOLATION PERFORMED BECAUSE ONLY     *IUNI0760
C*                        ONE POINT WAS IN X ARRAY.                           *IUNI0770
C*                    =-3 NO INTERPOLATION WAS PERFORMED BECAUSE              *IUNI0780
C*                        INSUFFICIENT POINTS WERE SUPPLIED FOR SECOND        *IUNI0790
C*                        ORDER INTERPOLATION.                                *IUNI0800
C*                    =-4 EXTRAPOLATION WAS PERFORMED                         *IUNI0810
C*                                                                            *IUNI0820
C*                    UPON RETURN THE PARAMETER IERR SHOULD BE TESTED IN      *IUNI0830
C*                    THE CALLING PROGRAM.                                    *IUNI0840
```

APPENDIX

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C*                                                                     *IUNT0850
C*    REQUIRED ROUTINES                NONE                            *IUNT0860
C*                                                                     *IUNT0870
C*    SOURCE                           CMPB ROUTINE MTLUP MODIFIED     *IUNT0880
C*                                     BY COMPUTER SCIENCES CORPORATION*IUNT0890
C*                                                                     *IUNT0900
C*    LANGUAGE                         FORTRAN                         *IUNT0910
C*                                                                     *IUNT0920
C*                                                                     *IUNT0930
C*    DATE RELEASED                    AUGUST 1,1973                   *IUNT0940
C*                                                                     *IUNT0950
C*    LATEST REVISION                  JUNE 9, 1975                    *IUNT0960
C*                                                                     *IUNT0970
C***********************************************************************IUNT0980
      DIMENSION X(1),Y(NMAX,1),YO(1)                                    IUNT0990
      NM1=N-1                                                           IUNT1000
      IERR=0                                                            IUNT1010
      J=1                                                               IUNT1020
C                                                                       IUNT1030
C              TEST FOR ZERO ORDER INTERPOLATION                        IUNT1040
C                                                                       IUNT1050
      DELX=X(2)-X(1)                                                    IUNT1060
      IF (IORDER .EQ. 0) GO TO 10                                       IUNT1070
      IF (N.LT. 2) GO TO 20                                             IUNT1080
      GO TO 50                                                          IUNT1090
   10 IERR=-1                                                           IUNT1100
      GO TO 30                                                          IUNT1110
   20 IERR=-2                                                           IUNT1120
   30 DO 40 NT=1,NTAB                                                   IUNT1130
         YO(NT)=Y(1,NT)                                                 IUNT1140
   40    CONTINUE                                                       IUNT1150
      RETURN                                                            IUNT1160
   50 IF (IPT .GT. -1) GO TO 65                                         IUNT1170
C                                                                       IUNT1180
C             CHECK FOR TABLE OF NODE POINTS BEING STRICTLY MONOTONIC   IUNT1190
C             THE SIGN OF DELX SIGNIFIES WHETHER TABLE IS IN            IUNT1200
C             INCREASING OR DECREASING ORDER.                           IUNT1210
C                                                                       IUNT1220
      IF (DELX .EQ. 0) GO TO 190                                        IUNT1230
      IF (N .EQ. 2) GO TO 65                                            IUNT1240
C                                                                       IUNT1250
C             CHECK FOR SIGN CONSISTENCY IN THE DIFFERENCES OF          IUNT1260
C             SUBSEQUENT PAIRS                                          IUNT1270
C                                                                       IUNT1280
      DO 60 J=2,NM1                                                     IUNT1290
         IF (DELX * (X(J+1)-X(J))) 190,190,60                           IUNT1300
   60    CONTINUE                                                       IUNT1310
C                                                                       IUNT1320
C             IPT IS INITIALIZED TO BE WITHIN THE INTERVAL              IUNT1330
C                                                                       IUNT1340
   65 IF (IPT .LT. 1) IPT=1                                             IUNT1350
      IF (IPT .GT. NM1) IPT=NM1                                         IUNT1360
      IN= SIGN (1.0,DELX *( X0-X(IPT)))                                 IUNT1370
   70 P= X(IPT) - X0                                                    IUNT1380
      IF (P* (X(IPT +1)- X0)) 90,180,80                                 IUNT1390
   80 IPT =IPT +IN                                                      IUNT1400
C                                                                       IUNT1410
C             TEST TO SEE IF IT IS NECCESARY TO EXTRAPOLATE             IUNT1420
C                                                                       IUNT1430
      IF (IPT.GT.0 .AND. IPT .LT. N) GO TO 70                           IUNT1440
      IERR=-4                                                           IUNT1450
      IPT=IPT- IN                                                       IUNT1460
C                                                                       IUNT1470
C             TEST FOR ORDER OF INTERPOLATION                           IUNT1480
C                                                                       IUNT1490
C                                                                       IUNT1500
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   90 IF (IORDER .GT. 1) GO TO 120                                      IUNT1510
C                                                                       IUNT1520
C          FIRST ORDER INTERPOLATION                                    IUNT1530
C                                                                       IUNT1540
      IPT1=IPT+1                                                        IUNT1550
      XTMP1=X0-X(IPT)                                                   IUNT1560
      XTMP2=X(IPT1)-X(IPT)                                              IUNT1570
      XTMP1=XTMP1/XTMP2                                                 IUNT1580
      DO 100 NT=1,NTAB                                                  IUNT1590
         YTMP=Y(IPT1,NT)-Y(IPT,NT)                                      IUNT1600
         Y0(NT)=Y(IPT,NT)+YTMP*XTMP1                                    IUNT1610
  100    CONTINUE                                                       IUNT1620
      IF (IERR .EQ. -4) IPT=IPT+IN                                      IUNT1630
      RETURN                                                            IUNT1640
C                                                                       IUNT1650
C          SECOND ORDER INTERPOLATION                                   IUNT1660
C                                                                       IUNT1670
  120 IF (N .EQ. 2) GO TO 200                                           IUNT1680
C                                                                       IUNT1690
C          CHOOSING A THIRD POINT SO AS TO MINIMIZE THE DISTANCE        IUNT1700
C          BETWEEN THE THREE POINTS USED TO INTERPOLATE                 IUNT1710
C                                                                       IUNT1720
      IF (IPT .EQ. NM1) GO TO  140                                      IUNT1730
      IF (IPT .EQ. 1) GO TO 130                                         IUNT1740
      A1=ABS(X0-X(IPT-1))                                               IUNT1750
      A2=ABS(X(IPT+2)-X0)                                               IUNT1760
      IF(A1-A2)140,130,130                                              IUNT1770
  130 L=IPT                                                             IUNT1780
      GO TO 150                                                         IUNT1790
  140 L=IPT -1                                                          IUNT1800
  150 V1=X(L)-X0                                                        IUNT1810
      V2=X(L+1)-X0                                                      IUNT1820
      V3=X(L+2)-X0                                                      IUNT1830
      DO 160 NT=1,NTAB                                                  IUNT1840
      YY1=(Y(L,NT) * V2 - Y(L+1,NT) * V1)/(X(L+1) - X(L))               IUNT1850
      YY2=(Y(L+1,NT)*V3-Y(L+2,NT) *V2)/(X(L+2)-X(L+1))                  IUNT1860
      Y0(NT)=(YY1*V3-YY2*V1)/(X(L+2)-X(L))                              IUNT1870
  160 CONTINUE                                                          IUNT1880
      IF (IERR .EQ. -4) IPT=IPT + IN                                    IUNT1890
      RETURN                                                            IUNT1900
  180 IF(P .NE. 0) IPT=IPT +1                                           IUNT1910
      DO 185 NT=1,NTAB                                                  IUNT1920
         Y0(NT)=Y(IPT,NT)                                               IUNT1930
  185    CONTINUE                                                       IUNT1940
      RETURN                                                            IUNT1950
C                                                                       IUNT1960
C          IERR IS SET TO THE SUBSCRIPT OF THE MEMBER OF THE TABLE      IUNT1970
C          WHICH IS OUT OF ORDER                                        IUNT1980
C                                                                       IUNT1990
  190 IERR=J +1                                                         IUNT2000
      RETURN                                                            IUNT2010
  200 IERR=-3                                                           IUNT2020
      RETURN                                                            IUNT2030
      END                                                               IUNT2040
```

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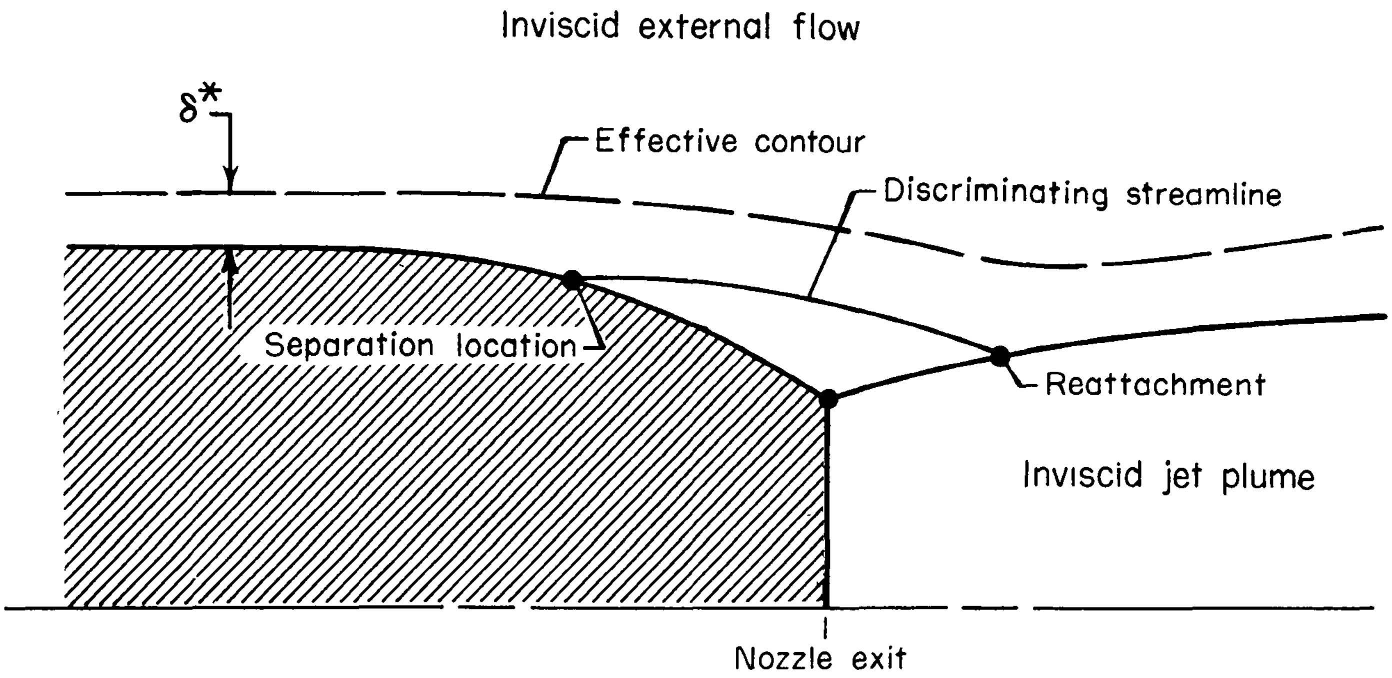


Figure 1.- Analytical model of flow over nozzle boattail.

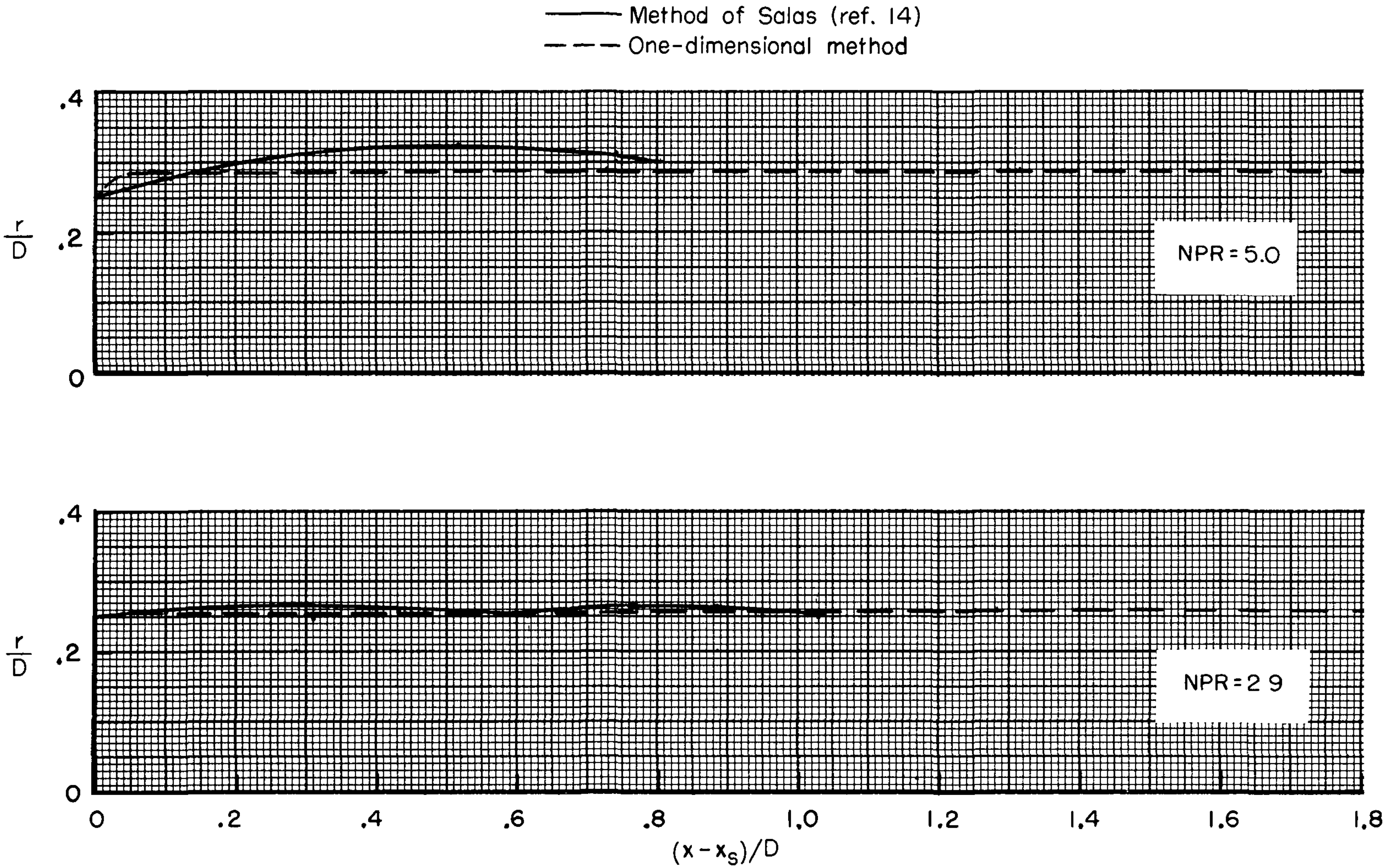
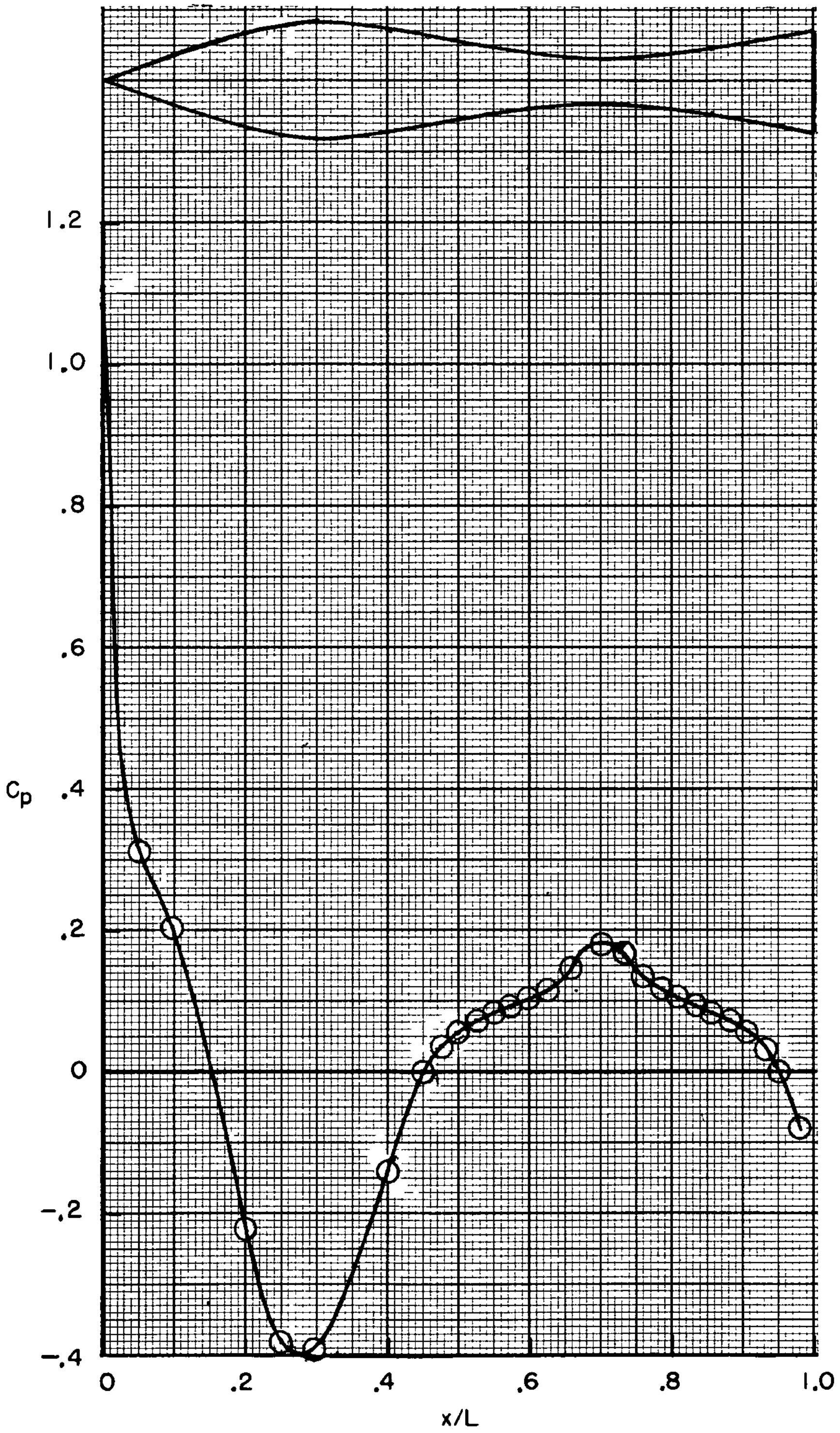


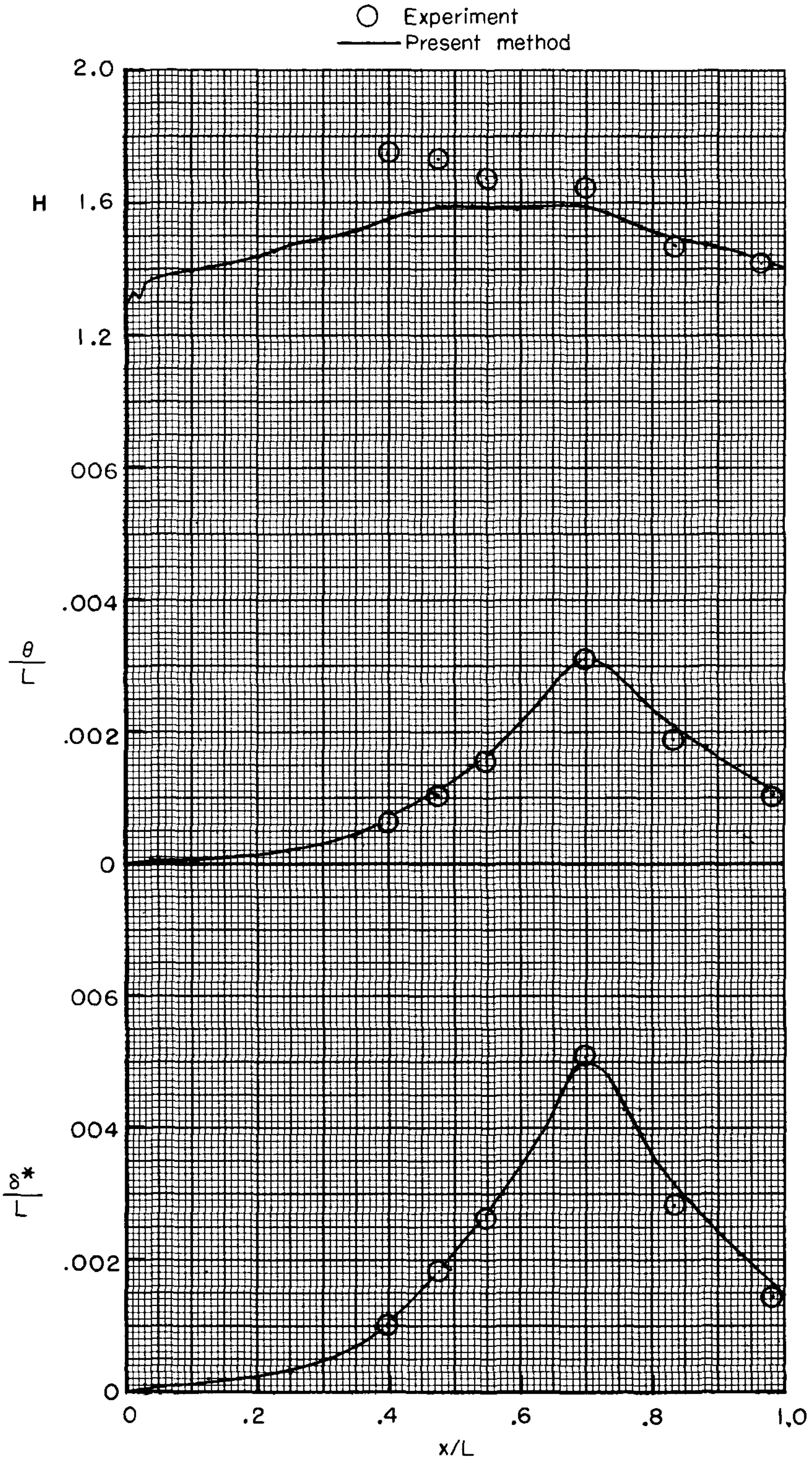
Figure 2.- Comparison of one-dimensional jet exhaust flow calculation with method of Salas (ref. 14).



P(x) input to stand-alone boundary layer procedure.

(a) Pressure distribution and body geometry.

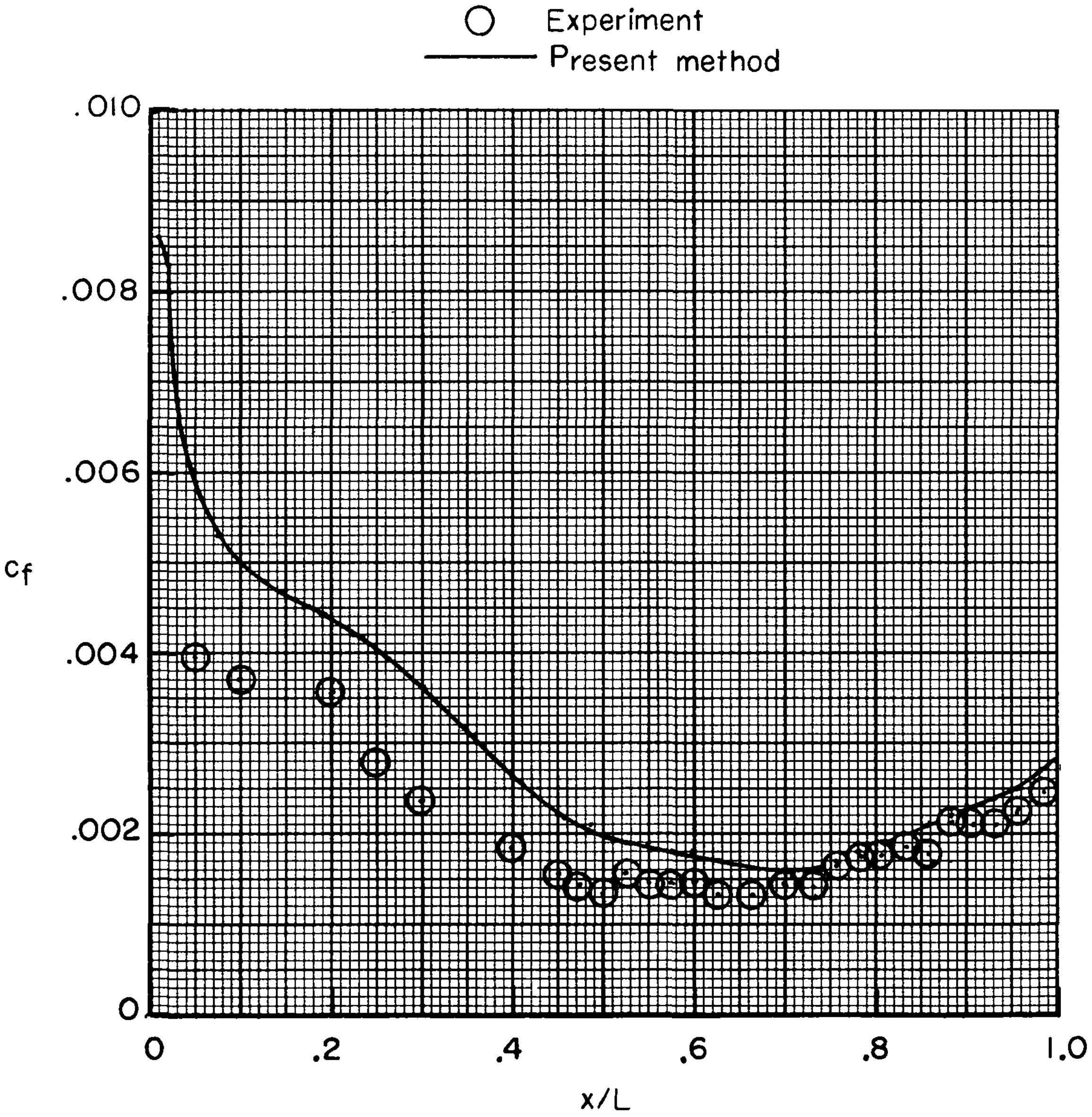
Figure 3.- Comparison of predicted boundary-layer characteristics with experiment of Winter, Rotta, and Smith (ref. 17). $M_\infty = 0.6$ and Reynolds number based on body length of 9.85×10^6.



(b) Displacement thickness, momentum thickness, and shape factor.

Figure 3.- Continued.

These are results from a stand-alone boundary-layer procedure (also next page).



(c) Skin friction.

Figure 3.- Concluded.

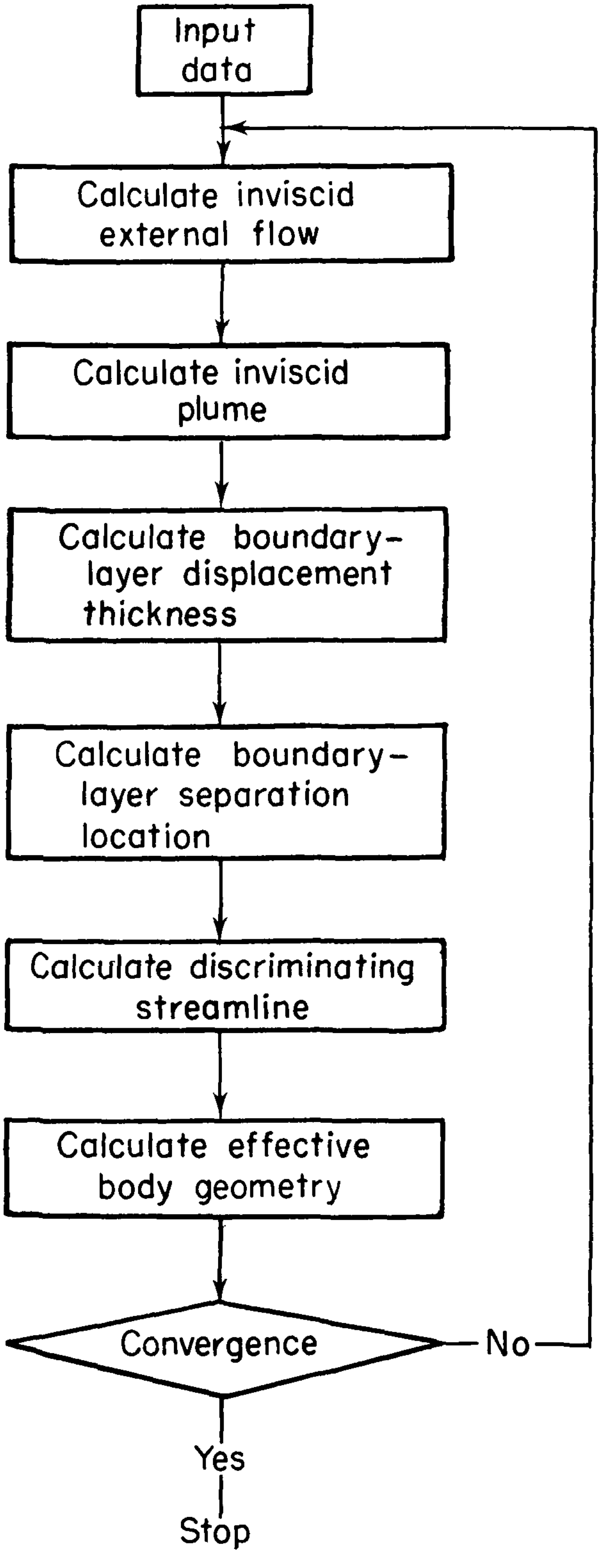


Figure 4.- Flow diagram of interaction procedure.

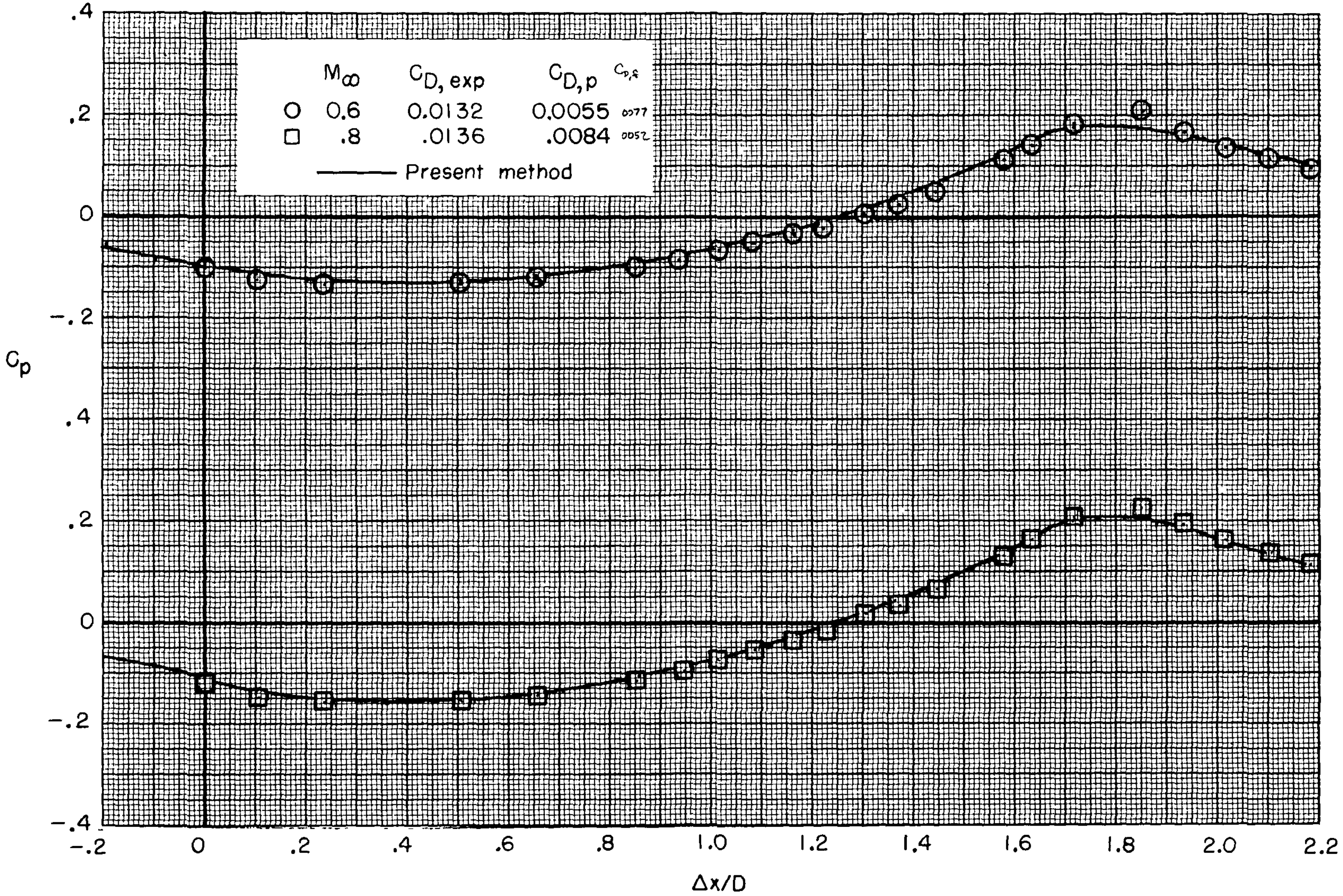
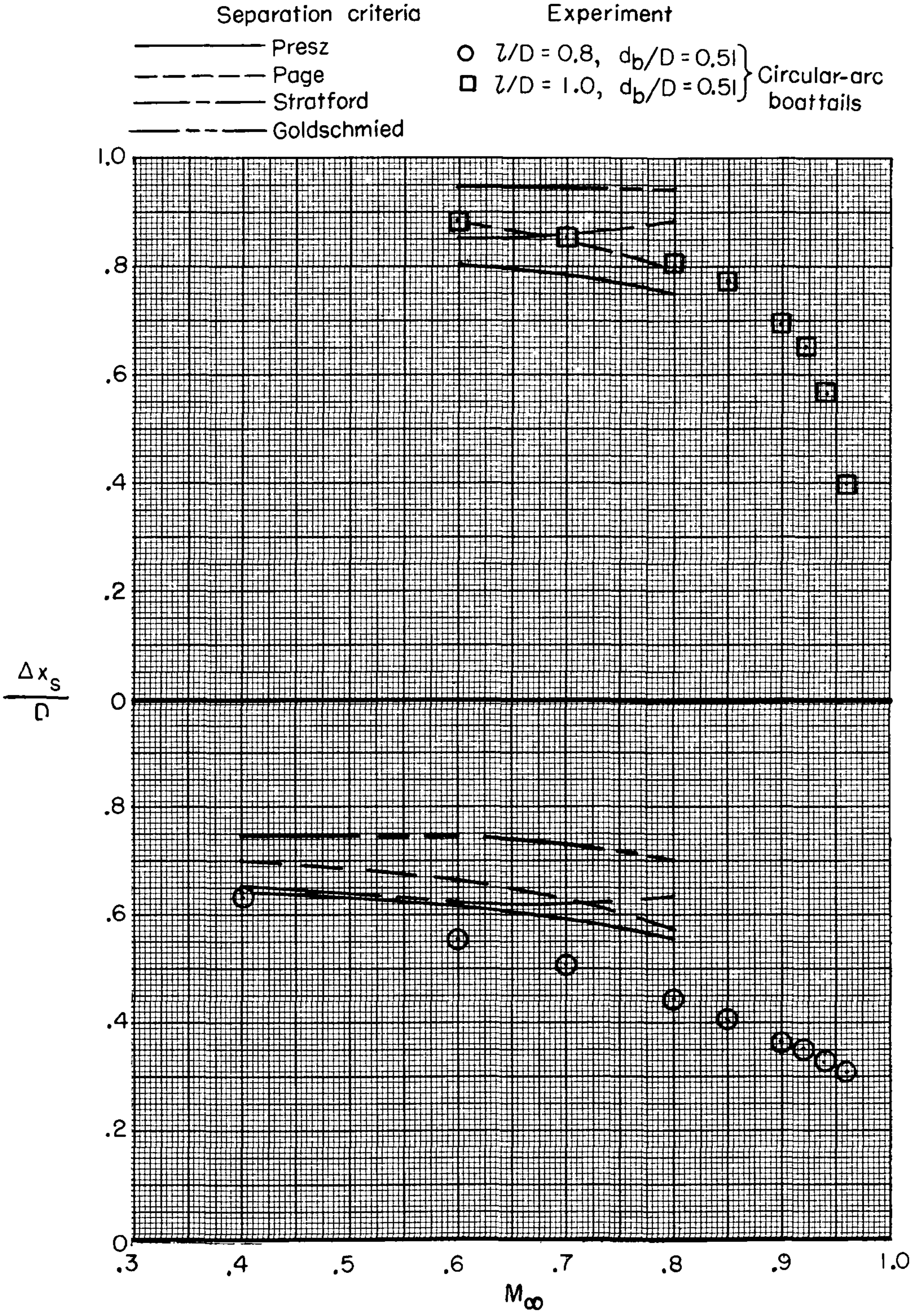


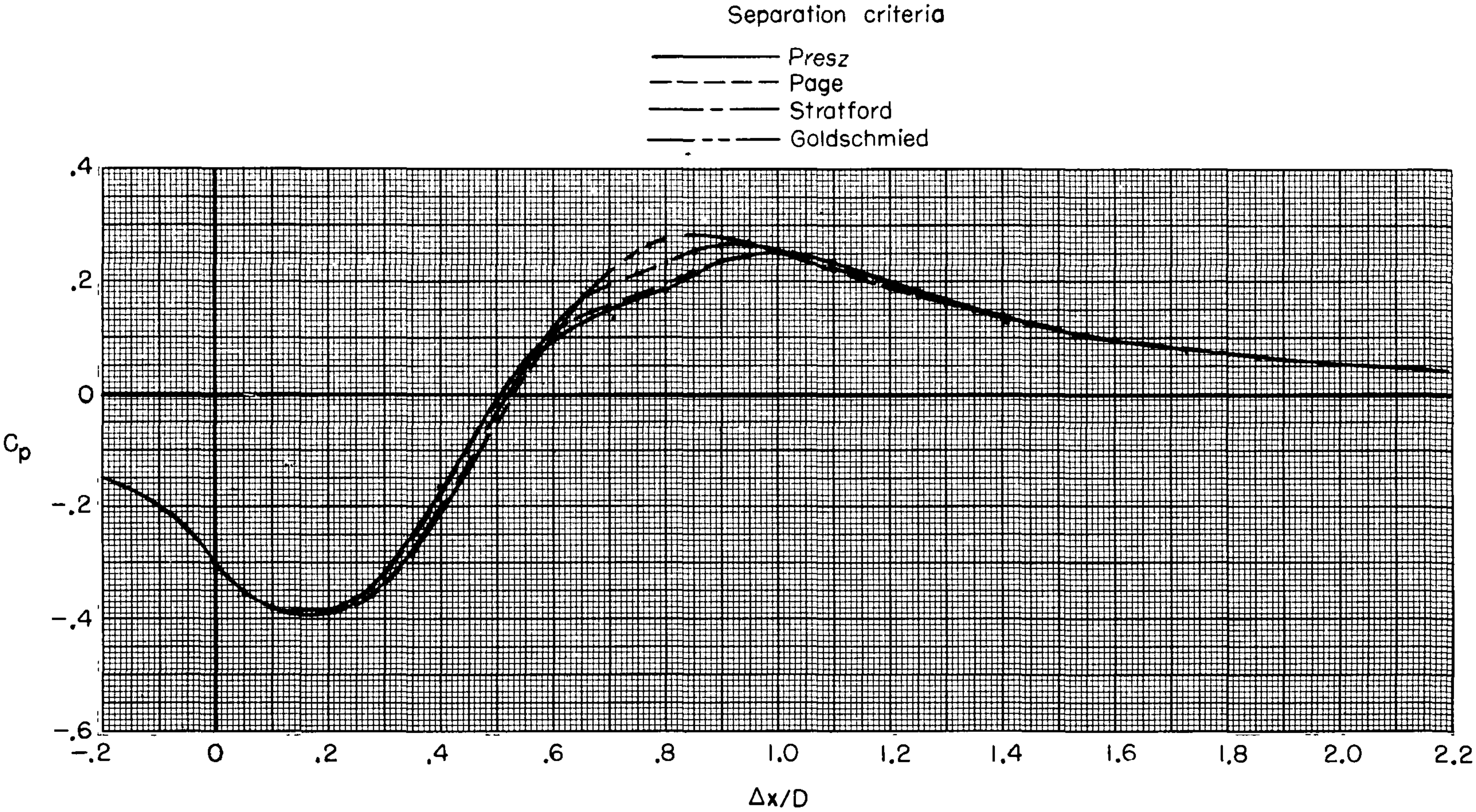
Figure 5.- Comparison of theory and experiment for flow over unseparated $l/D = 1.768$, $d_b/D = 0.51$ circular-arc nozzle with solid jet plume simulator. (Experimental data from ref. 22.)

TN-D-7192
Config #3



(a) Separation location.

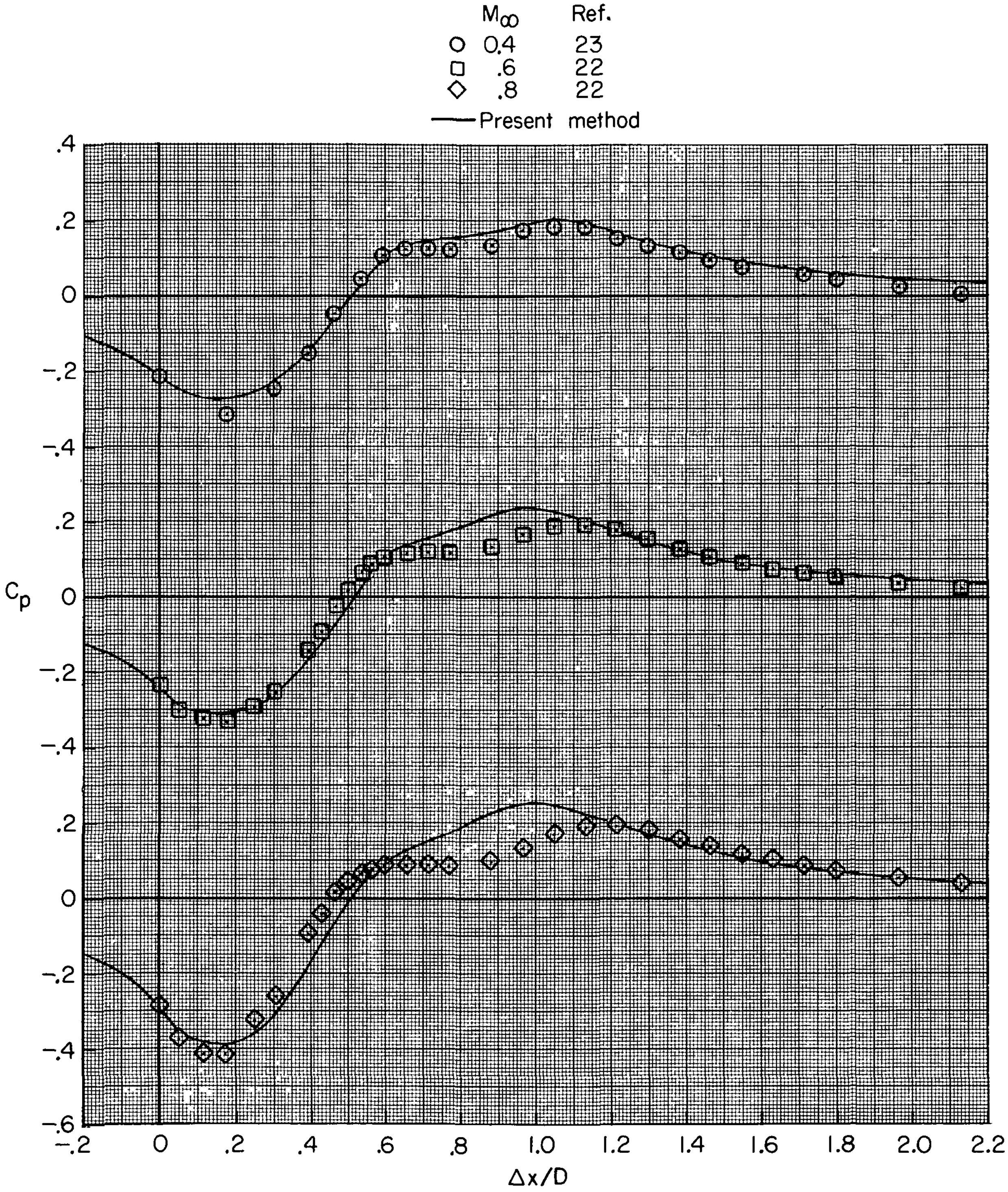
Figure 6.- Effect of separation location criteria. (Experimental data from ref. 21.)



(b) Predicted pressure distributions on $l/D = 0.8$, $d_b/D = 0.51$ circular-arc boattail at $M_\infty = 0.8$.

Figure 6.- Concluded.

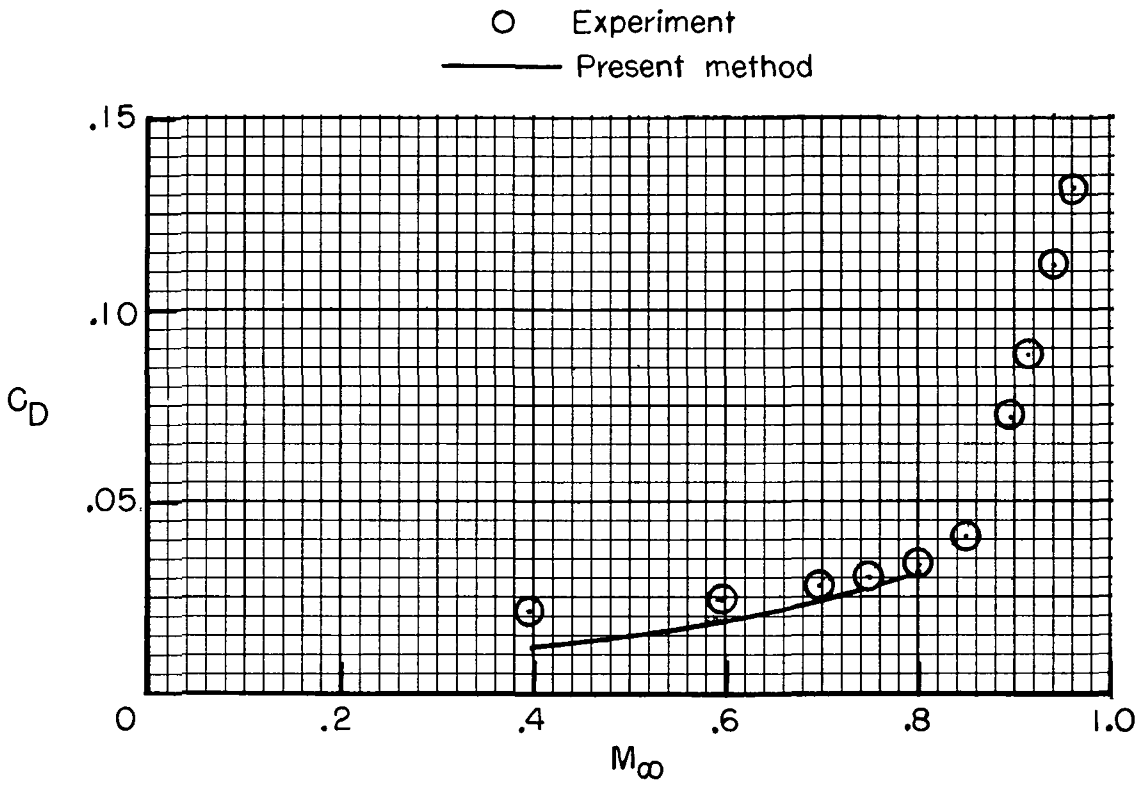
- you can get any pressure drag you want by altering this assumption!!



(a) Pressure distribution.

Figure 7.- Effect of Mach number on flow over $l/D = 0.8$, $d_b/D = 0.51$ circular-arc boattail with solid jet plume simulator.

Langley #1



(b) Pressure drag coefficient.

Figure 7.- Concluded.

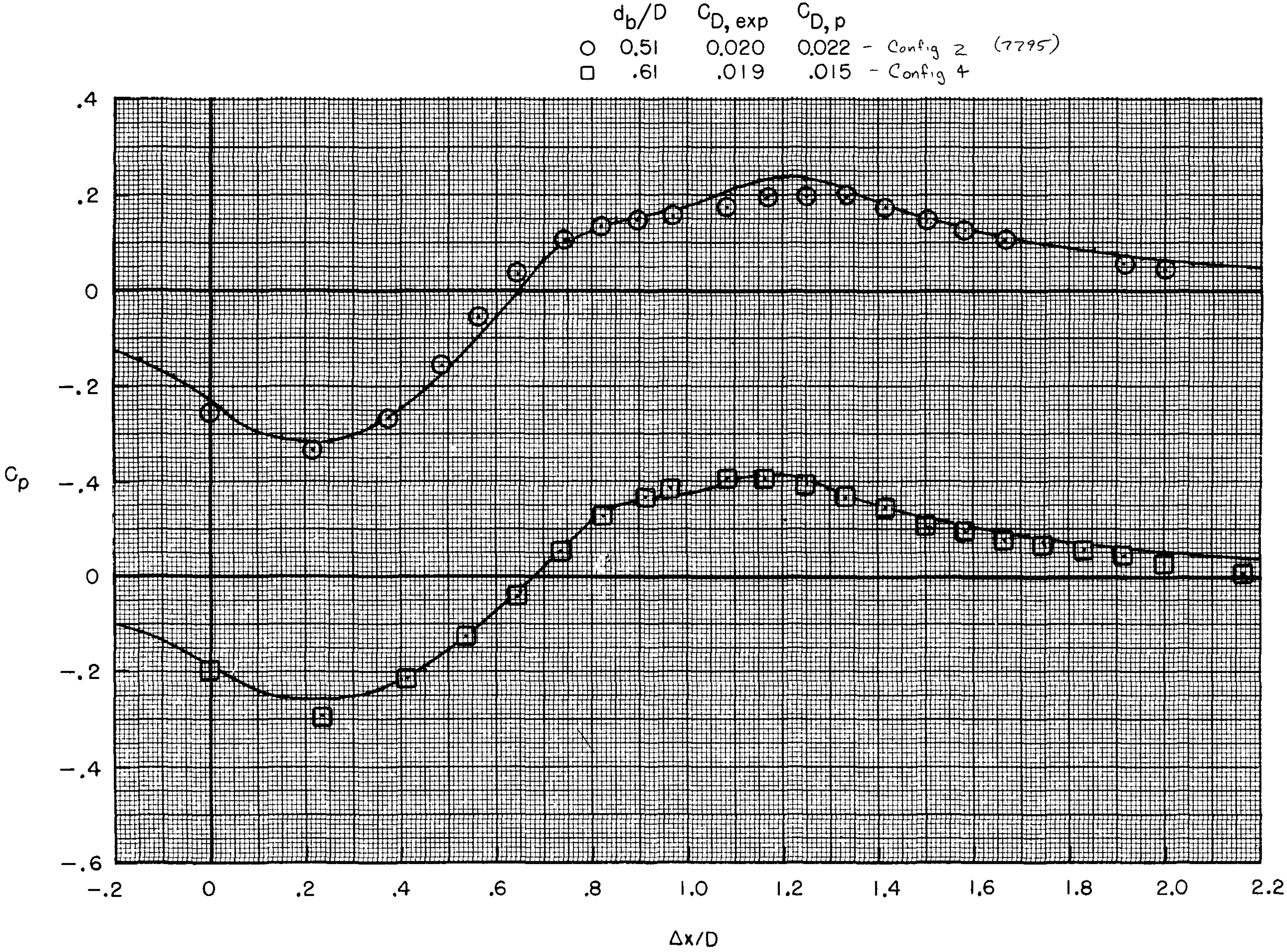
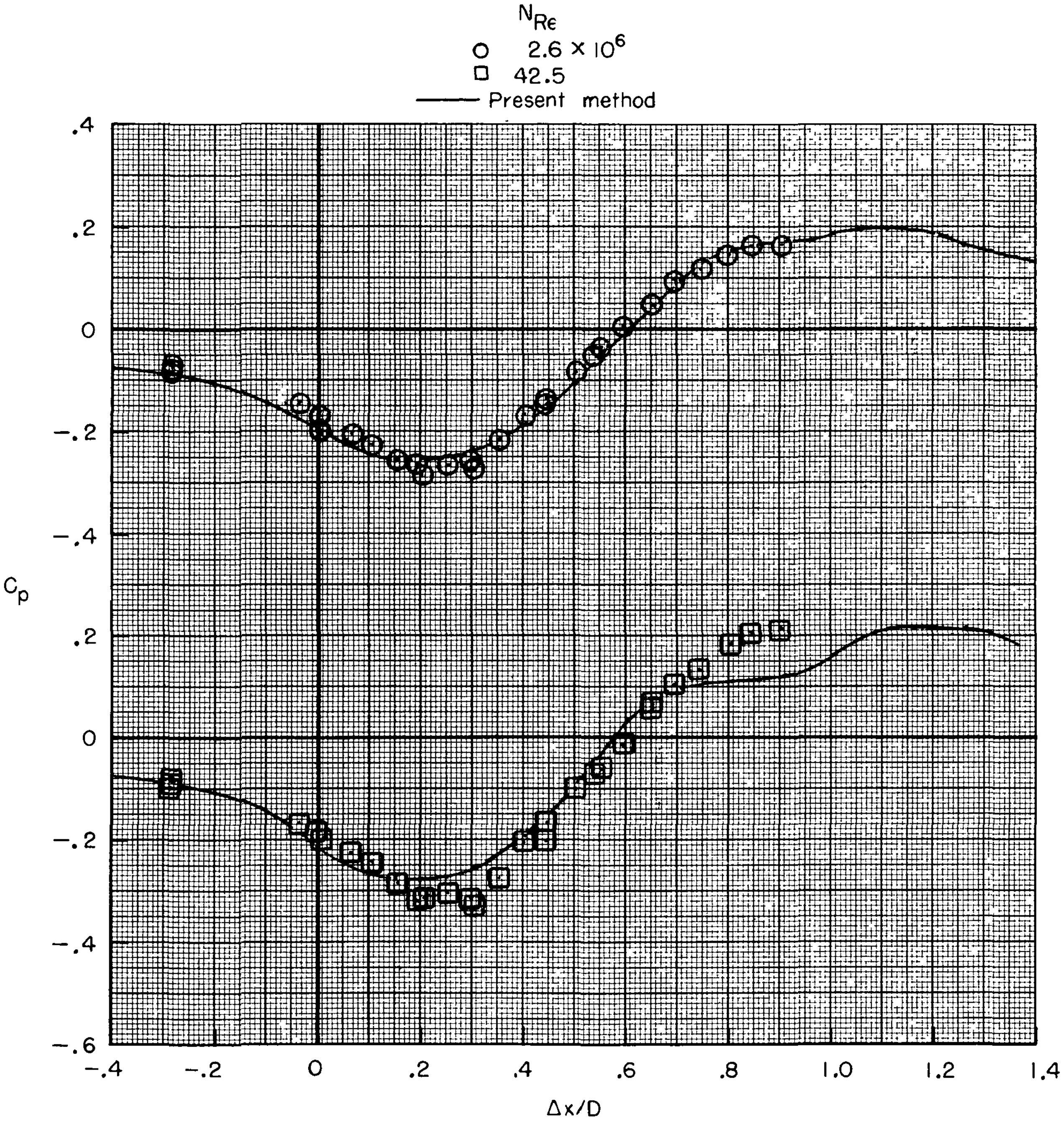


Figure 8.- Effect of afterbody closure on flow over $l/D = 1.0$ circular-arc boattails with solid jet plume simulators. $M_\infty = 0.8$. (Experimental data from ref. 23.)

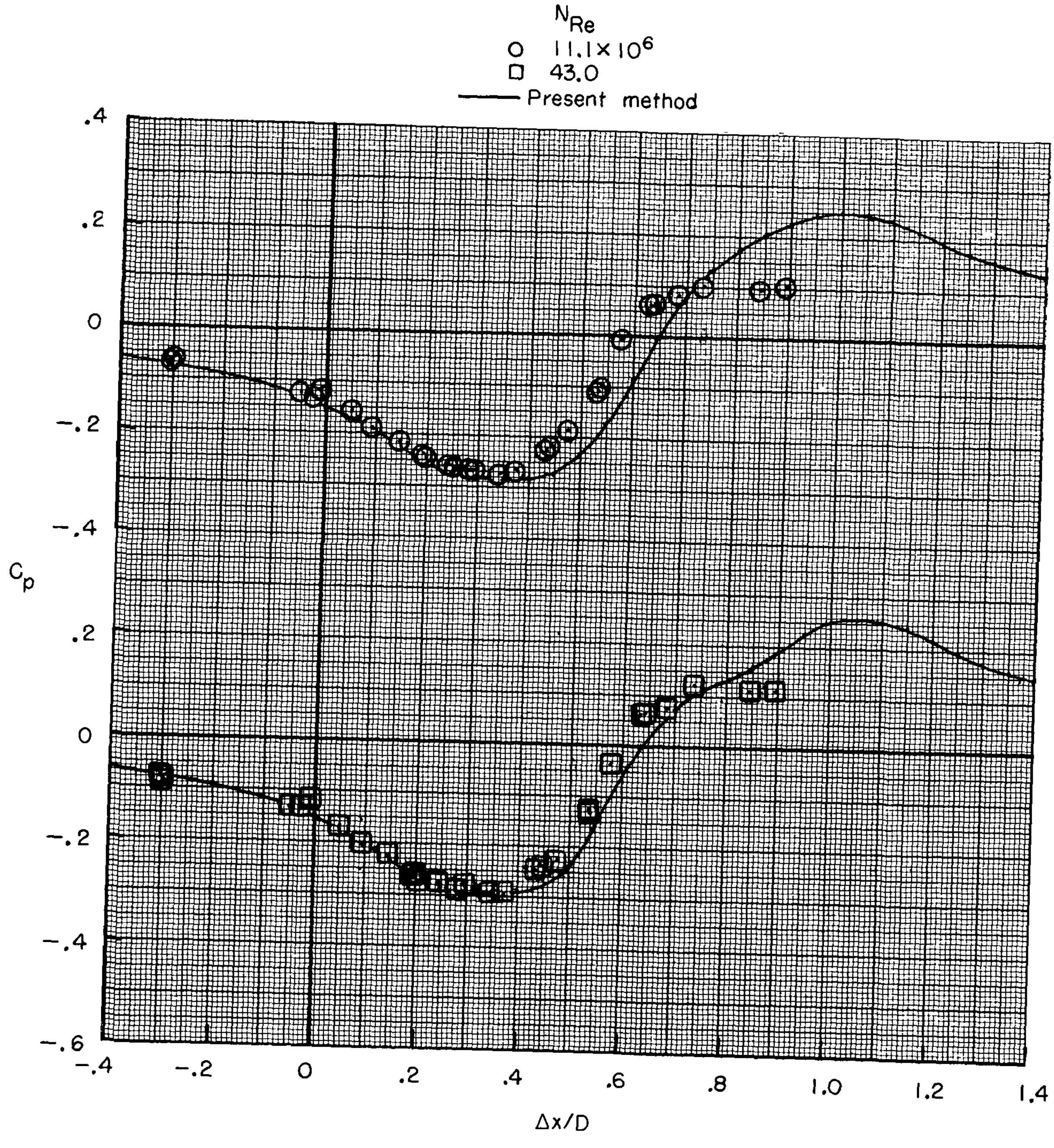
TN-D-7795



(a) Pressure distributions for $l/D = 0.961$, $d_b/D = 0.51$ circular-arc conic boattail.

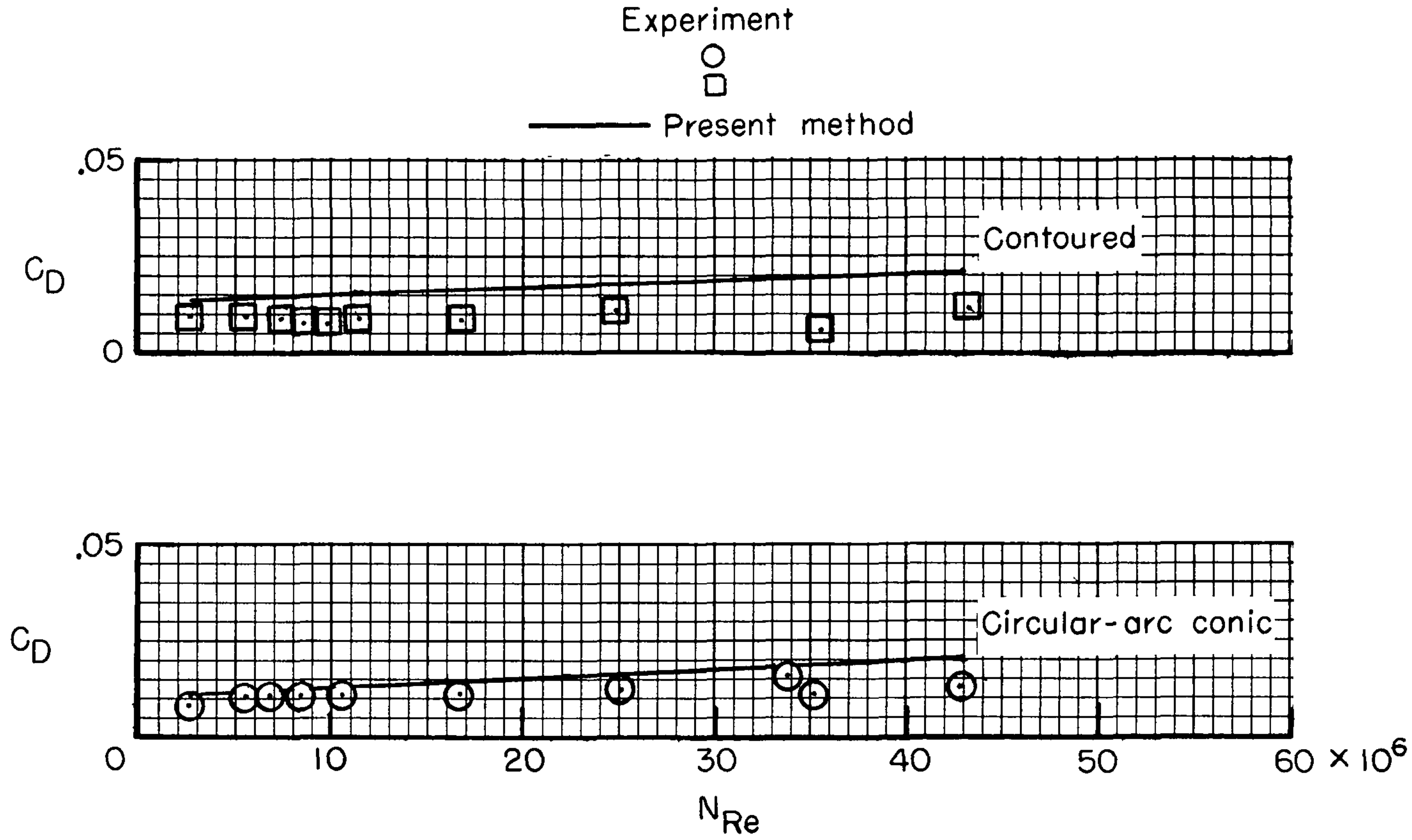
Figure 9.- Effect of Reynolds number on pressures and drag of afterbodies with solid jet plume simulators. $M_\infty = 0.6$. (Experimental data from ref. 1.)

TN-D-8210
"Circular-arc conic"



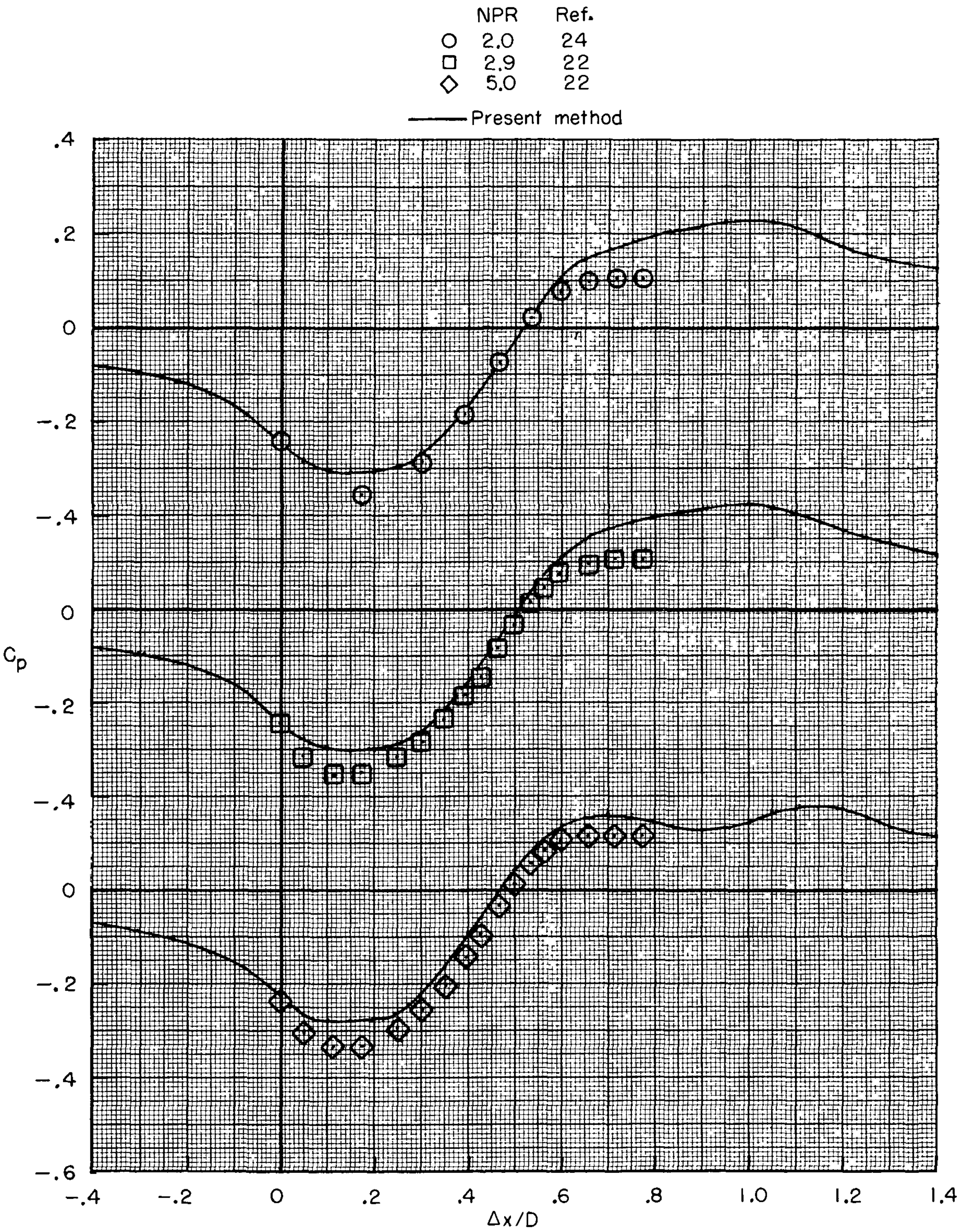
(b) Pressure distributions for $l/D = 0.95$, $d_b/D = 0.544$ contoured boattail.

Figure 9.- Continued.



(c) Drag coefficient.

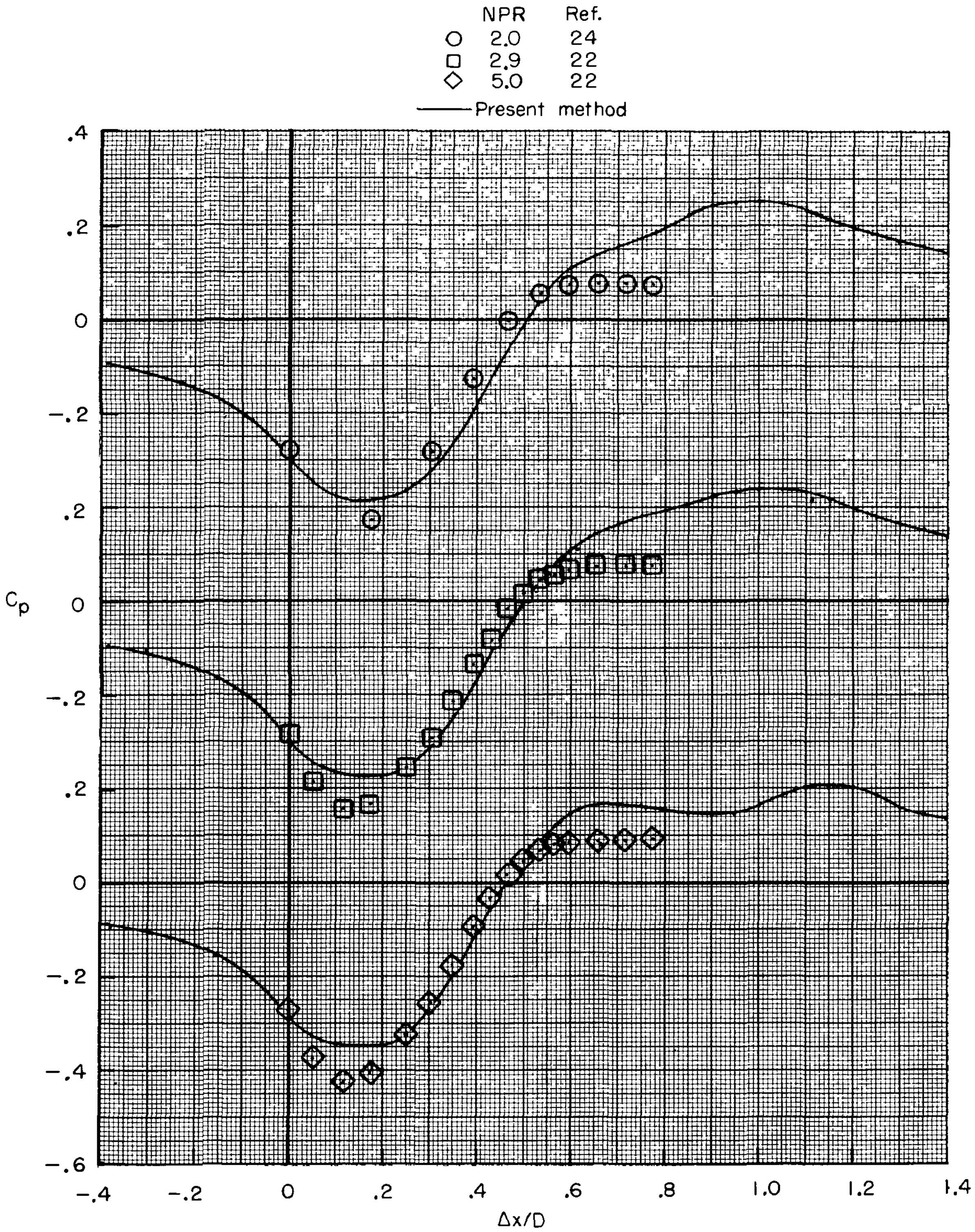
Figure 9.- Concluded.



(a) Pressure distribution at $M_\infty = 0.6$.

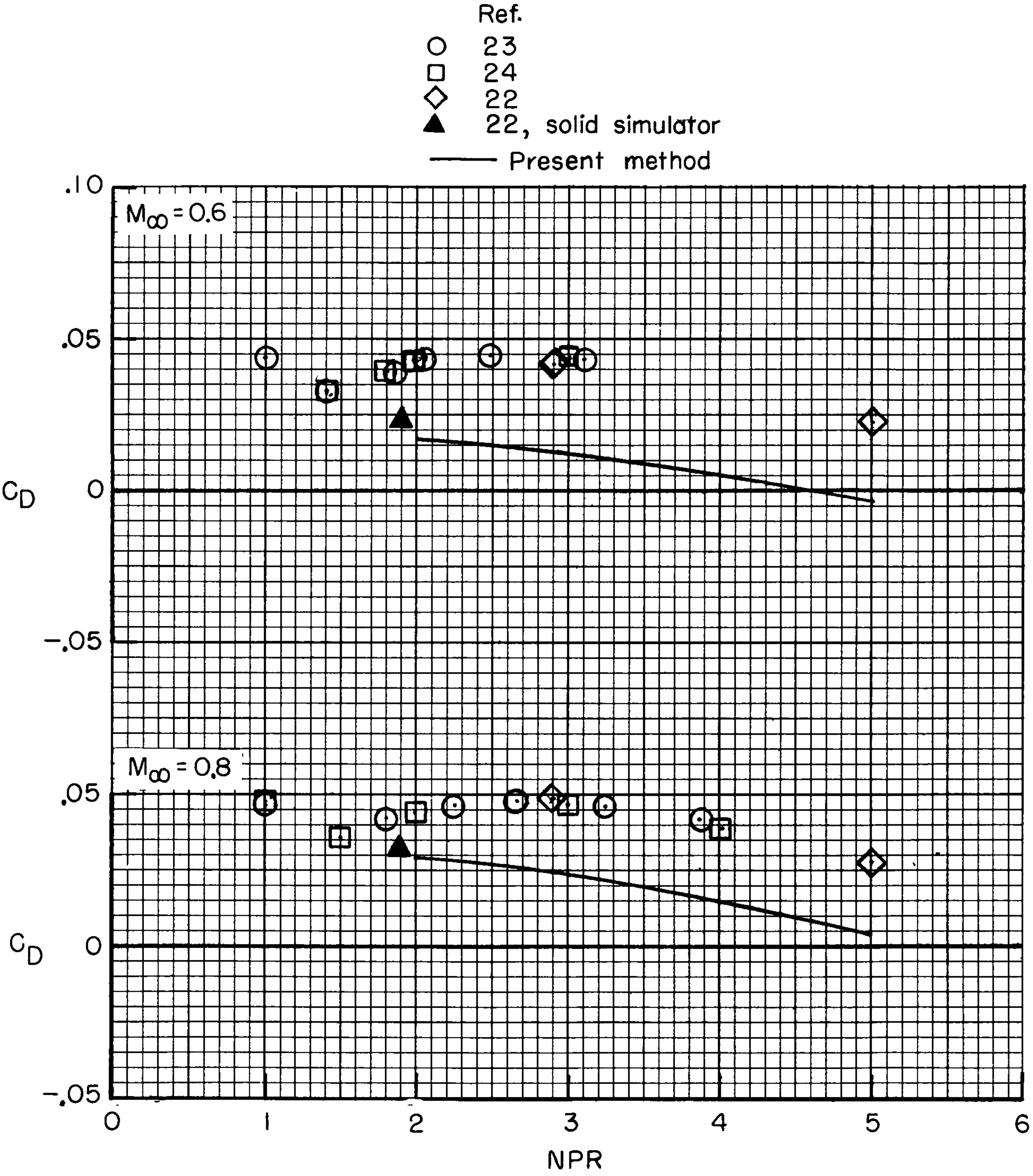
Figure 10.- Effect of NPR on pressures and drag for $l/D = 0.8$, $d_b/D = 0.51$ circular-arc nozzle.

prediction is far more sensitive to NPR than the data



(b) Pressure distribution at $M_\infty = 0.8$.

Figure 10.- Continued.



(c) Drag coefficient.

Figure 10.- Concluded.

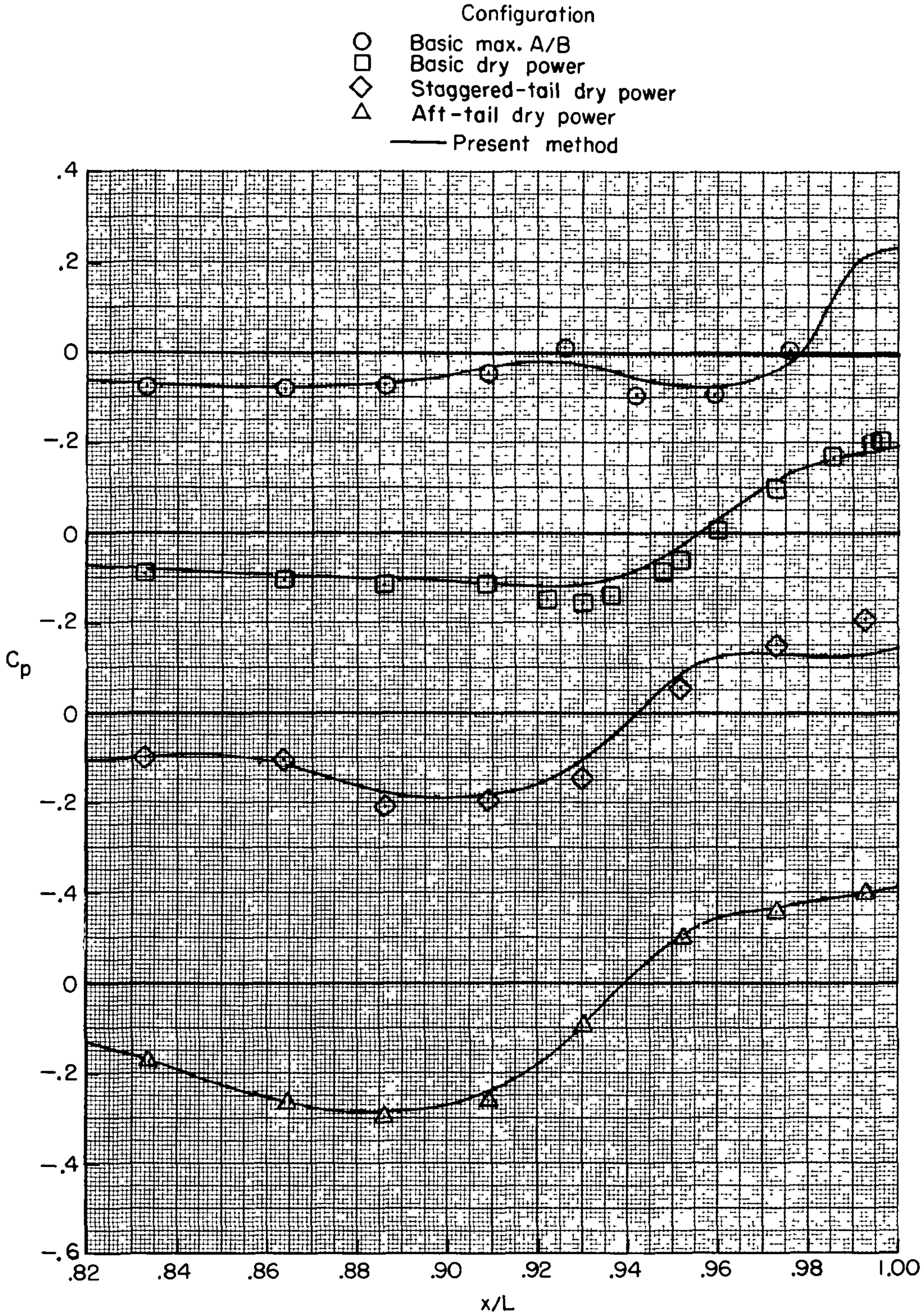


Figure 11.- Comparison of experimental and predicted pressures for equivalent bodies of Berrier (ref. 25). $M_\infty = 0.8$ and NPR = 2.5.

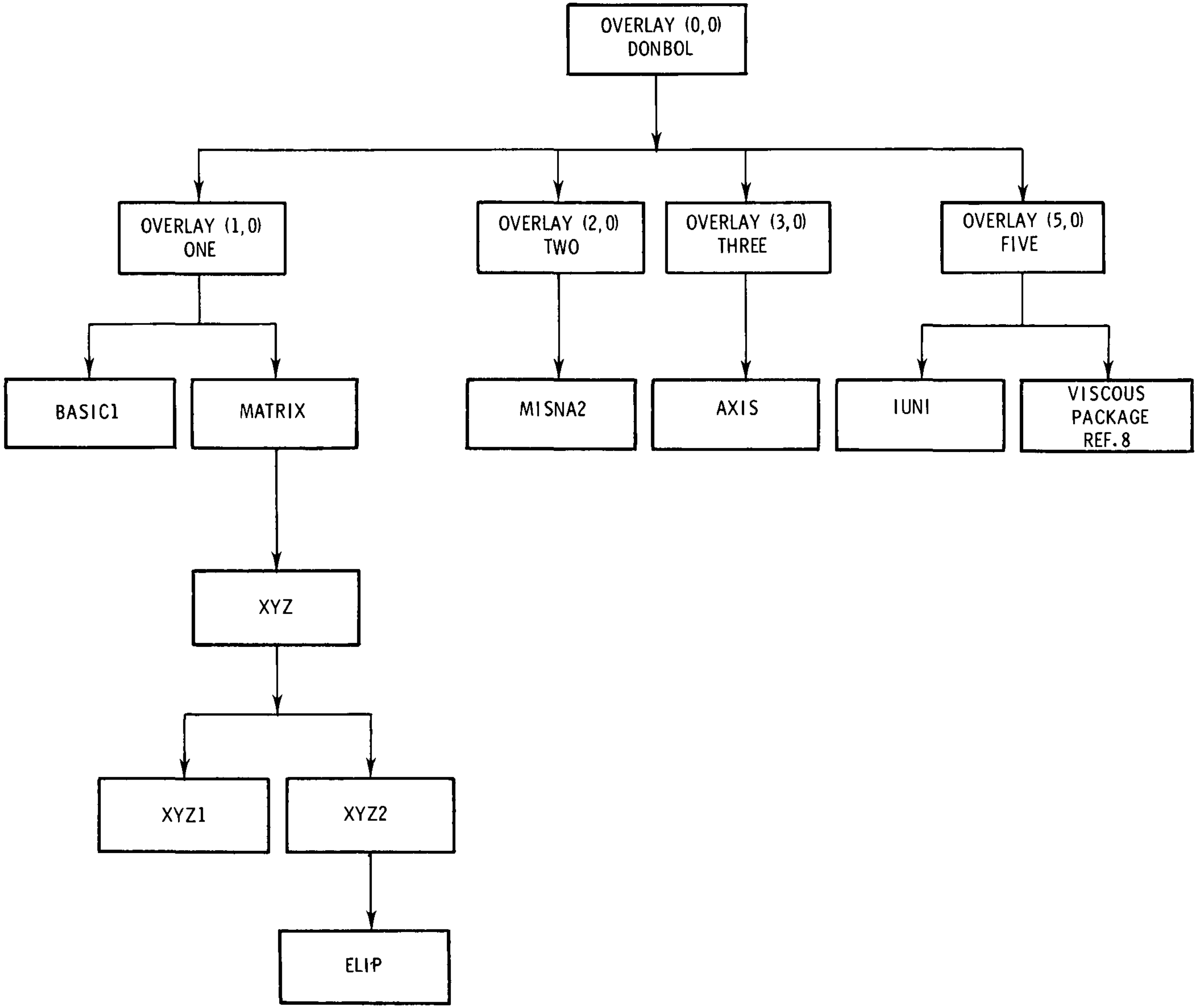


Figure 12.- Flow chart for program DONBOL.

```
**TEST CASE**  L/D=9 FOREBODY L/D=0.8 DB/D=0.51 CIRCULAR ARC NOZZLE  NPR=5.03
    2   15    1    0    15    2    2    1  113  135    1  135    1    1
0.80        100720.0  324.44     0.1524     0.0182415
1.000       332342.7  295.56     0.250
  167
  0.000000   .076271    .152542    .228814    .305085    .381356
   .457627   .533898    .610169    .686441    .762712    .838983
   .915254   .991525   1.067797   1.144068   1.220339   1.296610
  1.372881  1.449153   1.525424   1.601695   1.677966   1.754237
  1.830508  1.906780   1.983051   2.059322   2.135593   2.211864
  2.288136  2.364407   2.440678   2.516949   2.593220   2.669492
  2.745763  2.822034   2.898305   2.974576   3.050847   3.127119
  3.203390  3.279661   3.355932   3.432203   3.508475   3.584746
  3.661017  3.737288   3.813559   3.889831   3.966102   4.042373
  4.118644  4.194915   4.271186   4.347458   4.423729   4.500000
  4.576271  4.652542   4.728814   4.805085   4.881356   4.957627
  5.033898  5.110169   5.186441   5.262712   5.338983   5.415254
  5.491525  5.567797   5.644068   5.720339   5.796610   5.872881
  5.949153  6.025424   6.101695   6.177966   6.254237   6.330508
  6.406780  6.483051   6.559322   6.635593   6.711864   6.788136
  6.864407  6.940678   7.016949   7.093220   7.169492   7.245763
  7.322034  7.398305   7.474576   7.550847   7.627119   7.703390
  7.779661  7.855932   7.932203   8.008475   8.084746   8.161017
  8.237288  8.313559   8.389831   8.466102   8.542373   8.618644
  8.694915  8.771186   8.847458   8.923729   9.000000   9.050000
  9.100000  9.150000   9.200000   9.250000   9.300000   9.350000
  9.400000  9.450000   9.500000   9.550000   9.600000   9.650000
  9.700000  9.750000   9.800000   9.850000   9.900000   9.950000
 10.000000 10.050000  10.100000  10.150000  10.200000  10.250000
 10.300000 10.350000  10.400000  10.450000  10.500000  10.550000
 10.600000 10.664562  10.729125  10.793687  10.858250  10.922812
 10.987375 11.051937  11.116500  11.181062  11.245625  11.310187
 11.374750 11.439312  11.503875  11.568437  11.633000
  0.000000   .019011    .038021    .057032    .076043    .095053
   .114064   .133075    .152085    .171096    .190107    .209117
   .228128   .247139    .265867    .283850    .301088    .317584
   .333344   .348371    .362670    .376244    .389097    .401232
   .412653   .423362    .433361    .442654    .451243    .459130
   .466317   .472806    .478598    .483695    .488099    .491809
   .494827   .497155    .498791    .499738    .500000    .500000
   .500000   .500000    .500000    .500000    .500000    .500000
   .500000   .500000    .500000    .500000    .500000    .500000
   .500000   .500000    .500000    .500000    .500000    .500000
   .500000   .500000    .500000    .500000    .500000    .500000
   .500000   .500000    .500000    .500000    .500000    .500000
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   .500000   .500000    .500000    .500000    .500000    .500000
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   .500000   .500000    .500000    .500000    .500000    .500000
   .500000   .500000    .500000    .500000    .500000    .499125
   .496496   .492104    .485931    .477956    .468146    .456463
   .442859   .427277    .409646    .389885    .367897    .343565
   .316754   .287298    .255000    .250000    .250000    .250000
   .250000   .250000    .250000    .250000    .250000    .250000
   .250000   .250000    .250000    .250000    .250000    .250000
   .250000   .250000    .250000    .250000    .250000    .250000
   .250000   .250000    .250000    .250000    .250000    .250000
   .250000   .250000    .250000    .250000    .250000
   10
  8.800000  9.000000   9.200000   9.400000   9.600000   9.800000
  9.800000  9.800000   9.800000   9.800000
  0.60000    .600000    .600000    .600000    .600000   .600000
   .550000   .500000    .450000    .400000
```

Figure 13.- Sample input data

```
          DONBOL  ---  AN AXISYMMETRIC INVISCID/VISCID INTERACTION PROGRAM

                BY LAWRENCE E. PUTNAM, NASA, LANGLEY RESEARCH CENTER

  CASE TITLE = **TEST CASE**  L/D=9 FOREBODY L/D=0.8 DB/D=0.51 CIRCULAR ARC NOZZLE  NPR=5.03

             ***** CASE CONTROL DATA *****


             OFF-BODY POINTS
             LABRUJERE COMPRESSIBILITY CORRECTION
             MODIFIED RESHOTKO TUCKER BOUNDARY LAYER SOLUTION
             PRESZ MODIFIED CONTROL VOLUME DISCRIMINATING STREAMLINE SOLUTION
             PRESZ CONTROL VOLUME SEPARATION LOCATION CRITERIA
             START SEARCH FOR SEPARATION AT I = 113
             END SEARCH FOR SEPARATION AT I = 135
             JET EXHAUST PLUME CALCULATION
             NOZZLE EXIT AT I = 135
             SMOOTH AERODYNAMIC CONTOUR
             SMOOTH PRESSURE DISTRIBUTION

             FREE STREAM CONDITIONS
                    MACH NUMBER         =          .800
                    TOTAL PRESSURE      =  100720.000 PASCALS
                    TOTAL TEMPERATURE   =     324.440 KELVIN
                    REYNOLDS NUMBER     =      12.182 MILLION PER METER

             JET EXHAUST CONDITIONS AT NOZZLE EXIT
                    MACH NUMBER         =       1.000
                    TOTAL PRESSURE      =  332342.700 PASCALS
                    TOTAL TEMPERATURE   =     295.560 KELVIN
                    NPR                 =       5.030
```

(a) Page 1.

Figure 14.- Sample output data.

```
FOR ITERA=  0    8 ITERATIONS REQUIRED FOR CONVERGENCE IN MISNA2

FOR ITERA=  1    8 ITERATIONS REQUIRED FOR CONVERGENCE IN MISNA2

FOR ITERA=  2    8 ITERATIONS REQUIRED FOR CONVERGENCE IN MISNA2

FOR ITERA=  3    8 ITERATIONS REQUIRED FOR CONVERGENCE IN MISNA2

FOR ITERA=  4    8 ITERATIONS REQUIRED FOR CONVERGENCE IN MISNA2

FOR ITERA=  5    8 ITERATIONS REQUIRED FOR CONVERGENCE IN MISNA2

FOR ITERA=  6    8 ITERATIONS REQUIRED FOR CONVERGENCE IN MISNA2

FOR ITERA=  7    8 ITERATIONS REQUIRED FOR CONVERGENCE IN MISNA2

FOR ITERA=  8    8 ITERATIONS REQUIRED FOR CONVERGENCE IN MISNA2

FOR ITERA=  9    8 ITERATIONS REQUIRED FOR CONVERGENCE IN MISNA2

FOR ITERA= 10    8 ITERATIONS REQUIRED FOR CONVERGENCE IN MISNA2

FOR ITERA= 11    8 ITERATIONS REQUIRED FOR CONVERGENCE IN MISNA2

FOR ITERA= 12    8 ITERATIONS REQUIRED FOR CONVERGENCE IN MISNA2

FOR ITERA= 13    8 ITERATIONS REQUIRED FOR CONVERGENCE IN MISNA2

FOR ITERA= 14    8 ITERATIONS REQUIRED FOR CONVERGENCE IN MISNA2

FOR ITERA= 15    8 ITERATIONS REQUIRED FOR CONVERGENCE IN MISNA2
```

(b) Page 2.

Figure 14.- Continued.

```
**TEST CASE**  L/D=9 FOREBODY L/D=0.8 DB/D=0.51 CIRCULAR ARC NOZZLE  NPR=5.03          ITERATION NO  15

 MO =  .8000     TT = 324.44 KELVIN     PT =  100720.0 PASCALS     L =   .152400 METERS     SREF =   .018242 SQ METERS

  BOUNDARY LAYER SEPARATION AT X/L =  9.529286             BOUNDARY LAYER REATTACHMENT AT X/L = 11.633000

   X/L      R/L      CP       CF       CDP      CDF      CDT      RDS/L     RC/L   DEL*/L   DEL/L  THETA/L    H

  0.0000   0.0000   1.1704   .0095   0.0000   0.0000   0.0000   0.0000   .0001   0.0000   0.0000   0.0000   0.0000
   .0763    .0190    .4430   .0095    .0006    .0000    .0007    .0190   .0191    .0001    .0010    .0001   1.3777
   .1525    .0380    .2840   .0067    .0021    .0001    .0022    .0380   .0383    .0003    .0023    .0002   1.4627
   .2288    .0570    .2635   .0058    .0041    .0003    .0043    .0570   .0575    .0005    .0035    .0003   1.4864
   .3051    .0760    .2465   .0054    .0066    .0005    .0071    .0760   .0767    .0006    .0045    .0004   1.4909
   .3814    .0951    .2318   .0051    .0097    .0007    .0104    .0951   .0958    .0008    .0054    .0005   1.4944
   .4576    .1141    .2183   .0049    .0133    .0009    .0142    .1141   .1150    .0009    .0063    .0006   1.4974
   .5339    .1331    .2052   .0047    .0173    .0013    .0185    .1331   .1341    .0010    .0071    .0007   1.5003
   .6102    .1521    .1922   .0046    .0216    .0016    .0232    .1521   .1532    .0011    .0079    .0007   1.5030
   .6864    .1711    .1788   .0045    .0261    .0020    .0281    .1711   .1724    .0012    .0086    .0008   1.5056
   .7627    .1901    .1644   .0044    .0308    .0024    .0332    .1901   .1915    .0013    .0093    .0009   1.5082
   .8390    .2091    .1484   .0043    .0356    .0029    .0385    .2091   .2106    .0014    .0100    .0009   1.5108
   .9153    .2281    .1282   .0043    .0401    .0034    .0436    .2281   .2297    .0015    .0107    .0010   1.5131
   .9915    .2471    .1023   .0042    .0443    .0040    .0483    .2471   .2488    .0016    .0113    .0010   1.5158
  1.0678    .2659    .0722   .0042    .0476    .0046    .0522    .2659   .2675    .0016    .0118    .0011   1.5197
  1.1441    .2839    .0472   .0041    .0500    .0053    .0552    .2839   .2856    .0017    .0124    .0011   1.5262
  1.2203    .3011    .0259   .0041    .0514    .0060    .0574    .3011   .3029    .0018    .0130    .0012   1.5332
  1.2966    .3176    .0066   .0040    .0521    .0067    .0588    .3176   .3195    .0019    .0136    .0012   1.5398
  1.3729    .3333   -.0111   .0039    .0520    .0075    .0595    .3333   .3354    .0020    .0143    .0013   1.5460
  1.4492    .3484   -.0274   .0039    .0512    .0084    .0595    .3484   .3505    .0021    .0150    .0014   1.5517
  1.5254    .3627   -.0427   .0038    .0498    .0092    .0590    .3627   .3649    .0022    .0157    .0014   1.5571
  1.6017    .3762   -.0569   .0038    .0478    .0101    .0579    .3762   .3786    .0023    .0164    .0015   1.5620
  1.6780    .3891   -.0701   .0037    .0452    .0110    .0563    .3891   .3916    .0024    .0171    .0016   1.5667
  1.7542    .4012   -.0823   .0037    .0423    .0119    .0543    .4012   .4038    .0025    .0178    .0016   1.5711
  1.8305    .4127   -.0935   .0036    .0391    .0129    .0520    .4127   .4153    .0027    .0185    .0017   1.5753
  1.9068    .4234   -.1038   .0036    .0355    .0139    .0494    .4234   .4262    .0028    .0193    .0018   1.5792
  1.9831    .4334   -.1130   .0035    .0318    .0149    .0467    .4334   .4363    .0029    .0201    .0018   1.5829
  2.0593    .4427   -.1214   .0035    .0280    .0159    .0439    .4427   .4457    .0030    .0208    .0019   1.5864
  2.1356    .4512   -.1287   .0034    .0241    .0169    .0410    .4512   .4544    .0032    .0217    .0020   1.5897
  2.2119    .4591   -.1351   .0034    .0204    .0179    .0383    .4591   .4624    .0033    .0225    .0021   1.5928
  2.2881    .4663   -.1403   .0033    .0167    .0190    .0357    .4663   .4698    .0034    .0233    .0021   1.5957
  2.3644    .4728   -.1445   .0033    .0132    .0200    .0332    .4728   .4764    .0036    .0242    .0022   1.5984
  2.4407    .4786   -.1475   .0033    .0100    .0211    .0311    .4786   .4823    .0037    .0251    .0023   1.6009
  2.5169    .4837   -.1492   .0032    .0071    .0221    .0292    .4837   .4876    .0039    .0260    .0024   1.6032
  2.5932    .4881   -.1496   .0032    .0045    .0232    .0277    .4881   .4921    .0040    .0270    .0025   1.6054
```

(c) Page 3.

Figure 14.- Continued.

```
**TEST CASE**  L/D=9 FOREBODY L/D=0.8 DB/D=0.51 CIRCULAR ARC NOZZLE  NPR=5.03        ITERATION NO  15

 MO =  .8000     TT = 324.44 KELVIN     PT =  100720.0 PASCALS     L =   .152400 METERS     SREF =   .018242 SQ METERS

   BOUNDARY LAYER SEPARATION AT X/L =  9.529286              BOUNDARY LAYER REATTACHMENT AT X/L = 11.633000

    X/L       R/L      CP       CF       CDP       CDF       CDT      RDS/L     RC/L   DEL*/L     DEL/L  THETA/L    H

  2.6695    .4918  -.1484    .0031    .0024    .0242    .0266    .4918    .4960    .0042    .0280    .0026  1.6075
  2.7458    .4948  -.1452    .0031    .0006    .0252    .0258    .4948    .4992    .0044    .0290    .0027  1.6095
  2.8220    .4972  -.1397    .0030   -.0007    .0262    .0255    .4972    .5018    .0046    .0301    .0029  1.6116
  2.8983    .4988  -.1314    .0030   -.0016    .0272    .0256    .4988    .5036    .0048    .0313    .0030  1.6138
  2.9746    .4997  -.1173    .0029   -.0021    .0282    .0261    .4997    .5048    .0051    .0325    .0032  1.6169
  3.0508    .5000  -.0979    .0028   -.0022    .0291    .0270    .5000    .5054    .0054    .0339    .0033  1.6209
  3.1271    .5000  -.0790    .0028   -.0022    .0300    .0279    .5000    .5058    .0058    .0353    .0035  1.6240
  3.2034    .5000  -.0665    .0027   -.0022    .0309    .0288    .5000    .5060    .0060    .0366    .0037  1.6244
  3.2797    .5000  -.0576    .0027   -.0022    .0318    .0296    .5000    .5063    .0063    .0380    .0039  1.6234
  3.3559    .5000  -.0508    .0027   -.0022    .0326    .0305    .5000    .5065    .0065    .0393    .0040  1.6217
  3.4322    .5000  -.0454    .0026   -.0022    .0335    .0313    .5000    .5067    .0067    .0406    .0041  1.6196
  3.5085    .5000  -.0411    .0026   -.0022    .0343    .0321    .5000    .5069    .0069    .0419    .0043  1.6174
  3.5847    .5000  -.0374    .0026   -.0022    .0351    .0329    .5000    .5071    .0071    .0432    .0044  1.6152
  3.6610    .5000  -.0343    .0026   -.0022    .0359    .0338    .5000    .5073    .0073    .0444    .0045  1.6130
  3.7373    .5000  -.0317    .0026   -.0022    .0367    .0346    .5000    .5074    .0074    .0457    .0046  1.6108
  3.8136    .5000  -.0294    .0026   -.0022    .0375    .0354    .5000    .5076    .0076    .0469    .0047  1.6087
  3.8898    .5000  -.0275    .0026   -.0022    .0383    .0362    .5000    .5078    .0078    .0481    .0048  1.6068
  3.9661    .5000  -.0257    .0025   -.0022    .0391    .0370    .5000    .5079    .0079    .0493    .0050  1.6049
  4.0424    .5000  -.0242    .0025   -.0022    .0399    .0377    .5000    .5081    .0081    .0504    .0051  1.6031
  4.1186    .5000  -.0229    .0025   -.0022    .0407    .0385    .5000    .5083    .0083    .0516    .0052  1.6015
  4.1949    .5000  -.0217    .0025   -.0022    .0415    .0393    .5000    .5084    .0084    .0528    .0053  1.5999
  4.2712    .5000  -.0206    .0025   -.0022    .0423    .0401    .5000    .5086    .0086    .0539    .0054  1.5985
  4.3475    .5000  -.0197    .0025   -.0022    .0430    .0409    .5000    .5088    .0088    .0550    .0055  1.5971
  4.4237    .5000  -.0188    .0025   -.0022    .0438    .0416    .5000    .5089    .0089    .0562    .0056  1.5958
  4.5000    .5000  -.0180    .0025   -.0022    .0446    .0424    .5000    .5091    .0091    .0573    .0057  1.5946
  4.5763    .5000  -.0173    .0025   -.0022    .0453    .0432    .5000    .5092    .0092    .0584    .0058  1.5935
  4.6525    .5000  -.0167    .0025   -.0022    .0461    .0439    .5000    .5094    .0094    .0595    .0059  1.5924
  4.7288    .5000  -.0161    .0025   -.0022    .0469    .0447    .5000    .5095    .0095    .0605    .0060  1.5914
  4.8051    .5000  -.0156    .0025   -.0022    .0476    .0455    .5000    .5097    .0097    .0616    .0061  1.5905
  4.8814    .5000  -.0152    .0024   -.0022    .0484    .0462    .5000    .5098    .0098    .0627    .0062  1.5896
  4.9576    .5000  -.0148    .0024   -.0022    .0491    .0470    .5000    .5100    .0100    .0638    .0063  1.5888
  5.0339    .5000  -.0144    .0024   -.0022    .0499    .0477    .5000    .5101    .0101    .0648    .0064  1.5880
  5.1102    .5000  -.0141    .0024   -.0022    .0506    .0485    .5000    .5103    .0103    .0658    .0065  1.5872
  5.1864    .5000  -.0138    .0024   -.0022    .0514    .0492    .5000    .5104    .0104    .0669    .0066  1.5865
  5.2627    .5000  -.0135    .0024   -.0022    .0521    .0500    .5000    .5106    .0106    .0679    .0067  1.5859
```

(d) Page 4.

Figure 14.- Continued.

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**TEST CASE**  L/D=9 FOREBODY L/D=0.8 DB/D=0.51 CIRCULAR ARC NOZZLE  NPR=5.03          ITERATION NO  15

 MO =  .8000     TT = 324.44 KELVIN     PT =  100720.0 PASCALS     L =   .152400 METERS     SREF =   .018242 SQ METERS

  BOUNDARY LAYER SEPARATION AT X/L =  9.529286            BOUNDARY LAYER REATTACHMENT AT X/L = 11.633000

   X/L       R/L      CP        CF       CDP       CDF       CDT      RDS/L      RC/L   DEL*/L    DEL/L  THETA/L    H

  5.3390    .5000   -.0133    .0024   -.0022    .0529    .0507    .5000     .5107    .0107    .0689    .0067  1.5852
  5.4153    .5000   -.0131    .0024   -.0022    .0536    .0514    .5000     .5108    .0108    .0700    .0068  1.5846
  5.4915    .5000   -.0130    .0024   -.0022    .0543    .0522    .5000     .5110    .0110    .0710    .0069  1.5841
  5.5678    .5000   -.0128    .0024   -.0022    .0551    .0529    .5000     .5111    .0111    .0720    .0070  1.5835
  5.6441    .5000   -.0127    .0024   -.0022    .0558    .0536    .5000     .5113    .0113    .0730    .0071  1.5830
  5.7203    .5000   -.0127    .0024   -.0022    .0565    .0544    .5000     .5114    .0114    .0740    .0072  1.5825
  5.7966    .5000   -.0126    .0024   -.0022    .0573    .0551    .5000     .5116    .0116    .0750    .0073  1.5820
  5.8729    .5000   -.0126    .0024   -.0022    .0580    .0558    .5000     .5117    .0117    .0760    .0074  1.5816
  5.9492    .5000   -.0126    .0023   -.0022    .0587    .0566    .5000     .5118    .0118    .0769    .0075  1.5812
  6.0254    .5000   -.0127    .0023   -.0022    .0594    .0573    .5000     .5120    .0120    .0779    .0076  1.5807
  6.1017    .5000   -.0127    .0023   -.0022    .0602    .0580    .5000     .5121    .0121    .0789    .0077  1.5803
  6.1780    .5000   -.0128    .0023   -.0022    .0609    .0587    .5000     .5122    .0122    .0799    .0077  1.5800
  6.2542    .5000   -.0130    .0023   -.0022    .0616    .0594    .5000     .5124    .0124    .0808    .0078  1.5796
  6.3305    .5000   -.0131    .0023   -.0022    .0623    .0602    .5000     .5125    .0125    .0818    .0079  1.5793
  6.4068    .5000   -.0133    .0023   -.0022    .0630    .0609    .5000     .5126    .0126    .0827    .0080  1.5789
  6.4831    .5000   -.0135    .0023   -.0022    .0637    .0616    .5000     .5128    .0128    .0837    .0081  1.5786
  6.5593    .5000   -.0138    .0023   -.0022    .0645    .0623    .5000     .5129    .0129    .0846    .0082  1.5783
  6.6356    .5000   -.0141    .0023   -.0022    .0652    .0630    .5000     .5130    .0130    .0855    .0083  1.5779
  6.7119    .5000   -.0144    .0023   -.0022    .0659    .0637    .5000     .5132    .0132    .0865    .0083  1.5776
  6.7881    .5000   -.0148    .0023   -.0022    .0666    .0644    .5000     .5133    .0133    .0874    .0084  1.5773
  6.8644    .5000   -.0153    .0023   -.0022    .0673    .0651    .5000     .5134    .0134    .0883    .0085  1.5770
  6.9407    .5000   -.0157    .0023   -.0022    .0680    .0658    .5000     .5135    .0135    .0892    .0086  1.5767
  7.0169    .5000   -.0163    .0023   -.0022    .0687    .0665    .5000     .5137    .0137    .0901    .0087  1.5764
  7.0932    .5000   -.0169    .0023   -.0022    .0694    .0672    .5000     .5138    .0138    .0911    .0087  1.5762
  7.1695    .5000   -.0176    .0023   -.0022    .0701    .0679    .5000     .5139    .0139    .0920    .0088  1.5759
  7.2458    .5000   -.0184    .0023   -.0022    .0708    .0686    .5000     .5140    .0140    .0928    .0089  1.5756
  7.3220    .5000   -.0192    .0023   -.0022    .0715    .0693    .5000     .5141    .0141    .0937    .0090  1.5753
  7.3983    .5000   -.0202    .0023   -.0022    .0722    .0700    .5000     .5143    .0143    .0946    .0091  1.5749
  7.4746    .5000   -.0213    .0023   -.0022    .0729    .0707    .5000     .5144    .0144    .0955    .0091  1.5746
  7.5508    .5000   -.0225    .0023   -.0022    .0736    .0714    .5000     .5145    .0145    .0963    .0092  1.5743
  7.6271    .5000   -.0239    .0022   -.0022    .0743    .0721    .5000     .5146    .0146    .0972    .0093  1.5739
  7.7034    .5000   -.0255    .0022   -.0022    .0750    .0728    .5000     .5147    .0147    .0981    .0093  1.5735
  7.7797    .5000   -.0273    .0022   -.0022    .0757    .0735    .5000     .5148    .0148    .0989    .0094  1.5731
  7.8559    .5000   -.0294    .0022   -.0022    .0764    .0742    .5000     .5149    .0149    .0997    .0094  1.5727
  7.9322    .5000   -.0317    .0022   -.0022    .0771    .0749    .5000     .5149    .0149    .1005    .0095  1.5722
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(e) Page 5.

Figure 14.- Continued.

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**TEST CASE**  L/D=9 FOREBODY L/D=0.8 DB/D=0.51 CIRCULAR ARC NOZZLE  NPR=5.03        ITERATION NO  15

 MO =  .8000    TT = 324.44 KELVIN    PT =  100720.0 PASCALS    L =   .152400 METERS    SREF =   .018242 80 METERS

  BOUNDARY LAYER SEPARATION AT X/L =  9.529286          BOUNDARY LAYER REATTACHMENT AT X/L = 11.633000

    X/L       R/L       CP        CF        CDP       CDF       CDT      RDS/L     RC/L   DEL*/L    DEL/L   THETA/L    H

   8.0085    .5000   -.0344    .0022   -.0022    .0778    .0756    .5000    .5150    .0150    .1013    .0095   1.5716
   8.0847    .5000   -.0376    .0022   -.0022    .0785    .0763    .5000    .5151    .0151    .1021    .0096   1.5710
   8.1610    .5000   -.0413    .0022   -.0022    .0792    .0770    .5000    .5151    .0151    .1029    .0096   1.5703
   8.2373    .5000   -.0457    .0023   -.0022    .0799    .0777    .5000    .5151    .0151    .1036    .0097   1.5695
   8.3136    .5000   -.0512    .0023   -.0022    .0806    .0784    .5000    .5152    .0152    .1043    .0097   1.5686
   8.3898    .5000   -.0570    .0023   -.0022    .0813    .0792    .5000    .5151    .0152    .1050    .0097   1.5677
   8.4661    .5000   -.0652    .0023   -.0022    .0820    .0799    .5000    .5151    .0151    .1056    .0096   1.5663
   8.5424    .5000   -.0745    .0023   -.0022    .0828    .0806    .5000    .5150    .0150    .1062    .0096   1.5650
   8.6186    .5000   -.0868    .0023   -.0022    .0835    .0813    .5000    .5149    .0149    .1067    .0095   1.5633
   8.6949    .5000   -.1029    .0023   -.0022    .0843    .0821    .5000    .5147    .0147    .1071    .0094   1.5613
   8.7712    .5000   -.1246    .0024   -.0022    .0850    .0829    .5000    .5144    .0144    .1074    .0092   1.5590
   8.8475    .5000   -.1538    .0024   -.0022    .0858    .0837    .5000    .5139    .0140    .1076    .0090   1.5566
   8.9237    .5000   -.2017    .0025   -.0022    .0867    .0845    .5000    .5132    .0133    .1074    .0086   1.5543
   9.0000    .5000   -.2803    .0026   -.0022    .0876    .0854    .5000    .5120    .0123    .1069    .0079   1.5546
   9.0500    .4991   -.3242    .0027   -.0011    .0882    .0871    .4991    .5103    .0118    .1071    .0076   1.5587
   9.1000    .4965   -.3423    .0027    .0024    .0888    .0912    .4965    .5075    .0118    .1078    .0075   1.5623
   9.1500    .4921   -.3434    .0027    .0083    .0895    .0978    .4921    .5033    .0120    .1090    .0077   1.5647
   9.2000    .4859   -.3422    .0026    .0166    .0901    .1067    .4859    .4978    .0123    .1106    .0078   1.5668
   9.2500    .4780   -.3230    .0026    .0268    .0907    .1175    .4780    .4908    .0129    .1129    .0082   1.5682
   9.3000    .4681   -.2700    .0025    .0379    .0913    .1291    .4681    .4823    .0141    .1162    .0090   1.5700
   9.3500    .4565   -.1939    .0023    .0479    .0918    .1397    .4565    .4725    .0160    .1206    .0102   1.5763
   9.4000    .4429   -.1081    .0021    .0553    .0922    .1475    .4429    .4617    .0187    .1266    .0118   1.5915
   9.4500    .4273   -.0254    .0019    .0590    .0926    .1516    .4273    .4502    .0222    .1342    .0137   1.6177
   9.5000    .4096    .0471    .0017    .0584    .0929    .1513    .4096    .4387    .0265    .1435    .0160   1.6543
   9.5500    .3899    .1034    .0015    .0537    .0931    .1468    .3930    .4275    .0311    .1533    .0184   1.6952
   9.6000    .3679    .1426    .0014    .0455    .0933    .1388    .3806    .4170    .0352    .1617    .0203   1.7320
   9.6500    .3436    .1621    .0013    .0350    .0935    .1285    .3681    .4073    .0382    .1694    .0218   1.7521
   9.7000    .3168    .1632    .0013    .0235    .0937    .1171    .3559    .3986    .0396    .1761    .0226   1.7496
   9.7500    .2873    .1619    .0013    .0119    .0938    .1057    .3439    .3914    .0408    .1829    .0234   1.7444
   9.8000    .2550    .1518    .0013    .0009    .0939    .0948    .3319    .3851    .0412    .1893    .0238   1.7288
   9.8500    .2867    .1418    .0014   -.0006    .0940    .0935    .3520    .3790    .0379    .1784    .0221   1.7147
   9.9000    .2871    .1391    .0014   -.0006    .0942    .0936    .3399    .3730    .0390    .1853    .0228   1.7093
   9.9500    .2869    .1395    .0014   -.0006    .0943    .0937    .3272    .3666    .0406    .1933    .0238   1.7074
  10.0000    .2861    .1538    .0013   -.0006    .0944    .0938    .3136    .3599    .0438    .2038    .0255   1.7208
  10.0500    .2849    .1899    .0012   -.0006    .0945    .0939    .2996    .3531    .0503    .2180    .0285   1.7645
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attached

separated

↑
$C_f > 0$ in separated region

(f) Page 6.

Figure 14.- Continued.

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**TEST CASE**  L/D=9 FOREBODY L/D=0.8 DB/D=0.51 CIRCULAR ARC NOZZLE  NPR=5.03        ITERATION NO  15

 MO =  .8000     TT = 324.44 KELVIN     PT =  100720.0 PASCALS     L =   .152400 METERS     SREF =   .018242 SQ METERS

   BOUNDARY LAYER SEPARATION AT X/L =  9.529286            BOUNDARY LAYER REATTACHMENT AT X/L = 11.633000

     X/L       R/L       CP        CF        CDP       CDF       CDT       RDS/L     RC/L   DEL*/L    DEL/L  THETA/L    H

   10.1000   .2840    .2065    .0011   -.0006    .0946    .0940    .2858    .3469    .0552    .2312    .0309  1.7863
   10.1500   .2839    .2083    .0011   -.0006    .0947    .0941    .2835    .3422    .0558    .2340    .0313  1.7858
   10.2000   .2843    .2037    .0011   -.0006    .0948    .0942    .2839    .3389    .0550    .2338    .0310  1.7753
   10.2500   .2850    .1863    .0012   -.0006    .0949    .0943    .2845    .3366    .0523    .2317    .0299  1.7471
   10.3000   .2857    .1634    .0013   -.0006    .0950    .0944    .2853    .3349    .0492    .2292    .0286  1.7163
   10.3500   .2862    .1458    .0013   -.0006    .0952    .0946    .2859    .3334    .0470    .2276    .0277  1.6957
   10.4000   .2866    .1322    .0014   -.0006    .0953    .0947    .2864    .3322    .0455    .2266    .0271  1.6811
   10.4500   .2869    .1201    .0014   -.0006    .0954    .0948    .2868    .3312    .0443    .2259    .0265  1.6691
   10.5000   .2872    .1085    .0015   -.0006    .0955    .0950    .2872    .3303    .0431    .2252    .0260  1.6584
   10.5500   .2875    .0981    .0015   -.0006    .0957    .0951    .2875    .3297    .0422    .2248    .0256  1.6496
   10.6000   .2878    .0888    .0015   -.0006    .0958    .0952    .2877    .3292    .0414    .2244    .0252  1.6420
   10.6646   .2881    .0785    .0015   -.0006    .0960    .0954    .2881    .3286    .0405    .2241    .0248  1.6342
   10.7291   .2884    .0696    .0016   -.0006    .0962    .0956    .2883    .3282    .0398    .2240    .0245  1.6277
   10.7937   .2886    .0621    .0016   -.0006    .0964    .0958    .2886    .3279    .0393    .2241    .0242  1.6225
   10.8583   .2888    .0555    .0016   -.0006    .0966    .0960    .2888    .3276    .0388    .2242    .0240  1.6180
   10.9228   .2889    .0500    .0016   -.0006    .0968    .0962    .2889    .3274    .0385    .2244    .0238  1.6144
   10.9874   .2891    .0447    .0016   -.0006    .0970    .0964    .2891    .3272    .0381    .2246    .0237  1.6111
   11.0519   .2892    .0407    .0016   -.0006    .0972    .0966    .2892    .3271    .0379    .2250    .0236  1.6085
   11.1165   .2893    .0368    .0016   -.0006    .0974    .0968    .2893    .3270    .0377    .2253    .0235  1.6061
   11.1811   .2894    .0335    .0017   -.0006    .0976    .0970    .2894    .3269    .0375    .2257    .0234  1.6040
   11.2456   .2895    .0306    .0017   -.0006    .0978    .0972    .2895    .3269    .0374    .2262    .0233  1.6022
   11.3102   .2896    .0277    .0017   -.0006    .0980    .0974    .2896    .3269    .0373    .2266    .0233  1.6005
   11.3748   .2897    .0254    .0017   -.0006    .0982    .0976    .2896    .3268    .0372    .2271    .0233  1.5990
   11.4393   .2897    .0232    .0017   -.0006    .0985    .0979    .2897    .3268    .0371    .2276    .0232  1.5977
   11.5039   .2898    .0211    .0017   -.0006    .0987    .0981    .2898    .3268    .0370    .2281    .0232  1.5964
   11.5684   .2898    .0191    .0017   -.0006    .0989    .0983    .2898    .3268    .0370    .2286    .0232  1.5952
   11.6330   .2899    .0171    .0017   -.0006    .0991    .0985    .2899    .3268    .0369    .2290    .0232  1.5940

 FOR ITERA= 16     8 ITERATIONS REQUIRED FOR CONVERGENCE IN MISNA2
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Separated

(g) Page 7.

Figure 14.- Continued.

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                    POTENTIAL FLOW SOLUTION

     **TEST CASE**  L/D=9 FOREBODY L/D=0.8 DB/D=0.51 CIRCULAR ARC NOZZLE  NPR=5.03

OFF-BODY UNIFORM AXISYMMETRIC FLOW

          X/L          R/L          VX           VR           VT          ETA           ML           CP

 1     8.800000      .600000     1.062181     -.009934     1.062227     -.535866      .856848     -.125713
 2     9.000000      .600000     1.111166     -.035165     1.111723    -1.812641      .903119     -.227155
 3     9.200000      .600000     1.119641     -.109287     1.124962    -5.574925      .915665     -.254448
 4     9.400000      .600000     1.029521     -.147716     1.040064    -8.165084      .836438     -.080670
 5     9.600000      .600000      .956023     -.118833      .963380    -7.085490      .767182      .072730
 6     9.800000      .600000      .943930     -.082651      .947542    -5.004080      .753125      .103845
 7     9.800000      .550000      .937734     -.089026      .941950    -5.423231      .748182      .114777
 8     9.800000      .500000      .931133     -.095801      .936049    -5.874312      .742975      .126285
 9     9.800000      .450000      .924368     -.102942      .930082    -6.354575      .737722      .137886
10     9.800000      .400000      .917520     -.110636      .924166    -6.875620      .732524      .149355
```

(h) Page 8.

Figure 14.- Concluded.

1 Report No NASA TM-78779	2 Government Accession No	3 Recipient's Catalog No

4 Title and Subtitle DONBOL: A COMPUTER PROGRAM FOR PREDICTING AXISYMMETRIC NOZZLE AFTERBODY PRESSURE DISTRIBUTIONS AND DRAG AT SUBSONIC SPEEDS	5 Report Date May 1979 6 Performing Organization Code
7 Author(s) Lawrence E. Putnam	8 Performing Organization Report No L-12658
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16 Abstract

A Neumann solution for inviscid external flow has been coupled to a modified Reshotko-Tucker integral boundary-layer technique, the control volume method of Presz for calculating flow in the separated region, and an inviscid one-dimensional solution for the jet exhaust flow in order to predict axisymmetric nozzle afterbody pressure distributions and drag. The viscous and inviscid flows are solved iteratively until convergence is obtained. A computer algorithm of this procedure has been written and is called DONBOL. This paper provides a description of the computer program and a guide to its use. Comparisons of the predictions of this method with experiment show that the method accurately predicts the pressure distributions of boattail afterbodies which have the jet exhaust flow simulated by solid bodies. For nozzle configurations which have the jet exhaust simulated by high-pressure air, the present method significantly underpredicts the magnitude of nozzle pressure drag. This deficiency results because the method neglects the effects of jet plume entrainment. This method is limited to subsonic free-stream Mach numbers below that for which the flow over the body of revolution becomes sonic.

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