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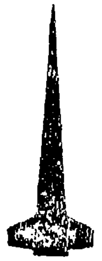

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~~REPORT NO.~~ RD-TR-69-14

ANALYSIS OF THE AXISYMMETRIC BASE-PRESSURE AND BASE-TEMPERATURE PROBLEM WITH SUPERSONIC INTERACTING FREESTREAM-NOZZLE FLOWS BASED ON THE FLOW MODEL OF KORST, ET AL

PART III: A COMPUTER PROGRAM AND REPRESENTATIVE RESULTS FOR CYLINDRICAL, BOATTAILED, OR FLARED AFTERBODIES

by

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February 1970

[redacted]

U.S. ARMY MISSILE COMMAND
Redstone Arsenal, Alabama

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ABSTRACT

The computer program presented and discussed in Part 1 of this report for analyzing the axisymmetric base-pressure and base-temperature problem with interacting supersonic free-stream and propulsive-nozzle flows has been improved and generalized to include the analysis of an afterbody upstream of the base region. The afterbody geometries considered are: cylindrical, conical, parabolic, and tangent-ogive boattails and conical flares. The FØRTRAN IV computer-program listing, as well as detailed information on program development, organization, and usage, are included herein. Theoretical afterbody and base-pressure results are presented for parametric variations in afterbody geometry and flow variables. In addition, a limited comparison between theoretical and experimental conical-afterbody and base-pressure data is made.

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NOMENCLATURE†

I. SYMBOLS

Text	Computer Program	Definition
a_1, a_2, a_3	CØEFF1, CØEFF2, CØEFF3	Coefficients in the mass and energy transfer rate equations due to mixing
A		Area
A, B, C	A,B,C	Coefficients in the second-degree afterbody equation
C_1, C_2, C_3	C1,C2,C3	Coefficients in the afterbody profile equation
c		Local speed of sound
C^2	CSQD--††	Crocco number squared, $(U/U_{max})^2$
C_{nr}	CNR--	Ratio of Crocco numbers, C_d/C_a
c_p		Specific heat at constant pressure
C_p	CPB,CP,CPBT	Pressure coefficient, $C_p = \left(\frac{p}{p_E} - 1\right)\Big/\left(\frac{\gamma_E}{2} M_E^2\right)$
C_D	CDB,CD,CDBT	Drag coefficient, $C_D = -C_p[1 - (R_{1I}/R_{2E})^2]$
C_T	CT	Ideal propulsive-nozzle thrust coefficient, $C_T = \left[\left(\frac{R_{1I}}{R_{2E}}\right)^2\Big/\frac{\gamma_E M_E^2}{2}\right]\left[\frac{p_{1I}}{p_E}(1 + \gamma_I M_{1I}^2) - 1\right]$
D	D--	Diameter
e		Energy transfer rate per unit width for the 2-D turbulent mixing region

---

† The NOMENCLATURE from Part I,[1], has been included herein for completeness.

†† Dashes indicate that additional alphanumeric symbols may be added for identification, e.g., corresponding to subscript notation.

Text	Computer Program	Definition
E		Approximate energy transfer rate due to mixing along the axisymmetric boundary
E_o		Energy transfer rate into the base region
E_{NI}		Reference energy transfer rate based on an ideal propulsive nozzle
$F(), f()$, etc.		Functional notation
g_c		32.174 [lb_m-ft/lb_f-sec^2]
g		Mass entrainment rate per unit width for the 2-D turbulent mixing region
G		Approximate mass flow rate due to entrainment by the axisymmetric mixing region
G_o		The "bleed" mass flow rate into the base region
G_{NI}		Reference mass flow rate for an ideal propulsive nozzle
$I_1(\eta, \Lambda_B, C_a^2)$ $I_3(\eta, \Lambda_B, C_a^2)$	EI1--- EI3---	Mixing integrals
	IN0PT	Input-option variable
M	EMN---	Mach number, V/c
M^*	EMS---	Mach star, V/c^*
	NPUNCH	Output-option variable
	NSHAPE	Afterbody shape specification variable
P	P------	Absolute pressure
r	REC0MP	Recompression coefficient, Eq. (2)
R	R---	Radius
R	GC	Gas constant, [lb_f-ft/lb_m-°R]

Text	Computer Program	Definition
F_{MF}	RMF	Nozzle-to-freestream momentum flux ratio
s,S	TJML-	Mixing length along the "corresponding" inviscid axisymmetric boundaries
T	T-----	Absolute temperature
U		x-component of the velocity
v		y-component of the velocity
V		Magnitude of the velocity
x,y		Intrinsic coordinates in the 2-D mixing region
X,R	X--,R--	Longitudinal and radial coordinates for axisymmetric flow
β	BETA--, BETD--, ANG---	Geometric flow angle
γ	GAMMA-	Ratio of the specific heats
$\varepsilon,\varepsilon_1,\varepsilon_2$		Small positive quantities
η	ETA--	Dimensionless coordinate in the mixing region, $(\sigma y/x)$
η_m	ETAM	Dimensionless shift of the 2-D mixing profile
θ	THE1--, THETA-	Flow angle
σ	SIGMA-	Empirical mixing parameter
ρ		Density
Λ	TR-0--	Stagnation temperature ratio
ϕ	PHI--	Velocity ratio

II. SUBSCRIPTS

Text	Computer Program	Definition
a		Adjacent inviscid flow; limiting location on the "positive" side of the mixing region
b		Adjacent quiescent region; limiting location on the "negative" side of the mixing region
B	----B-	Base region
BE	---BE-	Boundary, external
BI	---BI-	Boundary, internal
BS		Base-pressure and base-temperature solution
BT1, BT2	---BT1,---BT2	Initial and terminal points on the boattail, respectively
d	---D-	Discriminating streamline
E	--E--	External (free-stream) flow
F		Flare
I	----I-	Internal (nozzle) flow
imp	---IMP	At impingement point of the "corresponding" inviscid streams
j	----J-	Jet-boundary streamline
LMT	---LMT	Limiting value
MAX	----MX,---MAX	Maximum value
MIN	---MIN	Minimum value
o	---0-	Stagnation conditions
oa		Stagnation conditions for the adjacent inviscid flow
oE	---0E-	Stagnation conditions for the external flow

Text	Computer Program	Definition
oI	---0I-	Stagnation conditions for the internal flow
S	-----S	Slipline; after oblique shock system
SEP	---SEP	Boundary-layer separation
1I, 1E	----1I, ----1E	Internal or external stream's geometric separation point located at the terminus of the nozzle or afterbody, respectively
2E	----2E	Initial point on the afterbody

III. BARRED SYMBOLS (Dimensionless Ratios)

Text	Computer Program	Definition
$\overline{B},\overline{E}$	BLDR,ENGR	Dimensionless mass and energy transfer rates due to mixing
$\overline{B}_o,\overline{E}_o$	BLDR0, ENGR0	Dimensionless mass and energy transfer rates to the base region
$\Delta\overline{B},\Delta\overline{E}$	VAR	Dimensionless mass and energy difference function
$\overline{P}$	PR---E	Pressure ratio, P/P_E
$\overline{P}_B$	PRBE	Base-pressure ratio, P_B/P_E
$\overline{P}_{1I}$	PR1IE	Nozzle exit-plane static pressure ratio, P_{1I}/P_E
$\overline{P}_{oI}$	PR0IE	Internal stagnation-to-external static pressure ratio, P_{oI}/P_E
$\overline{R}_I$	(GCI/GCE)	Ratio of gas constants, R_I/R_E
$\overline{T}_B$	TRB01	Base-temperature ratio, T_B/T_{oI}
$\overline{T}_{oE}$	TR0EI	External-to-internal stream stagnation temperature ratio, T_{oE}/T_{oI}
$\overline{X}_{1I},\overline{R}_{1I}$	X1I,R1I	Dimensionless coordinates of the internal stream's geometric separation point; X_{1I}/R_{2E}, R_{1I}/R_{2E}
$\overline{X}_{1E},\overline{R}_{1E}$	X1E,R1E	Dimensionless coordinates of the external stream's geometric separation point; X_{1E}/R_{2E}, R_{1E}/R_{2E}
$\overline{X}_{2E}$	X2E	Dimensionless coordinate of the initial point on the afterbody; X_{2E}/R_{2E}

I. INTRODUCTION

As part of the continuing development of methods and computer programs for aerodynamic design, evaluation, and optimization studies related to the base-flow problem, the computer program developed and reported earlier in Part I of this report series [1]† has been generalized to include an afterbody analysis in conjunction with the base-flow analysis. The base-flow analysis is based on the component flow model of Korst, et al. [2], as modified by an empirical recompression coefficient. For cylindrical afterbodies, this empirical coefficient was determined by a detailed correlation of theoretical and experimental data and has been reported in Part II of this report series [3]. Herein, the "corresponding" inviscid flow-field component of the base-flow analysis includes the option of an afterbody upstream of the base region. The afterbody and flow-field analyses are by the *Method of Characteristics*; the afterbody geometries considered are: cylindrical, conical, parabolic, or tangent-ogive boattails and conical flares of moderate angle and length.

Under certain flow conditions, oblique shock waves can occur at the terminus of the afterbody and/or the propulsive nozzle; these oblique shock waves, if they occur, are treated approximately in the inviscid flow-field analyses. For these flow conditions, it is necessary to establish an upper limit on the trial values of the base-pressure ratio in the solution iteration sequence; this upper limit is established by the onset of boundary-layer separation at the afterbody and/or propulsive-nozzle terminus points. The boundary-layer separation criterion used herein is based on an approximate empirical formulation developed by Zukoski [4].

A parametric study of the base-flow problem for a representative set of flow conditions and afterbody geometries has been made; the results of this study are presented herein. These data are complementary to the parametric study previously conducted [1] for a cylindrical afterbody. In addition, a limited comparison is made between theoretically predicted values and an experimentally based correlation of Brazzel and Henderson [5] and the experimental data of Baughman and Kochendorfer [6].

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†Numbers in brackets refer to entries in REFERENCES.

II. THEORETICAL FLOW MODEL

The flow model of Korst, et al. [2], and the component aspects of this flow model have been discussed in Part I of this report series [1] and also in considerable detail in [7]; the discussion and analyses presented therein continue to be applicable. In particular, the turbulent-mixing component, the solution criteria, and the solution-seeking techniques have not been modified. The principal modifications made herein have been in the recompression and the "corresponding" inviscid flow-field components.

The "corresponding" inviscid flow-field analyses have been generalized to include an afterbody upstream of the base region and an approximate analysis of oblique shock waves which can occur under certain flow conditions. Under these flow conditions, the trial values of the base-pressure ratio are limited by an upper bound which is determined approximately for the onset of boundary-layer separation for either the free-stream or propulsive-nozzle flow as the case may be.

The recompression criterion which is instrumental in determining the base-pressure solution by linking the mixing and "corresponding" inviscid flow-field components has been modified by an empirical recompression coefficient. For cylindrical afterbodies, the recompression coefficient has been determined by a detailed correlation of theoretical-experimental data [3]. At present, a correlation study for boattailed and flared afterbodies similar to [3] is in progress and not yet complete.

The Two-Stream Axisymmetric Base-Pressure Program, TSABPP-2, presented herein is based on the following analyses in conjunction with Parts I and II [1,3], of this report series and [7]. The configuration and associated notation for TSABPP-2 are given in Fig. 1; an attempt has been made to retain a notation herein which is consistent with that of [1,3,7].

It should be noted that the uniform-flow free-stream conditions (E) are used as reference conditions throughout the analyses and the computer program.

A. "CORRESPONDING" INVISCID FLOW FIELDS

The supersonic flow fields are determined by the *Method of Characteristics* for irrotational axisymmetric flow. The external (free-stream) flow is assumed to be initially a uniform supersonic stream; downstream of this uniform external flow station, the flow can either immediately separate, as for a cylindrical afterbody, or continue over a prescribed afterbody before separating at the base. As before, the internal (propulsive-nozzle) flow is assumed to be from an ideal full-flowing supersonic conical-flow or uniform-flow nozzle. After the separation of the internal and external flows, the flow fields are calculated for a constant-pressure boundary condition and a trial value of the base-to-free-stream pressure ratio. At the impingement point of the inviscid streams, if it exists, the oblique-shock recompression system is determined.

The inviscid flow-field analyses have been subdivided for convenience of computer program development into two subprograms, ABTS and ACPBS. Subprogram ABTS† is used for the calculations of the flow field over the afterbody while subprogram ACPBS† is for calculation of the constant-pressure boundary flow fields. The free-stream flow conditions, the afterbody flow-field calculations, and the constant-pressure boundary flow-field calculations are linked, respectively, along characteristic curves which are specified or determined through points (2E) and (1E) of Fig. 1; the propulsive-nozzle flow conditions are linked with the constant-pressure boundary flow-field calculations along a characteristic curve specified or determined through point (1I) of Fig. 1.

The general case of a uniform external (free-stream) flow upstream of an afterbody is shown in Fig. 2(a). The afterbody flow-field calculations are made from the known uniform-flow characteristic through the initial point, (2E), on the afterbody. The flow-field calculations proceed from these known data on the II-characteristic along I-characteristics to the boundary points on the afterbody surface where the boundary condition of flow tangency is satisfied; these calculations are illustrated in Figs. 2(a) and 2(b). The afterbody geometries considered are: the ogive, parabola, and cone; the expressions used to define these afterbody meridional profiles are given in Fig. 2(b).

The foregoing calculation sequence is continued by advancing along the known II-characteristic until an I-characteristic is encountered which would intersect the afterbody surface after the terminus of the afterbody, as shown in Figs. 2(a) and 2(c). An iteration sequence is then initialized to find the I-characteristic

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† For program flexibility, the inviscid afterbody and constant-pressure boundary subprograms only are available as input options. See APPENDIX B for additional comments on the function and organization of these subprograms.

which passes through the terminus of the afterbody. The iteration sequence is initialized, as shown in Fig. 2(c), by the (i-1)-th I-characteristic which intersects with the afterbody and the next I-characteristic, $i^{(1)}$, which does not intersect the afterbody surface. The (i-1) and $i^{(1)}$ points on the known II-characteristic provide initial bounds on the origin of the I-characteristic which would pass through the terminus of the afterbody. By continuing the iteration sequence and successively reducing the bounds, the $i^{(n)}$ I-characteristic through the afterbody terminus, (1E), can be determined to the desired degree of accuracy. The foregoing calculation sequence completely determines the flow field over the afterbody; to link the afterbody and constant-pressure boundary flow fields, the II-characteristic through the afterbody terminus is determined, as shown in Figs. 2(a) and 2(d). This is accomplished (see Fig. 2(d)) by calculating along I-characteristics from points on the known II-characteristic to the unknown II-characteristic originating at the terminus of the afterbody. The desired number of points on this characteristic are determined by advancing, after the point $i^{(n)}$, along the known II-characteristic and repeating the foregoing calculation sequence. The afterbody and final afterbody II-characteristic calculations described above are made in subprogram ABTS.†

For the internal (propulsive-nozzle) flow, [1, pp. 4,5], the ideal uniform-flow propulsive-nozzle reduces to the trivial specification of the uniform Mach number and flow direction along the straight characteristic through the terminus of the nozzle. The ideal conical-flow nozzle is specified by the constant nozzle Mach number and the variable conical flow direction along the known non-characteristic curve through the nozzle terminus. Thus, the flow field between the non-characteristic curve and the initial characteristic is constructed to utilize the aforementioned constant-pressure boundary calculation sequence. For the ideal uniform-flow or conical-flow nozzles, respectively, the foregoing calculations are made in subroutines UFLØC†† and CNFLØC†† after the specification of the nozzle geometry, specific heat ratio, and the nozzle Mach number. UFLØC and CNFLØC are subroutines to subprogram ACPBS.

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†More generalized afterbody calculations could be carried out if the known II-characteristic is specified, e.g., as the final II-characteristic from a previous afterbody calculation rather than for uniform free-stream flow. Thus, by "bootstrapping" the afterbody calculations, more general inviscid afterbody analyses can be made.

††See APPENDIX B for additional comments on the function and organization of these subroutines and subprograms.

Subprograms ABTS and ACPBS only are available as input options; the applicable configurations and notation for these subprograms are shown for the afterbody analysis in Fig. 3(a) and for the constant-pressure boundary analyses in Fig. 3(b).

Shock waves occurring in three instances in the internal or external flow fields are considered approximately as reversible compressions in the flow-field analysis. In the afterbody calculations, the oblique shock wave for conical-flare configurations is approximated by a single-line reversible compression; in comparison with more exact analyses [8,9] the results of this simple approximation appear to be adequate for flares of moderate angle and length. For certain combinations of geometry and operating conditions, oblique shock waves can occur at the geometric separation points of the internal and/or external streams as a result of relatively high values of the base pressure. Examples of these flow conditions would be the oblique shock waves occurring in the external flow field prior to or at onset of plume-induced separation of the external flow, or for nozzle geometries with large exit flow angles and/or highly overexpanded nozzle flows. Fortunately, these compressions are often relatively weak and as a consequence the oblique shock waves can be approximated by reversible compressions at the internal and/or external terminus points (1I), (1E) as the case may be.

B. TURBULENT-MIXING COMPONENT

The turbulent-mixing component of the base-flow analysis discussed in Part I of this report is unaffected with the exception of the introduction of an empirical coefficient in the recompression criterion. The empirical recompression coefficient r is defined [1,3] by

$$\frac{P_{od}}{P_d} = r\left(\frac{P_S}{P_B}\right) \geq 1 \tag{1}$$

For cylindrical afterbodies, a convenient expression for r which gives good correlation between theory and experiment has been found to be, [3],

$$r = 0.483 + 1.088\bar{R}_{1I} - 0.874\bar{R}_{1I}^2 + 0.303\bar{R}_{1I}^3 \tag{2}$$

A similar experimental-theoretical correlation is unavailable at this time for boattailed or flared afterbodies; consequently, the value of $r = 1$ for the unmodified flow model is incorporated in the computer program. As an alternative, however, r is also available as an input option.

C. TURBULENT BOUNDARY-LAYER SEPARATION CRITERION

To establish an upper bound on the trial-solution values of the base-pressure ratio, an approximate empirical turbulent boundary-layer separation criterion proposed by Zukoski [4] is used. Zukoski's empirical relationship has the simple form

$$\frac{P_{SEP}}{P} = [1 + 0.365M] \tag{3}$$

Thus, according to this criterion, the separation-to-local static pressure ratio is linearly related to the local Mach number at the boundary-layer separation point.

For specified values of the Mach numbers, M_{1E} and M_{1I}, and the nozzle static-to-freestream or stagnation-to-freestream pressure ratio, $\bar{P}_{1I}$ or $\bar{P}_{oI}$, the pressure ratios for boundary-layer separation at locations (1E) and (1I) are estimated for the freestream as

$$(\bar{P}_{SEP})_E = [1 + 0.365M_{1E}]\,\bar{P}_{1E} \tag{4}$$

and for the propulsive nozzle as

$$(\bar{P}_{SEP})_I = [1 + 0.365M_{1I}]\,\bar{P}_{1I} \tag{5}$$

The upper limit imposed on the trial-solution values of the base-pressure ratio is based on boundary-layer separation occurring at either location (1E) or (1I) whichever would correspond to a lower value of the base-pressure ratio. Thus if $(\bar{P}_{SEP})_E > (\bar{P}_{SEP})_I$, the upper limit on the base-pressure ratio is

$$(\bar{P}_B)_{MAX} = (\bar{P}_{SEP})_I \tag{6}$$

or conversely if $(\bar{P}_{SEP})_E < (\bar{P}_{SEP})_I$, then

$$(\bar{P}_B)_{MAX} = (\bar{P}_{SEP})_E \tag{7}$$

The base-pressure solution range is

$$(\overline{P}_B)_{MIN} < \overline{P}_B \leq (\overline{P}_B)_{MAX} \qquad (8)$$

where initially $(\overline{P}_B)_{MIN} = 0$ and $(\overline{P}_B)_{MAX}$ is determined from Eq. (6) or (7). As the solution iteration sequence progresses, both the lower and upper bounds on the base-pressure solution are changed, if possible, to reduce the possible solution interval. If a reduction in the upper bound on the solution interval and convergence to a solution are not achieved, the iteration sequence is terminated with boundary-layer separation possibly occurring.

III. COMPUTER PROGRAM

The complete computer-program listing† for TSABPP-2 developed for analyzing the two-stream axisymmetric base-pressure problem is contained in APPENDIX A. Many explanatory CØMMENTS regarding specific operational details of this program have been included in the program listing. In APPENDIX B, the main program, subprograms, and the various subroutines are identified, are ordered according to their first appearance in the calling sequence, and are briefly discussed as to their operational function.

The main program of TSABPP-2 is organized according to the summary flowchart of Fig. 4(a), [1, Fig. 7]. Subroutine INØUT has been significantly modified and re-organized from the earlier version (TSABPP-1) of this program [1] to achieve flexibility in the overall program so that the inviscid flow-field calculation subprograms are available as input options, to have more convenient input options, and to provide the option of an afterbody upstream of the base. The organization of INØUT is illustrated by the flowchart in Fig. 4(b).

A. PROGRAM INPUT

The input to TSABPP-2 is by cards. A complete list of the available input variables and their definitions is contained in Table 1; normally, it is necessary only to input a partial list of these variables depending on the input option selected and the extent to which the default-configuration data is used. There are four input data options specified by the variable INØPT which are available to the program user.

The first input option, INØPT=1, is by NAMELIST/DATA/.†† Table 2 defines the required input variables, the default-configuration data available, and the data-card(s) format. The second input option, INØPT=2, is by NAMELIST/DATA/ and a complete set of data cards which must specify all variables defined in Table 1.

---

†The program listing is in FØRTRAN IV as applicable to the IBM ØS 360/75. Program modifications necessary to adapt this program to an IBM 7094 FØRTRAN IV IBJØB system are detailed in APPENDIX D. The appropriate modifications and their location within the program are identified by the program-identification name and card number in columns 73 to 80.

††This input is used for the IBM ØS 360/75 FØRTRAN IV version. See APPENDIX D for the necessary modifications for the IBM 7094 FØRTRAN IV version.

Table 3 defines for this input option the variable locations and data-card formats. The foregoing input options (INØPT=1,2) are used for complete base-flow solution calculations.

The third input option, INØPT=3, is by NAMELIST/DATA/ for the calculation of internal-flow constant-pressure boundaries only. The required input data, the default-configuration data, and the input data-card format is specified in Table 4.

The fourth input option, INØPT=4, is by NAMELIST/DATA/ for the calculation of the external flow field only. The calculations include the afterbody and/or constant-pressure boundary flow-field calculations as specified by the input data. The required input data, the default-configuration data, and the input data-card format is specified in Table 5.

B. PROGRAM OUTPUT

The program output is in printed and an optional punched form. For a given configuration, the printed output data can be obtained at the option of the user in one of three levels of detail by specifying the print parameter NPRINT. The short-form printed output option, NPRINT=-1, consists only of the data required to specify the configuration, the current case, and the corresponding theoretical solution. The more detailed printed output options, NPRINT=0,1, include, in addition to the foregoing data, the iteration-step data. A detailed outline of the data printed for each value of the print parameter is given in Table 6. The optional punched output data, NPUNCH=1, summarizes the theoretical base-flow solution data for each input configuration and the cases considered. The punched output data is summarized in Table 7.

C. PROGRAM ERROR MESSAGES

Various program error messages can be generated during the base-flow solution iteration sequences. These messages are intended as information for the program user and, as such, do not, in general, require any action by the user. The error messages are divided into three categories:

i. Messages generated during the iteration sequence for the base-flow solution. For these cases, convergence to a solution is achieved and as a consequence, the error messages are not significant.

ii. Messages generated as a result of non-convergence to the base-flow solution. These messages indicate the problem areas encountered and why a solution could not be achieved; the solution iteration sequence is terminated.

iii. Messages resulting specifically from the inviscid flow-field calculations. The most common errors giving rise to these messages are excessive "foldback" of the characteristics network due to wave coalescence, non-convergence of a unit-process calculation, or compressions developing in the flow field that would give rise to locally subsonic flow. The flow-field calculations are terminated.

The origin and an explanation of the various possible error messages generated by the program and subroutines during execution are given in APPENDIX C. The messages are duplicated therein, referenced to the subroutine name, and ordered according to the sequence numbers assigned in APPENDIX B.

IV. REPRESENTATIVE THEORETICAL AFTERBODY AND BASE-FLOW SOLUTION RESULTS

Representative parametric afterbody and base-flow solution data are presented herein to demonstrate the qualitative behavior of the theoretical solutions over a range of geometric and flow variables, to demonstrate the capabilities of the component-model based computer program, and to complement the parametric base-flow solution data previously presented [1]. The trade-offs and interactions between the afterbody and base-flow components are of particular interest from the standpoints of possible afterbody-base drag reduction, as well as overall system optimization.

Theoretical-experimental comparisons are limited to a comparison with an empirical correlation developed by Brazzel and Henderson [5] and to a comparison with some experimental data obtained by Baughman and Kochendorfer [6].

A. PARAMETRIC VARIATIONS IN SELECTED GEOMETRIC AND FLOW VARIABLES

For the parametric study of the afterbody-base problem, several of the variables were restricted to mid-range values used in the parametric study of the base-flow problem with a cylindrical afterbody [1]. In addition, the afterbodies considered were limited to a one-caliber length; this limitation is not considered to be serious since other afterbody lengths would be expected to produce results similar to those presented herein. As a consequence of the foregoing restrictions, the parametric study has been principally confined to variations in afterbody geometry. The afterbody geometries considered are: conical and tangent-ogive boattails and conical flares; for each afterbody geometry, a series of configurations are considered. The configuration and flow data are summarized in Table 8 for this parametric study.

For each afterbody geometry, the data is presented in a series of figures which first present the individual theoretical afterbody and base-flow results followed by the combined afterbody-base results. The afterbody drag coefficients are presented in Figs. 5(a), 6(a) and 7(a) for the conical and tangent-ogive boattails and the conical flares, respespectively; the afterbody pressure distributions which were integrated to obtain the foregoing afterbody drag coefficients are presented in Figs. 5(b), 6(b) and 7(b) for the respective afterbody geometries. Figures 5(c,d) and 6(c,d) and 7(c,d) present the base-pressure ratio and the base drag coefficient, respectively, for each afterbody geometry; included in each figure for purposes of reference are the data for a cylindrical afterbody under similar operating conditions [1]. It is apparent from Figs. 5(c,d) and 6(c,d) that boattailing can significantly *increase* the base-pressure ratio and correspondingly *decrease* the base drag coefficient; the opposite behavior is seen from Figs. 7(c, d) to be the case for the conical-flare afterbody. For the conical-flare afterbody, the relative *decrease* in base-pressure ratio, although being relatively small, does give rise to a significant *increase* in the base drag coefficient. The overall afterbody-base drag coefficients are shown in Figs. 5(e,f), 6(e,f) and 7(e,f) for each afterbody configuration. Figures 5(e,f) and 6(e,f), and in particular, Fig. 5(f) and 6(f), show that the overall afterbody-base drag coefficient can be *minimized* by proper selection of the boattail; in all cases considered, boattailing tended to *reduce* significantly the overall afterbody-base drag. For the conical-flare afterbody, Figs. 7(e,f) show that such an afterbody significantly *increases* the overall afterbody-base drag.

The effects of base "bleed" on the overall boattail-base drag coefficient are shown in Fig. 5(g) for conical boattails at two fixed operating pressure ratios and parametric values of the base-bleed ratio. The overall drag coefficient is significantly *reduced* by base "bleed"; however, the effectiveness of base "bleed" *decreases* with *increasing* base-bleed ratios. The possibility of *minimizing* C_D by the proper selection of the base-bleed ratio and boattail angle is evident from Fig. 5(g).

Figure 8(a) summarizes the overall drag coefficient data for the conical-afterbody geometries; these data are presented as overall afterbody-base drag coefficient versus the base-to-body area ratio for parametric values of the operating pressure ratios. This particular set of coordinates has been suggested as a possible means of unifying and correlating conical-afterbody data. Brazzel and Henderson [5] have proposed an alternative correlation for conical-afterbody data based on a review of available experimental data; they found these experimental data could be correlated into a relatively narrow band if the ratio of the cylindrical-to-conical afterbody base-pressure ratios were plotted versus the base-to-body area ratio. The theoretical-solution data for the conical afterbodies are presented on this basis in Fig. 8(b). This particular system of coordinates does seem to correlate the theoretical-solution data by reducing the influence of the nozzle-to-freestream static pressure ratio.

B. LIMITED COMPARISON WITH EXPERIMENT

Included in Fig. 8(b) for comparison with the theoretical results of the parametric study for conical afterbodies is the experimental correlation curve determined by Brazzel and Henderson [5]. This empirical correlation curve is based on experimental data obtained over a relatively wide range of geometric and flow variables. While the reasons for the discrepancy between the slopes of the theoretical and experimental correlation curves are not readily apparent, the discrepancy can be partially attributed to the usual overestimation of the base-pressure ratio by the theoretical analysis. For cylindrical afterbodies, the overestimation of the base-pressure ratio can be significant depending on the flow geometry; an empirical modification to the theoretical model has been determined which reduces this discrepancy [1,3]. Experience has shown qualitatively that without empirical modifications to the flow model the agreement between the theoretical and experimental base-pressure results is usually better for conical afterbodies than for cylindrical afterbodies. Currently, thorough quantitative theoretical-experimental comparisons have not been completed for non-cylindrical afterbodies and, as a consequence, possible empirical modifications to the theoretical model are not yet available.

Figure 9(a) presents a comparison for several conical boattails between the experimental data of Baughman and Kochendorfer [6] and the inviscid afterbody analysis; the agreement between theory and experiment is reasonably good for these boattails. It should be noted, however, that boundary-layer effects can lead to significant discrepancies between the present inviscid afterbody analysis and experiment.

For the foregoing conical boattails, the base pressure coefficients determined by the experiments of Baughman and Kochendorfer [6] and the theoretical analysis are compared in Figs. 9(b,c). In Fig. 9(b), the propulsive-nozzle flow was from a converging nozzle; for these cases the theoretical-experimental agreement is acceptable. However, in Fig. 9(c) where the propulsive-nozzle Mach number has been increased, the theoretical results grouped together as indicated in the figure. Since the experimental data do not exhibit these trends, the agreement between theory and experiment is poor for these particular cases. However, the experimental data of Baughman and Kochendorfer does show trends with increasing propulsive-nozzle Mach number which are similar to the theoretical results presented in Fig. 9(c). Of the theoretical-experimental comparisons which have been made for various afterbody configurations, the comparisons presented in Figs. 9(b,c) represent qualitatively the maximum divergence between experiment and theory which has been encountered to date.

V. CONCLUSIONS

Due to the significant contribution of the base drag to the overall aerodynamic drag of a vehicle, any factors or modifications which could influence the combined afterbody-base drag must be considered. The component-model based computer program provides a quick, convenient, and effective means for conducting qualitative studies of the base-flow problem and the many variables involved. As a consequence, this computer program is well suited for optimization and system studies wherein significant variations in the variables must be considered. With the determination of suitable empirical modifications to the flow model, quantitative studies can also be made with confidence.

To further develop and expand the usefulness of this computer program, studies of the following factors should be continued:

i. the influence of the boundary layer on the afterbody flow-field calculations,

ii. the inclusion of the boundary layer as an equivalent base "bleed,"

iii. the detailed experimental-theoretical comparisons which could serve as the bases for empirical modifications to the component flow model,

iv. the continued development of empirical modifications to the flow model to improve the engineering usefulness of the computer program, and

v. the investigation of the fundamental processes involved.

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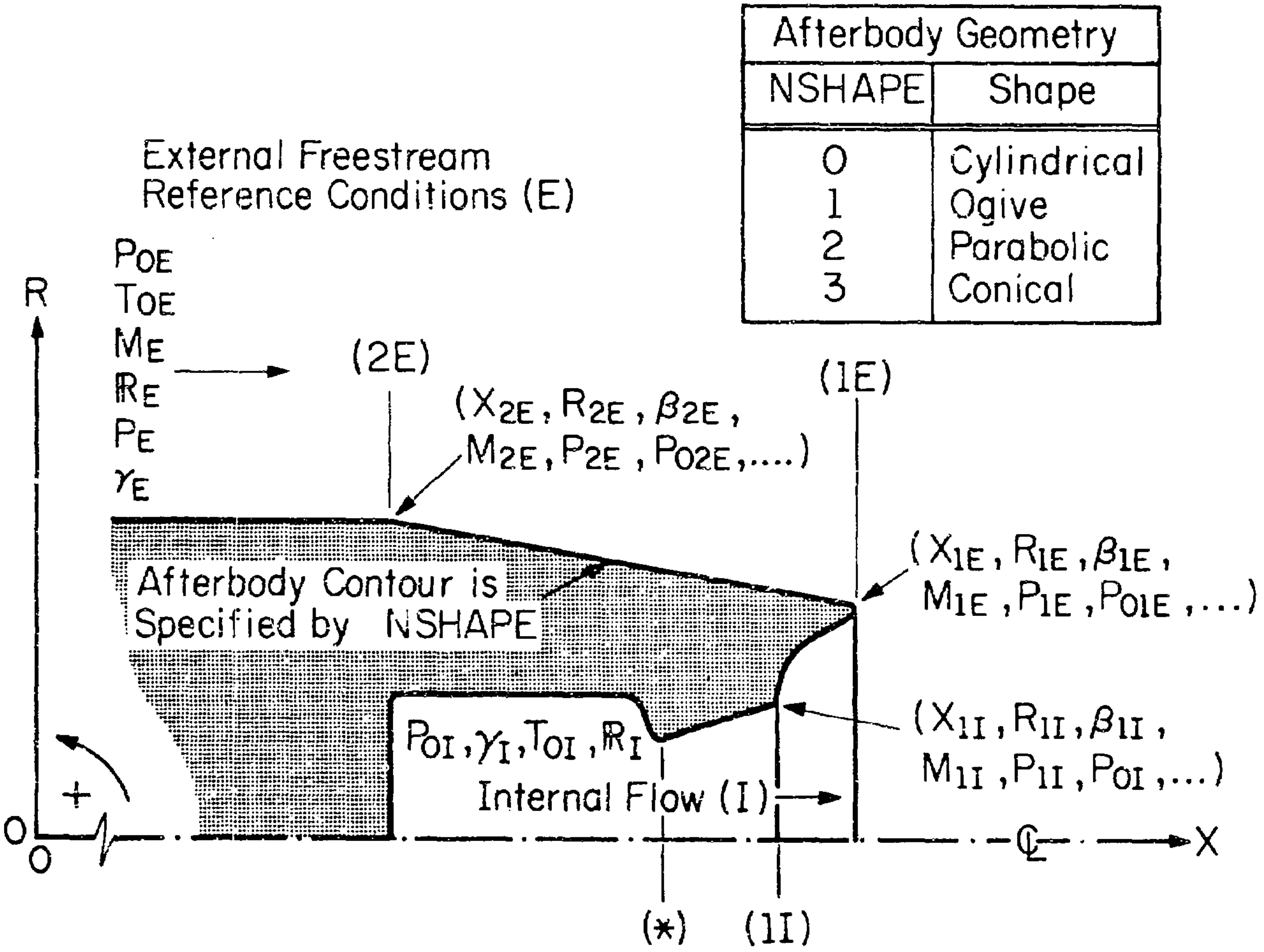
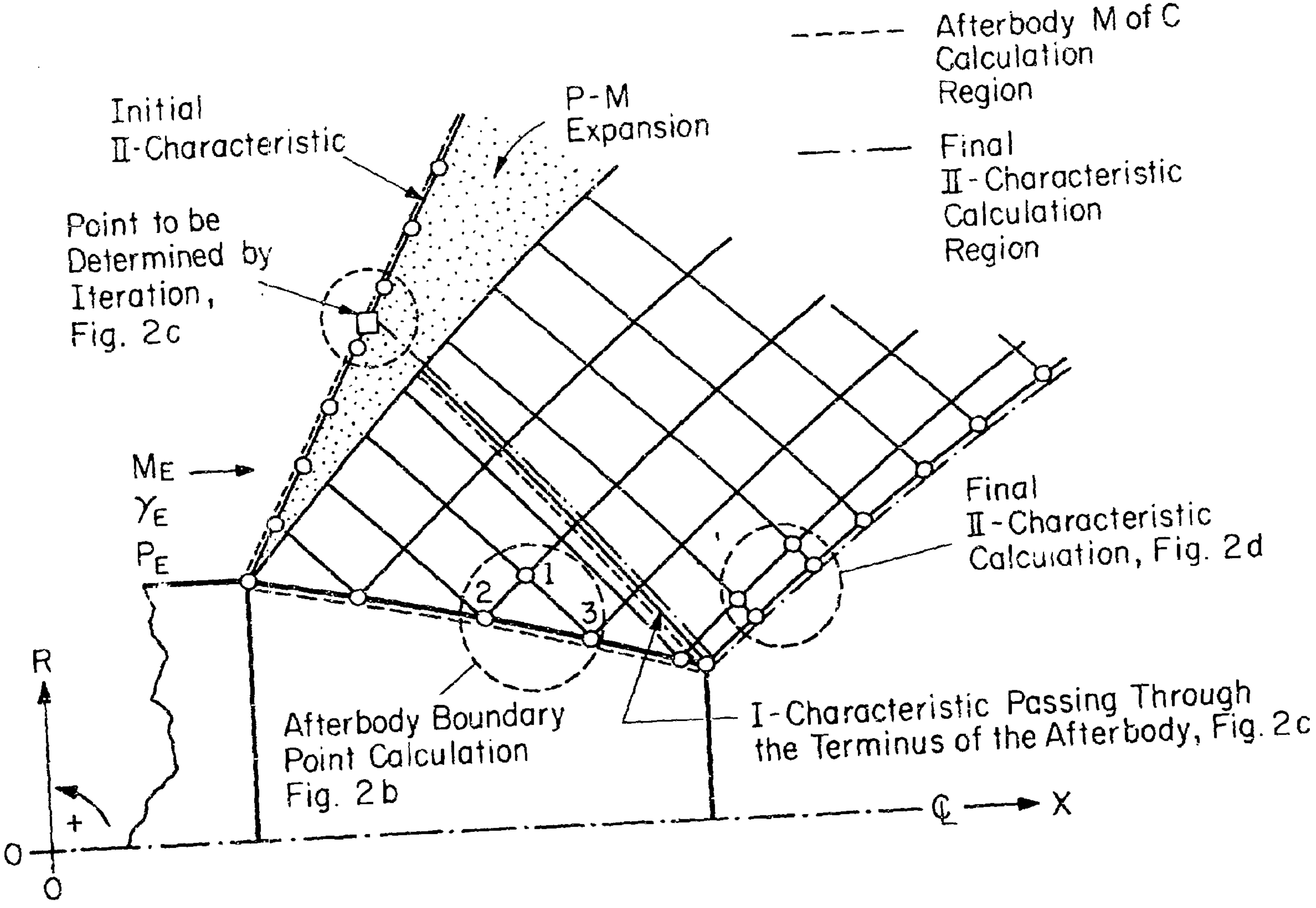


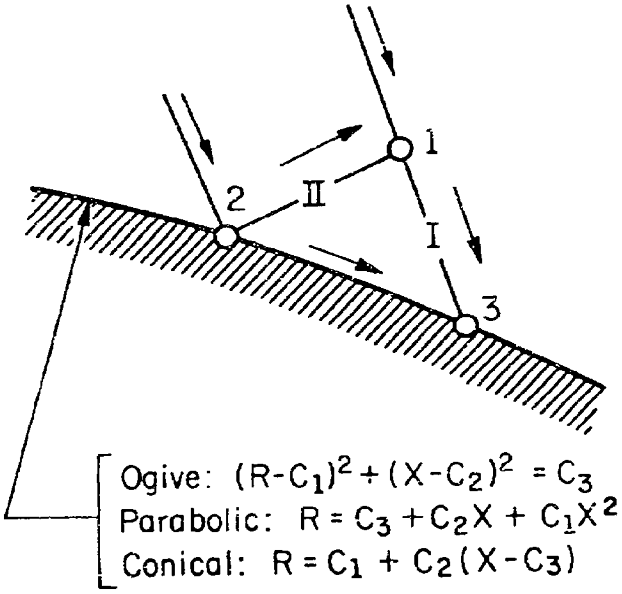
Afterbody Geometry	
NSHAPE	Shape
0	Cylindrical
1	Ogive
2	Parabolic
3	Conical

Figure 1 Two-stream axisymmetric base-flow configuration with an afterbody



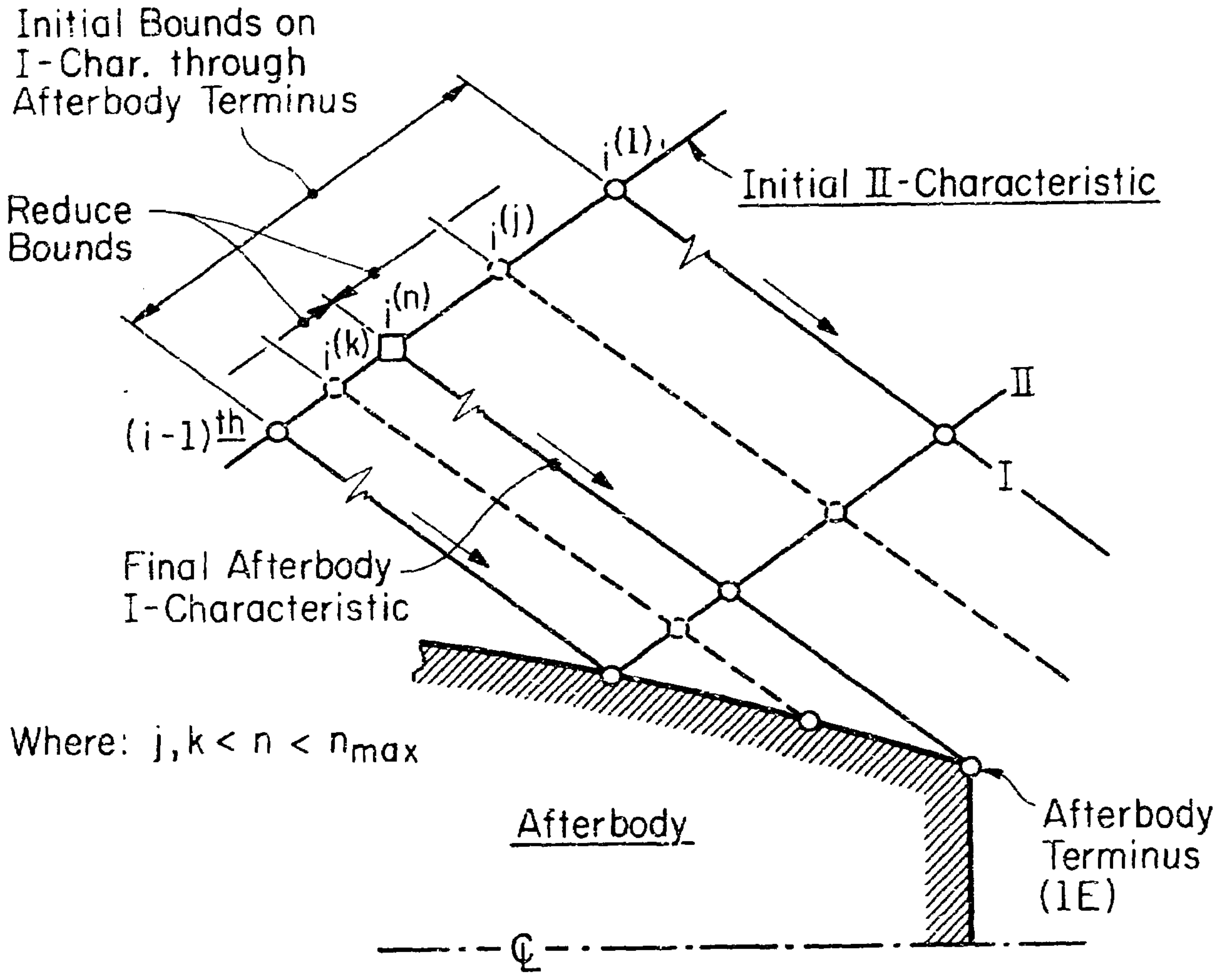
(a) Flowfield subdivision and unit processes

Figure 2 Inviscid afterbody-flowfield analysis



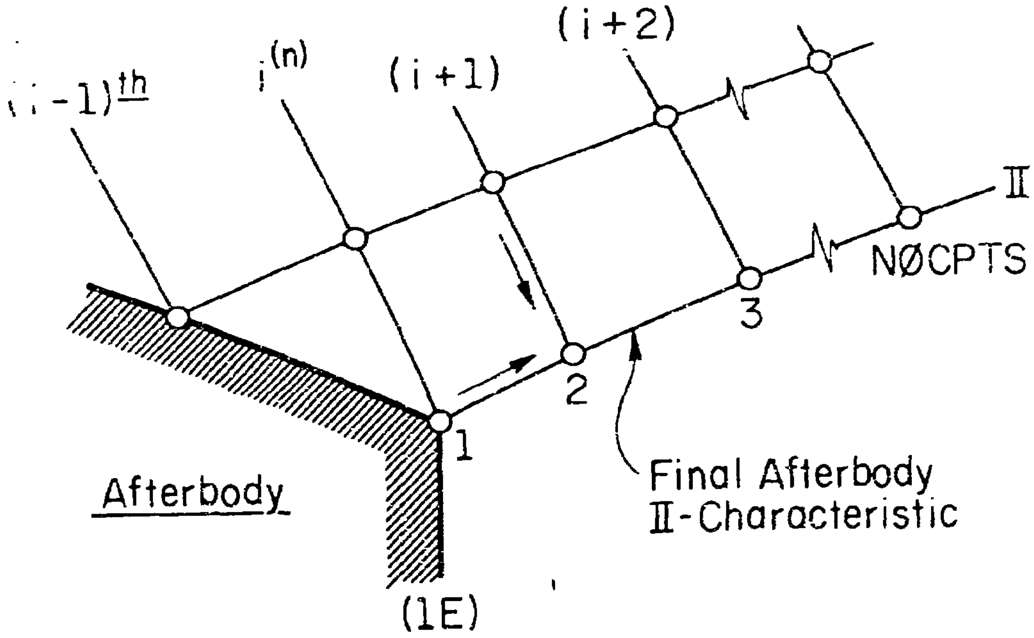
(b) Afterbody boundary-point calculation

Figure 2 continued



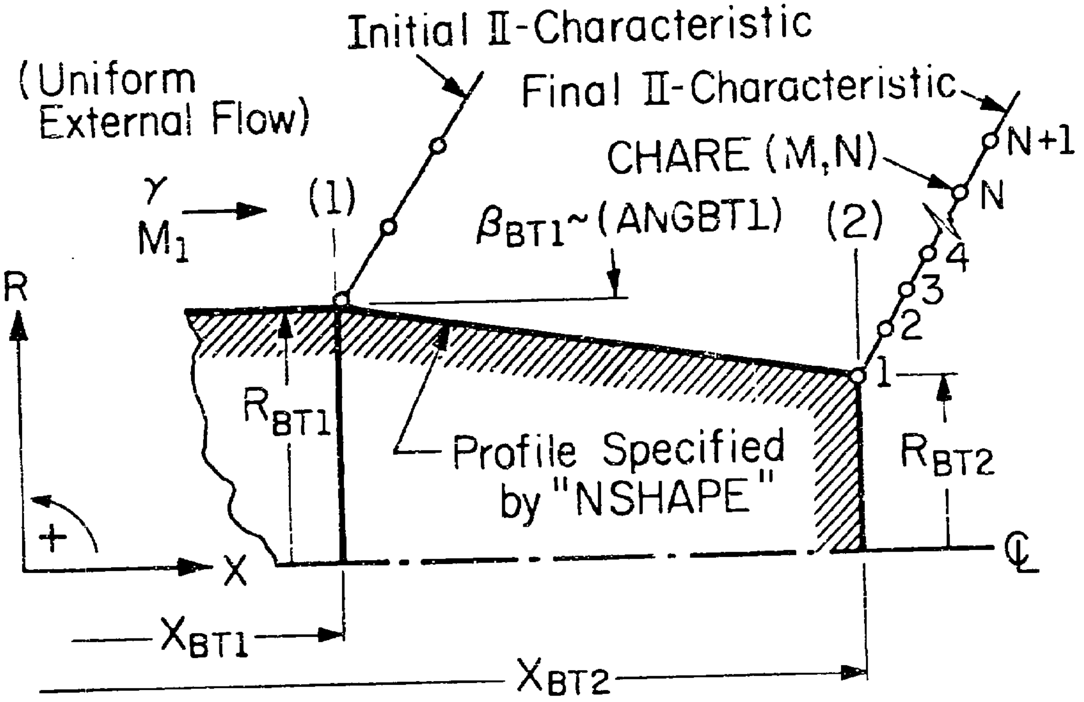
(c) Iterative procedure for determining the I-characteristic through the afterbody terminus

Figure 2 continued



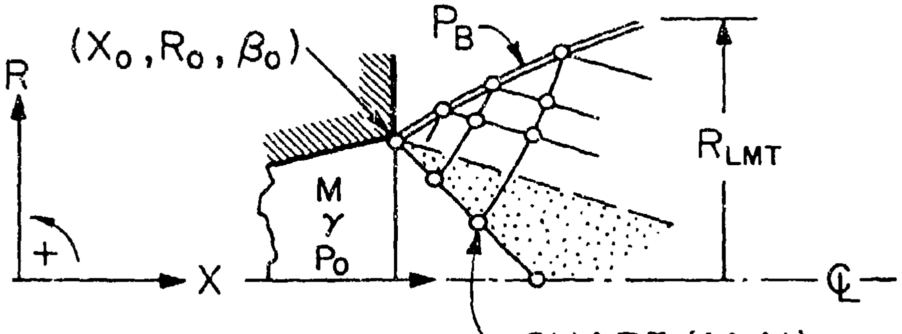
(d) Final afterbody II-characteristic for input to the external-flowfield subroutine ACPBS

Figure 2 continued

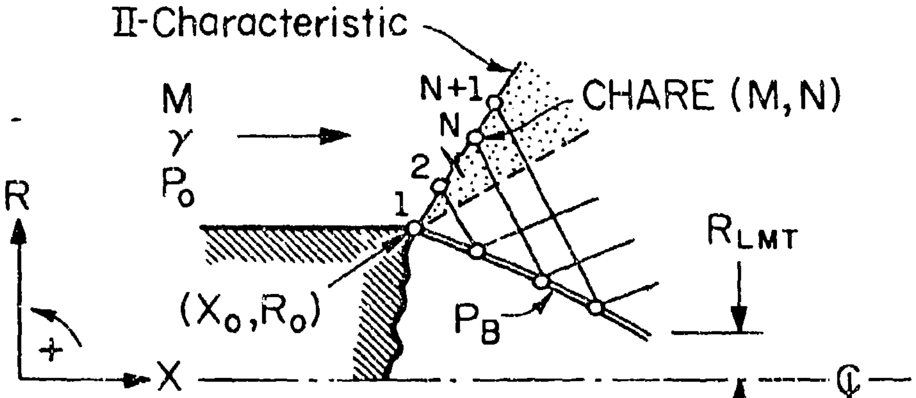


(a) Afterbody notation for subprogram ABTS

Figure 3 Afterbody and constant-pressure boundary subprograms



INTERNAL FLOW



EXTERNAL FLOW

(b) Constant-pressure boundary notation for subprogram ACPBS

Figure 3 continued

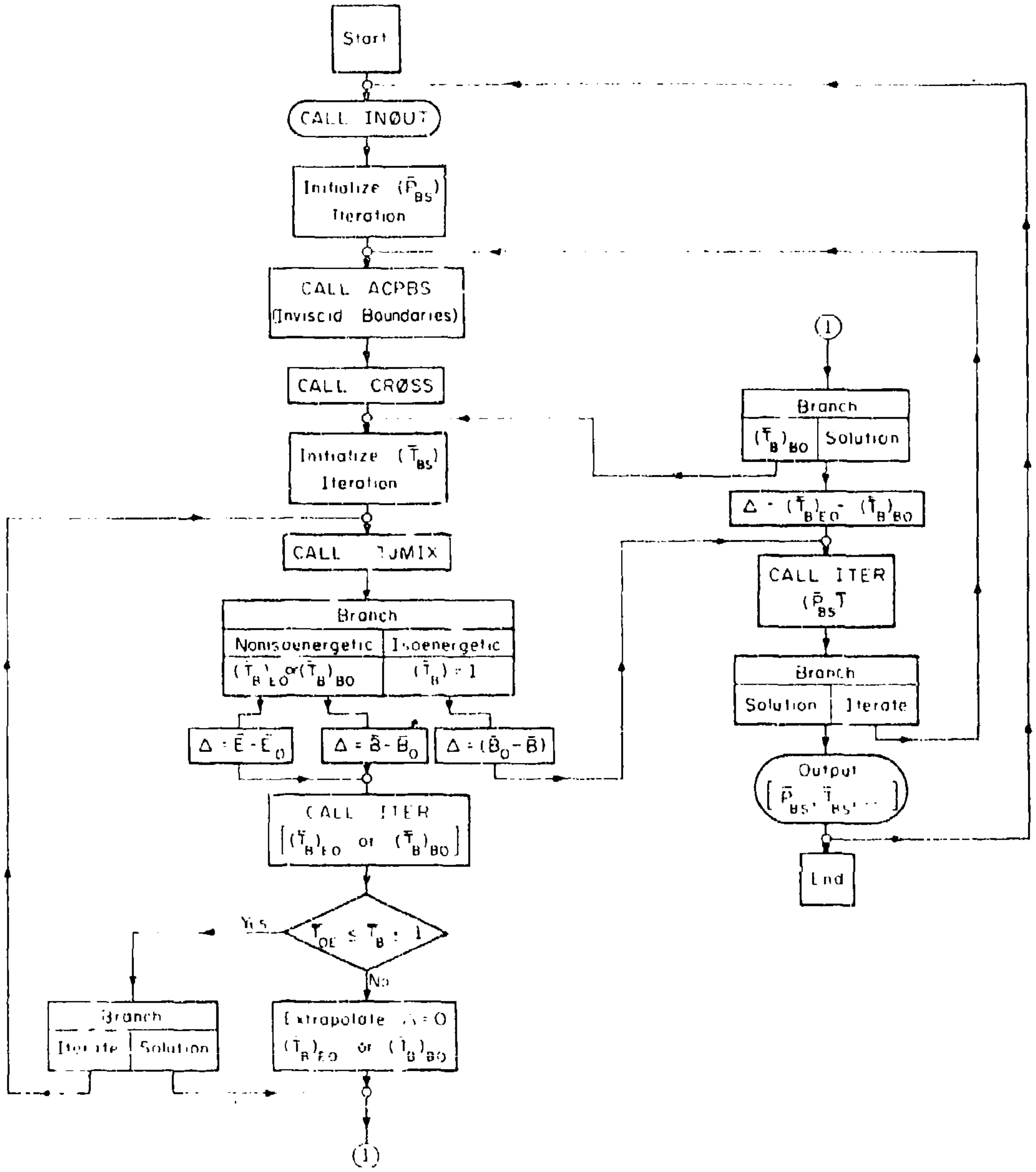


Figure 4(a) Flowchart of main program TSABPP-2

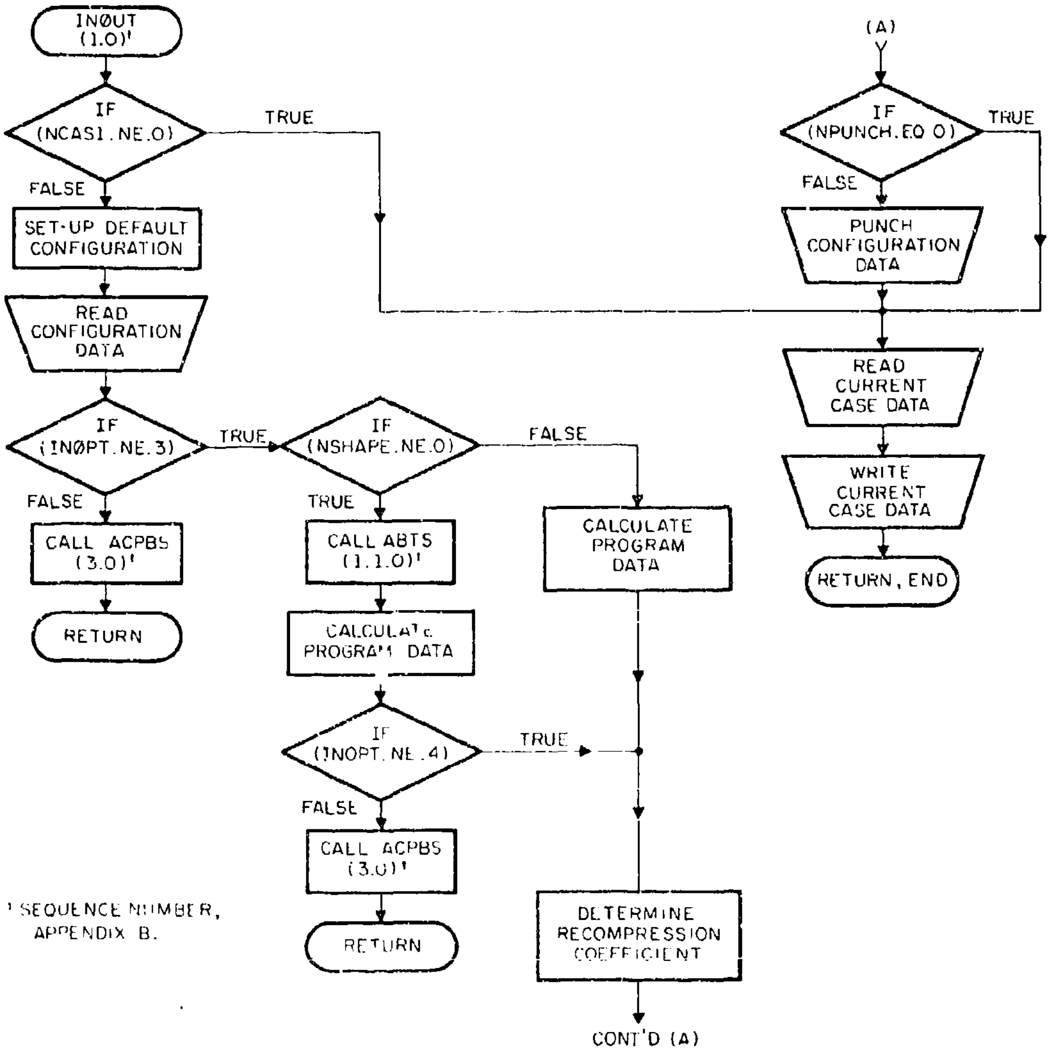


Figure 4(b) Flowchart of subroutine INØUT

TABLE 1

INPUT VARIABLE DEFINITIONS FOR PROGRAM TSABPP-2

```
      ************CØMPUTER PRØGRAM VARIABLE DEFINITIØNS************

A(20)          = CØNFIGURATIØN TITLE.

FØR EITHER THE INTERNAL (I) ØR EXTERNAL (E) STREAM:
X1,R1          = CØØRDINATES ØF PØINT WHERE SEPARATIØN ØCCURS.
                 (R1-S ARE PØSITIVE)
BETD1          = FLØW ANGLE*DEG.* AT (X1,R1).  CCW IS PØSITIVE.
                 ( BETD1I IS (+) AND BETD1E IS (+/-) )
GC             = GAS CØNSTANT*****(LBF-FT/LBM-R)
GAMMA          = RATIØ ØF SPECIFIC HEATS.
EMN1           = MACH NUMBER AT STATIØN (1)
NSHAPE         = 0, NØ AFTERBØDY.
               = 1, ØGIVE. =2, PARABØLIC. =3, CØNICAL.
X2E,R2E        = INITIAL CØØRDINATES ØF THE AFTERBØDY.
BETD2E         = INITIAL AFTERBØDY ANGLE AT (X2E,R2E) IN DEGREES.
                 (BETD2E (-) FØR EXPANSIØN.ØR.BETD2E (+) FØR CØMPRESSIØN)
EMNE           = EXTERNAL FREESTREAM MACH NØ.
TRØEI          = STAGNATIØN TEMPERATURE RATIØ ØF STREAMS, TØE/TØI.
PRØIE          = STAGNATIØN-TØ-STATIC PRESSURE RATIØ ØF STREAMS, PØI/PE.
PR1IE          = STATIC PRESSURE RATIØ ØF STREAMS, P1I/PE.
RECØMP         = RECØMPRESSIØN CØEFFICIENT

NØTE---          DEFAULT ØR INPUT VALUE ØF RECØMP=0.0 .AND.
                 1) NSHAPE=0, THEN RECØMP IS CALCULATED FRØM
                             EMPIRICAL EQN- INØU 2620.
                             (Ref.:  RD-TR-69-13)
                 2) NSHAPE=1,2,3, THEN RECØMP=1.0 IS CURRENTLY USED.

NPRINT         = -1, INPUT DATA AND BASE PRESSURE SØLN PRINTED.
               =  0, INPUT DATA, ITERATIØNS AND SØLN PRINTED.
               = +1, INPUT DATA, ITERATIØN, C.P.B. DATA, AND SØLN PRINTED.
NPUNCH         =  0, SUMMARY ØUTPUT DATA NØT PUNCHED
               =  1, SUMMARY ØUTPUT DATA PUNCHED
INØPT          =  1, INPUT BY NAMELIST/DATA/ØNLY.  THE DEFAULT CØNFIG.
                     SPECIFIED IN INØUT IS AVAILABLE.
               =  2, INPUT MUST BE SPECIFIED BY A CØMPLETE SET ØF DATA
                     CARDS FØLLØWING THE FIRST CARD: " &DATA INØPT=2 &END".
               =  3, INPUT SPECIFIED BY NAMELIST/DATA/ FØR CALCULATIØN ØF
                     INTERNAL-FLØW CØNSTANT-PRESSURE BØUNDARIES.
               =  4, INPUT SPECIFIED BY NAMELIST/DATA/ FØR CALCULATIØN ØF
                     EXTERNAL FLØW:  AFTERBØDY ØNLY (NCASE=0) AND/ØR
                     CØNSTANT-PRESSURE BØUNDARIES.
```

TABLE 1 (continued)

```
NCASE          = NØ. ØF PRESS. RATIØS FØR WHICH BASE-PRESSURE
                 CALCULATIØNS ARE TØ BE MADE FØR A GIVEN SET ØF
                 CØNDITIØNS AND GEØMETRY.
KPRESR         = 0, PR1IE IS INPUT, AND PRØIE IS CALCULATED.
               = 1, PRØIE IS INPUT, AND PR1IE IS CALCULATED.
PRATIØ,PR(I) = INPUT PRESSURE RATIØ(S).
BLDRØ,BRØ(I) = INPUT BLEED RATIØ(S).
ENGRØ,ERØ(I) = INPUT ENERGY RATIØ(S).
```

TABLE 3

TSABPP-2 INPUT OPTION 2 (INØPT=2) BY A COMPLETE SET OF DATA CARDS†

Card Number	Variables (Refer to Fig. 1)	Format Specification
1	&DATA INØPT=2 &END	(2 to 80)
2	Any alphanumeric title	(20A4)
3	X1I,R1I,BETD1I,GCI,GAMMAI, EMN1I,NSHAPE	(6F10.6,I1)
::::::::::	IF NSHAPE=0, CARD NØ. 4 IS:	
4	X1E,R1E,GCE,GAMMAE,EMNE	(5F10.6)
::::::::::	ØR, IF NSHAPE=1,2, ØR 3, CARD NØ. 4 IS:	
4	X2E,R2E,BETD2E,X1E,R1E,GCE, GAMMAE,EMNE	(8F10.6)
5	TRØEI,RECØMP	(2F10.6)
6	NPRINT,NCASE,NPUNCH,KPRESR	(I2,I3,2I1)
::::::::::	IF KPRESR=0, CARD NØ. 7 AND FØLLØWING ARE:	
7 • • •	PR1IE,BLRDØ,ENGRØ	(3F10.6)
::::::::::	ØR, IF KPRESR=1, CARD NØ. 7 AND FØLLØWING ARE:	
7 • • •	PRØIE,BLDRØ,ENGRØ	(3F10.6)

† Note: There are (6+NCASE) data cards per case.

TABLE 4

TSABPP-2 INPUT OPTION 3 (IN0PT=3) FOR CALCULATION OF INTERNAL-FLOW CONSTANT-PRESSURE BOUNDARIES ONLY. INPUT BY NAMELIST/DATA/: " &DATA IN0PT=3,A='...', etc. &END"

Variables	Default Values	Input Values (IN0PT=3)
IN0PT	1	3 †
A(20)	---	INPUT
X1I	0.0	*††
R1I	1.0	*
BETD1I	0.0	*
GAMMAI	1.4	*
EMN1I	0.0	INPUT
NCASE .LE. 20	0	INPUT
PR(I),I=1, NCASE	†††	INPUT

†Required input value.

††Optional input value.

†††PR(I)=PB/P0I.

TABLE 5

TSABPP-2 INPUT OPTION 4 (INOPT=4) FOR CALCULATION OF EXTERNAL FLOW ONLY: AFTERBODY AND/OR CONSTANT-PRESSURE BOUNDARIES. INPUT BY NAMELIST/DATA/:

" &DATA INOPT=4, A='...', etc. &END"

Variables	Default Values	Input Values (INOPT=4)	
INOPT	1	4 †	
A(20)	---	INPUT	
NSHAPE	0	0	1, 2, or 3
X2E	0.0	---	*††
R2E	1.0	---	*
BETD2E	0.0	---	INPUT
X1E	0.0	*	INPUT
R1E	1.0	*	INPUT
GAMMAE	1.4	*	*
EMNE	0.0	INPUT	INPUT
NCASE .LE. 20	0	INPUT	INPUT †††
PR(I),I=1,NCASE	††††	INPUT	INPUT

†Required input value.

††Optional input value.

†††Afterbody only: NCASE=0.

††††PR(I)=PB/POE.

TABLE 6

PRINTED OUTPUT DATA AND OPTIONS FOR THE TSABPP-2 PROGRAM

	Input option, INØPT=	1,2			3	4
	Printed Output Data	NPRINT=			•••	
		-1	0	+1		
1.0	Afterbody data	x†	x	x		x
1.1	Geometry and flow input data	x	x	x		x
1.2	Surface data: $[X,R,M,P/P_E,C_p]$	x	x	x		x
1.3	Drag coefficient, C_{DBT}	x	x	x		x
2.0	Identification heading	x	x	x	x	x
3.0	Summary of input data	x	x	x	x	x
4.0	Current iteration-step results		x	x		
4.1	(I) boundary data: $[X_{BI},R_{BI},\theta_{BI}]$			x	x	
4.2	(E) boundary data: $[X_{BE},R_{BE},\theta_{BE}]$			x		x
4.3	Inviscid impingement point data		x	x		
4.3.1	$[X,R,\theta,M,s]$		x	x		
4.3.2	$[\theta_S,P_S/P_B]$ for the shock system		x	x		
4.4	Turbulent mixing results		x	x		
4.4.1	Current trial input data		x	x		
4.4.2	Dimensionless mass and energy transfer ratios, $[\bar{B},\bar{E}]$		x	x		
4.4.3	Current base-pressure and base-temperature data $[\bar{P}_B,\bar{T}_B,\bar{B},\bar{E}]$ for $\Delta\bar{B}[\bar{P}_B,(\bar{T}_B)_{Bo}] = 0$ and $\Delta\bar{E}[\bar{P}_B,(\bar{T}_B)_{Bo}] = 0$		x	x		
5.0	Solution data $[\bar{P}_{BS},\bar{T}_{BS},C_{PB},C_{DB}]$ when $\Delta\bar{B}[\bar{P}_{BS},\bar{T}_{BS}] = 0$ and $\Delta\bar{E}[\bar{P}_{BS},\bar{T}_{BS}] = 0$	x	x	x		

†x = Data printed.

TABLE 5

TSABPP-2 INPUT OPTION 4 (INØPT=4) FOR CALCULATION OF EXTERNAL FLOW ONLY: AFTERBODY AND/OR CONSTANT-PRESSURE BOUNDARIES. INPUT BY NAMELIST/DATA/:

" &DATA INØPT=4, A='...', etc. &END"

Variables	Default Values	Input Values (INØPT=4)	
INØPT	1	4 †	
A(20)	---	INPUT	
NSHAPE	0	0	1, 2, or 3
X2E	0.0	---	*††
R2E	1.0	---	*
BETD2E	0.0	---	INPUT
X1E	0.0	*	INPUT
R1E	1.0	*	INPUT
GAMMAE	1.4	*	*
EMNE	0.0	INPUT	INPUT
NCASE .LE. 20	0	INPUT	INPUT †††
PR(I),I=1,NCASE	††††	INPUT	INPUT

†Required input value.

††Optional input value.

†††Afterbody only: NCASE=0.

††††PR(I)=PB/POE.

TABLE 6

PRINTED OUTPUT DATA AND OPTIONS FOR THE TSABPP-2 PROGRAM

Input option, INØPT=	1,2			3	4
Printed Output Data	NPRINT=			• • •	
	-1	0	+1		
1.0 Afterbody data	x†	x	x		x
1.1 Geometry and flow input data	x	x	x		x
1.2 Surface data: $[X,R,M,P/P_E,C_p]$	x	x	x		x
1.3 Drag coefficient, C_{DBT}	x	x	x		x
2.0 Identification heading	x	x	x	x	x
3.0 Summary of input data	x	x	x	x	x
4.0 Current iteration-step results		x	x		
4.1 (I) boundary data: $[X_{BI},R_{BI},\theta_{BI}]$			x	x	
4.2 (E) boundary data: $[X_{BE},R_{BE},\theta_{BE}]$			x		x
4.3 Inviscid impingement point data		x	x		
4.3.1 $[X,R,\theta,M,s]$		x	x		
4.3.2 $[\theta_s,P_s/P_B]$ for the shock system		x	x		
4.4 Turbulent mixing results		x	x		
4.4.1 Current trial input data		x	x		
4.4.2 Dimensionless mass and energy transfer ratios, $[\bar{B},\bar{E}]$		x	x		
4.4.3 Current base-pressure and base-temperature data $[\bar{P}_B,\bar{T}_B,\bar{B},\bar{E}]$ for $\Delta\bar{B}[\bar{P}_B,(\bar{T}_B)_{Bo}] = 0$ and $\Delta\bar{E}[\bar{P}_B,(\bar{T}_B)_{Bo}] = 0$		x	x		
5.0 Solution data $[\bar{P}_{BS},\bar{T}_{BS},C_{PB},C_{DB}]$ when $\Delta\bar{B}[\bar{P}_{BS},\bar{T}_{BS}] = 0$ and $\Delta\bar{E}[\bar{P}_{BS},\bar{T}_{BS}] = 0$	x	x	x		

†x = Data printed.

TABLE 7

PUNCHED OUTPUT DATA FOR THE TSABPP-2 PROGRAM (NPUNCH=1)

Punched Summary Output Data (NPUNCH=1)
1.0 *Flow Configuration*
1.1 Internal Flow: $[M_{1I}, \beta_{1I}, D_{1I}, R_I, \gamma_I]$
1.2 External Flow: (no afterbody) $[M_{1E}, \beta_{1E} = 0, D_{1E}, R_E, \gamma_E]$
1.3 Miscellaneous $[X_{1I}/D_{1E}, D_{1I}/D_{1E}, r, T_{oE}/T_{oI}]$
1.4 Afterbody $[\mathrm{NSHAPE}, X_{2E}/D_{2E}, \beta_{2E}, X_{1E}/D_{1E}, D_{1E}/D_{2E}, \beta_{1E}]$
2.0 *No-Solution Cases*
2.1 Current Values of: $[\overline{P}_{oI}, \overline{P}_{1I}, \overline{P}_B]$
2.2 Message: "NØ SØLUTION PB/PE=X.XXXXX"
2.3 Configuration Identification Heading, if Last Case
3.0 *Solution Cases*
3.1 Solution Values of: $[\overline{P}_{oI}, \overline{P}_{1I}, \overline{P}_B, C_{PB}, C_{DB}, R_{LF}, C_T]$
3.2 Configuration Identification Heading, if Last Case

TABLE 8

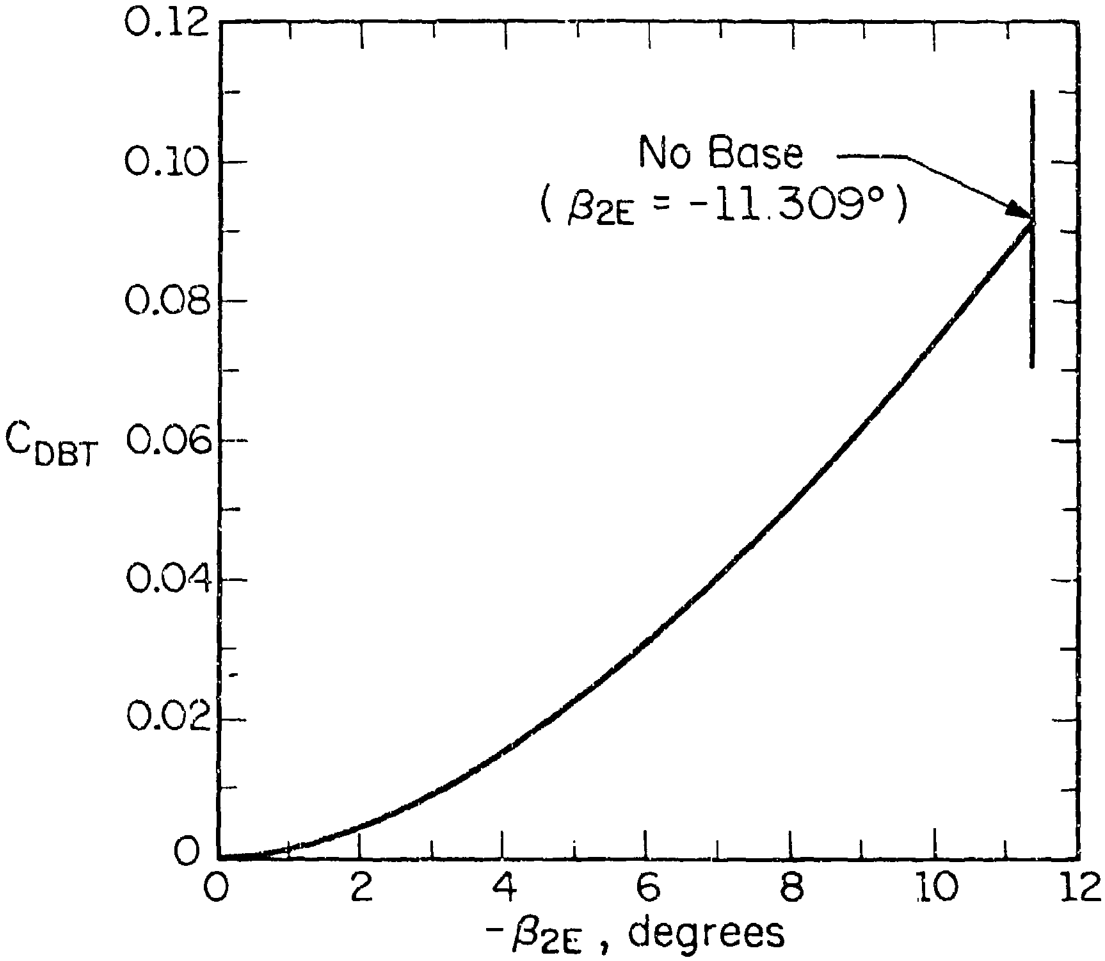
Summary of the configuration data for the parametric study of the afterbody influence on base-pressure ratio, base drag, and overall drag

Configuration Data

Variable	External Flow (E)		Internal Flow (I),(II)
γ	1.4		1.4
$\mathbb{R}\left[lb_f\text{-}ft/lb_m\text{-}°R\right]$	53.35		53.35
M	2.0		2.5
	(2E)	(1E)	
$\bar{X}$	0.0	2.0	2.0
$\bar{R}$	1.0	$\bar{R}_{1E}$	0.6
β (degrees)	β_{2E}	β_{1E}	0.0

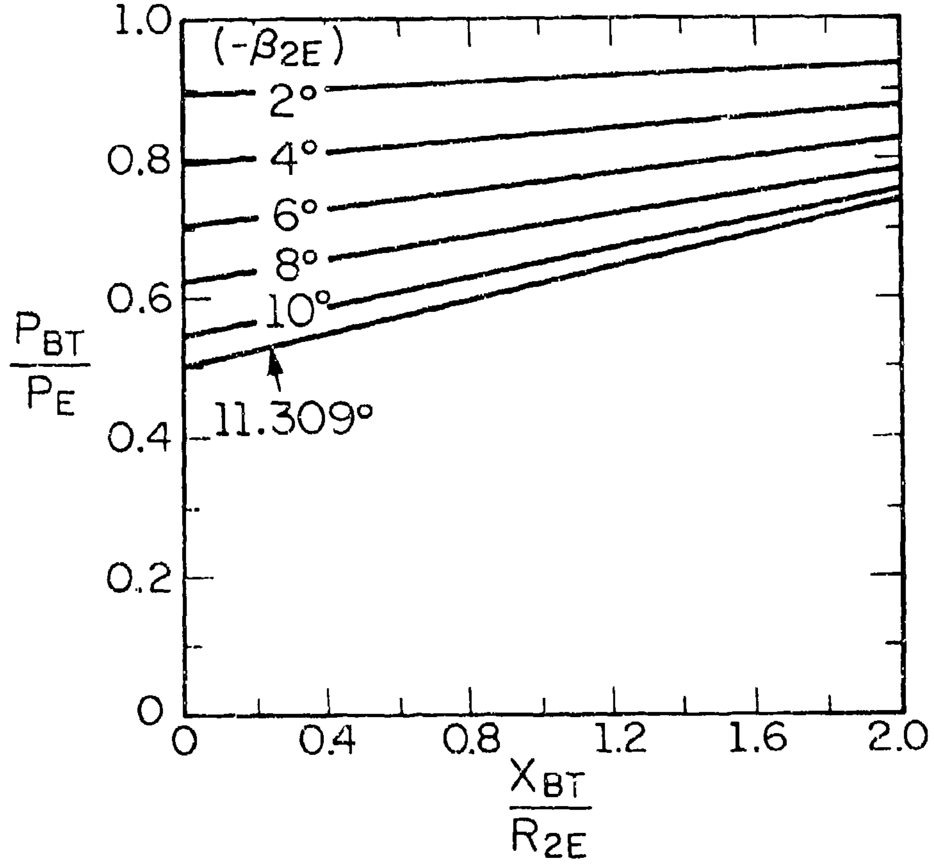
$\bar{T}_{OE} = 1$, $\bar{E}_0 = 0$, $r = 1.0$, $\bar{B}_0 = 0$ or as noted

Conical Boattail NSHAPE = 3		Tangent-Ogive Boattail (β_{2E} = 0°), NSHAPE = 1		Conical Flare NSHAPE = 3	
β_{2E}	$\bar{R}_{1E}$	Configuration Number	$\bar{R}_{1E}$	β_{2E}	$\bar{R}_{1E}$
0°	1.0	1	1.0	0°	1.0
-2	.9302	2	.9302	2	1.0698
-4	.8601	3	.8601	4	1.1398
-6	.7898	4	.7898	6	1.2102
-8	.7180	5	.7180	10	1.3527
-10	.6473	6	.6473	---	---
-11.309	.6000	7	.6000	---	---
Figs. 5		Figs. 6		Figs. 7	



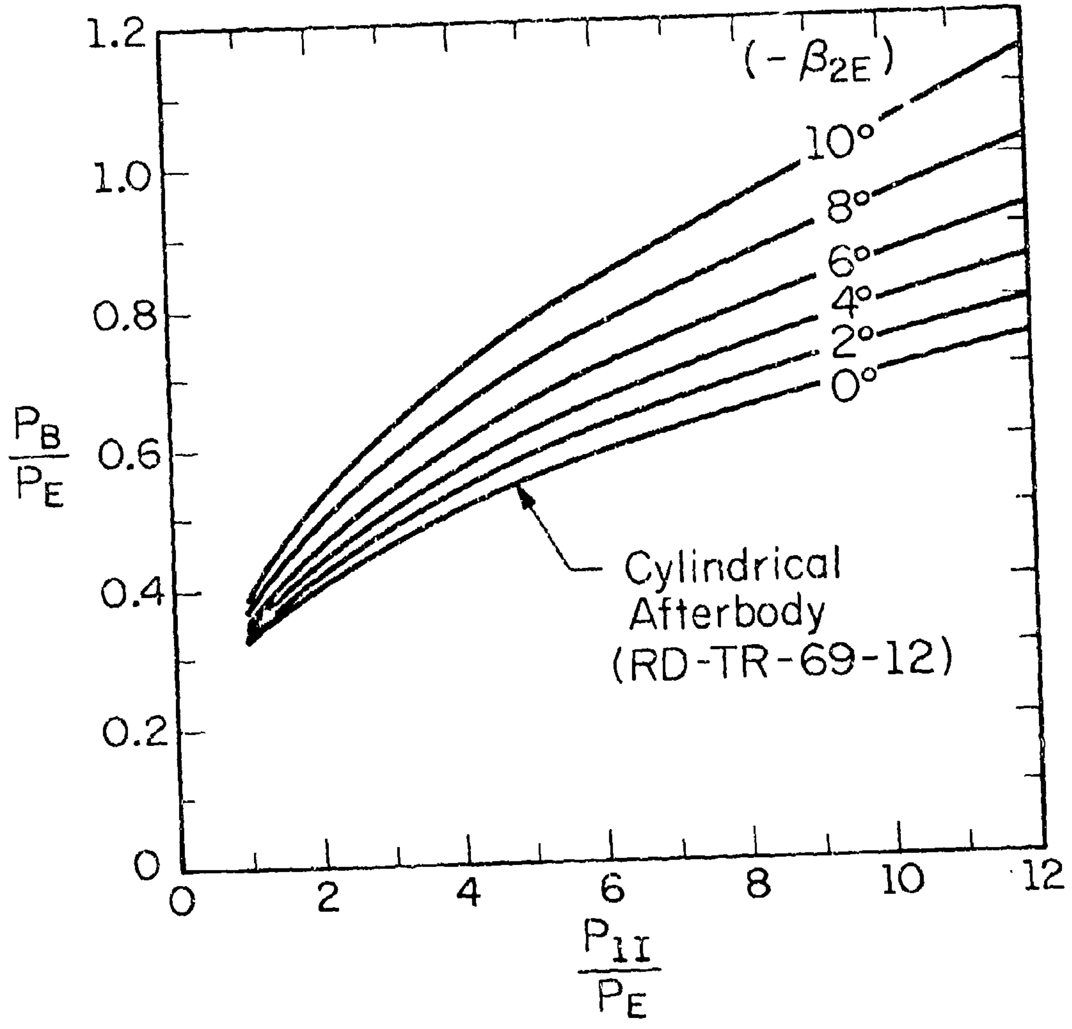
(a) Inviscid conical-boattail drag coefficients

Figure 5 Conical-boattail configurations



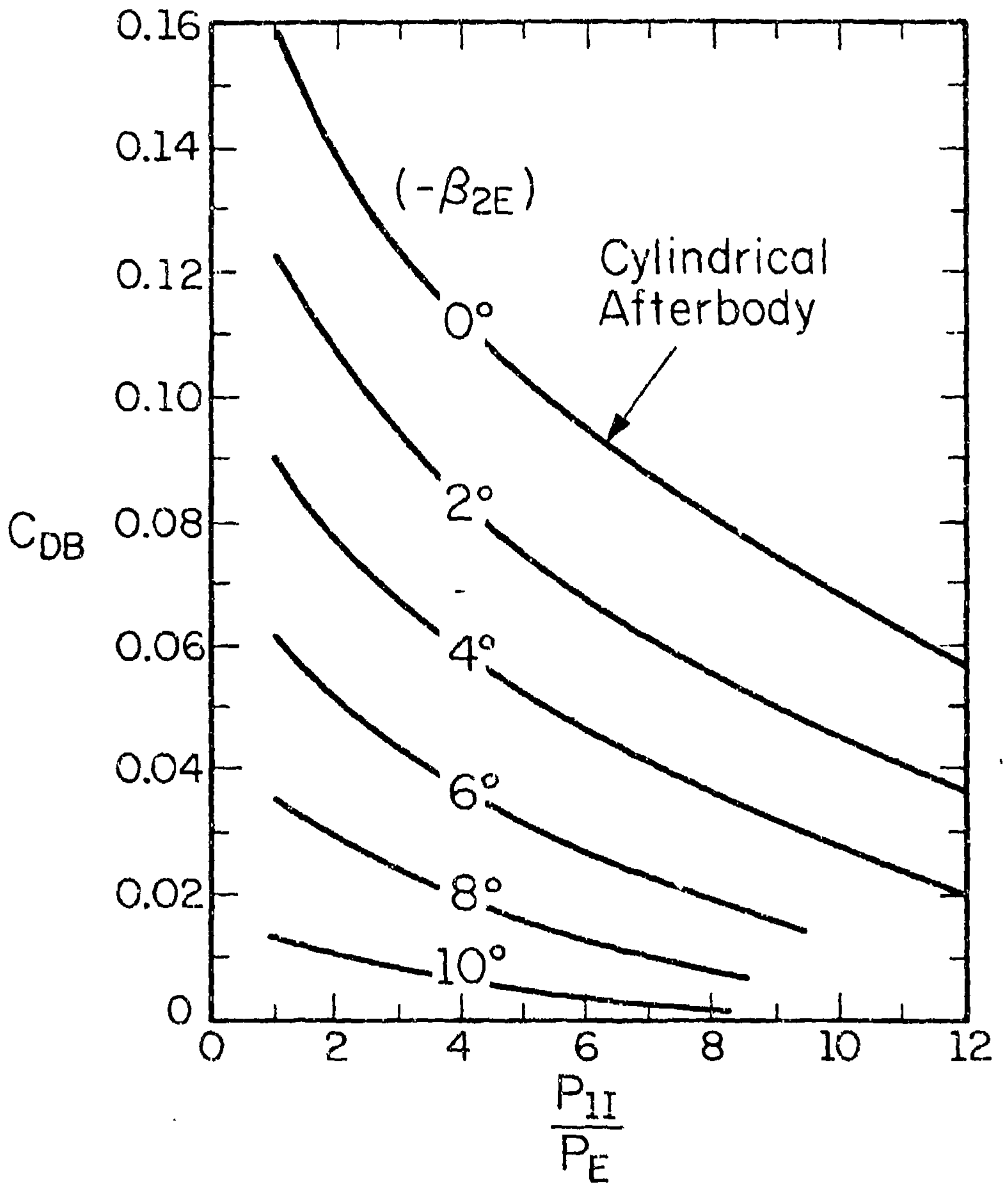
(b) Conical-boattail pressure distributions

Figure 5 continued



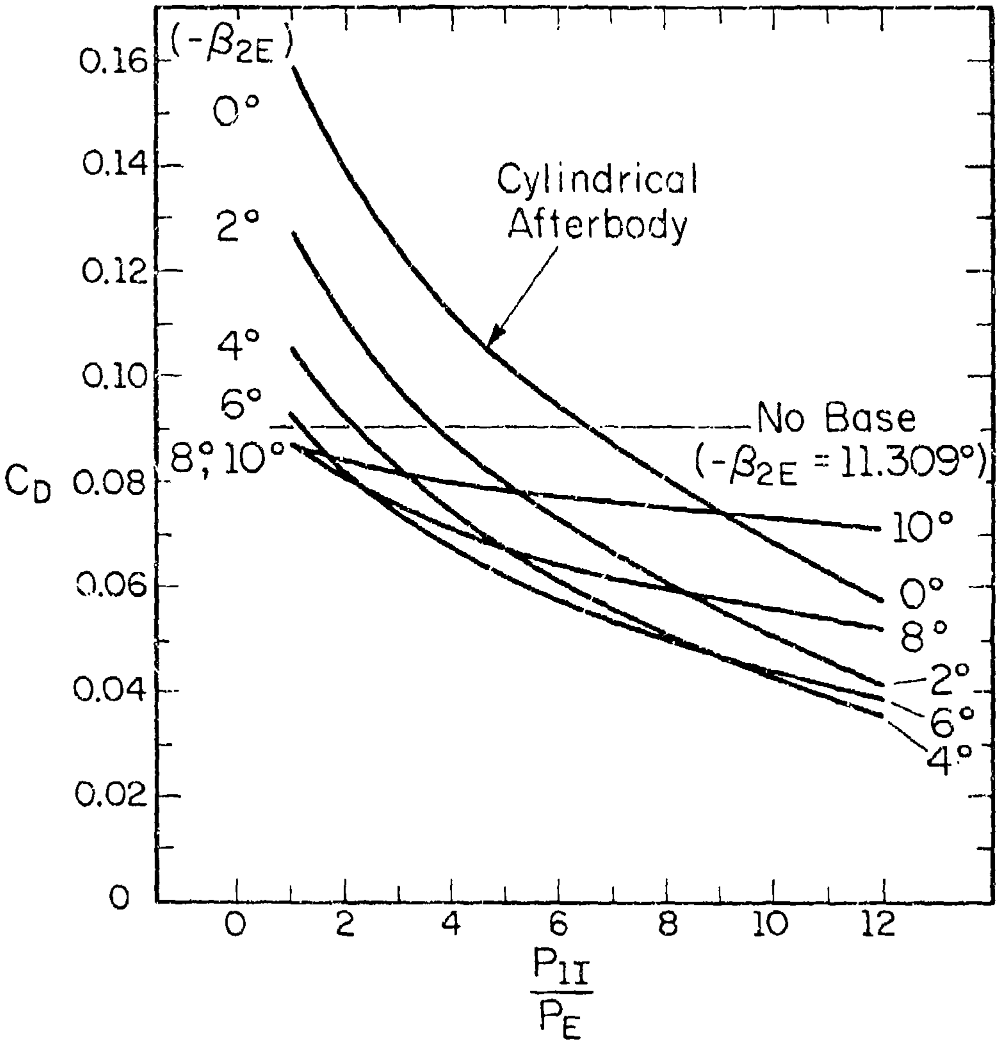
(c) Base-pressure ratio variations for several conical-boattail angles

Figure 5 continued



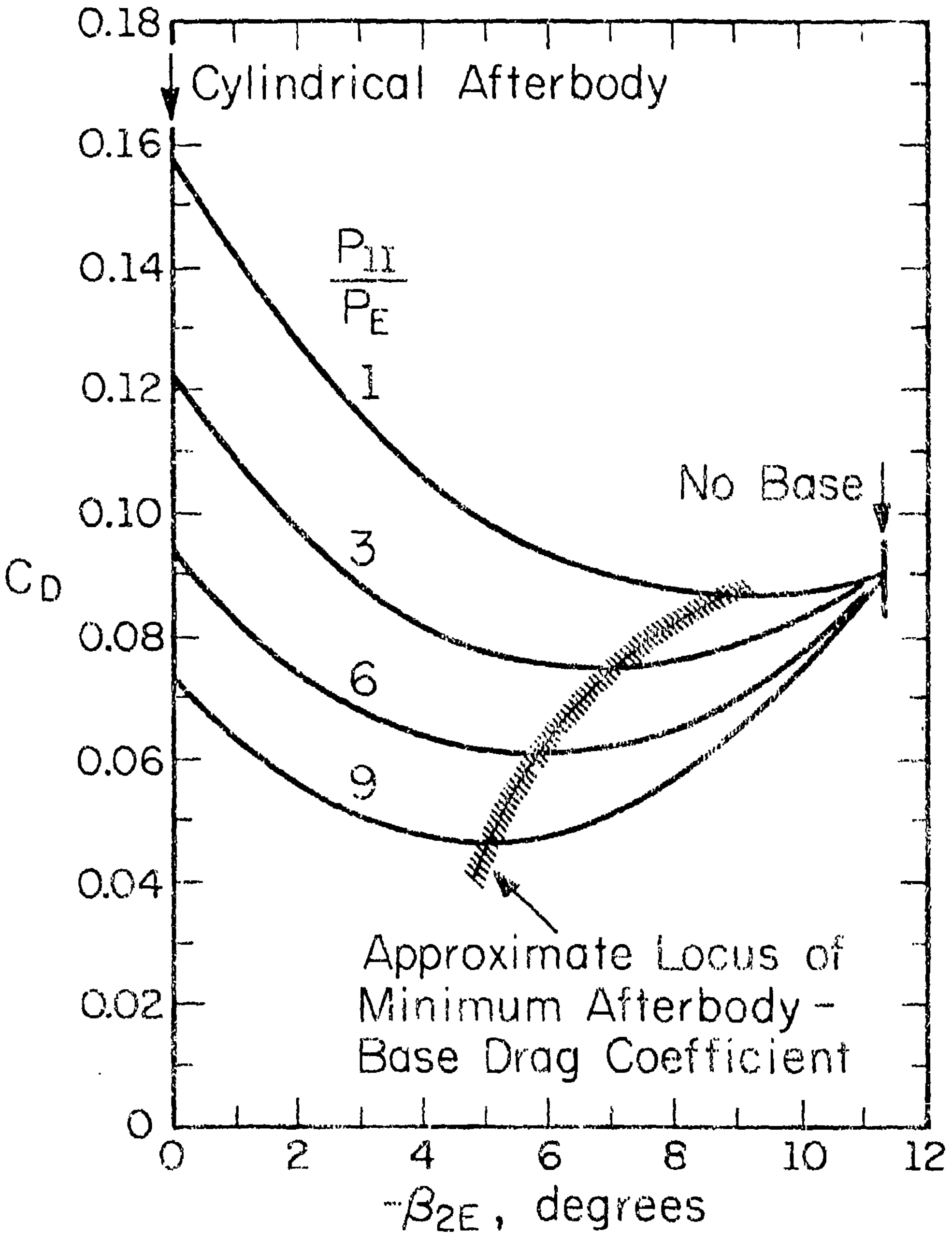
(d) Base drag coefficients for several conical-boattail angles

Figure 5 continued



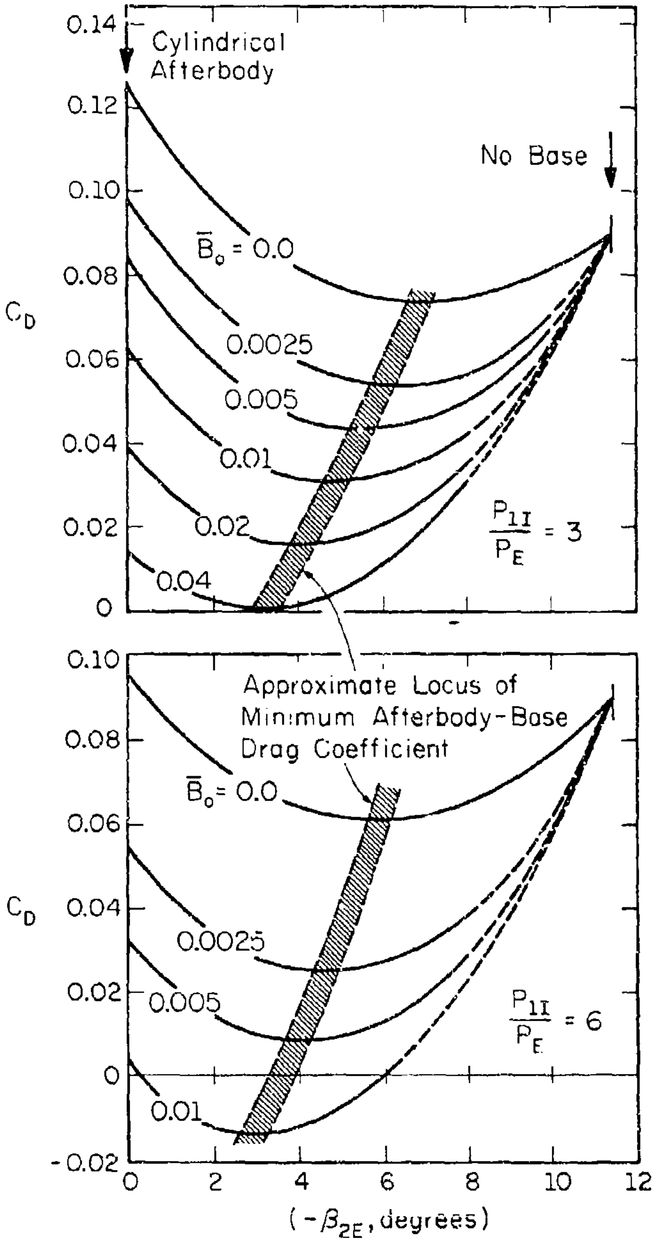
(e) Variations in the combined boattail-base drag coefficient for several conical-boattail angles

Figure 5 continued



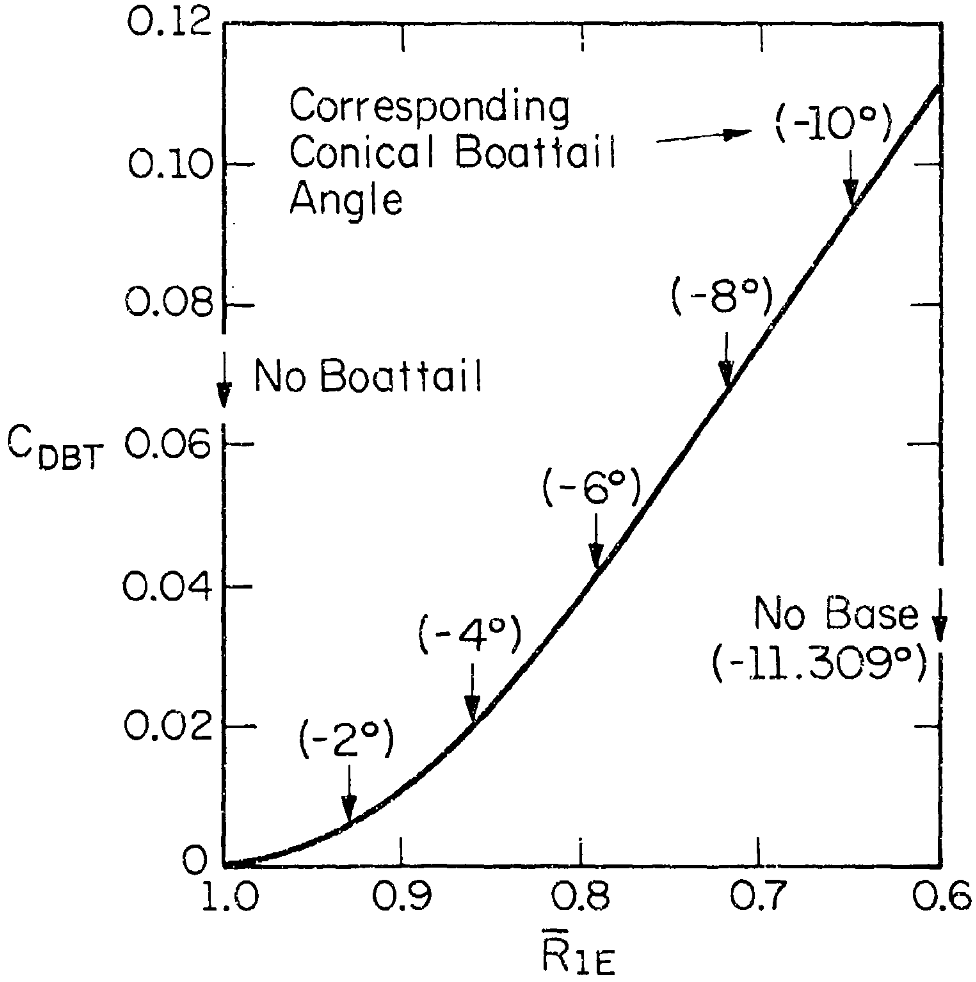
(f) Variations in the combined conical boattail-base drag coefficient for several pressure ratios

Figure 5 continued



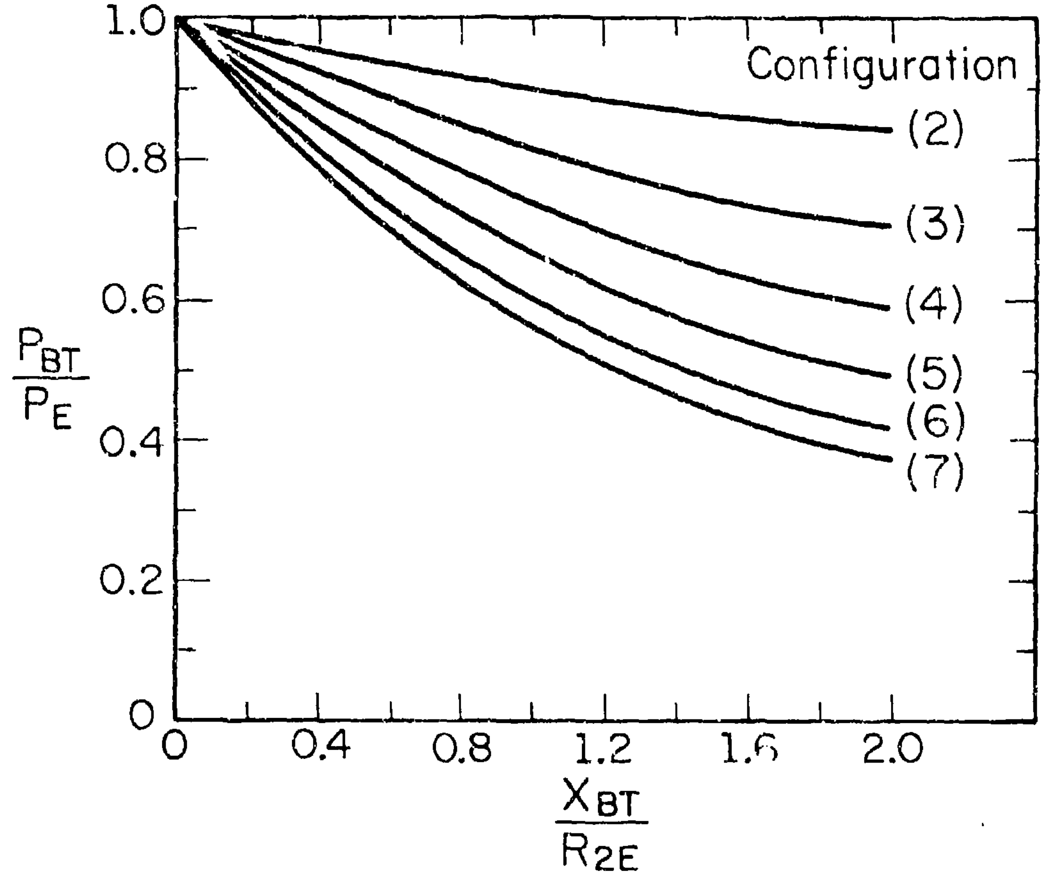
(g) Variations in the combined conical boattail-base drag coefficient for several base-bleed ratios at fixed operating pressure ratios

Figure 5 continued



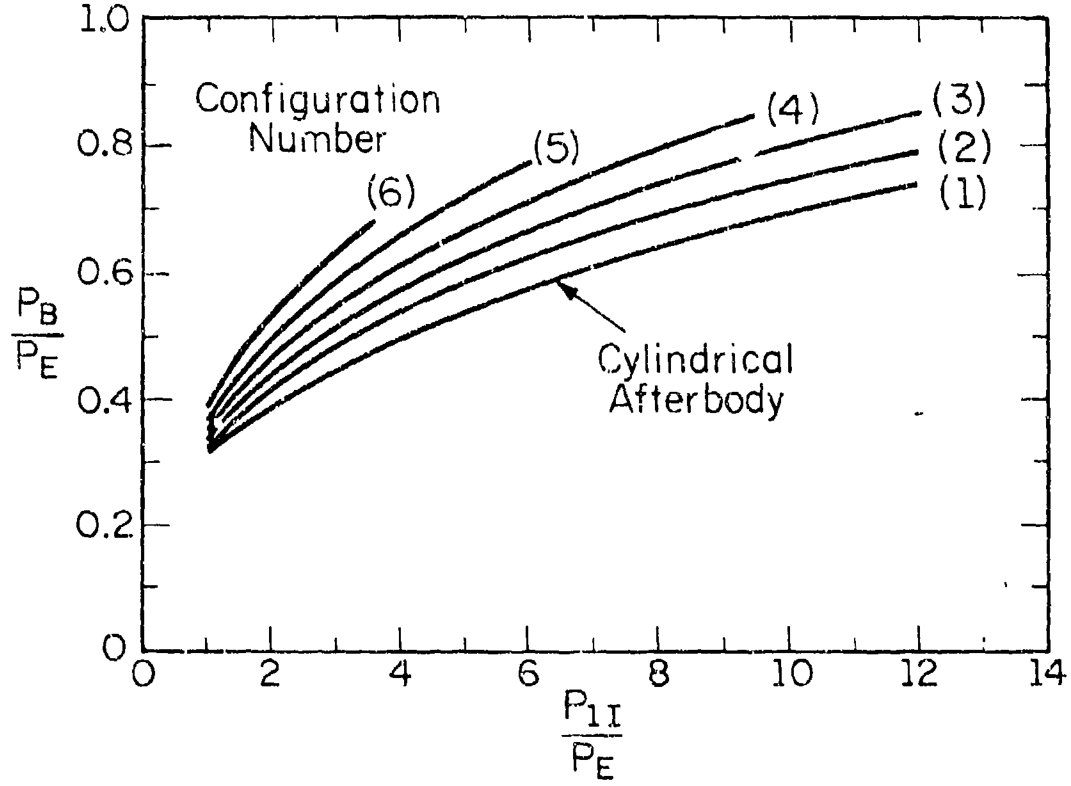
(a) Inviscid drag coefficients for tangent-ogive boattails ($\beta_{2E} = 0°$)

Figure 6 Tangent-ogive boattail configurations



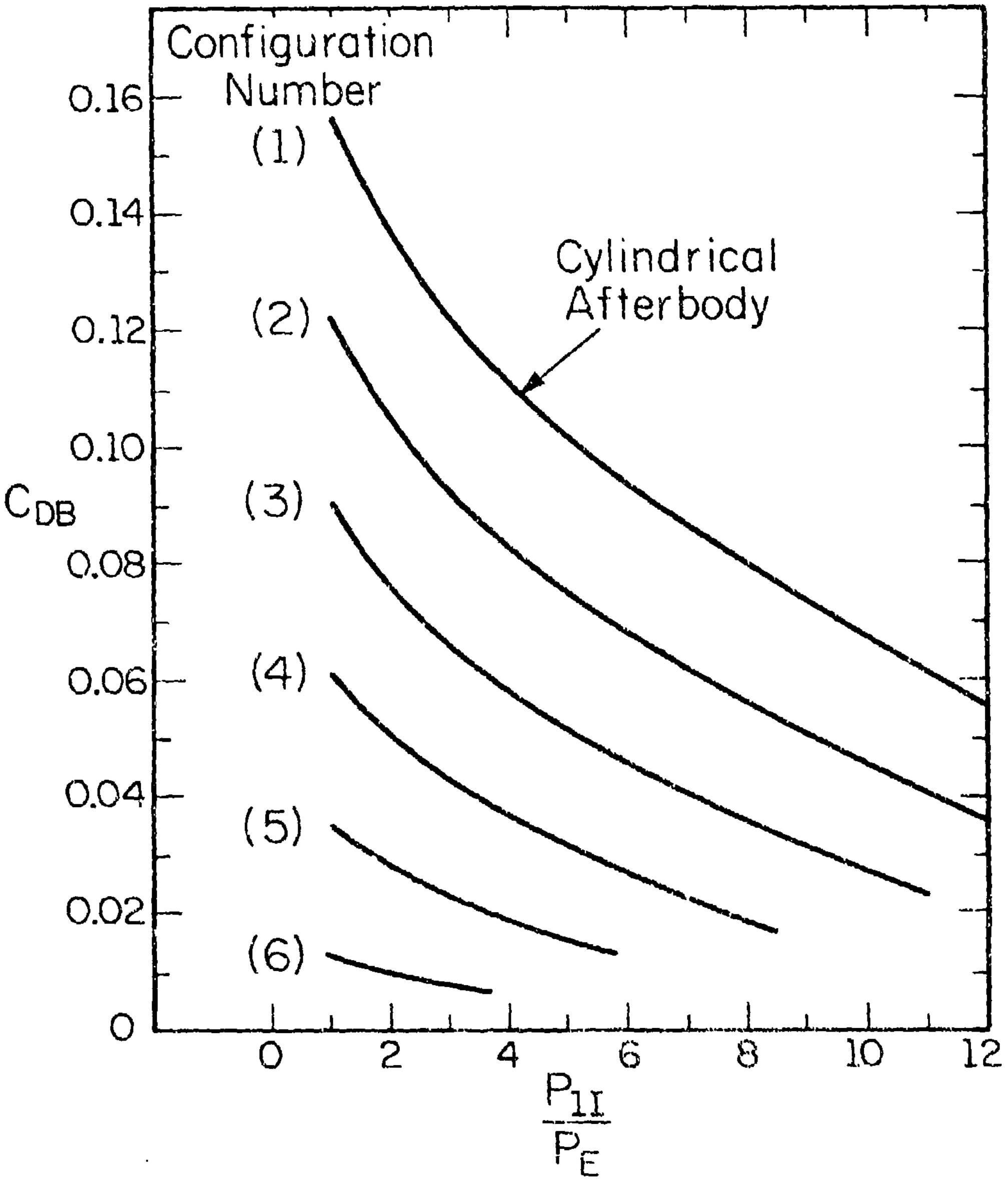
(b) Tangent-ogive boattail pressure distributions

Figure 6 continued



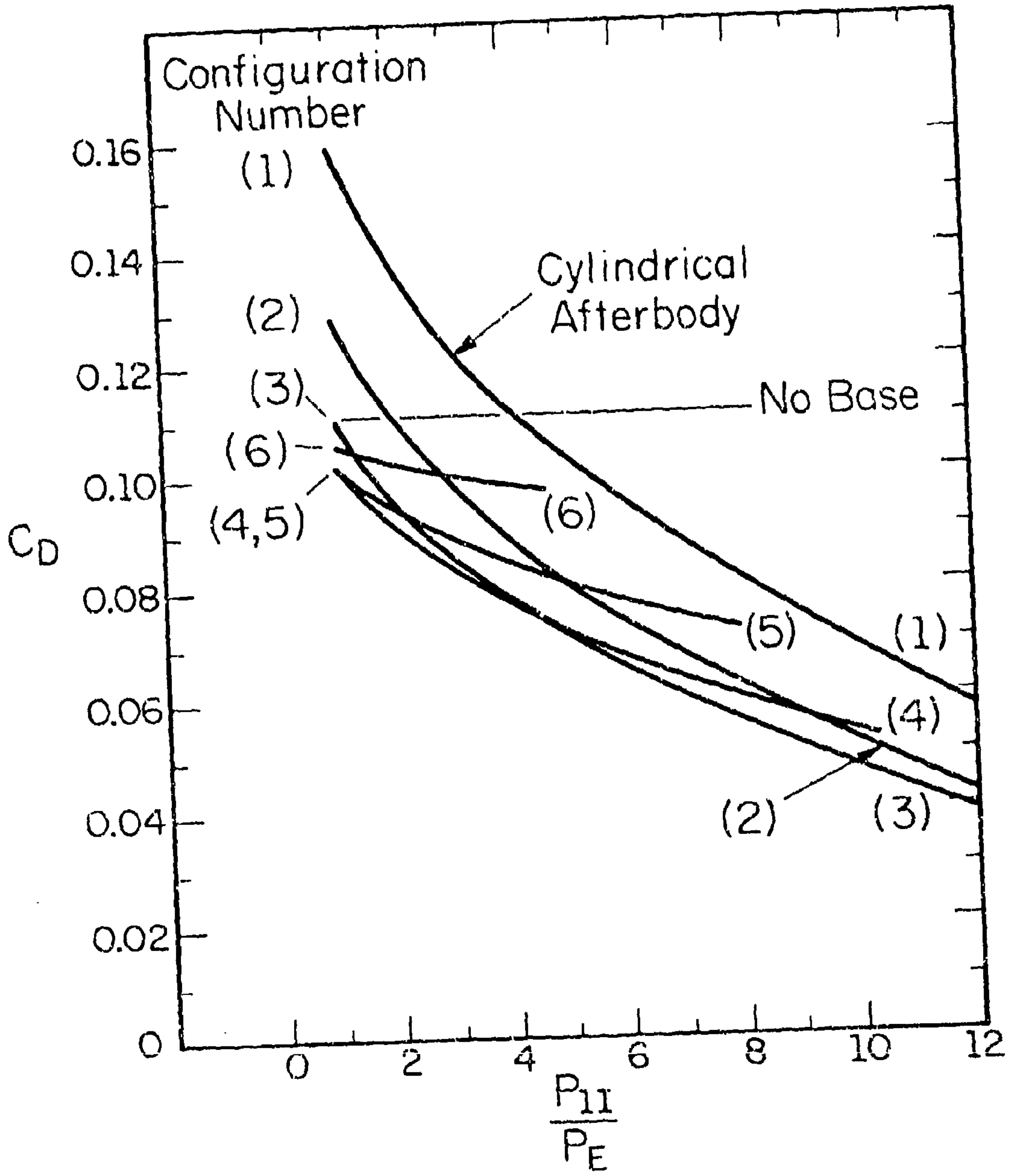
(c) Base-pressure ratio variations for several tangent-ogive boattails

Figure 6 continued



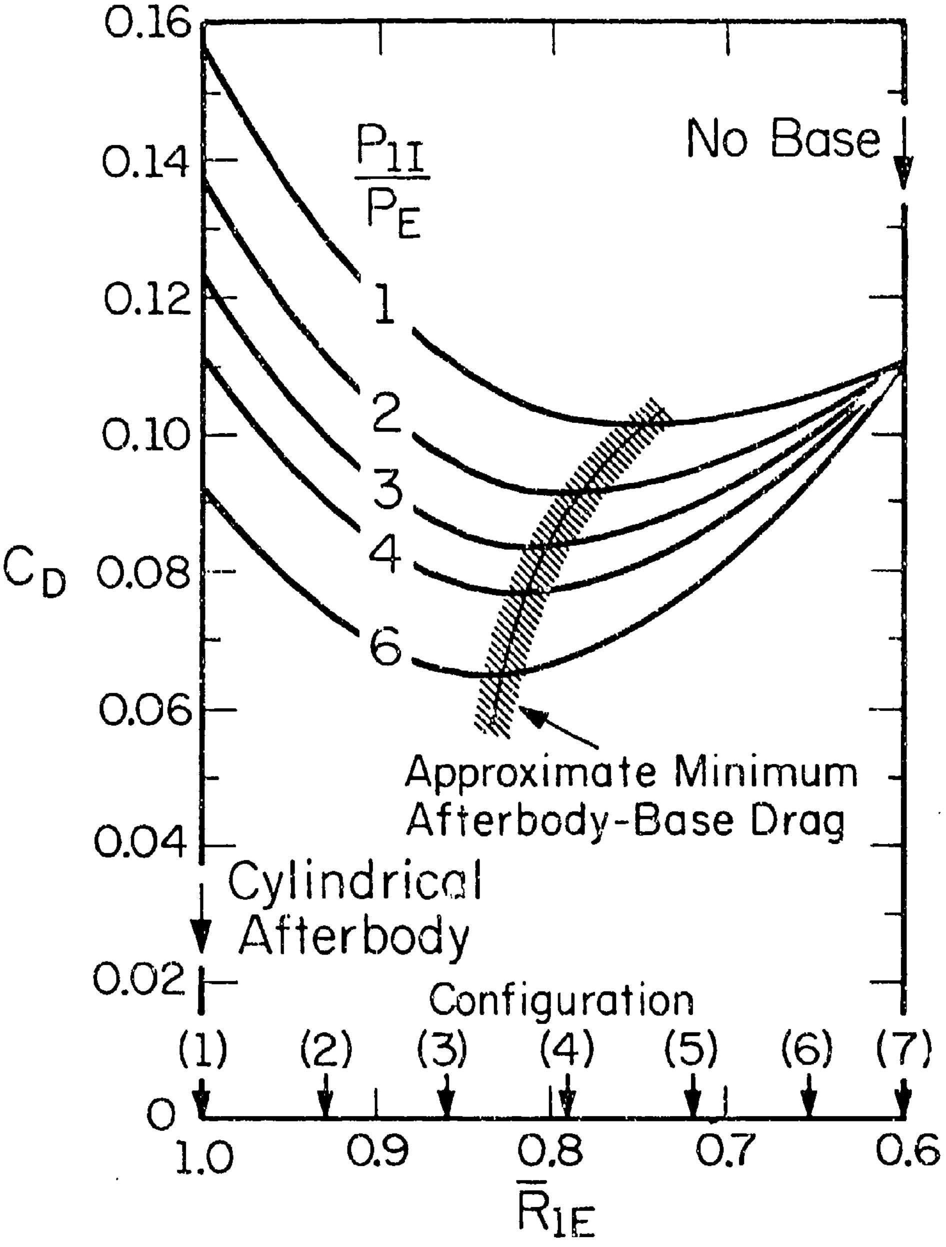
(d) Base drag coefficients for several conical-boattail angles

Figure 6 continued



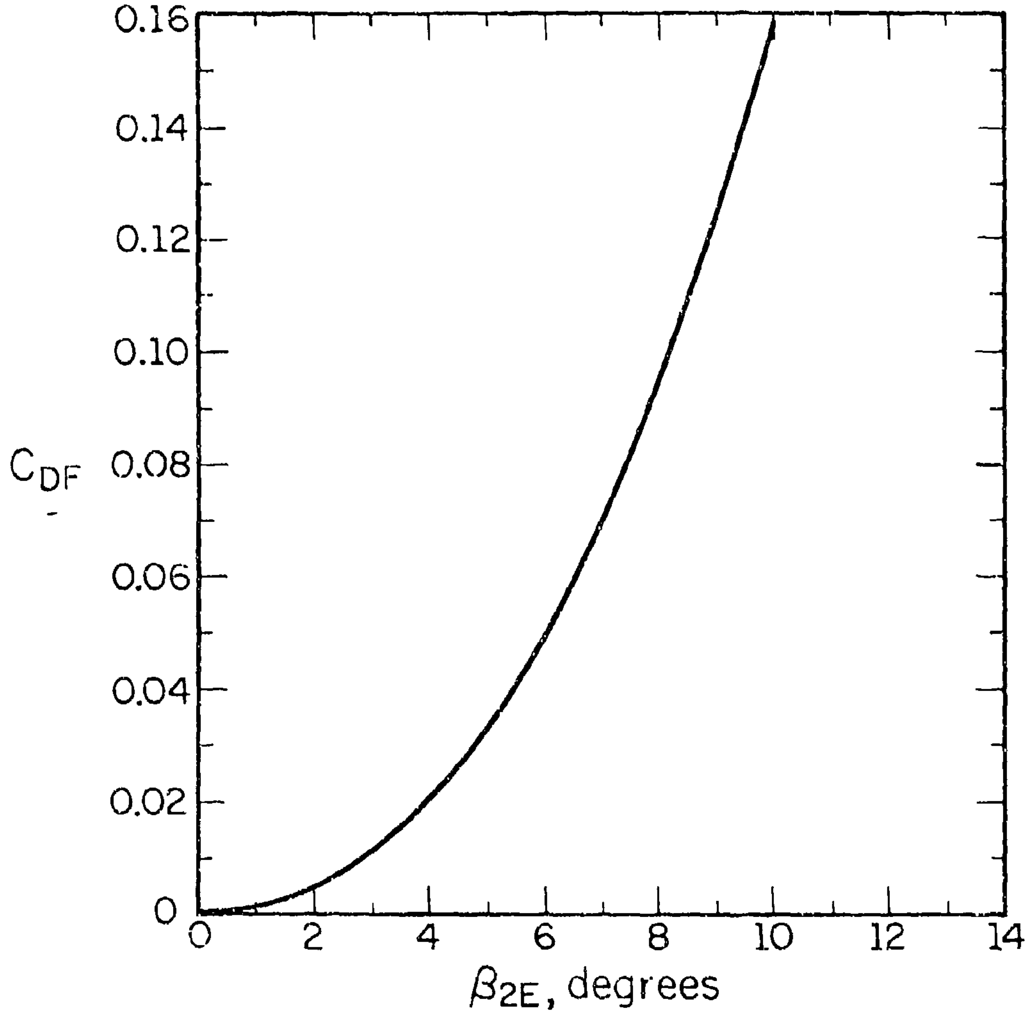
(e) Variations in the combined boattail-base drag coefficient for several tangent ogive boattails

Figure 6 continued



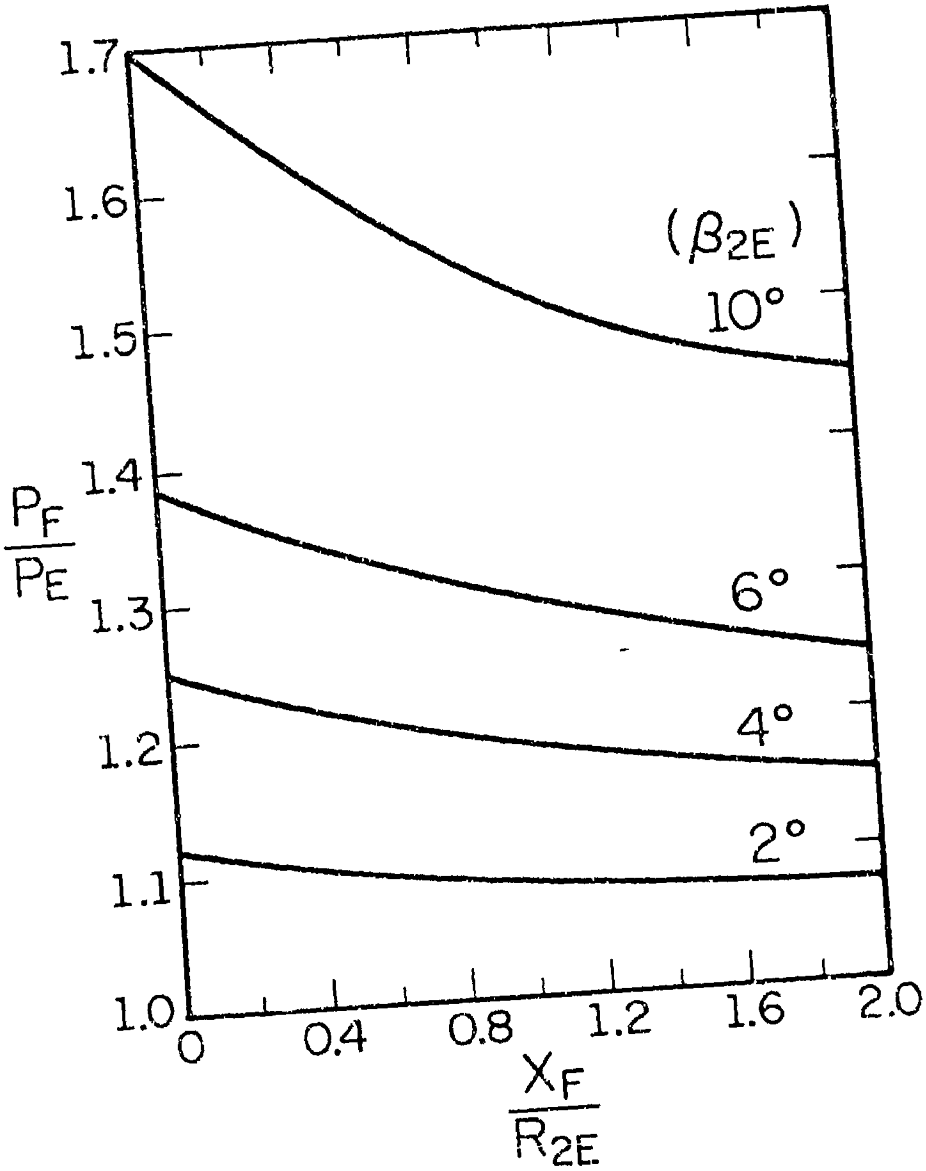
(f) Variations in the combined tangent-ogive boattail-base drag coefficients for several pressure ratios

Figure 6 continued



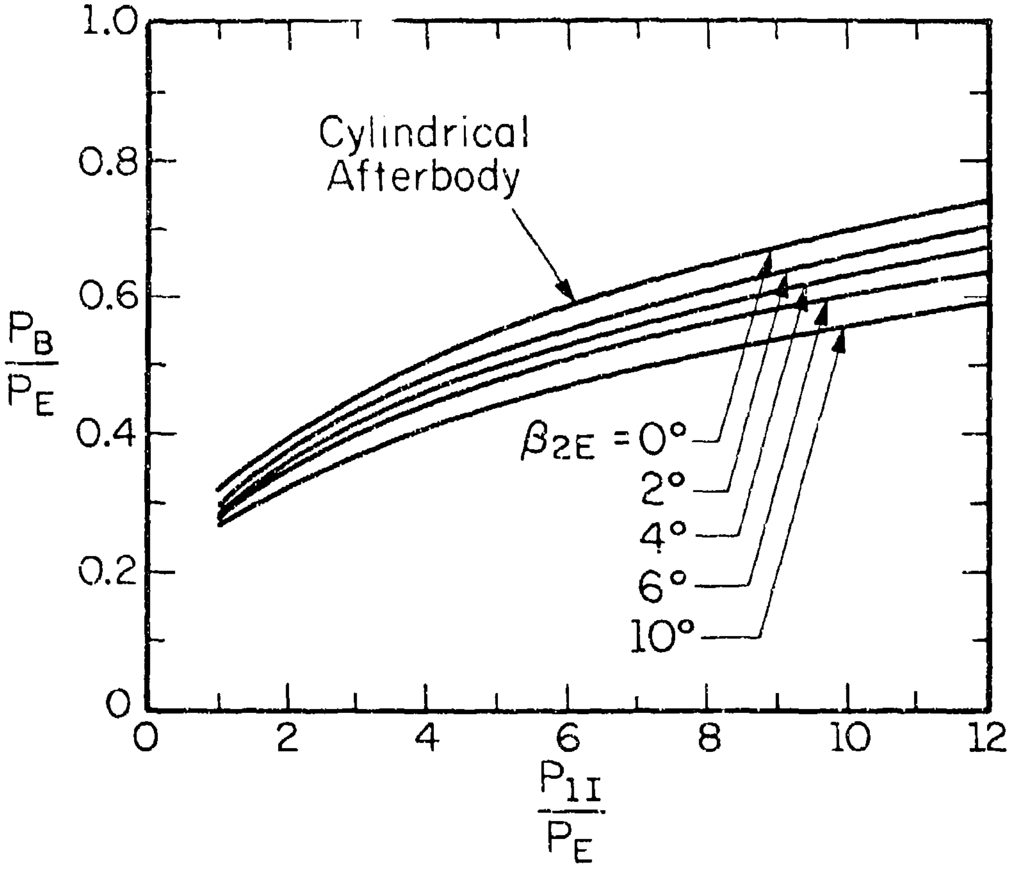
(a) Inviscid conical-flare drag coefficients (approximate analysis)

Figure 7 Conical-flare configurations



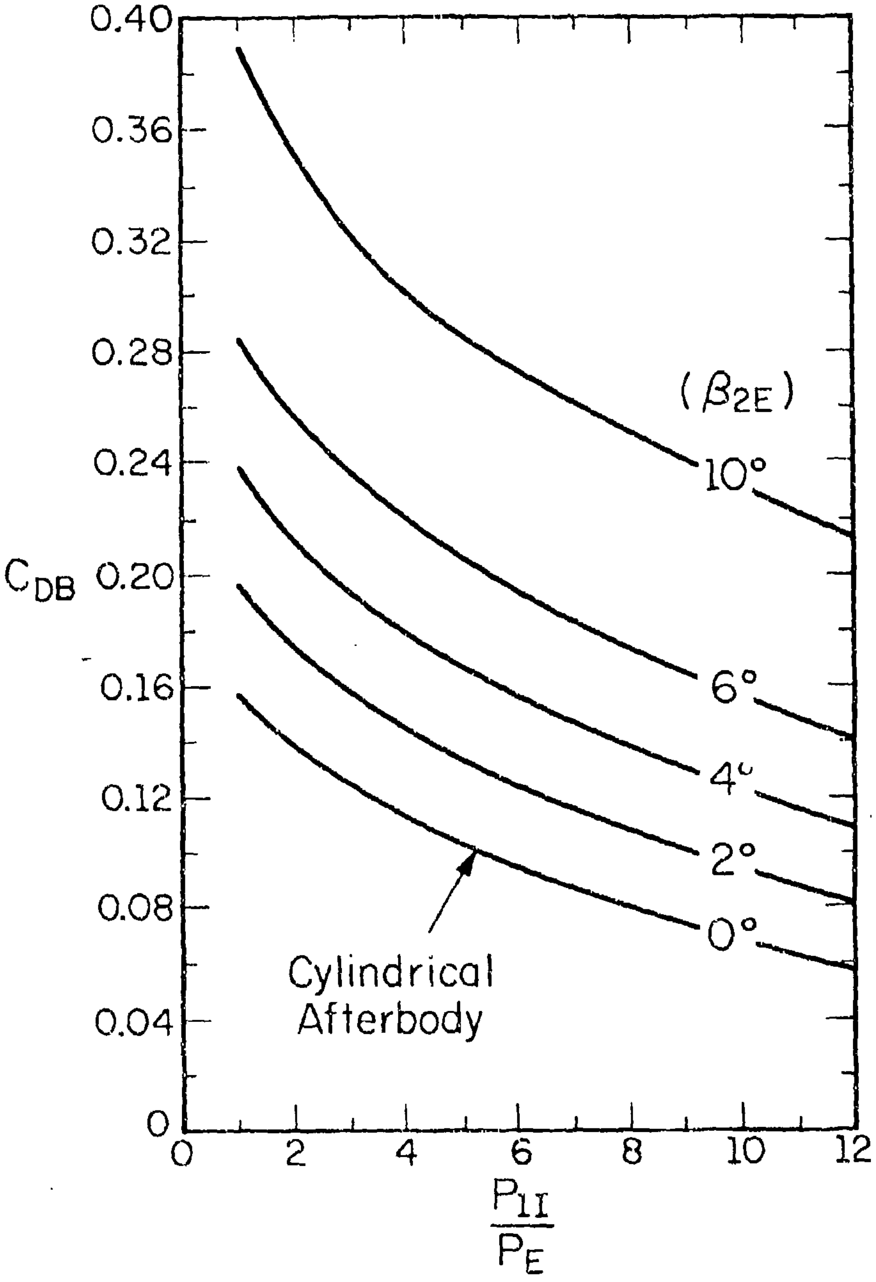
(b) Conical-flare pressure distributions (approximate analysis)

Figure 7 continued



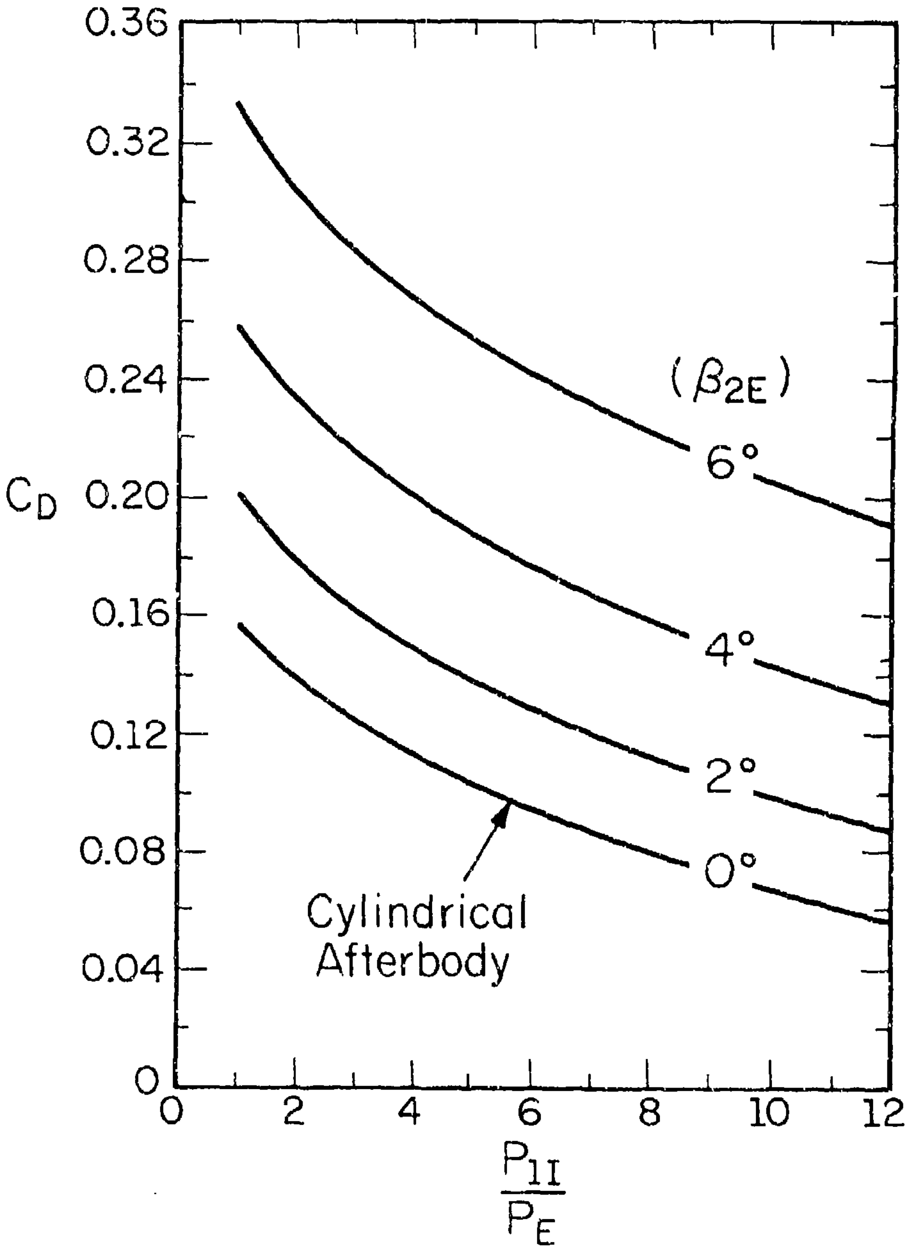
(c) Base-pressure ratio variations for several conical-flare angles

Figure 7 continued



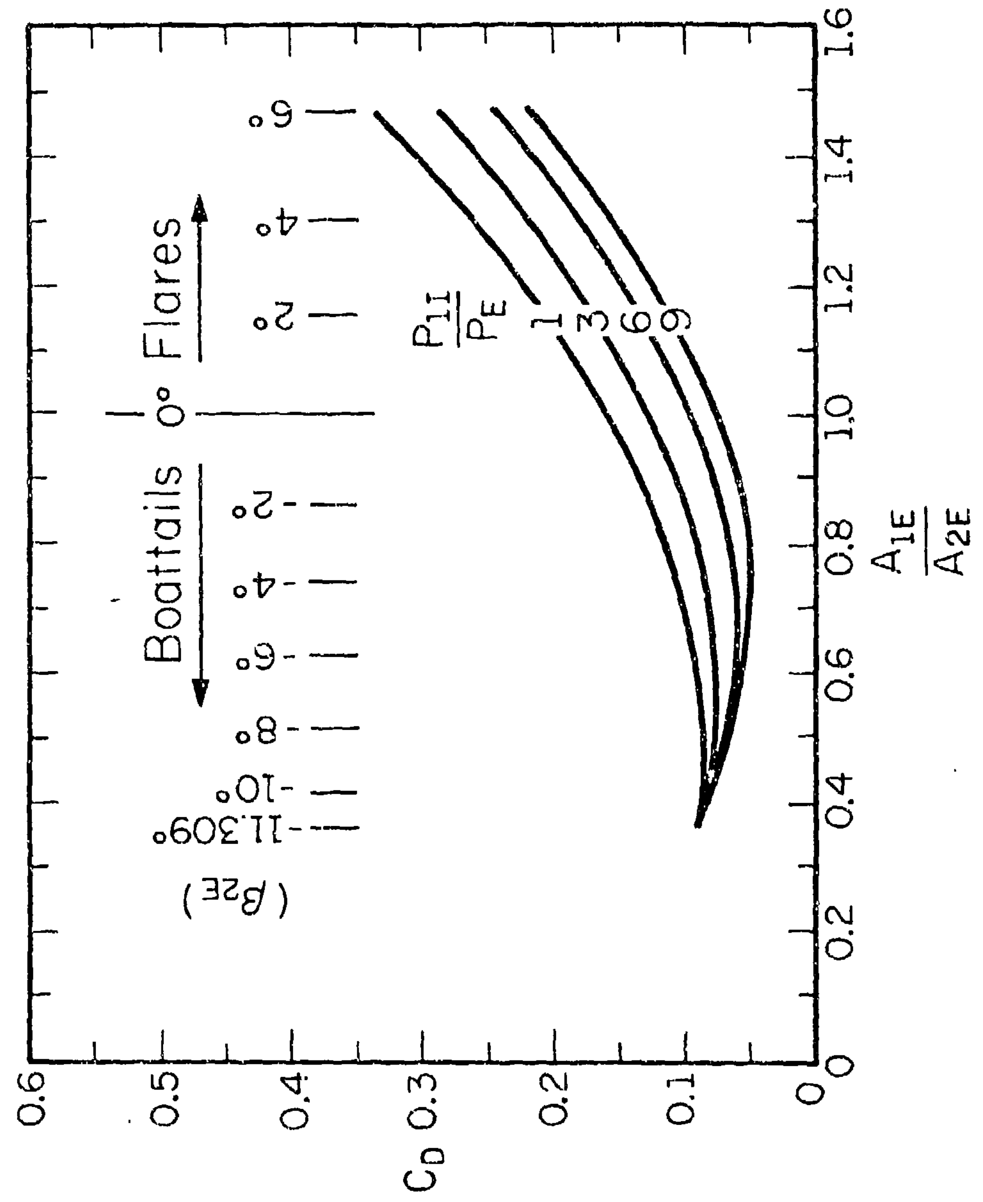
(d) Base drag coefficients for several conical-flare angles

Figure 7 continued



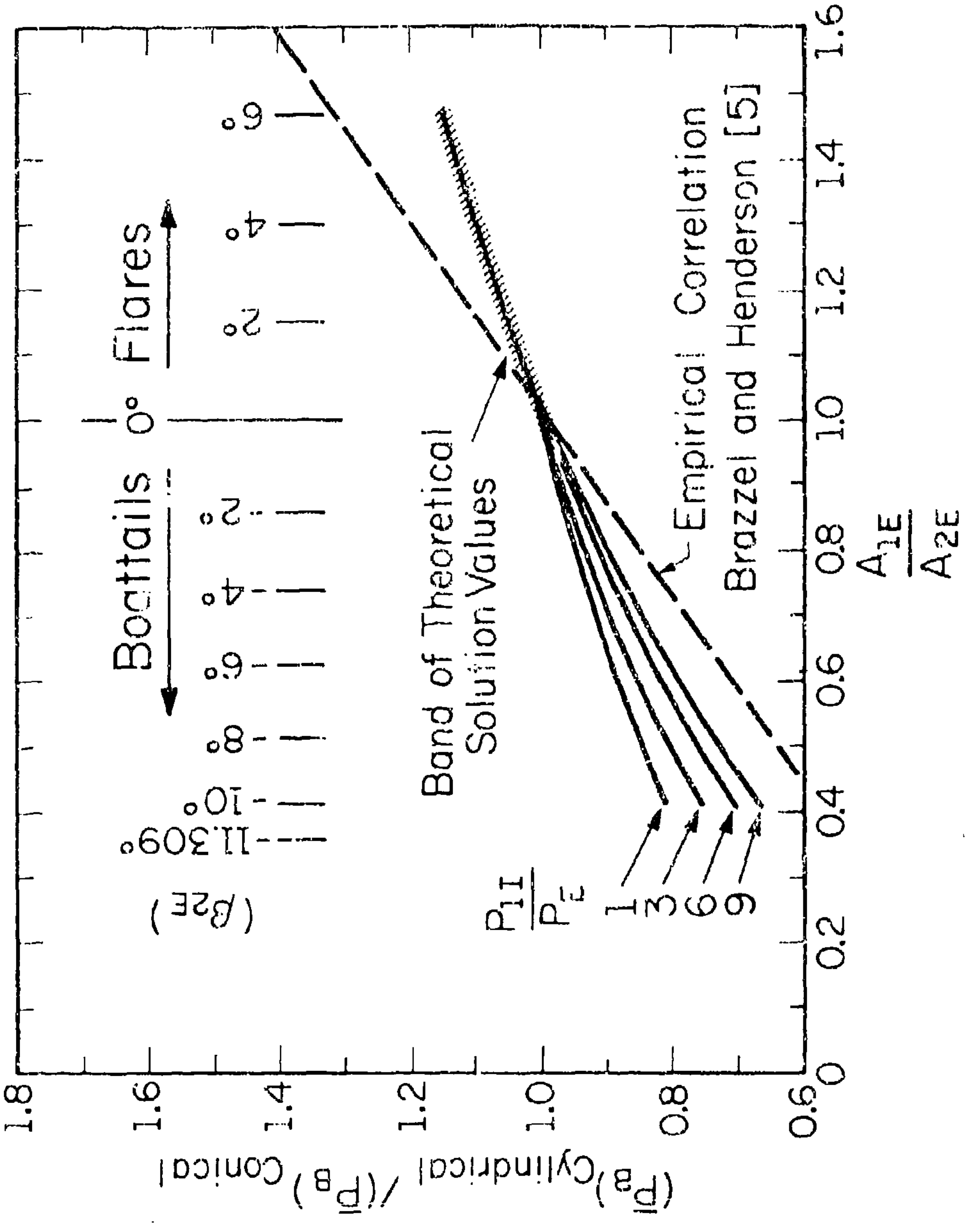
(e) Variation of the combined conical flare-base drag coefficient for several conical-flare angles

Figure 7 continued



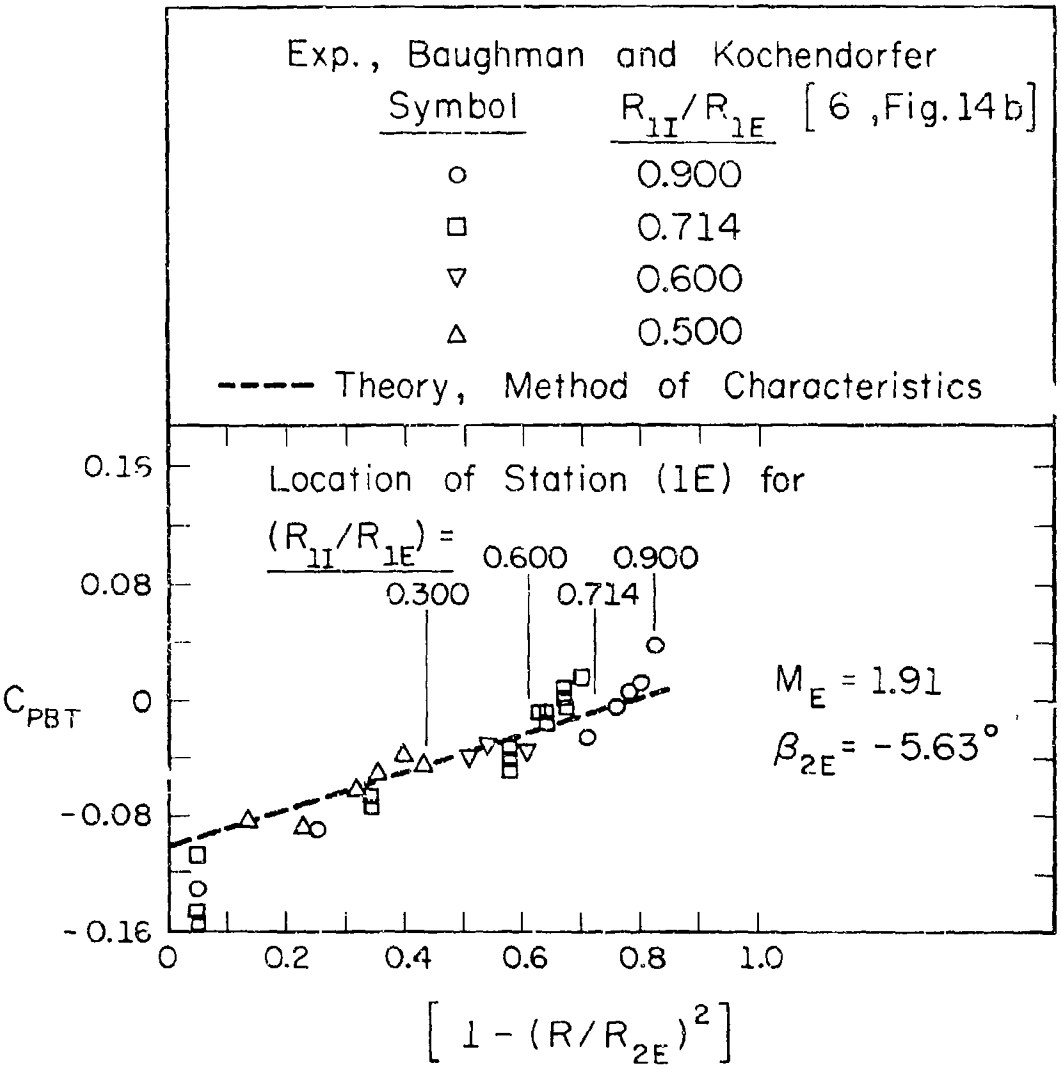
(a) Theoretical combined afterbody-base drag coefficient variation for conical afterbodies as a function of base-to-body area ratio

Figure 8. Conical-afterbody configurations



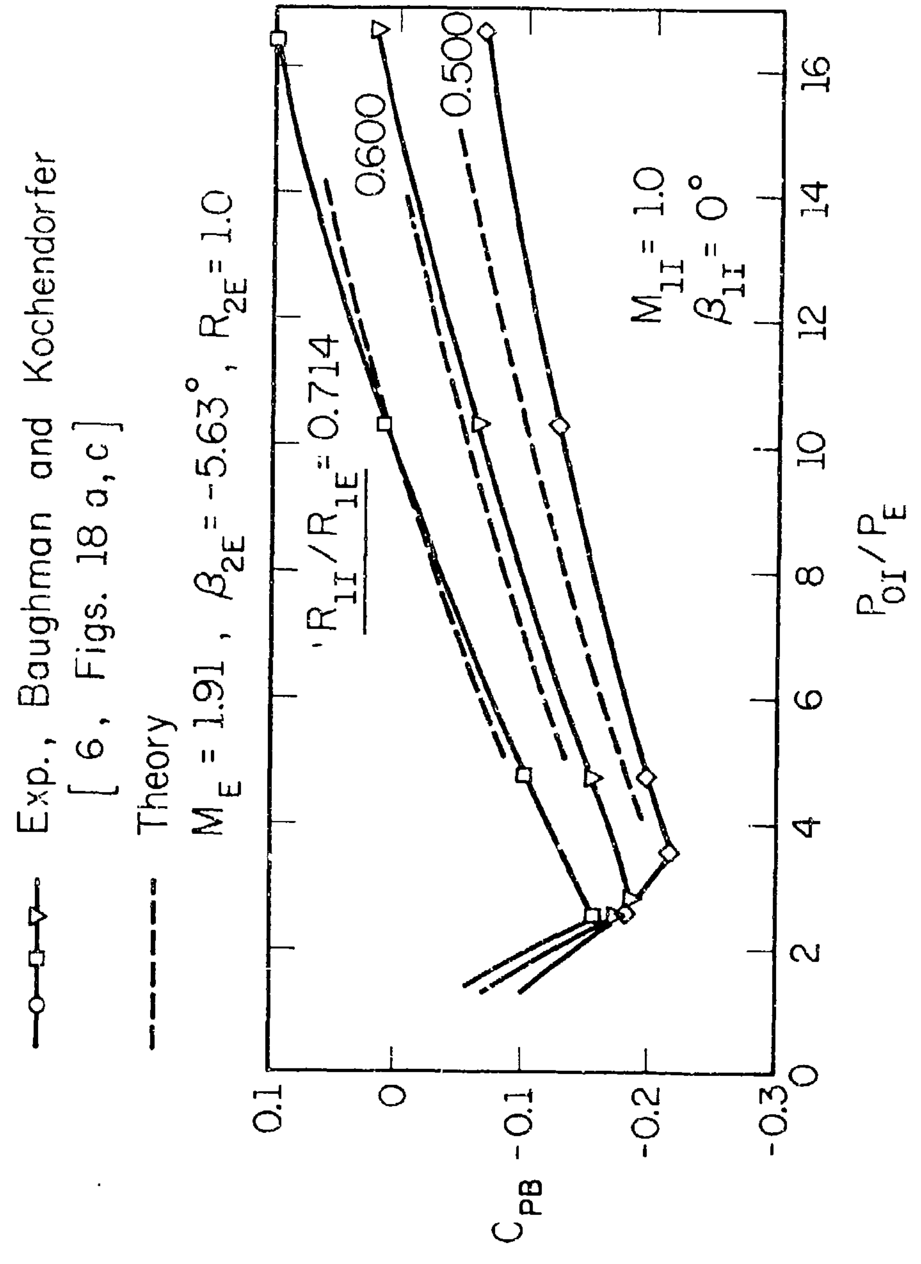
(b) Theoretical cylindrical-to-conical afterbody base-pressure ratio as a function of the base-to-body area ratio and a comparison with an empirical correlation

Figure 8 continued



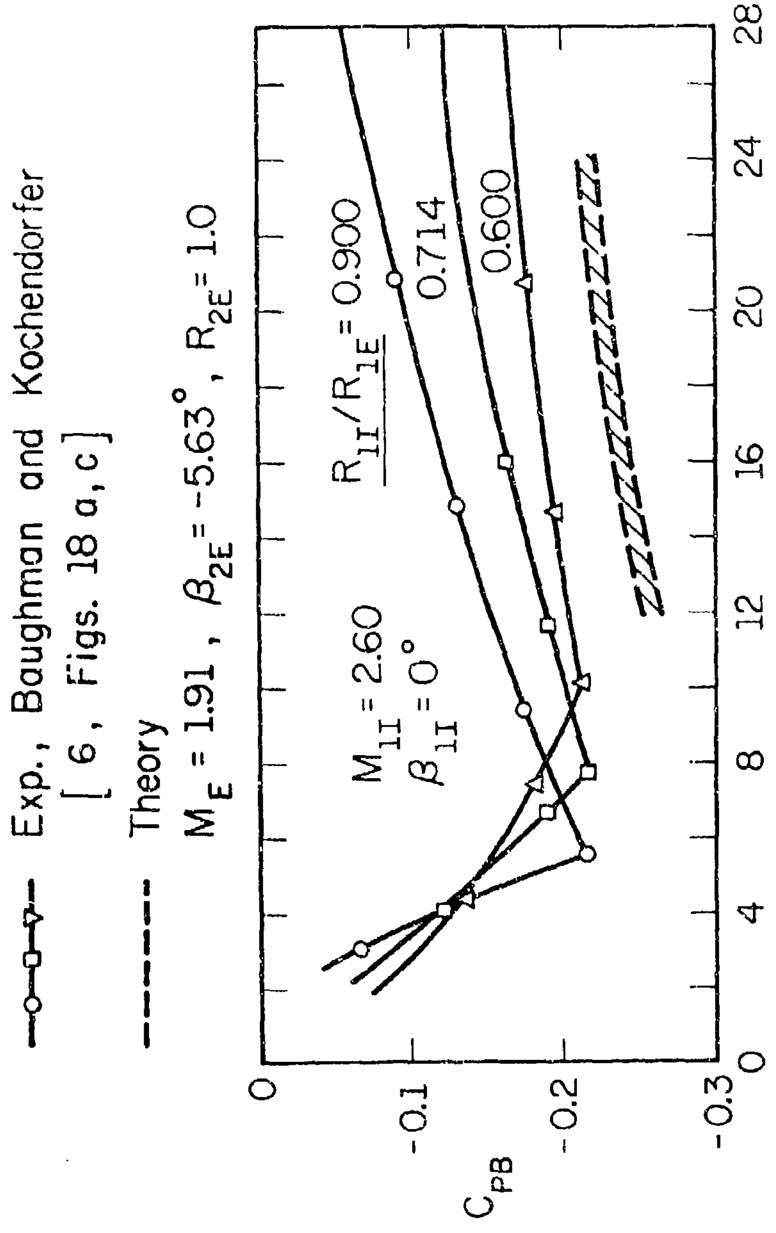
(a) Conical-boattail pressure coefficient

Figure 9 Comparison with the experiments of Baughman and Kochendorfer [6]



(b) Base pressure coefficient versus stagnation-to-freestream pressure ratio for several conical-boattail configurations ($M_E = 1.91$, $\beta_{2E} = -5.63°$, $M_{1I} = 1.0$)

Figure 9 continued



(c) Base pressure coefficient versus stagnation-to-freestream pressure ratio for several conical-boat-tail configurations ($M_E = 1.91$, $\beta_{2E} = -5.63°$, $M_{1I} = 2.60$)

Figure 9 continued

```
C     T W O - S T R E A M   A X I S Y M M E T R I C   B A S E
C     P R E S S U R E   P R O G R A M ,   T S A B P P  - 2 .
C     A F T E R B O D Y   O P T I O N A L   B E F O R E
C     E X T E R N A L   S T R E A M   S E P A R A T I O N   P O I N T .
C     ( 1 9 6 9 ,   F O R T R A N   I V )
C
C*****THIS PROGRAM IS BASED ON THE FLOW MODEL OF KORST, ET. AL.,
C     REFERENCE --- UNIVERSITY OF ILLINOIS REPORT NO. ME 392-5.
C
C*****WRITTEN BY --- A. L. ADDY, UNIVERSITY OF ILLINOIS.
C
C*****PROGRAM REFERENCES--- U.S. ARMY MISSILE COMMAND, REDSTONE ARSENAL,
C                          ALABAMA,  REPORTS NO. RD-TR-69-12,-13,-14.
C
C*****CONFIGURATION --- UNIFORM OR CONICAL SUPERSONIC INTERNAL (NOZZLE)
C                       FLOW AND UNIFORM SUPERSONIC EXTERNAL FLOW WITH
C                       OR WITHOUT AN AFTERBODY PRECEDING THE
C                       SEPARATION POINT.  AFTERBODIES---
C                            1)  OGIVE, PARABOLIC, AND CONICAL
C                                BOATTAILS.  (BETA2E .LT. 0.0)
C                            2)  APPROXIMATE ANALYSIS OF FLARES.
C                                (BETA2E .GT. 0.0)
C
C*****INPUT DATA  ---  SEE INOUT.
C     OUTPUT DATA ---  SEE INOUT, OUT1M,OUT2M, OUTBDY, AND CROSS.
C     INPUT/OUTPUT OPTIONS  ---  SEE INOUT.
C
C*****NOTE REGARDING I/O UNITS---
C                       UNIT = 5,  READ
C                       UNIT = 6,  PRINT
C                       UNIT = 7,  PUNCH
C
C*****MASTER REQUIRES --- INOUT, OUT1M, OUT2M, ACPBS, CROSS, TJMIX,
C                         ITER.  THE VARIOUS SUBROUTINES CALL OTHERS.
C
C
      DIMENSION PMB(100,5,2), CHARI(5,30), CHARE(5,30), P1(5), P2(5),
     1          P3(5), A(20), DATA(10,2), BPTI(5,30), BPTE(5,30)
      COMMON PMB, CHARI, CHARE, P1, P2, P3
      COMMON  /ERFVP/ PHI(350)
      COMMON  /DATAIO/  GCI,GAMMAI,EMS1I,X1I,R1I,BETA1I,
     1                  GCE,GAMMAE,EMS1E,X1 ,R1E,BETA1E,PRO1OE,
     2                  TROEI,PR1IE,RECOMP,A,EMN1I,PR1OI,EMN1E,PR1O1E,
     3                  NPRINT,NCAS1,NCASE,BLDRO,ENGRO,RE,EMNE,PREOE,
     4                  NPUNCH,PROEOI,PROIE,PO1EOI,NSHAPE,NPTSE,PR1I1E
C
      NCASE=0
    8 NCAS1=0
   10 IF(NCAS1.EQ.NCASE) NCAS1=0
C*****READ/WRITE BASE PRESSURE CASE INPUT DATA.
      CALL  INOUT
      IF(NCASE.EQ.0)  GO TO 8
C*****LIMITING RADII FOR (I) AND (E) STREAMS ARE SPECIFIED HERE.
      RLI=1.5*R1E
      RLE=0.5*R1I
C*****INITIALIZATION OF BASE PRESSURE I ERATION LOOP.
      DTRBOI=(1.0-TROEI)/2.0
      BPR=0.50
      BPRL=0.0
C*****EMPIRICAL SEPARATION PRESSURE RATIO EXPRESSION FROM---
C     ZUKOSKI, AIAA JOURNAL, OCTOBER 1967, VOL. 5, NO. 10, PP.1746-1753.
C     PRSEP = 1.0 + 0.365*(MACH NO.).
C*****EXTERNAL/INTERNAL FLOWS SEPARATION PRESSURE RATIOS.
```

```
      PRS1E = 1.0 + 0.365*EMN1E
      PRS1I = 1.0 + 0.365*EMN1I
      BPRR = PRS1E
      IF (((PRS1I/PRS1E)*PR1I1E) .LT. 1.0)   BPRR = PRS1I*PR1I1E
      NOSOLN=0
      NOSMAX = 10
      IBPR=1
      IBPRMX=15
      NBPR=1
      NTYPE=1
      IF(ABS (TROEI-1.0).LE.1.0E-03)  NTYPE=3
   20 IF (IBPR .LE. IBPRMX)    GO TO 40
C
      WRITE (6,22)             BPRL, BPR, BPRR
   22 FORMAT (//, 15X,
     1 53H ***MAXIMUM NO. OF BASE PRESS. ITERATIONS EXCEEDED*** ,/,
     2 15X,10H ***BPRL = ,F7.4,2X,7H BPR = ,F7.4,2X,
     3 7H BPRR = ,F7.4,4H ***,/  )
C
      IF((ABS(BPR-BPRR).LE.1.0E-3).OR.(BPR.GT.BPRR))  WRITE(6,24)
   24 FORMAT (15X,33H *** PROBABLE FLOW SEPARATION FOR    ,
     1          20H SPECIFIED DATA  ***   ,/)
C
      WRITE  (6,26)
   26 FORMAT (15X,
     1          53H ************************************************** /)
      GO TO 260
C
C*****CHECK THAT BPR IS IN THE SOLUTION RANGE, (BPRL,BPRR).
   40 IF ((BPR .GE. BPRL) .AND. (BPR .LE. BPRR))   GO TO 50
      BPR=(BPRL+BPRR)/2.0
C*****CALCULATE THE EXPANSION PRESSURE RATIOS FOR THE BOUNDARY CALCS.
   50 PRB1E = BPR
      PRB01E = BPR*PR101E
      PRB0I=PRB01E*P01E0I
      PRB1I=PRB0I/PR10I
      PRBE=(PRB01E*PR010E)/PRE0E
      PRB0E=PRB01E*PR010E
      CP=2.0*((PRBE-1.0)/(GAMMAE*(EMNL**2)))
      CD = -CP*((R1E**2-R1I**2)/RE**2)
C*****WRITE THE CURRENT TRIAL SOLUTION DATA.
      CALL OUTIM(IBPR,A,EMN1I,PR10I,PRB0I,PRB1I,PR0E0I,TROEI,PR1IE,
     1             EMN1E,PR101E,PRB01E,PRB1E,EMNE,PRE0E,PRB0E,PR01E,
     2             PRBE,NPRINT,BLDRO,ENGRO,NSHAPE)
C*****THE INTERNAL CONSTANT PRESSURE BNDRY IS CALCULATED FOR (PB/P0I).
   70 CALL ACPBS(GAMMAI,EMS1I,PRB0I,X1I,R1I,BETA1I,RLI,IBPR,NPTSI,
     1             NPRINT,1,LIMITI,BPTI,NSHAPE)
C*****THE EXTERNAL CONSTANT PRESSURE BNDRY IS CALCULATED FOR (PB/P01E).
   80 CALL ACPBS(GAMMAE,EMS1E,PRB01E,X1E,R1E,BETA1E,RLE,IBPR,NPTSE,
     1             NPRINT,2,LIMITE,BPTE,NSHAPE)
C*****IF IMPINGEMENT OCCURS, THE IMPINGEMENT POINT AND THE FLOW
C     PROPERTIES DOWNSTREAM OF THE RECOMPRESSION SHOCK SYSTEM ARE FOUND.
C
      CALL  CROSS(GAMMAI,BPTI,LIMITI,GAMMAE,BPTE,LIMITE,
     1              NIC,NEC,NSTOP,TJMLI,TJMLE,PRSHOK,NPRINT)
      IF(RECOMP*PRSHOK .LT. 1.0 .AND. NSTOP .EQ. 1)  NSTOP=2
      GO TO (90,82,84), NSTOP
C*****NO INVISCID SOLUTION TRIAL CASES.
C     NUMBER OF NO SOLUTION TRIALS = NOSMAX.
C*****NO SOLUTION---NO IMPINGEMENT OR INADMISSIBLE SHOCK SOLUTION.
   82 BPRR=BPR
      GO TO 86
C*****NO SOLUTION---SHOCK SYSTEM DOESNT EXIST FOR TRIAL VALUE OF BPR.
   84 BPRL=BPR
```

```
   86 BPR=(BPRL+BPRR)/2.
      NOSOLN=NOSOLN+1
      IF(NOSOLN.LE.NOSMAX)  GO TO 20
C*****MAXIMUM NUMBER OF NO-SOLUTION TRIALS EXCEEDED.
C
      WRITE (6,88)
   88 FORMAT(//,
     1 15X,49H ***MAXIMUM NO. OF NO SOLUTION TRIALS EXCEEDED** ,/,
     2 15X,49H *********************************************** /)
      GO TO 260
C
C*****START BASE PRESSURE AND TEMPERATURE RATIO ITERATION LOOPS.
   90 TRBOI=TROEI
      IE=1
      NE=1
  100 TRBOE=TRBOI/TROEI
C*****CALCULATION AND OUTPUT OF TURBULENT MIXING RESULTS.
      CALL  TJMIX(GAMMAI,GCI,BPTI(3,NIC),TRBOI,TJMLI,
     1             GAMMAE,GCE,BPTE(3,NEC),TRBOE,TJMLE,
     2             R1I,EMS1I,BETA1I,BPTI(2,NIC),PRSHOK,
     3             PO1EOI,TROEI,RECOMP,BLDR,ENGR)
      CALL OUT2M(PRBE,PRB1I,PROEOI,TRBOE,TRBOI,TROEI,PROIE ,PR1IE,
     1           BLDR,ENGR,NPRINT,CP,CD,BLDRO,ENGRO)
C*****SET-UP ITERATION LOOPS TO FIND---
C     NTYPE=1 (NONISOENERGETIC), TRBOI SO THAT ENGR=ENGRO.
C     NTYPE=2 (NONISOENERGETIC), TRBOI SO THAT BLDR=BLDRO.
C     NTYPE=3 (ISOENEGETIC), CONTINUE TO BASE PRESSURE ITERATION LOOP
C                          TO FIND BPR SO THAT BLDR=BLDRO.
C
      GO TO (124,126,210), NTYPE
C*****TRBOI ITERATION LOOPS FOR THE NON-ISOENERGETIC CASE.
  124 VAR=(ENGR-ENGRO)
      GO TO 130
  126 VAR=(BLDR-BLDRO)
  130 GO TO (140,142), NE
  140 DATA(IE,1)=TRBOI
      DATA(IE,2)=VAR
C*****ITERATION FOR TRBOI SUCH THAT ENGR=ENGRO OR BLDR=BLDRO.
C     (NOTE THAT TRBOI IS RESTRICTED TO THE RANGE (TROEI,1.0)   )
C
  142 CALL ITER(TRBOI,DTRBOI,1.0E-4,1.0,VAR,0.0, 1.0E-5,IE,NE,
     1          TRBOIN,VARN,TRBOIP,VARP,NSGNV1,NSGNV2)
      IF(TRBOI-1.0)150,150,160
  150 GO TO (100,100,200), NE
C*****EXTRAPOLATION, IF NECESSARY, FOR TEMPERATURE RATIO TRBOI
C     SUCH THAT ENGR=ENGRO OR BLDR=BLDRO.
C
  160 IE=IE-1
      IF(ABS (DATA(1,2))-ABS (DATA(IE,2)))  170,170,180
  170 I=1
      II=2
      GO TO 190
  180 I=IE-1
      II=IE
  190 RATIO=(DATA(II,1)-DATA(I,1))/(DATA(II,2)-DATA(I,2))
      TRBOI=DATA(I,1)-RATIO*DATA(I,2)
  200 GO TO (202,204), NTYPE
  202 TREO=TRBOI
      NTYPE=2
      GO TO 90
  204 TRBO=TRBOI
      NTYPE=1
C*****END TRBOI ITERATION LOOPS.
C*****CONTINUE THE BASE PRESSURE RATIO (BPR) ITERATION LOOP TO FIND
```

```
C      BPR SUCH THAT DVAR=0.
C*****FOR THE NON-ISOENERGETIC CASE.
       DVAR=(TRED-TRBO)
       GO TO 214
C*****FOR THE ISOENERGETIC CASE.
  210  DVAR=(BLDRO-BLDR)
  214  SIGN=DVAR/ABS(DVAR)
       IF(SIGN)  218,218,222
  218  BPRR=BPR
       GO TO 226
  222  BPRL=BPR
  226  IF(IBPR-1)  230,230,234
  230  DBPR=(BPRR-BPRL)/2.
       GO TO 238
  234  SIGN=1.0
       DBPR=-((BPR-BPR1)/(DVAR-DVAR1))*DVAR
  238  BPR1=BPR
       DVAR1=DVAR
C*****ITERATION FOR BPR SUCH THAT DVAR=0.
       CALL ITER(BPR,DBPR,1.0E-4,SIGN,DVAR,0.0,1.0E-5,IBPR,NBPR,
     1              BPRN,DVARN,BPRP,DVARP,NSGNB1,NSGNB2)
       GO TO (20 ,20 ,242), NBPR
C*****SOLUTION FOUND.
  242  GO TO (250,250,254), NTYPE
C*****WRITE SOLUTION DATA.
C
  250  WRITE (6,252)
  252  FORMAT(//, 20X, 32H ***NON-ISOENERGETIC SOLUTION*** ,/,
     1              20X, 32H ******************************** ,//)
       GO TO 258
C
  254  WRITE (6,256)
  256  FORMAT(//,  27X, 28H ***ISOENERGETIC SOLUTION*** ,/
     1               27X, 28H ****************************    /)
C
  258  CALL OUT2M(PRBE,PRB1I,PROEOI,TRBOE,TRBOI,TROEI,PROIE ,PR1IE,
     1              BLDR,ENGR,1,CP,CD,BLDRO,ENGRO)
       IF(NPUNCH) 10,10,270
C*****PUNCH SOLUTION DATA.
  260  IF(NPUNCH) 10,10,265
C
  265  WRITE (7,267)             PROIE, PR1IE, PRBE
  267  FORMAT(2F11.4,5X,11HNO SOLUTION, 5X, 9H PB/PE  = F8.5)
       GO TO 280
C
  270  R1IE=R1I/RE
C*****CT---I/QA (THRUST COEFFICIENT).
       CT = ((R1IE**2)/(0.5*GAMMAE*(EMN E**2)))*(PR1IE*(1.0+GAMMAI*
     1      (EMN1I**2))-1.0)
C*****RMF---JET-TO-FREESTREAM MOMENTUM FLUX RATIO.
       RMF = (GAMMAI*(EMN1I**2)*(R1IE**2)*PR1IE)/(GAMMAE*(EMNE**2))
C
       WRITE (7,272)             PROIE,PR1IE,PRBE,CP,CD,RMF,CT
  272  FORMAT(2F11.4,5F11.5)
C
  280  IF (NCAS1 .EQ. NCASE) WRITE (7,282) (A(I),I=1,20)
  282  FORMAT (    20A4,/,80H++++++++++++++++++++++++++++++++++++++++++++++++
     1++++++++++++++++++++++++++++++++)
C
C*****GO TO NEXT CASE.
       GO TO 10
       END
```

```
      SUBROUTINE INOUT                                                  INOU  10
C                                                                       INOU  20
C*****SUBROUTINE READS IN THE INPUT DATA AND THEN CALCULATES THE INPUT  INOU  30
C     DATA FOR THE MASTER PROGRAM.  THE IDENTIFICATION, HEADINGS AND    INOU  40
C     INPUT DATA ARE THEN WRITTEN OUT.                                  INOU  50
C                                                                       INOU  60
C                                                                       INOU  70
C     ***VARIABLES***                                                   INOU  80
C                                                                       INOU  90
C                                                                       INOU 100
C     FOR EITHER THE INTERNAL  (I)  OR EXTERNAL  (E)  STREAM            INOU 110
C                                                                       INOU 120
C     BETD1   = FLOW ANGLE (IN DEGREES) AT (X1,R1).  CCW IS POSTIVE.    INOU 130
C               ( BETD1I IS (+) AND BETD1E IS (-) )                     INOU 140
C     BETD2E  = INITIAL BOATTAIL ANGLE AT (X2E,R2E).                    INOU 150
C     BLDRO   = SPECIFIED VALUE OF THE BLEED RATIO.                     INOU 160
C     ENGRO   = SPECIFIED VALUE OF THE ENERGY RATIO.                    INOU 170
C     EMNE    = EXTERNAL FREESTREAM MACH NUMBER.                        INOU 180
C     EMS1I   = MACH STAR AT  (1I).                                     INOU 190
C     GAMMA   = RATIO OF SPECIFIC HEATS.                                INOU 200
C     GC      = GAS CONSTANT    (LBF-FT/LBM-R)                          INOU 210
C     INOPT   = 1, INPUT BY NAMELIST /DATA/ ONLY.  THE DEFAULT          INOU 220
C                   CONFIGURATION SPECIFIED IN INOUT IS AVAILABLE. _    INOU 230
C             = 2, INPUT MUST BE SPECIFIED BY A COMPLETE SET OF DATA    INOU 240
C                   CARDS FOLLOWING THE FIRST CARD--- '&DATA INOPT=2 &END'INOU 250
C             = 3, INPUT SPECIFIED BY NAMELIST /DATA/ FOR CALCULATION   INOU 260
C                   OF INTERNAL-FLOW CONSTANT-PRESSURE BOUNDARIES.      INOU 270
C             = 4, INPUT SPECIFIED BY NAMELIST /DATA/ FOR CALCULATION   INOU 280
C                   OF EXTERNAL FLOW---AFTERBODY ONLY (NCASE=0) AND/OR  INOU 290
C                   CONSTANT-PRESSURE BOUNDARIES.                       INOU 300
C     KPRESR  = 0, PR1IE IS INPUT, AND PROIE IS CALCULATED.             INOU 310
C             = 1, PROIE IS INPUT, AND PR1IE IS CALCULATED.             INOU 320
C     NCASE   = NUMBER OF PRESSURE RATIOS, P1I/PE , FOR WHICH BASE      INOU 330
C               PRESSURE CALCULATIONS ARE TO BE MADE FOR A GIVEN SET OF INOU 340
C               CONDITIONS AND GEOMETRY.                                INOU 350
C     NPUNCH  = 0, SUMMARY OUTPUT DATA NOT PUNCHED.                     INOU 360
C             = 1, SUMMARY OUTPUT DATA PUNCHED.                         INOU 370
C     NPRINT  = -1, INPUT DATA AND BASE PRESSURE SOLN PRINTED.          INOU 380
C             =  0, INPUT DATA, ITERATIONS AND SOLN PRINTED.            INOU 390
C             = +1, INPUT DATA, ITERATION, C.P.B. DATA, AND SOLN PRINTED.INOU 400
C     NSHAPE  = 0, NO BOATTAIL.                                         INOU 410
C             = 1, OGIVE BOATTAIL.                                      INOU 420
C             = 2, PARABOLIC BOATTAIL.                                  INOU 430
C             = 3, CONICAL BOATTAIL.                                    INOU 440
C     PR1IE   = STATIC PRESSURE RATIO OF STREAMS, P1I/PE.               INOU 450
C     PROEOI  = STAGNATION PRESSURE RATIO OF STREAMS, POE/POI.          INOU 460
C     PROIE   = INTERNAL STREAM STAGNATION PRESSURE TO EXTERNAL STREAM  INOU 470
C               STATIC PRESSURE RATIO (NOZZLE CHAMBER TO FREESTREAM     INOU 480
C               STATIC PRESSURE RATIO), POI/PE.                         INOU 490
C     RECOMP  = RECOMPRESSION COEFFICIENT.                              INOU 500
C     NOTE --- IF THE INPUT VALUE OF RECOMP=0.0 .AND.                   INOU 510
C               1) NSHAPE=0, THEN RECOMP IS CALCULATED FROM             INOU 520
C                            EMPIRICAL EQUATION ON CARD NO. INOU2620.   INOU 530
C               2) NSHAPE=1,2,3, THEN RECOMP=1.0 IS CURRENTLY USED.     INOU 540
C     TROEI   = STAGNATION TEMPERATURE RATIO OF STREAMS, TOE/TOI.       INOU 550
C     X1,R1   = COORDINATES OF POINT WHERE SEPARATION OCCURS.           INOU 560
C               (R1'S ARE POSITIVE)                                     INOU 570
C     X2E,R2E = INITIAL COORDINATES OF THE BOATTAIL.                    INOU 580
C                                                                       INOU 590
C                                                                       INOU 600
C     ***PRESSURE RATIO NOTATION***                                     INOU 610
C                                                                       INOU 620
C                                                                       INOU 630
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C       PRIOI  = PII/POI,    PRIIE  = PII/PE,    PROIE  = POI/PE,          INOU 640
C       PRIIIE = PII/PIE,    POIEOI = POIE/POI,  PRIOIE = PIE/POIE,        INOU 650
C       PROIOE = POII/POE,   PREOE  = PE/POE,    PROEOI = POE/POI,         INOU 660
C       PRBIE  = PB/PIE,     PRBOIE = PB/POIE,   PRBII  = PB/PII,          INOU 670
C       PRBOI  = PB/POI,     PRBE   = PB/PE,     PRIEE  = PIE/PE.          INOU 680
C                                                                          INOU 690
C                                                                          INOU 700
C       ***PROGRAM INPUT***                                                INOU 710
C                                                                          INOU 720
C                                                                          INOU 730
C*****COMPLETE INPUT DATA FOR DEFAULT OPTION (INOPT=1).                    INOU 740
C                                                                          INOU 750
C        &DATA  A='...',XII=,RII=,BETDII=,GCI=,GAMMAI=,EMNII=,TROEI=,      INOU 760
C        RECOMP=,NSHAPE=,X2E=,R2E=,BETD2E=,XIE=,RIE=.GCE=,GAMMAE=,EMNE=,   INOU 770
C        INOPT=,NPRINT=,NPUNCH=,KPRESR=,NCASE=,PR=,BRO=,ERO=, &END .       INOU 780
C                                                                          INOU 790
C       IT IS NOT NECESSARY TO SPECIFY ALL OF THE VARIABLES SINCE ALL OR   INOU 800
C       PART OF THE DEFAULT CONFIGURATION CAN BE USED.  HOWEVER, THE       INOU 810
C       FOLLOWING  MINIMUM DATA MUST BE SPECIFIED FOR EACH CONFIGURATION   INOU 820
C       (SEE  TABLES 1,2,3,4,5. REPORT  RD-TR-69-14).                      INOU 830
C                                                                          INOU 840
C       IF NSHAPE=0 (DEFAULT VALUE)                                        INOU 850
C                                                                          INOU 860
C        &DATA  A='...',RII=,EMNII=,EMNE=,NCASE=,PR=-,-,....,  &END        INOU 870
C                                                                          INOU 880
C       IF NSHAPE=1,2,3 (SPECIFIED BELOW)                                  INOU 890
C                                                                          INOU 900
C        &DATA  A='...',RII=,EMNII=,NSHAPE=,BETD2E=,XIE=,RIE=,EMNE=,       INOU 910
C        NCASE=,PR=-,-,....,  &END                                         INOU 920
C                                                                          INOU 930
C*****INPUT DATA AND FORMATS FOR OPTION 2 (INOPT=2).                       INOU 940
C                                                                          INOU 950
C       **CARD 1**      &DATA INOPT=2, +END                                INOU 960
C       **CARD 2**    ANY ALPHANUMERIC HEADING IN COLUMNS 1 TO 80.         INOU 970
C       **CARD 3**    XII, RII, BETDII, GCI, GAMMAI, EMNII,                INOU 980
C                     NSHAPE                               (6F10.6,I1)     INOU 990
C       IF NSHAPE = 0, CARD NO. 4 IS--                                     INOU1000
C       **CARD 4**    XIE, RIE, GCE, GAMMAE, EMNE          (5F10.6)        INOU1010
C                                                                          INOU1020
C       IF NSHAPE = 1,2, OR 3, CARD NO. 4 IS--                             INOU1030
C       **CARD 4**    X2E, R2E, BETD2E, XIE, RIE, GCE,                     INOU1040
C                     GAMMAE, EMNE                         (8F10.6)        INOU1050
C                                                                          INOU1060
C       **CARD 5**    TROEI, RECOMP                                        INOU1070
C       **CARD 6**    NPRINT, NCASE, NPUNCH, KPRESR        (I2,I3,2I1)     INOU1080
C                                                                          INOU1090
C       IF KPRESR = 0, CARD NO. 7 AND FOLLOWING ARE--                      INOU1100
C       **CARD 7 AND FOLLOWING**   PRIIE, BEDRO, ENGRO     (3F10.6)        INOU1110
C                                                                          INOU1120
C       IF KPRESR = 1, CARD NO. 7 AND FOLLOWING ARE--                      INOU1130
C       **CARD 7 AND FOLLOWING**   PROIE, BEDRO, ENGRO     (3F10.6)        INOU1140
C                                                                          INOU1150
C       NOTE THAT THERE ARE (6+NCASE) DATA CARDS PER CASE.                 INOU1160
C                                                                          INOU1170
C*****INPUT FOR INTERNAL-FLOW CONSTANT-PRESSURE BOUNDARIES (INOPT=3)       INOU1180
C                                                                          INOU1190
C        &DATA A='...',INOPT=3,EMNII=,BETDII=,RII=,NCASE=,PR=-,-,....,     INOU1200
C        GAMMAI ,  &END                                                    INOU1210
C                                                                          INOU1220
C*****INPUT FOR EXTERNAL-FLOW AFTERBODY AND/OR CONSTANT-PRESSURE           INOU1230
C       BOUNDARIES (INOPT=4)                                               INOU1240
C                                                                          INOU1250
C        &DATA A='...',INOPT=4,NCASE=,EMNE=,NSHAPE=,BETD2E=,R2E=,XIE=,     INOU1260
C        RIE=,PR=-,-,....,GAMMAE=,  &END                                   INOU1270
```

```
C
C
      EMNMSE(EMS,GAMMA)=SQRT(((2.0+(EMS**2))/(GAMMA+1.0))/
     1                  (1.0-((GAMMA-1.0)/(GAMMA+1.0))*(EMS**2))    )
      EMSMNE(EMN,GAMMA)=SQRT((0.5*(GAMMA+1.0)*(EMN**2))/
     1                  (1.0+0.5*(GAMMA-1.0)*(EMN**2)))
      PRMNE(EMN,GAMMA)=(1.0+((GAMMA-1.0)/2.0)*(EMN**2))**
     1                 (-GAMMA/(GAMMA-1.0))
C
      COMMON PMB, CHARI, CHARE, P1, P2, P3
      COMMON  /DATAIO/  GCI,GAMMAI,EMS1I,X1I,R1I,BETA1I,
     1                  GCE,GAMMAE,EMS1E,X1E,R1E,BETA1E,PRO1OE,
     2                  TROFI,PR1IE,RECOMP,A,EMN1I,PR1OI,EMN1E,PR1O1E,
     3                  NPRINT,NCAS1,NCASE,BLDRO,ENGRO,RE,EMNE,PREOE,
     4                  NPUNCH,PROEOI,PROIE,PO1EOI,NSHAPE,NPTSE,PR1I1E
      DIMENSION PMB(100,5,2), CHARI(5,30), CHARE(5,30), P1(5), P2(5),
     1          P3(5), A(20), PR(20), BRO(20), ERO(20), BPT(5,30)
      NAMELIST /DATA/ A,X1I,R1I,BETD1I,GCI,GAMMAI,EMN1I,NSHAPE,X2E,R2E,
     1                BETD2E,X1E,R1E,GCE,GAMMAE,EMNE,TROFI,RECOMP,INOPT,
     2                NPRINT,NCASE,NPUNCH,KPRESR,PR,BRO,ERO
C
      IF (NCAS1.NE.0) GO TO 80
C*****INITIALIZE THE *DEFAULT CONFIGURATION* DATA.
C*****FOR THE INTERNAL STREAM--
      X1I=0.0
      R1I=1.0
      BETD1I=0.0
      GCI=53.35
      GAMMAI=1.4
      EMN1I=0.0
C*****FOR THE EXTERNAL STREAM--
      NSHAPE=0
      X2E=0.0
      R2E=1.0
      BETD2E=0.0
      X1E=0.0
      R1E=1.0
      BETD1E=0.0
      BETA1E=0.0
      GCE=53.35
      GAMMAE=1.4
      EMNE=0.0
      RECOMP=0.0
      TROFI=1.0
C*****FOR THE BLEED AND ENERGY RATIOS--
      NCASE=0
      DO 8 I=1,20
      BRO(I)=0.0
    8 ERO(I)=0.0
C*****INPUT/OUTPUT OPTIONS--
      INOPT=1
      NPRINT=-1
      NPUNCH=1
C*****INPUT DATA PRESSURE RATIO (POI/PE IS THE DEFAULT VALUE)--
      KPRESR=1
C*****READ INPUT DATA BY NAMELIST /DATA/ .
      READ (5,DATA)
      IF(INOPT.NE.2)  GO TO 44
C*****READ INPUT DATA FOR OPTION 2 (INOPT=2).
      READ (5,10)         (A(I),I=1,20),
     1                    X1I, R1I, BETD1I, GCI, GAMMAI, EMN1I, NSHAPE
   10 FORMAT (20A4,/,6F10.6,I1)
C
      IF(NSHAPE.NE.0)  GO TO 30
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C                                                                       INOU1920
      READ (5,20)         X1E, R1E, GCE, GAMMAE, EMNE                   INOU1930
   20 FORMAT (5F10.6)                                                   INOU1940
      GO TO 40                                                          INOU1950
C                                                                       INOU1960
   30 READ (5,32)         X2E, R2E, BETD2E, X1E, R1E, GCE, GAMMAE, EMNE INOU1970
   32 FORMAT (8F10.6)                                                   INOU1980
C                                                                       INOU1990
   40 READ (5,42)         TROEI, RECOMP, NPRINT, NCASE, NPUNCH, KPRESR  INOU2000
   42 FORMAT (2F10.6,/,I2,I3,2I1)                                       INOU2010
      GO TO 50                                                          INOU2020
C*****CALCULATION OF PROGRAM DATA.                                      INOU2030
   44 IF(INOPT.GT.2)  WRITE (6,46) A                                    INOU2040
   46 FORMAT(1H1, ///////////, 20X, 20A4)                               INOU2050
   50 BETA1I= 0.0174532*BETD1I                                          INOU2060
      EMS1I = EMSMNE(EMN1I,GAMMAI)                                      INOU2070
      PR10I = PRMNE(EMN1I,GAMMAI)                                       INOU2080
      IF(INOPT.NE.3)  GO TO 54                                          INOU2090
C*****CALCULATION OF THE INTERNAL-FLOW CONSTANT-PRESSURE BOUNDARIES.    INOU2100
      DO 52 I=1,NCASE                                                   INOU2110
   52 CALL ACPBS(GAMMAI,EMS1I,PR(I),X1I,R1I,BETA1I,2.0*R1I,I,NPT,+1,1,  INOU2120
     1             LIMIT,BPT,NSHAPE)                                    INOU2130
      NCASE=0                                                           INOU2140
      RETURN                                                            INOU2150
C*****CONTINUATION OF PROGRAM DATA CALCULATION.                         INOU2160
   54 D1I = 2.0*R1I                                                     INOU2170
      D1E = 2.0*R1E                                                     INOU2180
      X1ID1E = X1I/D1E                                                  INOU2190
      EMSE  = EMSMNE(EMNE,GAMMAE)                                       INOU2200
      PREOE = PRMNE(EMNE,GAMMAE)                                        INOU2210
      RIE1 = R1I/R1E                                                    INOU2220
      IF(NSHAPE.NE.0)  GO TO 56                                         INOU2230
C*****UNIFORM EXTERNAL FLOW WITHOUT A BOATTAIL.                         INOU2240
      RE = R1E                                                          INOU2250
      EMN1E = EMNE                                                      INOU2260
      EMS1E = EMSE                                                      INOU2270
      PR101E = PREOE                                                    INOU2280
      PR010E = 1.0                                                      INOU2290
      GO TO 58                                                          INOU2300
C*****AFTERBODY BEFORE THE EXTERNAL STREAM@S SEPARATION POINT.          INOU2310
   56 BETA2E=0.0174532*BETD2E                                           INOU2320
      CALL ABTS(GAMMAE,EMSE,X2E,R2E,BETA2E,X1E,R1E,NSHAPE,              INOU2330
     1             1,NPTSE,NERROR,CDBT)                                 INOU2340
C*****SET-UP DATA FOR EXTERNAL STREAM@S SEPARATION POINT.               INOU2350
      X1E=CHARE(1,1)                                                    INOU2360
      R1E=CHARE(2,1)                                                    INOU2370
      EMS1E = CHARE(3,1)                                                INOU2380
      EMN1E = EMNMSE(EMS1E,GAMMAE)                                      INOU2390
      BETA1E = CHARE(4,1)                                               INOU2400
      BETD1E = 57.2957795*BETA1E                                        INOU2410
      PR101E = PRMNE(EMN1E,GAMMAE)                                      INOU2420
      PR010E=1.0                                                        INOU2430
      RE = R2E                                                          INOU2440
      D2E = 2.0*R2E                                                     INOU2450
      X2ED2E = X2E/D2E                                                  INOU2460
      X1ED2E = X1E/D2E                                                  INOU2470
      DR1E2E = D1E/D2E                                                  INOU2480
   58 IF(INOPT.NE.4)  GO TO 62                                          INOU2490
C*****CALCULATION WITH OR WITHOUT AN AFTERBODY OF THE EXTERNAL-FLOW     INOU2500
C      CONSTANT-PRESSURE BOUNDARIES ONLY.                               INOU2510
C                                                                       INOU2520
      IF(NCASE.EQ.0)  RETURN                                            INOU2530
      DO 60 I=1,NCASE                                                   INOU2540
   60 CALL ACPBS(GAMMAE,EMS1E,PR(I),X1E,R1E,BETA1E,0.25*R1E,I,NPT,+1,   INOU2550
     1             2,LIMIT,BPT,NSHAPE)                                  INOU2560
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      NCASE=0                                                           INOU2570
      RETURN                                                            INOU2580
C*****RECOMPRESSION COEFFICIENT DETERMINATION.                          INOU2590
   62 IF(RECOMP.GT.1.0E-03)  GO TO 66                                   INOU2600
      IF(NSHAPE.NE.0)  GO TO 64                                         INOU2610
C*****FOR CYLINDRICAL AFTERBODIES.                                      INOU2620
      RECOMP = .483 + 1.088*RIE1 - 0.874*RIE1**2 + 0.303*RIE1**3        INOU2630
      GO TO 66                                                          INOU2640
C*****FOR BOATTAILED AFTERBODIES.                                       INOU2650
   64 RECOMP = 1.0                                                      INOU2660
C*****PUNCH OUTPUT HEADINGS AND CASE DATA.                              INOU2670
   66 IF(NPUNCH.EQ.0)  GO TO 80                                         INOU2680
C                                                                       INOU2690
      WRITE (7,68)            A                                         INOU2700
   68 FORMAT(20A4)                                                      INOU2710
C                                                                       INOU2720
      WRITE (7,70)                EMN1I, BETD1I, D1I, GCI, GAMMAI,      INOU2730
     1                            EMNE, BETD1E, D1E, GCE, GAMMAE,       INOU2740
     2                            X1ID1E, RIE1, RECOMP, TROEI           INOU2750
   70 FORMAT (9X,3HM1I,8X,6HBETA1I,9X,3HD1I,10X,3HGCI,9X,6HGAMMAI,/,    INOU2760
     1         F13.3,F13.2,F13.4,F13.2,F13.3,//,                        INOU2770
     2         10X,2HME,8X,6HBETA1E,9X,3HD1E,10X,3HGCE,9X,6HGAMMAE,/,   INOU2780
     3         F13.3, 13.2,F13.4,F13.2,F13.3,//                         INOU2790
     4         7X,7HX1I/D1E,6X,7HD1I/D1E,7X,6HRECOMP,6X,7HTOE/TOI,/,    INOU2800
     5         F13.2,F13.4,1X,2F13.5,// )                               INOU2810
C                                                                       INOU2820
      IF(NSHAPE.EQ.0)  GO TO 74                                         INOU2830
C                                                                       INOU2840
      WRITE (7,72)        NSHAPE, X2ED2E, BETD2E, X1ED2E, DR1E2E, BETD1E INOU2850
   72 FORMAT (5X,17HBOATTAIL - NSHAPE ,4X,7HXLT/D2E ,4X,                INOU2860
     1         7HTHETA2E ,5X,6HXB/D2E ,5X,6HDB/D2E ,5X,                 INOU2870
     2         7HTHETA1E,/,19X,I1,2X,5F11.3,//,                         INOU2880
     3         5X,6HPOI/PE,5X,6HP1I/PE,6X,5HPB/PE,7X,3HCPB,8X,3HCDB,8X, INOU2890
     4         3HRME,8X,2HCT)                                           INOU2900
      GO TO 80                                                          INOU2910
C                                                                       INOU2920
   74 WRITE (7,76)                                                      INOU2930
   76 FORMAT( 4X,7HPOI/P1E,4X,7HP1I/P1E,5X,6HPB/P1E,7X,3HCPB,8X,3HCDB,  INOU2940
     1         8X,3HRME,8X,2HCT)                                        INOU2950
C                                                                       INOU2960
   80 NCASI = NCASI + 1                                                 INOU2970
C*****TRANSFER OR READ NEW CASE DATA.                                   INOU2980
      GO TO (82,84), INOPT                                              INOU2990
   82 PRATIO=PR(NCASI)                                                  INOU3000
      BLDRO=BRO(NCASI)                                                  INOU3010
      ENGRO=ERO(NCASI)                                                  INOU3020
      GO TO 88                                                          INOU3030
C                                                                       INOU3040
   84 READ (5,86)          PRATIO, BLDRO, ENGRO                         INOU3050
   86 FORMAT(3F10.6)                                                    INOU3060
C                                                                       INOU3070
   88 IF(KPRESR.NE.0)  GO TO 90                                         INOU3080
C*****FOR P1I/PE (PR1IE) INPUT.                                         INOU3090
      PR1IE=PRATIO                                                      INOU3100
      PROIE=PR1IE/PR1OI                                                 INOU3110
      GO TO 92                                                          INOU3120
C*****FOR POI/PE (PROIE) INPUT.                                         INOU3130
   90 PROIE=PRATIO                                                      INOU3140
      PR1IE = PROIE*PR1OI                                               INOU3150
C*****CALCULATE VARIOUS PRESSURE RATIOS FROM NEW CASE DATA.             INOU3160
   92 PROEOI=PR1OI/(PREOE*PR1IE)                                        INOU3170
      PO1EOI=PROEOI*PRO1OE                                              INOU3180
      PR1I1E=PR1OI/(PO1EOI*PR1O1E)                                      INOU3190
      PR1EE=PR1O1E*PRO1OE/PREOE                                         INOU3200
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C*****PRINT CASE DATA.                                                  INOU3210
      WRITE  (6,94)            (A(I),I=1,20), NCAS1                     INOU3220
   94 FORMAT(1H1,5X,20A4,20X,15HPROBLEM NUMBER I3,//)                   INOU3230
C                                                                       INOU3240
      IF(NSHAPE.EQ.0)  GO TO 180                                        INOU3250
      GO TO (100,120,140),NSHAPE                                        INOU3260
C                                                                       INOU3270
  100 WRITE (6,110)                                                     INOU3280
  110 FORMAT (29X,21H ***OGIVE BOATTAIL*** //)                          INOU3290
      GO TO 160                                                         INOU3300
C                                                                       INOU3310
  120 WRITE (6,130)                                                     INOU3320
  130 FORMAT (27X,25H ***PARABOLIC BOATTAIL*** //)                      INOU3330
      GO TO 160                                                         INOU3340
C                                                                       INOU3350
  140 WRITE (6,150)                                                     INOU3360
  150 FORMAT (28X,23H ***CONICAL BOATTAIL*** //)                        INOU3370
C                                                                       INOU3380
  160 WRITE (6,170)             X2E, R2E, BETD2E, EMNE, CDBT, P1EE      INOU3390
  170 FORMAT (15X,6H X2E= ,F6.3,7X,6H R2E= ,F6.3,9X,14H BETA2E(DEG)= ,  INOU3400
     1        F7.3,/,15X,8H EMNE = ,F7.4, 4X,8H CDBT = ,F6.3,           INOU3410
     2        7X,9H P1E/PE = F7.5,//)                                   INOU3420
C                                                                       INOU3430
  180 WRITE(6,190) NCAS1,GAMMAI,GCI,X1I,R1I,BETD1I,EMN1I,EMS1I,PR1OI,   INOU3440
     1                      GAMMAE,GCE,X1E,R1E,BETD1E,EMN1E,EMS1E,PR1OIE  INOU3450
  190 FORMAT(10X,41H ****TWO-STREAM BASE PRESSURE PROGRAM**** ,5X,      INOU3460
     1  10H PROB. NO. I4,//,27X,23H ******INPUT DATA******,//,          INOU3470
     2  28X,22H ***INTERNAL STREAM***, //,                              INOU3480
     3  15X,9H GAMMAI= F5.3, 5X,16H GAS CONSTANT = F7.2,11H LB-FT/LB-R, INOU3490
     4  / ,15X,6H X1I= F6.3,7X,6H R1I= F6.3,9X,14H BETA1I(DEG)= F7.3,/, INOU3500
     5  15X,8H EMN1I =F7.4,4X,8H EMS1I =F7.4,6X,10H P1I/POI =F7.5,      INOU3510
     6  //,28X,22H ***EXTERNAL STREAM***, //,                           INOU3520
     7  15X,9H GAMMAE= F5.3, 5X,16H GAS CONSTANT = F7.2,11H LB-FT/LB-R, INOU3530
     8  / ,15X,6H X1E= F6.3,7X,6H R1E= F6.3,9X,14H BETA1E(DEG)= F7.3,/, INOU3540
     9  15X,8H EMN1E =F7.4,4X,8H EMS1E =F7.4,6X,11H P1E/POIE =F7.5//)   INOU3550
C                                                                       INOU3560
      WRITE (6,200)             PR1IE, TROEI, BLDRO, ENGRO              INOU3570
  200 FORMAT(21X,36H ******BASE PRESSURE CASE DATA******, //,           INOU3580
     1  15X,11H P1I/PE   = F9.4,17X,11H TOE/TOI = F8.5,/,               INOU3590
     2  15X, 9H BLDRO = F12.5, 16X, 9H ENGRO = F12.5,//)                INOU3600
C                                                                       INOU3610
      WRITE (6,210)             RECOMP                                  INOU3620
  210 FORMAT( 18X, 32H  **RECOMPRESSION COEFFICIENT =  F5.3, 3H***, /,  INOU3630
     1 15X,51H **********************************************    /)     INOU3640
C                                                                       INOU3650
      RETURN                                                            INOU3660
      END                                                               INOU3670
```

```
      SUBROUTINE OUTIM(I,A,EMN1I,PR1OI,PRBOI,PRB1I,PROEOI,TROEI,PR1IE,
     1                  EMN1E,PR1O1E,PRBO1E,PRB1E,EMNE,PREOE,PRBOE,PROIE,
     2                  PRBE,NPRINT,BLDRO,ENGRO,NSHAPE)
C
C*****SUBROUTINE WRITES OUT HEADINGS AND CURRENT DATA USED FOR THE
C     INVISCID FLOW FIELD CALCULATIONS.
C
C     ***VARIABLES***
C
C     I      = I-TH VALUE OF THE INPUT BASE PRESSURE RATIO.
C     A      = HEADING CARD DATA.
C
C     *** FOR EITHER STREAM AT (1I), (1E), OR (E--FREESTREAM).
C
C     EMN    = MACH NUMBER.
C     PREO   = PRESSURE RATIO, PE/PO.
C     PR1O   - PRESSURE RATIO AT (1), P1/PO.
C     PRBO   = BASE PRESSURE RATIO, PB/PO.
C     PRB1   = BASE PRESSURE RATIO, PB/P1.
C
C     PR1IE  = INPUT STATIC PRESSURE RATIO OF STREAMS, P1I/PE.
C     TROEI  = STAGNATION TEMPERATURE RATIO OF STREAMS,  TOE/TOI.
C     PROEOI= STAGNATION PRESSURE RATIO OF STREAMS, POE/POI.
C     NPRINT= SEE SUBROUTINE *INOUT*.
C     BLDRO,ENGRO = SPECIFIED VALUES OF THE BLEED AND ENERGY RATIOS.
C     NSHAPE= 0, NO BOATTAIL.
C           = 1,2 OR 3---OGIVE, PARABOLIC, OR CONICAL BOATTAILS.
C
      DIMENSION  A(20)
      IF(NPRINT) 107,107,99
C
   99 WRITE (6,100)            (A(J),J=1,20),PR1IE,TROEI,PROEOI,PROIE,
     1                          BLDRO,ENGRO,I
  100 FORMAT(1H1, 5X, 20A4, //,
     1 15X,51H *********TWO-STREAM BASE PRESSURE PROGRAM**********, //,
     2 27X,25H ******CURRENT DATA******,//,
     3 15X,11H P1I/PE   = F9.4,17X,11H TOE/TOI = F8.5,//,
     4 15X,11H POE/POI = F9.5,17X,11H POI/PE   = F8.3,//,
     5 15X, 9H BLDRO = F12.5, 16X, 9H ENGRO = F12.5,//,
     6 22X,31H TRIAL BASE PRESSURE RATIO NO. ,I4,/,
     7 22X,31H ***** **** ********* ***** *** ,//)
C
      WRITE (6,111)            EMN1I,PR1OI,PRBOI,PRB1I,
     1                          EMN1E,PR1O1E,PRBO1E,PRB1E
  111 FORMAT(28X,22H ***INTERNAL STREAM***, //,
     1 15X,8H EMN1i = F7.4,25X,10H P1I/POI = F8.6,//,
     2 15X,9H PB/POI = F8.6,23X,9H PB/P1I = F8.6,//,
     3 28X,22H ***EXTERNAL STREAM***, //,
     4 15X,8H EMN1E = F7.4,25X,11H P1E/PO1E = F8.6,//,
     5 15X,9H PB/PO1E= F8.6,23X,9H PB/P1E = F8.6,//)
C
      WRITE (6,102)            EMNE,PREOE,PRBOE,PRBE
  102 FORMAT(30X,17H ***FREESTREAM*** , //,
     1 15X,7H EMNE = F7.4, 23X, 9H PE/POE = F8.6, //,
     2 15X, 9H PB/POE = F8.6, 20X, 9H PB/PE   = F8.6,//)
C
      IF(NSHAPE) 103,103,105
C
  103 WRITE (6,104)
  104 FORMAT(21X,32H *** NO BOATTAIL BEFORE BASE ***   , /)
      RETURN
C
  105 WRITE (6,106)            NSHAPE
  106 FORMAT(25X, 27H *** BOATTAIL --- NSHAPE - I1, 4H ***   ,/)
C
  107 RETURN
      END
```

```
      SUBROUTINE ACPBS(GAMMA,EMS1,PRATIO,XCO,RCO,BETAO,RLMT,NCALC,NPTS,
     1                  NPRINT,NFLOW,NBPTS,BPTS,NSHAPE)
C
C*****AXISYMMETRIC CONSTANT PRESSURE BOUNDARY SUBPROGRAM (ACPBS).
C
C     INTERNAL FLOW (NFLOW=1) --- UNIFORM OR CONICAL SUPERSONIC FLOW.
C                                 CALCULATIONS ARE FOR THE *LOWER-HALF*
C                                 OF THE FLOW FIELD.
C
C     EXTERNAL FLOW (NFLOW=2) --- INITIALLY UNIFORM SUPERSONIC FLOW.
C                                 CALCULATIONS ARE FOR THE *UPPER-HALF*
C                                 OF THE FLOW FIELD.
C
C     NOTE --- INPUT AND OUTPUT DATA ARE FOR THE *UPPER-HALF* OF FLOW
C              FIELD. THE ADJUSTMENT OF THESE DATA FOR THE CALCULATIONS
C              IS MADE INTERNALLY.
C
C     SUBPROGRAM REQUIRES---OUTPUT,PMSBR,UFLOC,CNFLOC,EPS,APS,CPBS,
C                           MCDATA,OUTBDY,TEST.
C
C     ***VARIABLES***
C
C     GAMMA = RATIO OF THE SPECIFIC HEATS.
C     EMS1  = INITIAL MACH STAR AT POINT 1.
C     PRATIO= EXPANSION PRESSURE RATIO (P/PO).
C     XCO   = LONGITUDINAL COORDINATE WHERE EXPANSION IS CENTERED.
C     RCO   = RADIAL COORDINATE WHERE EXPANSION IS CENTERED, POSTIVE.
C     BETAO = FLOW ANGLE, RADIANS, AT (XCO,RCO) FOR INTERNAL FLOW, POS.
C     RLMT  = LIMITING VALUE OF THE RADIUS FOR TERMINATING CALCULATIONS.
C             (MAX. R FOR INTERNAL FLOW AND MIN. R FOR EXTERNAL FLOW)
C     NCALC = CURRENT CALCULATION NUMBER
C           = 1, THE INITIAL CHARACTERISTIC DATA IS CALCULATED.
C        .GT.1, INITIAL CHAR. DATA TAKEN FROM ONE OF THE STORED ARRAYS.
C     NPTS  = NO. OF POINTS OR INCREMENTS ON INIT. . II-CHARACTERISTIC.
C     NPRINT= -1 OR 0, C.P.B. DATA NOT PRINTED.
C             +1, C.P.B. DATA PRINTED.
C     NFLOW = 1, INTERNAL FLOW.
C             2, EXTERNAL FLOW.
C     NBPTS = NUMBER OF BOUNDARY POINTS CALCULATED.
C     BPTS  = BOUNDARY POINT DATA ARRAY, N=1,LIMIT.
C     PMB, CHARI, CHARE = ARRAYS FOR METHOD OF CHARACTERISTICS.
C
C      ***OUTPUT DATA (IN ORDER)***
C
C     INPUT DATA TO ACPBS
C     PRATIO= EXPANSION PRESSURE RATIO (P/PO).
C     EMN2  = MACH NUMBER ALONG BOUNDARY AFTER EXPANSION.
C     EMS2  = MACH STAR ALONG BOUNDARY AFTER EXPANSION.
C     X     = LONGITUDINAL COORDINATE OF BOUNDARY POINT.
C     R     = RADIAL COORDINATE OF BOUNDARY POINT.
C     THETA = LOCAL FLOW ANGLE AT BOUNDARY POINT (IN DEGREES).
C

      DIMENSION PMB(100,5,2), CHARI(5,30), CHARE(5,30), P1(5), P2(5),
     1    P3(5), BPTS(5,30), SIGN
      COMMON PMB, CHARI, CHARE,     P2, P3
C*****INPUT DATA, SOME OUTPUT DATA, AND COLUMN HEADINGS ARE PRINTED.
      CALL OUTPUT(GAMMA,EMS1,PRATIO,BETAO,NPRINT,NFLOW)
C*****SET INPUT DATA FOR THE FLOW FIELD CALCULATIONS.
      GO TO (2,4), NFLOW
    2 RC=-RCO
      XC=XCO
      BETA=-BETAO
```

```
      GO TO 6
    4 RC=RCO
      XC=XCO
      BETA=BETAO
    6 CONTINUE
C*****SET SIGNS FOR CONVERTING OUTPUT DATA TO THE *UPPER-HALF*
C      OF THE FLOW FIELD.
C
      DO 30 M=1,5
      GO TO (10,20), NFLOW
   10 SIGN(M)=(-1.0)**(M+1)
      GO TO 30
   20 SIGN(M)=1.0
   30 CONTINUE
C*****THE MAXIMUM NUMBER OF FAMILY I CHARACTERISTICS FOR WHICH
C      CALCULATIONS ARE MADE IS SPECIFIED HERE (MAX. LIMIT IS 30).
C
      LIMIT=30
C*****THE INITIAL II-CHAR. IS NOW SUBDIVIDED AND THE INITIAL CHAR.
C      DATA CALCULATED (MAX. NO. OF INCREMENTS = 29).
C
      IF(NCALC-1) 50,50,110
   50 GO TO (60,90), NFLOW
C*****FOR INTERNAL FLOW FIELD.
   60 IF(ABS (BETA)-1.0E-4) 70,70,80
C*****FOR UNIFORM FLOW.
   70 CALL UFLOC(GAMMA,EMS1,XC,RC,NPTS,CHARI,NFLOW)
      GO TO 110
C*****FOR CONICAL FLOW.
   80 CALL CNFLOC(GAMMA,EMS1,BETA,XC,RC,NPTS)
      GO TO 110
C*****FOR EXTERNAL FLOW FIELD.
   90 IF(NSHAPE) 96,96,100
C*****FOR UNIFORM EXTERNAL FLOW WITHOUT A BOATTAIL.
   96 CALL UFLOC(GAMMA,EMS1,XC,RC,LIMIT-1,CHARE,NFLOW)
      NPTS=LIMIT
      GO TO 110
C*****FOR UNIFORM EXTERNAL FLOW WITH A BOATTAIL.
  100 LIMIT=NPTS
C*****THE PRANDTL-MEYER EXPANSION AT (XC,RC) IS NOW SUBDIVIDED.
  110 CALL  PMSBR(GAMMA,EMS1,PRATIO,BETA,XC,RC,K)
C*****K1 IS NUMBER OF FAMILY II CHAR. FOR SUBDIVIDED EXPANSION.
      K1 = K + 1
C*****STORAGE OF INITIAL BOUNDARY POINT DATA.
      NBPTS=1
      DO 120 M=1,4
  120 BPTS(M,1)=SIGN(M)*PMB(K1,M,1)
C*****THE INITIAL BOUNDARY POINT DATA IS PRINTED.
      CALL OUTBDY(1,NPRINT,BPTS)
C*****THE FLOW FIELD CALCULATIONS ARE NOW MADE ALONG FAMILY I CHARS.
C      STARTING FROM THE INPUT POINTS ON THE SUBDIVIDED INITIAL
C      FAMILY II CHARACTERISTICS TO THE BOUNDARY.  THIS SEQUENCE IS
C      NOT APPLICABLE FOR THE FIRST AND SUBSEQUENT AXIS POINTS.
C
      DO 180 N=2,NPTS
C*****LOAD INITIAL FAMILY II CHARACTERISTIC DATA.
      DO 150 M=1,4
      GO TO (130,140), NFLOW
  130 PMB(1,M,2)=CHARI(M,N)
      GO TO 150
  140 PMB(1,M,2)=CHARE(M,N)
  150 CONTINUE
C*****CALCULATIONS ARE FOR THE CURRENT N-TH POINT ON THE INITIAL
C      FAMILY II CHARACTERISTIC.
```

```
C                                                                       ACPB1280
      DO 160 L=1,K                                                      ACPB1290
C*****CALCULATIONS ARE FOR THE CURRENT L-TH EXPANSION INCREMENT.         ACPB1300
C*****LOAD DATA/ FIELD POINT CALCULATION/ STORE DATA.                    ACPB1310
      CALL MCDATA(1,L,L+1,L3,KPTS)                                      ACPB1320
      CALL FPS(GAMMA, P1, P2, P3, NERROR)                               ACPB1330
      IF(NERROR) 270,154,154                                            ACPB1340
  154 CALL MCDATA(2,L1,L2,L+1,KPTS)                                     ACPB1350
  160 CONTINUE                                                          ACPB1360
C*****ALL FIELD POINTS ON N-TH FAMILY I CHAR. HAVE BEEN CALCULATED.      ACPB1370
C*****LOAD DATA/ BOUNDARY POINT CALCULATION/ STORE DATA.                 ACPB1380
      CALL MCDATA(1,K+1,K+1,L3,KPTS)                                    ACPB1390
      CALL CPBS(GAMMA, P1, P2, P3, NERROR)                              ACPB1400
      IF(NERROR) 270,164,164                                            ACPB1410
  164 CALL MCDATA(2,L1,L2,K+2,KPTS)                                     ACPB1420
      NBPTS=NBPTS+1                                                     ACPB1430
      DO 170 M=1,4                                                      ACPB1440
  170 BPTS(M,N)=SIGN(M)*P3(M)                                           ACPB1450
C*****CHARACTERISTICS DATA SHIFT.                                        ACPB1460
      CALL MCDATA(3,L1,L2,L3,K+2)                                       ACPB1470
C*****THE CURRENT BOUNDARY POINT DATA IS NOW PRINTED.                    ACPB1480
      CALL OUTBDY(N,NPRINT,BPTS)                                        ACPB1490
      CALL TEST(RLMT,NSTMT,NFLOW,N,BPTS)                                ACPB1500
      GO TO (180,260), NSTMT                                            ACPB1510
C*****ADVANCE INDEX FOR NEXT INPUT POINT ON INITIAL CHARACTERISTIC.      ACPB1520
  180 K=K+1                                                             ACPB1530
      GO TO (190,260), NFLOW                                            ACPB1540
C*****THIS SEQUENCE APPLIES ONLY TO THE INTERNAL FLOW WHERE THE AXIS     ACPB1550
C     POINTS ARE CONSIDERED.                                            ACPB1560
C*****THE NUMBER OF POINTS TO BE CALCULATED ALONG EACH FAMILY I CHAR.    ACPB1570
C     IS NOW CONSTANT AND GIVEN BY K1.                                  ACPB1580
C                                                                       ACPB1590
  190 K1=K+1                                                            ACPB1600
      KPTS=K1+1                                                         ACPB1610
      N=NPTS                                                            ACPB1620
C*****THE ELEMENTS IN THE N-TH COLUMN OF THE PMB ARRAY ARE SHIFTED       ACPB1630
C     DOWN ONE ROW TO SET-UP THE CALCULATION SEQUENCE.                  ACPB1640
C                                                                       ACPB1650
      DO 210 L=1,K1                                                     ACPB1660
      L1 = K1-L+1                                                       ACPB1670
      DO 200 M=1,4                                                      ACPB1680
  200 PMB(L1+1,M,1)=PMB(L1,M,1)                                         ACPB1690
  210 CONTINUE                                                          ACPB1700
C*****THE CALCULATIONS ARE NOW MADE ALONG THE (N+1)-TH FAMILY I CHAR.    ACPB1710
  220 N=N+1                                                             ACPB1720
C*****LOAD DATA/ AXIS POINT CALCULATION/ STORE DATA.                     ACPB1730
      CALL MCDATA(1,1,2,L3,KPTS)                                        ACPB1740
      CALL APS (GAMMA, P2, P3, NERROR)                                  ACPB1750
      IF(NERROR) 270,224,224                                            ACPB1760
  224 CALL MCDATA(2,L1,L2,1,KPTS)                                       ACPB1770
C*****CALCULATION OF REMAINDER OF FIELD POINTS ON N-TH FAMILY I CHAR.    ACPB1780
      DO 230 L=2,K1                                                     ACPB1790
C*****LOAD DATA/ FIELD POINT CALCULATION/ STORE DATA.                    ACPB1800
      CALL MCDATA(1,L-1,L+1,L3,KPTS)                                    ACPB1810
      CALL FPS(GAMMA, P1, P2, P3, NERROR)                               ACPB1820
      IF(NERROR) 270,228,228                                            ACPB1830
  228 CALL MCDATA(2,L1,L2,L,KPTS)                                       ACPB1840
  230 CONTINUE                                                          ACPB1850
C*****LOAD DATA/ BOUNDARY POINT CALCULATION/ STORE DATA.                 ACPB1860
      CALL MCDATA(1,K1,K1+1,L3,KPTS)                                    ACPB1870
      CALL CPBS(GAMMA, P1, P2, P3, NERROR)                              ACPB1880
      IF(NERROR) 270,234,234                                            ACPB1890
  234 CALL MCDATA(2,L1,L2,K1+1,KPTS)                                    ACPB1900
      NBPTS=NBPTS+1                                                     ACPB1910
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```
      DO 240 M=1,4                                                      ACPB1920
  240 BPTS(M,N)=SIGN(M)*P3(M)                                           ACPB1930
C*****CHARACTERISTICS DATA SHIFT.                                       ACPB1940
      CALL MCDATA(3,L1,L2,L3,KPTS)                                      ACPB1950
C*****THE CURRENT BOUNDARY POINT DATA IS PRINTED.                       ACPB1960
      CALL OUTBDY(N,NPRINT,BPTS)                                        ACPB1970
      CALL TEST(RLMT,NSTMT,NFLOW,N,BPTS)                                ACPB1980
      GO TO (250,260), NSTMT                                            ACPB1990
C*****COMPARISON WITH LIMITING NUMBER OF FLOW FIELD CALCULATIONS.       ACPB2000
  250 IF(N-LIMIT) 220,260,260                                           ACPB2010
C*****IF NEGATIVE, CONTINUE CALCULATIONS.                               ACPB2020
C*****IF ZERO OR POSTIVE, RETURN TO MASTER.                             ACPB2030
  260 CONTINUE                                                          ACPB2040
  270 RETURN                                                            ACPB2050
      END                                                               ACPB2060
```

```
      SUBROUTINE CROSS(GAMMAI,BPTI,LIMITI,GAMMAE,BPTE,LIMITE,NIC,NEC,
     1                    NSTOP,TJMLI,TJMLE,PRSHOK,NPRINT)
C
C*****THIS SUBROUTINE CALCULATES THE IMPINGEMENT POINT OF THE
C      SUPERSONIC INTERNAL (I) AND EXTERNAL (E) STREAMS.
C
C      SUBROUTINE REQUIRES---PRSHK,SLIP.
C
C      ***VARIABLES***
C
C      GAMMAI = RATIO OF THE SPECIFIC HEATS FOR THE INTERNAL STREAM.
C      BPTI   = INTERNAL STREAM BOUNDARY DATA.
C      LIMITI = NUMBER OF INTERNAL STREAM BOUNDARY POINTS.
C      GAMMAE = RATIO OF THE SPECIFIC HEATS FOR THE EXTERNAL STREAM.
C      BPTE   = EXTERNAL STREAM BOUNDARY DATA.
C      LIMITE = NUMBER OF EXTERNAL STREAM BOUNDARY POINTS.
C      NIC    = LOCATION NO. OF INTERNAL STREAM IMPINGEMENT POINT.
C      NEC    = LOCATION NO. OF EXTERNAL STREAM IMPINGEMENT POINT.
C      NSTOP  = 0, SOLUTION FOUND.
C             = 1, NO IMPINGEMENT.
C             = 2, NO SHOCK SOLUTION.
C             = 3, IMPINGEMENT BEFORE SEPARATION.
C      TJMLI  = INTERNAL TURBULENT JET MIXING LENGTH.
C      TJMLE  = EXTERNAL TURBULENT JET MIXING LENGTH.
C      PRSHOK = STATIC PRESS. RATIO (RISE) ACROSS OBLIQUE SHOCK SYSTEM.
C      NPRINT = SEE SUBROUTINE *INOUT*.
C
C      BPTI(M,N) AND BPTE(M,N) ARE BOUNDARY POINT DATA ARRAYS WHERE
C                M=1,4  AND INDICATES VARIABLE AS IN PMB ARRAY.
C                N=1,LIMITI OR LIMITE  INDICATES THE BOUNDARY POINT.
C
C
      EMNMSF(EMS,GAMMA)=SQRT(((2.0*(EMS**2))/(GAMMA+1.0))/
     1                  (1.0-((GAMMA-1.0)/(GAMMA+1.0))*(EMS**2))  )
      DIMENSION XI(30),RI(30),XE(30),RE(30),BPTI(5,30),BPTE(5,30)
C*****LOADING OF CONSTANT-PRESSURE BOUNDARY POINT DATA.
      DO 10 N=1,LIMITI
      XI(N) = BPTI(1,N)
   10 RI(N) = BPTI(2,N)
      DO 20 N=1,LIMITE
      XE(N) = BPTE(1,N)
   20 RE(N) = BPTE(2,N)
C*****SET INITIAL VALUES.
      NSTOP=1
      PRSHOK=0.0
      NIMAX=LIMITI-1
      NEMAX=LIMITE-1
C*****CHECK FOR IMPINGEMENT UPSTREAM OF THE SEPARATION POINTS.
C*****FOR THE INTERNAL STREAM.
      SE=0.0
      NE=1
      DO 30 NI=1,NIMAX
      SI = (RI(NI+1) - RI(NI))/(XI(NI+1) - XI(NI))
      IF(ABS(SE-SI) .LT. 1.0E-05)  GO TO 30
      XIMP = (RI(NI) - RE(NE) + SE*XE(NE) - SI*XI(NI))/(SE - SI)
      IF((XIMP.GE.XI(NI)).AND.(XIMP.LE.XI(NI+1)).AND.
     1   (XIMP.LE.XE(NE)))  GO TO 50
   30 CONTINUE
C*****FOR THE EXTERNAL STREAM.
      SI=0.0
      NI=1
      DO 40 NE=1,NEMAX
      SE = (RE(NE+1) - RE(NE))/(XE(NE+1) - XE(NE))
```

```
      IF(ABS(SE-SI) .LT. 1.0E-05)  GO TO 40
      XIMP = (RI(NI) - RE(NE) + SE*XE(NE) - SI*XI(NI))/(SE - SI)
      IF((XIMP.GE.XE(NE)).AND.(XIMP.LE.XE(NE+1)).AND.
     1   (XIMP.LE.XI(NI)))  GO TO 70
   40 CONTINUE
      GO TO 100
C*****IF IMPINGEMENT OCCURS.
   50 RIMP = (SE*SI*(XE(NE)-XI(NI)) + SE*RI(NI) - SI*RE(NE))/(SE-SI)
C
      WRITE (6,60)            XIMP,RIMP
   60 FORMAT( 15X, 48H ******IMPINGEMENT OF THE INTERNAL STREAM OCCURS /
     1 21X, 47H BEFORE SEPARATION OF THE EXTERNAL STREAM****** , /,
     2 16X, 27H IMPINGEMENT OCCURS AT X = F10.6, 5X, 9H AND R = F10.6 /)
      GO TO 90
C
   70 RIMP = (SE*SI*(XE(NE)-XI(NI)) + SE*RI(NI) - SI*RE(NE))/(SE-SI)
C
      WRITE  (6,80)           XIMP,RIMP
   80 FORMAT( 15X, 48H ******IMPINGEMENT OF THE EXTERNAL STREAM OCCURS /
     1 21X, 47H BEFORE SEPARATION OF THE INTERNAL STREAM****** , /,
     2 16X, 27H IMPINGEMENT OCCURS AT X = F10.6, 5X, 9H AND R = F10.6 /)
C
   90 NSTOP=3
      GO TO 230
C*****CALCULATION OF CONSTANT-PRESSURE BOUNDARIES IMPINGEMENT POINT.
  100 DO 120 NI=1,NIMAX
      SI = (RI(NI+1) - RI(NI))/(XI(NI+1) - XI(NI))
      DO 110 NE=1,NEMAX
      SE = (RE(NE+1) - RE(NE))/(XE(NE+1) - XE(NE))
      IF(ABS(SE-SI) .LT. 1.0E-05)  GO TO 110
      XIMP = (RI(NI) - RE(NE) + SE*XE(NE) - SI*XI(NI))/(SE - SI)
      IF((XIMP.GE.XI(NI)) .AND. (XIMP.LE.XI(NI+1)) .AND.
     1   (XIMP.GE.XE(NE)) .AND. (XIMP.LE.XE(NE+1)))  GO TO 140
  110 CONTINUE
  120 CONTINUE
C*****FOR NO IMPINGEMENT OF THE STREAMS.
      WRITE (6,130)
  130 FORMAT(16X, 41H ***IMPINGEMENT DOES NOT OCCUR WITHIN THE  ,/,
     1   19X, 44H RANGE OF CONSTANT-PRESSURE BOUNDARY DATA***   /)
      NSTOP=2
      GO TO 230
C*****FOR IMPINGEMENT OF THE STREAMS.
  140 RIMP = (SE*SI*(XE(NE)-XI(NI)) + SE*RI(NI) - SI*RE(NE))/(SE-SI)
      NIC=NI+1
      NEC=NE+1
C*****INTERPOLATION FOR THE FLOW VARIABLES AT THE IMPINGEMENT POINT.
      DO 150 M=3,4
      BPTI(M,NIC) = BPTI(M,NIC-1) + ((XIMP - XI(NIC-1))/
     1               (XI(NIC) - XI(NIC-1)))*(BPTI(M,NIC) - BPTI(M,NIC-1))
  150 BPTE(M,NEC) = BPTE(M,NEC-1) + ((XIMP - XE(NEC-1))/
     1              (XE(NEC) - XE(NEC-1)))*(BPTE(M,NEC) - BPTE(M,NEC-1))
C*****STORE COORDINATES OF THE IMPINGEMENT POINT.
      BPTI(1,NIC) = XIMP
      BPTI(2,NIC) = RIMP
      BPTE(1,NEC)= XIMP
      BPTE(2,NEC) = RIMP
C*****CALCULATION OF THE MIXING LENGTHS.
      TJMLI=0.0
      DO 160 N=2,NIC
  160 TJMLI=TJMLI+SQRT((BPTI(1,N)-BPTI(1,N-1))**2
     1   +(BPTI(2,N)-BPTI(2,N-1))**2)
      TJMLE=0.0
      DO 170 N=2,NEC
  170 TJMLE=TJMLE+SQRT((BPTE(1,N)-BPTE(1,N-1))**2
```

```
     1    +(BPTE(2,N)-BPTE(2,N-1))**2)                                  CROS1280
C*****OUTPUT IMPINGEMENT POINT DATA.                                    CROS1290
      EMNI = EMNMSF(BPTI(3,NIC),GAMMAI)                                 CROS1300
      THETDI = 57.2957795*BPTI(4,NIC)                                   CROS1310
      EMNE = EMNMSF(BPTE(3,NEC),GAMMAE)                                 CROS1320
      THETDE = 57.2957795*BPTE(4,NEC)                                   CROS1330
      IF(NPRINT.LT.0) GO TO 200                                         CROS1340
C                                                                       CROS1350
      WRITE (6,180)                                                     CROS1360
 180  FORMAT( 1H1 )                                                     CROS1370
C                                                                       CROS1380
      WRITE (6,190)            XIMP,RIMP,EMNI,THETDI,TJMLI,             CROS1390
     1                         XIMP,RIMP,EMNE,THETDE,TJMLE              CROS1400
 190  FORMAT(//,18X,42H***AT INTERNAL STREAM IMPINGEMENT POINT*** ,//,  CROS1410
     1 5X, 5H X = F10.6, 5X, 5H R = F10.6, 5X, 12H MACH NO. = F10.6,//, CROS1420
     2 5X, 15H THETA(DEG.) = F10.6, 5X, 17H MIXING LENGTH = F10.6,//,   CROS1430
     3 18X,  43H ***AT EXTERNAL STREAM IMPINGEMENT POINT*** ,//,        CROS1440
     4 5X, 5H X = F10.6, 5X, 5H R = F10.6, 5X, 12H MACH NO. = F10.6,//, CROS1450
     5 5X, 15H THETA(DEG.) = F10.6, 5X, 17H MIXING LENGTH = F10.6,//)   CROS1460
C                                                                       CROS1470
C*****CALCULATION OF THE RECOMPRESSION SHOCK SYSTEM.                    CROS1480
C*****CALCULATION OF THE SLIPLINE ANGLE.                                CROS1490
 200  CALL SLIP(BPTI(3,NIC),BPTI(4,NIC),GAMMAI,                         CROS1500
     1           BPTE(3,NEC),BPTE(4,NEC),GAMMAE,                        CROS1510
     2           THETAS,NSTOP)                                          CROS1520
C*****DOES THE SOLUTION FOR THE SLIPLINE ANGLE EXIST.                   CROS1530
      GO TO (210,230,230), NSTOP                                        CROS1540
C*****CALCULATION OF THE STATIC PRESSURE RATIO ACROSS THE SHOCK SYSTEM. CROS1550
C     (NOTE  PRSHOKI=PRSHOKE=PRSHOX.)                                   CROS1560
C                                                                       CROS1570
 210  DELTAI = (BPTI(4,NIC) - THETAS)                                   CROS1580
      PRSHOK = PRSHK(BPTI(3,NIC),DELTAI,GAMMAI)                         CROS1590
      THETAS = 57.2957795*THETAS                                        CROS1600
      IF(NPRINT.LT.0) GO TO 230                                         CROS1610
C*****OUTPUT OF SHOCK SYSTEM DATA.                                      CROS1620
C                                                                       CROS1630
      WRITE (6,220)            THETAS,PRSHOK                            CROS1640
 220  FORMAT(15X, 48H ***OBLIQUE SHOCK SYSTEM AT IMPINGEMENT POINT***//,CROS1650
     1        5X, 23H SLIPLINE ANGLE(DEG.) = F10.6,                     CROS1660
     2        5X, 24H STATIC PRESSURE RATIO = F10.6,//)                 CROS1670
C                                                                       CROS1680
 230  RETURN                                                            CROS1690
      END                                                               CROS1700
```

```
      SUBROUTINE TJMIX(GAMMA1,GC1,EMS1,TRBO1,TJML1,
     1                 GAMMA2,GC2,EMS2,TRBO2,TJML2,
     2                 RN1,EMSN1,BETAN1,RIMP,PRSHOK,
     3                 PRO21,TRO21,RECOMP,BLDR,ENGR)
C
C*****THIS SUBROUTINE CALCULATES THE DIMENSIONLESS BLEED AND
C     ENERGY RATIOS FOR THE TWO-STREAM INTERACTION PROBLEM.
C
C     SUBROUTINE REQUIRES---TEGRAL.
C
C     ***VARIABLES***
C
C     FOR EITHER STREAM 1 OR 2
C
C     GAMMA  = RATIO OF SPECIFIC HEATS.
C     GC     = GAS CONSTANT---(LBF-FT/LBM-R).
C     EMS    = MACH STAR AT IMPINGEMENT POINT.
C     THETA  = FLOW ANGLE AT IMPINGEMENT POINT (IN RADIANS).
C     TRBO   = BASE TO FREE-STREAM STAGNATION TEMPERATURE RATIO.
C     TJML   = TURBULENT JET MIXING LENGTH.
C
C     RN1    = NOZZLE EXIT RADIUS OF STREAM 1 (INTERNAL).
C     EMSN1  = NOZZLE EXIT MACH STAR OF STREAM 1.
C     BETAN1 = NOZZLE EXIT FLOW ANGLE AT RN1 (IN RADIANS).
C     RIMP   = RADIAL COORDINATE OF IMPINGEMENT POINT.
C     PRSHOK = STATIC PRESSURE RATIO (RISE) OF OBLIQUE SHOCK SYSTEM.
C
C     PRO21  = STAGNATION PRESSURE RATIO, PO2/PO1.
C     TRO21  = RATIO OF STAGNATION TEMPERATURES OF THE TWO STREAMS.
C     RECOMP = RECOMPRESSION COEFFICIENT.
C
C     BLDR   = MASS BLEED RATIO REFERENCED TO FLOW OF STREAM 1,
C              (G BLEED)/(G NOZZLE1).
C     ENGR   = ENERGY BLEED RATIO, (OMEGAB)/((G NOZZLE1)*CP1*TO1),
C              WHERE OMEGAB IS REFFERENCED TO T=0.
C
C
      CR2MSF(EMS,GAMMA) = ((GAMMA-1.0)/(GAMMA+1.0))*(EMS**2)
      EMNMSF(EMS,GAMMA)=SQRT  (((2.0*(EMS**2))/(GAMMA+1.0))/
     1                   (1.0-((GAMMA-1.0)/(GAMMA+1.0))*(EMS**2))   )
      EMSPRF(PR,GAMMA)=SQRT  (((GAMMA+1.0)/(GAMMA-1.0))*
     1                  (1.0-PR**((GAMMA-1.0)/GAMMA)))
      WTFLMS (EMS,GAMMA)=SQRT  (2.0*GAMMA/(GAMMA+1.0))*
     1                    (EMS/(1.0-((GAMMA-1.0)/(GAMMA+1.0))*(EMS**2)))
      PRMSF(EMS,GAMMA)=(1.0-((GAMMA-1.0)/(GAMMA+1.0))*EMS**2)**
     1                  (GAMMA/(GAMMA-1.0))
      SIGMAF(EMN) = (12.0 + 2.758*EMN)
      PHIDF(CNR,TRBO) = CNR*(0.5*CNR*(1.0-TRBO) +
     1                   SQRT  ((CNR**2)*((0.5*(1.0-TRBO))**2)+TRBO))
C*****CALCULATION OF DISCRIMINATING STREAMLINE VELOCITY RATIOS
C     BASED ON THE RECOMPRESSION COEFFICIENT.  SINCE THE PRESSURE RATIO
C     ACROSS THE OBLIQUE SHOCK SYSTEM IS EQUAL FOR STREAMS 1 AND 2,
C     THE DISCRIMINATING STREAMLINE STAGNATION PRESSURE RATIO, P/POD,
C     IS ALSO THE SAME.
C
      PROD=(1.0/(RECOMP*PRSHOK))
C*****FOR STREAM 1.
  100 CSQD1D = CR2MSF(EMSPRF(PROD,GAMMA1),GAMMA1)
      CSQD1 = CR2MSF(EMS1,GAMMA1)
      C1 = SQRT  (CSQD1)
      CNR1 = SQRT  (CSQD1D/CSQD1)
      PHID1 = PHIDF(CNR1,TRBO1)
      CALL TEGRAL(PHID1,CSQD1,TRBO1,E11J1,E11O1,E13J1,E13O1)
```

```
C*****FOR STREAM 2.                                                     TJMI 640
      CSQD2D = CR2MSF(EMSPRF(PROD,GAMMA2),GAMMA2)                       TJMI 650
      CSQD2 = CR2MSF(EMS2,GAMMA2)                                       TJMI 660
      C2=SQRT  (CSQD2)                                                  TJMI 670
      CNR2 = SQRT  (CSQD2D/CSQD2)                                       TJMI 680
      PHID2 = PHIDF(CNR2,TRBD2)                                         TJMI 690
      CALL TEGRAL(PHID2,CSQD2,TRBD2,FI1J2,FI1D2,FI3J2,FI3D2)            TJMI 700
C*****EVALUATION OF BLEED AND ENERGY RATIOS.                            TJMI 710
      SIGMA1 = SIGMAF(EMNMSF(EMS1,GAMMA1))                              TJMI 720
      SIGMA2 = SIGMAF(EMNMSF(EMS2,GAMMA2))                              TJMI 730
      PRBN1=PRMSF(EMS1,GAMMA1)/PRMSF(EMSN1,GAMMA1)                      TJMI 740
      COEFF1=((1.)+COS (BETAN1))/SIGMA1)*(RIMP/RN1)*(TJML1/RN1)*(PRPN1)*TJMI 750
     1  SQRT  (2.)*GAMMA1/(GAMMA1-1.0))*(1.0/WTFLMS (EMSN1,GAMMA1))     TJMI 760
      COEFF2=(TJML2/TJML1)*(SIGMA1/SIGMA2)*SQRT  ((1.0/TR021)*          TJMI 770
     1        (GAMMA2/GAMMA1)*(GC1/GC2)*((GAMMA1-1.0)/(GAMMA2-1.0)))    TJMI 780
      COEFF3=(SIGMA1/SIGMA2)*(TJML2/TJML1)*SQRT  ((GC2/GC1)*(TR021))*   TJMI 790
     1        (((GAMMA2/GAMMA1)*((GAMMA1-1.0)/(GAMMA2-1.0)))**1.5)      TJMI 800
      BLDR=-COEFF1*(C1*(FI1D1-FI1J1) + COEFF2*C2*(FI1D2-FI1J2))         TJMI 810
      ENGR=-COEFF1*(C1*(FI3D1-TRBD1*FI1J1) + COEFF3*C2*                 TJMI 820
     1       (FI3D2-TRBD2*FI1J2))                                       TJMI 830
      RETURN                                                            TJMI 840
      END                                                               TJMI 850
```

```
      SUBROUTINE OUT2M(PRBE,PRBII,PROEOI,TRBOE,TRBOI,TROEI,PROIE,         OTM2  10
     1                   PRIIE,BLDR,ENGR,NPRINT,CP,CD,BLDRO,ENGRO)         OTM2  20
C                                                                         OTM2  30
C*****OUT2M WRITES OUT THE CALCULATED MIXING RESULTS AND CURRENT DATA.    OTM2  40
C                                                                         OTM2  50
C     ***VARIABLES***                                                     OTM2  60
C                                                                         OTM2  70
C     PRB    = BASE PRESSURE RATIO, PB/PE.                                OTM2  80
C     PRBII  = BASE PRESSURE RATIO,  PB/PII.                              OTM2  90
C     PROEOI = STAGNATION PRESSURE RATIO, POE/POI.                        OTM2 100
C     TRBOE  = BASE TEMPERATURE RATIO, TB/TOE.                            OTM2 110
C     TRBOI  = BASE TEMPERATURE RATIO, TB/TOI.                            OTM2 120
C     TROEI  = STAGNATION TEMPERATURE RATIO, TOE/TOI.                     OTM2 130
C     PROIE  = INTERNAL STAGNATION TO EXT. STATIC PRESS. RATIO, POI/PE.   OTM2 140
C     PRIIE  = INPUT STATIC PRESSURE RATIO, PII/PE.                       OTM2 150
C     BLDR,ENGR    = SEE SUBROUTINE *TJMIX* FOR DEFINITIONS.              OTM2 160
C     NPRINT = SEE SUBROUTINE *INOUT*.                                    OTM2 170
C     CP     = BASE PRESSURE COEFFICIENT.                                 OTM2 180
C     CD     = BASE DRAG COEFFICIENT.                                     OTM2 190
C     BLDRO,ENGRO = SPECIFIED VALUES OF THE BLEED AND ENERGY RATIOS.      OTM2 200
C                                                                         OTM2 210
C                                                                         OTM2 220
      IF (NPRINT.LT.0) GO TO 103                                          OTM2 230
C                                                                         OTM2 240
      WRITE (6,100)           PRIIE,TROEI,PROEOI,PROIE,BLDRO,ENGRO        OTM2 250
 100  FORMAT(19X, 41H ******TURBULENT JET MIXING RESULTS******, //,       OTM2 260
     1  30X, 19H ***CURRENT DATA*** ,//,                                  OTM2 270
     2  14X, 11H PII/PE   = F8.5, 17X, 11H TOE/TOI = F8.5,//,             OTM2 280
     3  14X, 11H POE/POI = F8.5, 17X, 11H POI/PE   =  F8.3 ,//,           OTM2 290
     4  14X,  9H BLDRO = F12.5, 15X, 9H ENGRO = F12.5,//)                 OTM2 300
C                                                                         OTM2 310
      WRITE (6,101)           BLDR,ENGR                                   OTM2 320
 101  FORMAT(30X, 18H ***MIXING DATA***,//,                               OTM2 330
     1  14X,  8H BLDR = F12.5, 16X, 8H ENGR = F12.5,//)                   OTM2 340
C                                                                         OTM2 350
      WRITE (6,102)           TRBOE,TRBOI,PRBE ,PRBII,CP,CD               OTM2 360
 102  FORMAT (16X,45H ***BASE PRESSURE AND TEMPERATURE RESULTS***   ,//,  OTM2 370
     1  14X, 10H TB/TOE = F8.5, 18X, 10H TB/TOI = F8.5, //,               OTM2 380
     2  14X, 10H PB/PE   = F8.5, 18X, 10H PB/PII = F8.5, //,              OTM2 390
     3  14X, 10H CP-B    = F8.5, 18X, 10H CD-B    = F8.5 ,//,             OTM2 400
     4  20X, 40H ******END OF CURRENT CASE RESULTS****** /,               OTM2 410
     5  20X, 40H ***************************************, //)             OTM2 420
C                                                                         OTM2 430
 103  RETURN                                                              OTM2 440
      END                                                                 OTM2 450
```

```
      SUBROUTINE ITER(X,DX,ERRORX,SIGN,Y,YGIVEN,ERRORY,NIT,NTYPE,
     1                XNEG,YNEG,XPOS,YPOS,NSIGN1,NSIGN2)
C
C*****SUBROUTINE PERFORMS AN ITERATION TO FIND X SUCH THAT THE ABSOLUTE
C     VALUE OF (Y-YGIVEN) IS LESS THAN OR EQUAL TO ERRORY OR THE
C     ABSOLUTE VALUE OF (X(I+1)-X(I)) IS LESS THAN OR EQUAL TO ERRORX.
C
C     ***VARIABLES***
C
C     X      = INDEPENDENT VARIABLE.
C     DX     = INCREMENT IN INDEPENDENT VARIABLE.
C     ERRORX = MAXIMUM VALUE OF ABS(X(I+1)-X(I)) FOR SOLUTION.
C     SIGN   = +1.0 OR -1.0, DEFINES INCREMENTING FROM X INITIAL.
C     Y      = DEPENDENT VARIABLE.
C     YGIVEN = GIVEN VALUE OF DEPENDENT VARIABLE.
C     ERRORY = MAXIMUM VALUE OF ABS(Y-YGIVEN).
C     NIT    = INCREMENT NUMBER.
C     NTYPE  = 1, INCREMENT.
C            = 2, INTERPOLATION.
C            = 3, SOLUTION.
C
      DY=Y-YGIVEN
      IF(ABS (DY)-ERRORY) 90,90,10
   10 IF(DY) 20,90,30
   20 NSIGN2=-1
      XNEG=X
      YNEG=Y
      GO TO 40
   30 NSIGN2=+1
      XPOS=X
      YPOS=Y
   40 GO TO (50,80), NTYPE
   50 IF(NIT-1) 70,70,60
   60 NSIGN=NSIGN1*NSIGN2
      IF(NSIGN) 80,80,70
   70 NSIGN1=NSIGN2
      NIT=NIT+1
C*****INCREMENT TO FIND SOLUTION INTERVAL.
      X=X+SIGN*DX
      GO TO 100
C*****INTERPOLATION FOR SOLUTION.
   80 NTYPE=2
      NIT=NIT+1
      XSAVE=X
      RATIO=(XPOS-XNEG)/(YPOS-YNEG)
      X=XNEG+RATIO*(YGIVEN-YNEG)
C*****ACCELERATION OF CONVERGENCE OF ITERATION--REF. WEGSTEIN, NBS.
      A = 1.0/RATIO
      IF(A-1.0) 82,88,82
   82 Q = A/(A-1.0)
      XWGSTN = Q*XSAVE + (1.0-Q)*X
      IF(XNEG-XWGSTN) 84,86,88
   84 IF(XWGSTN-XPOS) 86,86,88
   86 X=XWGSTN
   88 IF(ABS(X-XSAVE) - ERRORX) 90,90,100
   90 NTYPE=3
  100 RETURN
      END
```

```
      SUBROUTINE AB[illegible](GAMMA,EM[illegible]                              [illegible]
     1                    NPRINT,N[illegible]                                     [illegible]
C                                                                                 [illegible]
C****************[illegible]                                                      [illegible]
C                                                                                 [illegible]
C      A X I S Y M M [illegible]                                                  [illegible]
C                                                                                 [illegible]
C****************[illegible]                                                      [illegible]
C                                                                                 [illegible]
C      WRITTEN BY -- A. [illegible]                                               [illegible]
C                                                                                 [illegible]
C      [illegible]                                                                [illegible]
C              [illegible]                                                        [illegible]
C              [illegible] MADE INTERNALLY.                                       [illegible]
C                                                                                 ABTS 150
C      [illegible]                                                                ABTS 160
C                                  BTITER.                                        ABTS 170
                                                                                  ABTS 180
C      ***VARIABLES***                                                            ABTS 190
C                                                                                 ABTS 200
C      GAMMA  = RATIO OF SPECIFIC HEATS.                                          ABTS 210
C      EMS1   = INITIAL FREESTREAM MACH STAR AT STATION 1.                        ABTS 220
C      XBT1,RBT1 = COORDINATES OF FIRST POINT ON BOATTAIL.                        ABTS 230
C      ANGBT1 = INITIAL BOATTAIL ANGLE AT STATION 1.                              ABTS 240
C               NEGATIVE AND IN RADIANS.                                          ABTS 250
C      XBT2,RBT2 = FINAL POINT ON BOATTAIL.                                       ABTS 260
C      NSHAPE = SEE SUBROUTINE *BTCNST*.                                          ABTS 270
C      NPRINT = -1 OR 0, B.B.P. DATA NOT PRINTED.                                 ABTS 280
C               +1, B.B.P. DATA PRINTED.                                          ABTS 290
C      NOCPTS = NUMBER OF II-CHAR. POINTS CALCULATED ON CHAR. THROUGH (2)ABTS 300
C      NERROR = SEE SUBROUTINE *BTITER*.                                          ABTS 310
C                                                                                 ABTS 320
C      ***OUTPUT DATA (IN ORDER)***                                               ABTS 330
C                                                                                 ABTS 340
C      INPUT DATA TO ABTS                                                         ABTS 350
C      X        = LONGITUDINAL COORDINATE OF BOUNDARY POINT.                      ABTS 360
C      R        = RADIAL COORDINATE OF BOUNDARY POINT.                            ABTS 370
C      THETA    = LOCAL FLOW ANGLE AT BOUNDARY POINT (IN DEGREES).                ABTS 380
C                                                                                 ABTS 390
C      NOTE --- THE II-CHAR. DATA THROUGH (XBT2,RBT2) IS TRANSMITTED TO          ABTS 400
C               THE MASTER PROGRAM THROUGH *COMMON* IN THE ARRAY CHARE.          ABTS 410
C                                                                                 ABTS 420
C                                                                                 ABTS 430
      PRMSF(EMS,GAMMA)=(1.0-((GAMMA-1.0)/(GAMMA+1.0))*EMS**2)**                  ABTS 440
     1                  (GAMMA/(GAMMA-1.0))                                      ABTS 450
      EMNMSF(EMS,GAMMA)=SQRT  (((2.0*(EMS**2))/(GAMMA+1.0))/                     ABTS 460
     1                   (1.0-((GAMMA-1.0)/(GAMMA+1.0))*(EMS**2))   )            ABTS 470
      DIMENSION PMB(100,5,2), CHARI(5,30), CHARE(5,30), P1(5), P2(5),             ABTS 480
     1   P3(5), CIID(5)                                                           ABTS 490
      COMMON PMB,CHARI,CHARE,P1,P2,P3                                             ABTS 500
      CALL BTCNST(XBT1,RBT1,ANGBT1,XBT2,RBT2,NSHAPE,C1,C2,C3)                    ABTS 510
C*****INPUT DATA, SOME OUTPUT DATA, AND COLUMN HEADINGS ARE PRINTED.              ABTS 520
      CALL OUTBT1(GAMMA,EMS1,XBT1,RBT1,ANGBT1,XBT2,RBT2,NSHAPE,                   ABTS 530
     1            C1,C2,C3,NPRINT)                                                ABTS 540
C*****SET INITIAL VALUES.                                                         ABTS 550
      NGOTO=1                                                                     ABTS 560
      NOCPTS=1                                                                    ABTS 570
      NI=1                                                                        ABTS 580
      PR1D1=PRMSF(EMS1,GAMMA)                                                     ABTS 590
      EMN1=EMNMSF(EMS1,GAMMA)                                                     ABTS 600
C*****NUMBER OF POINTS CALCULATED ON THE II-CHARACTERISTIC ORIGINATING            ABTS 610
C     AT (XBT2,RBT2) IS SPECIFIED HERE.   (LIMIT MAX. = 30).                      ABTS 620
C                                                                                 ABTS 630
```

```
      LIMITF=31
C*****FOR UNIFORM FLOW.
   10 EMS=EMS1
      DR=0.02*RBT1
      DX=SQRT   (EMN1**2-1.0)*DR
      GO TO 30
C*****LOAD INITIAL VALUES AT (XBT1,RBT1) INTO THE PMB ARRAY.
   30 PMB(1,1,1)=XBT1
      PMB(1,2,1)=RBT1
      PMB(1,3,1)=EMS
      PMB(1,4,1)=0.0
      IF(ABS (ANGBT1)-1.0E-3) 40,40,50
C*****BOATTAIL WITH ZERO INITIAL TURNING ANGLE.
   40 K=0
      GO TO 70
C*****FOR AN AFTERBODY WITH INITIAL TURNING ANGLE.
   50 IF (ANGBT1) 52,52,54
C*****FOR A BOATTAIL (BETA2E NEGATIVE).
   52 K=(ABS (57.29578*ANGBT1)+1.0)
      GO TO 56
C*****APPROXIMATE ANALYSIS FOR A FLARE (BETA2E POSITIVE).
   54 K = 1
   56 FK = K
      DTA=ANGBT1/FK
C*****CALCULATION OF CHAR. ARRAY DATA FOR POINTS L=1,K+1 AND N=1.
      DO 60 L=1,K
      PMB(L+1,1,1)=PMB(L,1,1)
      PMB(L+1,2,1)=PMB(L,2,1)
      PMB(L+1,4,1)=PMB(L,4,1) + DTA
   60 PMB(L+1,3,1)=EMSPM(PMB(1,3,1),PMB(1,4,1),PMB(L+1,4,1),GAMMA)
C*****K1 IS NUMBER OF FAMILY II CHAR. FOR SUBDIVIDED EXPANSION.
   70 K1=K+1
C*****THE INITIAL BOUNDARY POINT DATA IS PRINTED.
      DO 80 M=1,4
   80 P3(M)=PMB(K1,M,1)
      CALL OUTBT2(GAMMA,EMS1,EMN1,PRIO1,P3,N1,NGOTO,NPRINT,C0)
C*****THE FLOW FIELD CALCULATIONS ARE NOW MADE ALONG FAMILY I
C     CHARACTERISTICS STARTING FROM THE INPUT POINTS ON THE SUBDIVIDED
C     INITIAL FAMILY FOR THE FIRST AND SUBSEQUENT AXIS POINTS.
   82 N1=N1+1
C*****CALCULATION OF THE INITIAL II-CHARACTERISTIC DATA POINT.
C*****LOAD CURRENT II-CHARACTERISTICS DATA POINTS INTO PMB ARRAY.
   88 PMB(1,1,2)=PMB(1,1,1) + DX
      PMB(1,2,2)=PMB(1,2,1) + DR
      PMB(1,3,2)=EMS
      PMB(1,4,2)=PMB(1,4,1)
      GO TO (90,94,100), NGOTO
   90 DO 92 M=1,4
   92 CII0(M)=PMB(1,M,2)
      GO TO 98
   94 DO 96 M=1,4
   96 PMB(1,M,2)=CII0(M)
   98 IF(K) 140,140,100
C*****CALCULATIONS ARE FOR THE CURRENT N-TH POINT ON THE INITIAL
C     FAMILY II CHARACTERISTIC.
C
  100 DO 110 L=1,K
C*****CALCULATIONS ARE FOR THE CURRENT L-TH EXPANSION INCREMENT.
C*****LOAD DATA/ FIELD POINT CALCULATION/ STORE DATA.
      CALL MCDATA(1,L,L+1,L3,KPTS)
      CALL FPS(GAMMA,P1,P2,P3,NERROR)
      IF(NERROR) 210,110,110
  110 CALL MCDATA(2,L1,L2,L+1,KPTS)
C*****ALL FIELD POINTS ON N-TH FAMILY I CHAR. HAVE BEEN CALCULATED.
```

```
      GO TO (140,140,120), NGOTO                                        ABTS1280
C*****STORE BOATTAIL II-CHARACTERISTIC DATA.                            ABTS1290
  120 NOCPTS=NOCPTS+1                                                   ABTS1300
      DO 130 M=1,4                                                      ABTS1310
  130 CHARE (M,NOCPTS)=P3(M)                                            ABTS1320
C*****CHARACTERISTICS DATA SHIFT.                                       ABTS1330
      CALL MCDATA(3,L1,L2,L3,K+1)                                       ABTS1340
      IF(NOCPTS-LIMITE) 82,200,200                                      ABTS1350
C*****LOAD DATA/ BOUNDARY POINT CALCULATION/ STORE DATA.                ABTS1360
  140 CALL MCDATA(1,K+1,K+1,L3,KPTS)                                    ABTS1370
      CALL  BTBPS(GAMMA,P1,P2,P3,NSHAPE,C1,C2,C3,NERROR)                ABTS1380
      IF(NERROR) 200,144,144                                            ABTS1390
C*****CONTINUE BOATTAIL CALCULATION, ITERATE FOR I-CHARACTERISTIC       ABTS1400
C     THROUGH THE BOATTAIL END POINT (XBT2,RBT2), OR CALCULATE THE      ABTS1410
C     II-CHARACTERISTIC ORIGINATING AT THE POINT (XBT2,RBT2).           ABTS1420
C                                                                       ABTS1430
  144 CALL BTITER(XBT1,XBT2,P3,C110,NGOTO,NERROR)                       ABTS1440
      IF(NERROR) 200,146,146                                            ABTS1450
  146 GO TO (170,94,150), NGOTO                                         ABTS1460
C*****LOAD FIRST BOATTAIL II-CHARACTERISTIC POINT.                      ABTS1470
  150 DO 160 M=1,4                                                      ABTS1480
  160 CHARE (M,1)=P3(M)                                                 ABTS1490
  170 CALL MCDATA(2,L1,L2,K+2,KPTS)                                     ABTS1500
C*****THE CURRENT BOUNDARY POINT DATA IS NOW PRINTED.                   ABTS1510
      CALL OUTBT2(GAMMA,EMS1,EMN1,PR101,P3,NI,NGOTO,NPRINT,CD)          ABTS1520
C*****CHARACTERISTICS DATA SHIFT.                                       ABTS1530
      CALL MCDATA(3,L1,L2,L3,K+2)                                       ABTS1540
C*****ADVANCE INDEX FOR NEXT INPUT POINT ON INITIAL CHARACTERISTIC.     ABTS1550
      K=K+1                                                             ABTS1560
      GO TO 82                                                          ABTS1570
  200 RETURN                                                            ABTS1580
      END                                                               ABTS1590
```

```
      SUBROUTINE BTCNST(XBT1,RBT1,ANGBT1,XBT2,RBT2,NSHAPE,C1,C2,C3)
C
C     ***VARIABLES***
C
C     XBT1   = INITIAL LONGITUDINAL BOATTAIL COORDINATE.
C     RBT1   = INITIAL RADIAL BOATTAIL COORDINATE.
C     ANGBT1 = INITIAL BOATTAIL TURNING ANGLE, RADIANS, CCW(+).
C     XBT2   = TERMINAL LONGITUDINAL BOATTAIL COORDINATE.
C     RBT2   = TERMINAL RADIAL BOATTAIL COORDINATE.
C     NSHAPE = 1, OGIVE BOATTAIL.
C            = 2, PARABOLIC BOATTAIL.
C            = 3, CONICAL BOATTAIL.
C     C1,C2,C3 = COEFFICIENTS IN THE BOATTAIL PROFILE EQUATIONS.
C
C
      SLOPE1= TAN (ANGBT1)
      GO TO (10,20,30), NSHAPE
C*****OGIVE BOATTAIL (NSHAPE=1).
   10 C1=(0.5)*(  (XBT2-XBT1)**2-2.0*SLOPE1*RBT1*(XBT2-XBT1)+RBT2**2
     1   -RBT1**2)  /  (RBT2-RBT1-1.0*SLOPE1*(XBT2-XBT1)  )
      C2= XBT1 + SLOPE1*(RBT1-C1)
      C3= (XBT1-C2)**2 + (RBT1-C1)**2
      GO TO 40
C*****PARABOLIC BOATTAIL (NSHAPE=2).
   20 C1=( RBT2-RBT1-SLOPE1*(XBT2-XBT1) ) /
     1      ( XBT1**2+XBT2**2 -2.0*XBT1*XBT2 )
      C2=SLOPE1 -2.0*C1*XBT1
      C3=RBT1 -   ( C2*XBT1 + C1*(XBT1**2) )
      GO TO 40
C*****CONICAL BOATTAIL (NSHAPE=3).
   30 C1=RBT1
      C2=SLOPE1
      C3=XBT1
      RBT2=RBT1+SLOPE1*(XBT2-XBT1)
C
   40 RETURN
      END
```

```
      SUBROUTINE OUTBT1(GAMMA,EMS1,XBT1,RBT1,ANGBT1,XBT2,RBT2,NSHAPE,
     1                  C1,C2,C3,NPRINT)
C
C*****THIS SUBROUTINE PRINTS INPUT DATA, SOME OUTPUT DATA, AND
C     HEADINGS FOR THE BOATTAIL CALCULATIONS.
C
      PRMSF(EMS,GAMMA)=(1.0-((GAMMA-1.0)/(GAMMA+1.0))*EMS**2)**
     1                 (GAMMA/(GAMMA-1.0))
      EMNMSF(EMS,GAMMA)=SQRT  (((2.0*(EMS**2))/(GAMMA+1.0))/
     1                 (1.0-((GAMMA-1.0)/(GAMMA+1.0))*(EMS**2))   )
      IF(NPRINT) 10,10,100
 100  EMN1=EMNMSF(EMS1,GAMMA)
      PR101=PRMSF(EMS1,GAMMA)
      BETAD=57.2958*ANGBT1
C
 200  WRITE (6,1)              GAMMA,EMN1,PR101
   1  FORMAT(1H1,///,21X,23H AXISYMMETRIC BOATTAIL /,
     1 15X,30H WITH UNIFORM SUPERSONIC FLOW //,
     2 21X,20H *** INPUT DATA *** //,
     3 7X,9H GAMMA = F5.3,3X,12H MACH NO. = F5.3,3X, 8H P,PO = F6.4//)
C
 500  GO TO (2,4,6), NSHAPE
C
   2  WRITE (6,3)
   3  FORMAT(1H ,19X,27H * OGIVE BOATTAIL PROFILE *)
      GO TO 8
C
   4  WRITE (6,5)
   5  FORMAT(1H ,19X,32H * PARABOLIC BOATTAIL PROFILE * )
      GO TO 8
C
   6  WRITE (6,7)
   7  FORMAT(1H ,19X,30H * CONICAL BOATTAIL PROFILE * )
C
   8  WRITE (6,9)              XBT1,RBT1,BETAD,XBT2,RBT2,C1,C2,C3
   9  FORMAT(1H ,//,7X, 8H XBT1 = F6.3,3X, 8H RBT1 = F6.3,
     1 4X,10H ANGBT1 = F8.3//,7X,8H XBT2 = F6.3,3X,8H RBT2 = F6.3//,
     2 7X,8H C1    = F7.3,2X,8H C2    = F7.3,3X,10H C3      = F7.3///,
     3 20X,37H *** BOATTAIL SURFACE OUTPUT DATA *** //,
     4 12X,1HX,14X,1HR,10X,8HMACH NO.,9X,4HP/P1,9X,9HCP(LOCAL) //)
C
  10  RETURN
      END
```

```
      SUBROUTINE BTBPS(GAMMA,P1,P2,P3,NSHAPE,C1,C2,C3,NERROR)
C
C     B O A T T A I L   B O U N D A R Y   P O I N T
C     S U B R O U T I N E  ( B T B P S ) .
C
C*****THIS SUBROUTINE CALCULATES A POINT P3 ON THE BOATTAIL WALL
C     GIVEN THE PROPERTIES OF A POINT P1 IN THE FLOW FIELD.
C
C     ***VARIABLES***
C
C     GAMMA  = RATIO OF SPECIFIC HEATS.
C     PI(J)  = J-TH FLOW VARIABLE AT THE POINT I WHERE I=1,2,OR 3.
C     P1(J) AND P2(J),J=1,5 = FLOW VARIABLES AT KNOWN POINTS 1 AND 2.
C     P3(J),J=1,5 = FLOW VARIABLES AT THE UNKNOWN POINT 3.
C     THE J SUBSCRIPT INDICATES THE FOLLOWING VARIABLES---
C               J=1 CORRESPONDS TO X.
C               J=2 CORRESPONDS TO R.
C               J=3 CORRESPONDS TO MACH STAR (EMS).
C               J=4 CORRESPONDS TO THETA IN RADIANS (THET).
C     NSHAPE = SEE BELOW.
C     C1,C2,C3 = CONSTANTS IN THE BOATTAIL PROFILE EQUATIONS.
C     NERROR = A CONTROL VARIABLE FOR CHECKING THE POSSIBILITY THAT
C              THE CURRENT CHARACTERISTIC MISSES THE BOATTAIL AND AN
C              ITERATION IS REQUIRED.
C              NERROR =-1 ... ERROR IN CALCULATION.
C              NERROR = 0 ... NO ITERATION REQUIRED.
C              NERROR = 1 ... AN ITERATION IS REQUIRED.
C
C
C     POINTS 1 AND 3 ARE ASSUMED CONNECTED BY FAMILY I WHERE
C     POINT 3 IS ON THE WALL.
C
C     THE BOATTAIL PROFILE IS SPECIFIED BY EQUATIONS OF THE FORM---
C
C               1.  IF NSHAPE=1      OGIVE
C                   R= C1 + SQRT( C3 - (X-C2)**2 )
C
C               2.  IF NSHAPE=2      PARABOLIC
C                   R= C3 + C2*X + C1*(X**2)
C
C               3.  IF NSHAPE=3      CONICAL
C                   R= C1 + C2*(X-C3)
C
C     WHERE C1,C2,AND C3 HAVE BEEN CALCULATED FROM THE INPUT DATA
C     IN SUBROUTINE *BTCNST*.
C
C
      ALPHAF(EMSTAR,GAMMA)=ATAN (SQRT((1.0 - ((GAMMA-1.0)/(GAMMA+1.0))
     1   *(EMSTAR**2))/(EMSTAR**2-1.0)))
      AVGF(A,B) = (A + B)/2.0
      PCOEFF(EMSTAR,ALPHA)=EMSTAR*TAN (ALPHA)
      QCOEFF(NPOINT,RADIUS,EMSTAR,THETA,ALPHA)=((EMSTAR/RADIUS)*
     1   (TAN (ALPHA)**2)*TAN (THETA))/(TAN (THETA) + ((-1.0)**NPOINT)*
     2   TAN (ALPHA))
      HOCOEF (RADIUS,EMSTAR,THETA,ALPHA)=((EMSTAR/RADIUS)*TAN (ALPHA)*
     1    SIN (ALPHA)*SIN (THETA))
C*****NPOINT IN  QCOEFF()  INDICATES THE KNOWN POINT BEING USED--1 OR 2.
      DIMENSION P1(5), P2(5), P3(5)
C*****ERROR FLAG SET.
      NERROR=0
      NCOUNT=0
      NCTMAX=15
      EMSMAX=SQRT  ((GAMMA+1.0)/(GAMMA-1.0))
```

```
C*****KNOWN INPUT DATA FROM POINTS 1 AND 2.
      X1=P1(1)
      R1=P1(2)
      EMS1=P1(3)
      THET1=P1(4)
      R2=P2(2)
      EMS2=P2(3)
      THET2=P2(4)
C*****FOR AN INITIAL ESTIMATE OF THE VALUES AT POINT 3.
      R3=AVGF(R1,R2)
      EMS3=AVGF(EMS1,EMS2)
      THET3=AVGF(THET1,THET2)
      GO TO 17
C*****ITERATION FOR VARIABLES AT POINT 3.
C*****IF NSHAPE = 1,  OGIVE.
    1 A=1.0 + (TAN (DIFF13))**2
      B=2.0*(R1-C1)*TAN (DIFF13) -2.0*C2-2.0*X1*(TAN (DIFF13) )**2
      C= C2**2 - C3 + (  (R1-C1)-X1*TAN (DIFF13) )**2
      DISCR=B**2-4.0*A*C
      IF(DISCR) 19,19,3
    3 X3=(-B-SQRT  (B**2-4.0*A*C))/(2.0*A)
      R3=R1+(X3-X1)*TAN (DIFF13)
      THET3=ATAN ( (C2-X3)/(R3-C1) )
      GO TO 10
C*****IF NSHAPE = 2,  PARABOLIC.
    4 A=C1
      B=C2-TAN (DIFF13)
      C=C3-R1+X1*(TAN (DIFF13))
      DISCR=B**2-4.0*A*C
      IF(DISCR) 19,19,6
    6 X3= (-B+SQRT  (B**2-4.0*A*C))/(2.0*A)
      R3=R1+(X3-X1)*TAN (DIFF13)
      THET3=ATAN (C2+2.0*C1*X3)
      GO TO 10
C*****IF NSHAPE = 3,  CONICAL.
    7 X3 = (C1-R1-C2*C3+X1*TAN (DIFF13) ) / (TAN (DIFF13) - C2 )
      R3=R1+(X3-X1)*TAN (DIFF13)
      IF(R3) 19,19,9
    9 THET3=ATAN (C2)
C*****TEST AND EVALUATION FOR HORIZONTAL I-CHARACTERISTICS.
   10 IF(ABS (DIFF13)-1.0E-3) 11,11,12
C*****FOR I HORIZONTAL.
   11 PROD13=HQCOEF (R13,EMS13,THET13,ALPH13)*(X3-X1)
      GO TO 13
C*****FOR I-CHARACTERISTIC, O.K.
   12 PROD13=QCOEFF(1,R13,EMS13,THET13,ALPH13)*(R3-R1)
C*****CALCULATION OF FLOW VARIABLES AT POINT 3.
   13 EMS3=EMS1-P13*(THET3-THET1)+PROD13
      DIFFMS=(EMS3-SAVE1)/SAVE1
      IF((EMS3.LT.1.0) .OR. (EMS3.GT.EMSMAX)) GO TO 20
      IF(ABS (DIFFMS) .LE. 1.0E-4) GO TO 18
   17 NCOUNT=NCOUNT+1
      IF(NCOUNT .GT. NCTMAX)  GO TO 18
      SAVE1 = EMS3
      R13=AVGF(R1,R3)
      EMS13=AVGF(EMS1,EMS3)
      THET13=AVGF(THET1,THET3)
      ALPH13=ALPHAF(EMS13,GAMMA)
      DIFF13=THET13-ALPH13
      P13=PCOEFF(EMS13,ALPH13)
      GO TO (1,4,7), NSHAPE
   18 P3(1) = X3
      P3(2)=R3
      P3(3)=EMS3
```

```
      P3(4)=THET3                                                       BTBP1280
      IF(NCOUNT .GT. NCTMAX)  WRITE (6,180) NCOUNT,DIFFMS               BTBP1290
  180 FORMAT(/, 5X,37H *** CONVERGENCE ERROR IN *BTBPS*, ( ,I3,2H , ,   BTBP1300
     1   E10.3,6H ) ***  /)                                             BTBP1310
      RETURN                                                            BTBP1320
   19 NERROR=+1                                                         BTBP1330
      RETURN                                                            BTBP1340
   20 NERROR=-1                                                         BTBP1350
      WRITE (6,21)                                                      BTBP1360
   21 FORMAT(//,23X,32H *** ERROR IN  *BTBPS* CALC. ***  //)            BTBP1370
      RETURN                                                            BTBP1380
      END                                                               BTBP1390
```

```
      SUBROUTINE OUTBT2(GAMMA,EMS1,EMN1,PR101,P3,NI,NGOTO,NPRINT,CD)
C
C*****THIS SUBROUTINE PRINTS THE CALCULATED BOATTAIL SURFACE DATA
C     AT THE LOCATION, N= NOBPTS, IN THE BPTS(M,N) ARRAY.
C
C     ***VARIABLES***
C
C     GAMMA  = RATIO OF SPECIFIC HEATS.
C     EMS1   = FREESTREAM MACH STAR.
C     EMN1   = FREESTREAM MACH NUMBER.
C     PR101  = FREESTREAM STATIC-TO-STAGNATION PRESSURE RATIO.
C     P3(J)  = BOATTAIL BOUNDARY POINT DATA.
C     THE J SUBSCRIPT INDICATES THE FOLLOWING VARIABLES---
C               J=1 CORRESPONDS TO X.
C               J=2 CORRESPONDS TO R.
C               J=3 CORRESPONDS TO MACH STAR (EMS).
C               J=4 CORRESPONDS TO THETA IN RADIANS (THETA).
C     NI     = 1, ...   LOCATES THE BOUNDARY POINT ON THE BOATTAIL
C                       SURFACE.
C     NGOTO  = 1, NORMAL BOATTAIL CALCULATION.
C            = 2, ITERATION FOR I-CHARACTERISTIC THROUGH (XBT2,RBT2).
C            = 3, CALCULATION OF II-CHARACTERISTIC THROUGH (XBT2,RBT2).
C     NPRINT = SEE SUBROUTINE *ABTS*.
C
C
      PRMSF(EMS,GAMMA)=(1.0-((GAMMA-1.0)/(GAMMA+1.0))*EMS**2)**
     1                  (GAMMA/(GAMMA-1.0))
      EMNMSF(EMS,GAMMA)=  SQRT(((2.0*(EMS**2))/(GAMMA+1.0))/
     1                    (1.0-((GAMMA-1.0)/(GAMMA+1.0))*(EMS**2))   )
      DIMENSION P3(5)
      IF(NPRINT) 80,80,10
   10 X=P3(1)
      R=P3(2)
      EMS=P3(3)
      EMN=EMNMSF(EMS,GAMMA)
      PROBO1=1.0
      PRB1=(PRMSF(EMS,GAMMA)/PR101)*PROBO1
C*****THE LOCAL PRESSURE COEFFICIENT IS CALCULATED.  CP IS BASED ON
C     THE FREESTREAM MACH NUMBER AND PRESSURE.
C
      CP=(PRB1-1.0)/(0.5*GAMMA*(EMN1**2))
      WRITE (6,20) X,R,EMN,PRB1,CP
   20 FORMAT(7X,F10.5,5X,F10.5,5X,F10.5,5X,F10.5,5X,F10.5)
C*****THE BOATTAIL DRAG COEFFICIENT IS CALCULATED.  CD IS REFERENCED
C     TO THE FREESTREAM PRESSURE AND MACH NUMBER CONDITIONS.
C
      IF(NI-1) 30,30,40
C*****INITIALIZE CD CALCULATION.
   30 CD=0.0
      DENOM=0.5*GAMMA*(EMN1**2)*(R**2)
      GO TO 50
   40 AVGPR=(0.5*(PRMSF(EMSL,GAMMA)+PRMSF(EMS,GAMMA))*PROBO1)/PR101
      CD=CD+(((1.0-AVGPR)*(RL**2-R**2))/DENOM)
   50 RL=R
      EMSL=EMS
      GO TO (80,80,60), NGOTO
   60 WRITE (6,70) CD
   70 FORMAT(/,25X,28H *** DRAG COEFFICIENT, CD = F8.5,3H*** , //)
   80 RETURN
      END
```

```
      SUBROUTINE BTITER(XBT1,XBT2,P3,CIID,NGOTO,NERROR)
C
C*****SUBROUTINE CONTROLS BOATTAIL ITERATION FOR I-CHARACTERISTIC
C     PASSING THROUGH (XBT2,RBT2).
C
C     ***VARIABLES***
C
C     XBT2    = LONGITUDINAL COORD. OF TERMINAL POINT OF THE BOATTAIL.
C     P3      = CURRENT BOUNDARY POINT FROM SUBROUTINE *BTBPS*.
C     CIID    = CURRENT INITIAL II-CHARACTERISTIC DATA POINT.
C     NGOTO   = 1, BOATTAIL CALCULATION.
C             = 2, ITERATION FOR I-CHARACTERISTIC THROUGH (XBT2,RBT2).
C             = 3, CALCULATION OF II-CHARACTERISTIC THROUGH (XBT2,RBT2).
C     NERROR  = -1, ERROR IN ITERATION, GO TO NEXT CASE.
C             = 0, BOUNDARY POINT CALCULATION O.K.
C             = 1, ERROR IN BOUNDARY POINT CALCULATION, START ITERATION.
C
C
      DIMENSION P3(5), SAVEL(5), SAVER(5), CIID(5)
      XBT = (XBT2-XBT1)
C*****ERROR OR ITERATION DETECTION.
      GO TO (10,60), NGOTO
   10 IF(NERROR) 20,20,50
   20 IF(XBT2-P3(1)) 50,190,30
   30 ITER=1
      DO 40 M=1,4
   40 SAVEL(M)=CIID(M)
      RETURN
C*****ITERATION SEQUENCE.
   50 NGOTO=2
   60 IF(NERROR) 70,70,110
   70 IF(ABS((XBT2-P3(1))/XBT)-1.0E-4) 190,190,80
   80 IF(XBT2-P3(1)) 110,190,90
   90 DO 100 M=1,4
  100 SAVEL(M)=CIID(M)
      GO TO 130
  110 DO 120 M=1,4
  120 SAVER(M)=CIID(M)
  130 IF(ITER-15) 160-160,140
  140 NERROR=-1
      WRITE (6,150)
  150 FORMAT(//,5X,67H *** MAX. NO. ITERATIONS EXCEEDED IN SBR. BTITER.
     1 GO TO NEXT CASE. //)
      RETURN
  160 IF(ABS ((SAVEL(1)-SAVER(1))/XBT)-1.0E-4) 190,190,170
  170 ITER=ITER+1
C*****INTERVAL HALVE FOR VALUES ON INITIAL II-CHARACTERISTIC.
      DO 180 M=1,4
  180 CIID(M)=0.5*(SAVEL(M)+SAVER(M))
      RETURN
C*****SOLUTION FOUND.
  190 NGOTO=3
      RETURN
      END
```

```
      SUBROUTINE UFLOC(GAMMA,EMS,XC,RC,N1,CHAR,NFLOW)
C
C*****THIS SUBROUTINE SUBDIVIDES THE INITIAL FAMILY II CHARACTERISTIC
C     AND CALCULATES THE INPUT DATA FOR POINTS ON THIS CHARACTERISTIC
C     FOR UNIFORM FLOW.
C
C     ***VARIABLES***
C
C     GAMMA = RATIO OF THE SPECIFIC HEATS.
C     EMS   = APPROACH MACH STAR.
C     XC    = LONGITUDINAL COORDINATE WHERE EXPANSION IS CENTERED.
C     RC    = RADIAL COORDINATE WHERE EXPANSION IS CENTERED.
C             NEGATIVE FOR INTERNAL FLOW AND POSITIVE FOR EXTERNAL FLOW.
C     N1    = NUMBER OF INCREMENTS OF INITIAL CHAR. (MAX. IS 29)
C     CHAR  = INITIAL CHARACTERISTIC DATA ARRAY.
C     NFLOW = 1, INTERNAL FLOW.
C           = 2, EXTERNAL FLOW.
C
C
      EMNMSF(EMS,GAMMA)=SQRT(((2.0*(EMS**2))/(GAMMA+1.0))/
     1                  (1.0-((GAMMA-1.0)/(GAMMA+1.0))*(EMS**2))  )
      DIMENSION CHAR(5,30)
      GO TO (10,20), NFLOW
C*****FOR INTERNAL FLOW.
   10 N1=15
      FN1=N1 -
      DR=ABS (RC)/FN1
      GO TO 30
C*****FOR EXTERNAL FLOW.
   20 DR=0.03*ABS (RC)
   30 DX=DR*SQRT((EMNMSF(EMS,GAMMA))**2-1.0)
      NPTS=N1+1
      DO 40 N=1,NPTS
      FN=N-1
      CHAR (1,N) = XC + FN*DX
      CHAR (2,N) = RC + FN*DR
      CHAR (3,N) = EMS
   40 CHAR (4,N) = 0.0
      RETURN
      END
```

```
      SUBROUTINE CNFLOC(GAMMA,EMS,BETA,XC,RC,N1)
C
C*****FOR INTERNAL CONICAL FLOW, THIS SUBROUTINE SUBDIVIDES THE
C     NON-CHARACTERISTIC UNIFORM FLOW CURVE THROUGH THE POINT (XC,RC)
C     AND THEN CALCULATES THE INPUT DATA ALONG THE FAMILY II
C     CHARACTERISTIC WHICH ORIGINATES AT THIS POINT.
C
C     SUBROUTINE REQUIRES---FPS,APS.
C
C     ***VARIABLES***
C
C     GAMMA = RATIO OF THE SPECIFIC HEATS.
C     EMS   = APPROACH MACH STAR.
C     BETA  = FLOW ANGLE, NEGATIVE, (IN RADIANS), AT (XC,RC).
C     XC    = LONGITUDINAL COORDINATE WHERE EXPANSION IS CENTERED.
C     RC    = RADIAL COORDINATE WHERE EXPANSION IS CENTERED.
C     N1    = NUMBER OF INCREMENTS OF INITIAL CHAR. (MAX. IS 29)
C
C
      DIMENSION PMB(100,5,2), CHARI(5,30), CHARE(5,30), P1(5), P2(5),
     1   P3(5)
      COMMON PMB, CHARI, CHARE, P1, P2, P3
C
      RCONE=RC/SIN (BETA)
C*****SUBDIVISION OF THE NON-CHARACTERISTIC CURVE INTO N2 INCREMENTS.
C     (N1=2*N2).  TO CHANGE THE NUMBER OF INCREMENTS CHANGE ONLY N2.
C     (MAXIMUM N2 IS 14).
C
      N2=10
      FN2=N2
      N1=2*N2
C*****STORE INITIAL DATA POINT.
      PMB(1,1,1)=XC
      PMB(1,2,1)=RC
      PMB(1,3,1)=EMS
      PMB(1,4,1)=BETA
      DO 10 M=1,4
   10 CHARI(M,1)=PMB(1,M,1)
C*****THE FLOW FIELD CALCULATIONS ARE NOW MADE ALONG FAMILY I
C     CHARACTERISTICS STARTING FROM THE POINTS ON THE SUBDIVIDED
C     NON-CHARACTERISTICS CURVE.  THIS SEQUENCE IS NOT APPLICABLE FOR
C     CALCULATIONS INVOLVING OTHER THAN THE FIRST AXIS POINT.
C*****THE CALCULATED FLOW FIELD DATA FOR THE (N1+1) POINTS ON THE
C     FAMILY II CHARACTERISTIC ORIGINATING AT (XC,RC) WILL BE STORED AT
C     CHARI(M,N), WHERE N=1,N1+1.
C
      DO 40 N=1,N2
C*****CALCULATE DATA ON THE NON-CHARACTERISTIC INPUT CURVE.
      FN=N
      ANGLER=BETA*(1.0-FN/FN2)
      PMB(N+1,1,2)=XC+RCONE*(COS(ANGLER)-COS(BETA))
      PMB(N+1,2,2)=RCONE*SIN(ANGLER)
      PMB(N+1,3,2)=EMS
      PMB(N+1,4,2)=ANGLER
      KPTS=N+1
      DO 20 I=1,N
      L=N-I+1
C*****LOAD DATA/ CALCULATE FIELD POINT/ STORE DATA.
      CALL MCDATA(1,L+1,L,L3,KPTS)
      CALL FPS(GAMMA,P1,P2,P3,NERROR)
      CALL MCDATA(2,L1,L2,L,KPTS)
   20 CONTINUE
C*****STORE INITIAL CHARACTERISTICS DATA.
```

```
      DO 30 M=1,4                                                       CNFL 640
   30 CHARI(M,N+1)=PMB(1,M,2)                                           CNFL 650
C*****SHIFT METHOD OF CHARACTERISTICS DATA.                             CNFL 660
      CALL MCDATA(3,L1,L2,L3,KPTS)                                      CNFL 670
   40 CONTINUE                                                          CNFL 680
C*****THE CALCULATION SEQUENCE IS NOW MODIFIED FOR SUBSEQUENT AXIS      CNFL 690
C     AND FIELD POINT CALCULATIONS.                                     CNFL 700
C                                                                       CNFL 710
      DO 90 N=1,N2                                                      CNFL 720
      NI=N2+N                                                           CNFL 730
      L=N2+1-N                                                          CNFL 740
C*****LOAD DATA/ CALCULATE FIELD POINT/ STORE DATA.                     CNFL 750
      CALL MCDATA(1,L,L,L3,KPTS)                                        CNFL 760
      CALL APS (GAMMA,P2,P3,NERROR)                                     CNFL 770
      CALL MCDATA(2,L1,L2,L,KPTS)                                       CNFL 780
      IF(N1-NI) 70,70,50                                                CNFL 790
   50 NII=L-1                                                           CNFL 800
      LII=L                                                             CNFL 810
      DO 60 I=1,NII                                                     CNFL 820
C*****LOAD DATA/ CALCULATE FIELD POINT/ STORE DATA.                     CNFL 830
      CALL MCDATA(1,LII,LII-1,L3,KPTS)                                  CNFL 840
      CALL FPS(GAMMA,P1,P2,P3,NERROR)                                   CNFL 850
      CALL MCDATA(2,L1,L2,LII-1,KPTS)                                   CNFL 860
   60 LII=LII-1                                                         CNFL 870
C*****STORE INITIAL CHARACTERISTICS DATA.                               CNFL 880
   70 DO 80 M=1,4                                                       CNFL 890
   80 CHARI(M,NI+1)=PMB(1,M,2)                                          CNFL 900
C*****SHIFT METHOD OF CHARACTERISTICS DATA.                             CNFL 910
      CALL MCDATA(3,L1,L2,L3,L)                                         CNFL 920
   90 CONTINUE                                                          CNFL 930
      RETURN                                                            CNFL 940
      END                                                               CNFL 950
```

```
      SUBROUTINE PMSBR(GAMMA,EMSTAR,PRATIO,BETA,XC,RC,K)
C
C*****THIS SUBROUTINE SUBDIVIDES THE INITIAL PRANDTL-MEYER EXPANSION
C     (WAVES OF FAMILY II) INTO APPROXIMATELY 1 DEGREE INCREMENTS.
C     INPUT DATA IS THEN CALCULATED FOR THE METHOD OF CHARACTERISTICS
C     NET AT THE POINT WHERE THE EXPANSION IS CENTERED.
C
C     SUBROUTINE REQUIRES---EMSPM.
C
C     ***VARIABLES***
C
C     GAMMA  = RATIO OF SPECIFIC HEATS.
C     EMSTAR = APPROACH MACH STAR.
C     PRATIO = EXPANSION PRESSURE RATIO (P/PO).
C     BETA   = INITIAL FLOW ANGLE IN RADIANS.
C     XC     = LONGITUDINAL COORDINATE WHERE EXPANSION IS CENTERED.
C     RC     = RADIAL COORDINATE WHERE EXPANSION IS CENTERED.
C     K      = NUMBER OF INCREMENTS OF THE TURNING ANGLE.
C     PMB    = A 3-DIMENSIONAL ARRAY, PMB(L,M,N), OF DATA FOR THE
C                METHOD OF CHARACTERISTICS NET.  THE SUBSCRIPTS L,M,N
C                HAVE THE FOLLOWING RANGES AND MEANINGS---
C                L=1,K+1 AND CORRESPONDS TO THE L-TH POINT OF THE
C                         SUBDIVIDED PRANDTL-MEYER EXPANSION.
C                M=1 CORRESPONDS TO X.
C                M=2 CORRESPONDS TO R.
C                M=3 CORRESPONDS TO MACH STAR (EMS).
C                M=4 CORRESPONDS TO THETA IN RADIANS (THETA).
C                N=1,2 CORRESPONDS TO THE PREVIOUS OR CURRENT I-CHAR.
C                L,N=1 AT POINT WHERE THE INITIAL FLOW CONDITIONS ARE
C                       SPECIFIED AND THE P-M EXPANSION IS CENTERED.
C
C
      OMEGAF(A,B)=SQRT((B+1.0)/(B-1.0))*ATAN (SQRT((A**2-1.0)/
     1 ((B+1.0)/(B-1.0)-A**2)))-ATAN (SQRT(((B+1.0)/(B-1.0))*
     2 ((A**2-1.0)/((B+1.0)/(B-1.0)-A**2))))
      EMSPRF(A,B)=SQRT(((B+1.0)/(B-1.0))*(1.0-A**((B-1.0)/B)))
      DIMENSION PMB(100,5,2), CHARI(5,30), CHARE(5,30), P1(5), P2(5),
     1   P3(5)
      COMMON PMB, CHARI, CHARE, P1, P2, P3
C
      EMS1=EMSTAR
      EMS2=EMSPRF(PRATIO,GAMMA)
C*****FOR WAVES OF FAMILY II.
      ANGLER=-(OMEGAF(EMS2,GAMMA) - OMEGAF(EMS1,GAMMA))
      IF (ANGLER)10,10,20
   10 K=(ABS (57.29578*ANGLER)+1.0)
      GO TO 30
   20 K = 1
   30 FK=K
      DELTA=ANGLER/FK
C*****KNOWN INITIAL INPUT DATA FOR PMB ARRAY.
      PMB(1,1,1)=XC
      PMB(1,2,1)=RC
      PMB(1,3,1)=EMS1
      PMB(1,4,1)=BETA
C*****CALCULATION OF ARRAY DATA FOR POINTS L=1,K+1 AND N=1.
      DO 1 L=1,K
      PMB(L+1,1,1)=PMB(L,1,1)
      PMB(L+1,2,1)=PMB(L,2,1)
      PMB(L+1,4,1)=PMB(L,4,1) + DELTA
    1 PMB(L+1,3,1)=EMSPM(EMS1,PMB(1,4,1),PMB(L+1,4,1),GAMMA)
      RETURN
      END
```

```
      FUNCTION EMSPM(EMSTAR,THETA1,THETA2,GAMMA)
C
C*****THIS FUNCTION CALCULATES THE FINAL MACH STAR AFTER A
C     PRANDTL-MEYER EXPANSION OR COMPRESSION GIVEN INITIAL M*
C     AND THE TURNING ANGLE IN RADIANS.
C
C     *** VARIABLES ***
C
C     EMSPM  = FINAL MACH STAR AFTER THE TURN OF (THETA2 - THETA1).
C     EMSTAR = APPROACH MACH STAR.
C     THETA1 = APPROACH FLOW ANGLE (IN RADIANS).
C     THETA2 = FINAL FLOW ANGLE (IN RADIANS).
C     GAMMA  = RATIO OF SPECIFIC HEATS.
C
C     THE SIGN CONVENTION FOR ANGLES IS CW(-) AND CCW(+).
C
C
      OMEGAF(A,B)=  SQRT((B+1.0)/(B-1.0))*ATAN (  SQRT((A**2-1.0)/
     1 ((B+1.0)/(B-1.0)-A**2)))-ATAN (  SQRT(((B+1.0)/(B-1.0))*
     2 ((A**2-1.0)/((B+1.0)/(B-1.0)-A**2))))
C*****SET INITIAL VALUES.
      NIT = 0
      NITMAX = 20
      NTYPE=1
C*****NTYPE=1, INTERVAL HALVE.  NTYPE=2, INTERPOLATE.
      RATIO=0.5
      ANGLE=(THETA2-THETA1)
      IF(ANGLE)  20,20,10
C*****FOR A REVERSIBLE COMPRESSION.
   10 EMSN=1.0
      OMEGAN=0.0
      EMSP=EMSTAR
      GO TO 30
C*****FOR A REVERSIBLE EXPANSION.
   20 EMSN=EMSTAR
      OMEGAN=OMEGAF(EMSN,GAMMA)
      EMSP=  SQRT((GAMMA+1.0)/(GAMMA-1.0))
C*****EVALUATE OMEGA FUNCTION FOR CONDITION *2*.
   30 OMEGA2=(OMEGAF(EMSTAR,GAMMA)-ANGLE)
C*****DOES THE SOLUTION EXIST.
      IF(OMEGA2)  40,60,70
   40 WRITE (6,50)
   50 FORMAT(//,10X,25H *** ERROR IN -EMSPM- ***  /)
      RETURN
   60 EMSPM=1.0
      RETURN
C*****INITIALLY INTERVAL HALVE AND THEN INTERPOLATE.
   70 NIT = NIT + 1
      IF(NIT .GT. NITMAX) GO TO 140
      EMST=EMSN+RATIO*(EMSP-EMSN)
      OMEGAT=OMEGAF(EMST,GAMMA)
      DIFFO=(OMEGAT-OMEGA2)/OMEGA2
      IF(ABS (DIFFO)-1.0E-4)  140,140,80
   80 IF(DIFFO)  90,140,100
   90 EMSN=EMST
      OMEGAN=OMEGAT
      GO TO 110
  100 EMSP=EMST
      OMEGAP=OMEGAT
      NTYPE=2
  110 DIFFMS = (EMSP-EMSN)/EMSN
      IF(ABS(DIFFMS) - 1.0E-4)  140,140,120
  120 GO TO (70,130), NTYPE
```

```
C*****INTERPOLATE FOR THE SOLUTION.                                      EMSP 640
  130 RATIO=(OMEGA2-OMEGAN)/(OMEGAP-OMEGAN)                              EMSP 650
      GO TO 70                                                          EMSP 660
C*****SOLUTION FOUND.                                                    EMSP 670
  140 EMSPM=EMST                                                        EMSP 680
      IF(NIT .GT. NITMAX) WRITE (6,150) NIT,DIFFO                       EMSP 690
  150 FORMAT(/,5X,34H ***CONVERGENCE ERROR IN EMSPM, ( , I3, 2H , ,     EMSP 700
     1   E10.3, 6H ) ***  /)                                            EMSP 710
      RETURN                                                            EMSP 720
      END                                                               EMSP 730
```

```
      SUBROUTINE OUTBDY(N,NPRINT,BPTS)
C
C*****SUBROUTINE PRINTS THE CURRENT CALCULATED BOUNDARY POINT DATA.
C
C     ***VARIABLES***
C
C     N      = NUMBER OF CURRENT BOUNDARY POINT.
C     NPRINT = -1 OR 0, C.P.B. DATA NOT PRINTED.
C              +1, C.P.B. DATA PRINTED.
C     BPTS(M,N) = CURRENT BOUNDARY DATA.
C                 M=1 CORRESPONDS TO X.
C                 M=2 CORRESPONDS TO R.
C                 M=3 CORRESPONDS TO MACH STAR (EMS).
C                 M=4 CORRESPONDS TO THETA IN RADIANS (THETA).
C
C
      DIMENSION BPTS(5,30)
C
      IF(NPRINT) 2,2,1
    1 X=BPTS(1,N)
      R=BPTS(2,N)
      THETA=57.29578*BPTS(4,N)
C
      WRITE (6,10)           X, R, THETA
   10 FORMAT(F15.6, F29.6, F30.6)
C
    2 RETURN
      END
```

```
      SUBROUTINE MCDATA(NOP,L1,L2,L3,KPTS)
C
C*****SUBROUTINE LOADS, STORES, OR SHIFTS
C     METHOD OF CHARACTERISTICS DATA.
C
C     NOP =  1, LOADS PMB DATA IN P1,P2.
C         =  2, STORES P3 DATA IN PMB.
C         =  3, SHIFTS PMB DATA FROM I-2 TO I-1.
C
C
      DIMENSION PMB(100,5,2), CHARI(5,30), CHARE(5,30), P1(5), P2(5),
     1   P3(5)
      COMMON PMB, CHARI, CHARE, P1, P2, P3
C
      GO TO (10,30,50), NOP
C
   10 DO 20 M=1,4
      P1(M)=PMB(L1,M,2)
   20 P2(M)=PMB(L2,M,1)
      RETURN
C
   30 DO 40 M=1,4
   40 PMB(L3,M, 2)=P3(M)
      RETURN
C
   50 DO 70 KII=1,KPTS
      DO 60 M=1,4
   60 PMB(KII,M, 1)=PMB(KII,M, 2)
   70 CONTINUF
      RETURN
C
      END
```

```
      SUBROUTINE FPS(GAMMA,P1,P2,P3,NERROR)
C
C*****AXISYMMETRIC FIELD POINT SUBROUTINE  (FPS)
C
C     ***VARIABLES***
C
C     GAMMA  = RATIO OF SPECIFIC HEATS.
C     PI(J)  = J-TH FLOW VARIABLE AT THE POINT I WHERE I=1,2,OR 3.
C     P1(J) AND P2(J),J=1,4 = FLOW VARIABLES AT KNOWN POINTS 1 AND 2.
C     P3(J),J=1,4 = FLOW VARIABLES AT THE UNKNOWN POINT 3.
C     THE J SUBSCRIPT INDICATES THE FOLLOWING VARIABLES---
C                J=1 CORRESPONDS TO X.
C                J=2 CORRESPONDS TO R.
C                J=3 CORRESPONDS TO MACH STAR (EMS).
C                J=4 CORRESPONDS TO THETA IN RADIANS (THET).
C     NERROR = -1, ERROR IN CALCULATION.
C            = 0, CALCULATION O.K.
C
C     POINTS 1 AND 3 ARE ASSUMED CONNECTED BY FAMILY I.
C     POINTS 2 AND 3 ARE ASSUMED CONNECTED BY FAMILY II.
C
C
      ALPHAF(EMSTAR,GAMMA)=ATAN (SQRT((1.0 - ((GAMMA-1.0)/(GAMMA+1.0))
     1   *(EMSTAR**2))/(EMSTAR**2-1.0)))
      AVGF(A,B) = (A + B)/2.0
      PCOEFF(EMSTAR,ALPHA)=EMSTAR*TAN (ALPHA)
      QCOEFF(NPOINT,RADIUS,EMSTAR,THETA,ALPHA)=((EMSTAR/RADIUS)*
     1   (TAN (ALPHA)**2)*TAN (THETA))/(TAN (THETA) + ((-1.0)**NPOINT)*
     2   TAN (ALPHA))
      HQCOEF (RADIUS,EMSTAR,THETA,ALPHA)=((EMSTAR/RADIUS)*TAN (ALPHA)*
     1    SIN (ALPHA)*SIN (THETA))
C*****NPOINT IN  QCOEFF()  INDICATES THE KNOWN POINT BEING USED--1 OR 2.
      DIMENSION P1(5), P2(5), P3(5)
C*****ERROR FLAG SET.
      NCOUNT=0
      NCTMAX=15
      NERROR=0
      EMSMAX=SQRT  ((GAMMA+1.0)/(GAMMA-1.0))
C*****KNOWN INPUT DATA FROM POINTS 1 AND 2.
      X1=P1(1)
      R1=P1(2)
      EMS1=P1(3)
      THET1=P1(4)
C
      X2=P2(1)
      R2=P2(2)
      EMS2=P2(3)
      THET2=P2(4)
C*****FOR INITIAL ESTIMATE OF AVERAGE VALUES BETWEEN POINTS 1-3 AND 2-3.
      R3=AVGF(R1,R2)
      EMS3=AVGF(EMS1,EMS2)
      THET3=AVGF(THET1,THET2)
      GO TO 11
C*****ITERATION FOR VARIABLES AT POINT 3.
    1 X3=(R2 - R1 + X1*YAN (DIFF13) - X2*TAN (SUM23))/
     1   (TAN (DIFF13) - TAN (SUM23))
      R3=(R1 + (X3 - X1)*TAN (DIFF13))
C*****TEST AND EVALUATION FOR HORIZONTAL I OR II CHARACTERISTICS.
      IF(ABS (DIFF13)-1.0E-3) 2,2,3
C*****FOR I HORIZONTAL.
    2 PROD13=HQCOEF (R13,EMS13,THET13,ALPH13)*(X3-X1)
      GO TO 4
    3 PROD13=QCOEFF(1,R13,EMS13,THET13,ALPH13)*(R3-R1)
```

```
   4  IF(ABS (SUM23)-1.0E-3) 5,5,6
C*****FOR II HORIZONTAL.
   5  PROD23=HQCOEF (R23,EMS23,THET23,ALPH23)*(X3-X2)
      GO TO 7
   6  PROD23=QCOEFF(2,R23,EMS23,THET23,ALPH23)*(R3-R2)
C*****CALCULATION OF FLOW VARIABLES AT POINT 3.
   7  THET3=(P13*THET1 + P23*THET2 + PROD13 - PROD23 + EMS1 - EMS2)/
     1   (P13+P23)
      EMS3=EMS1 - P13*(THET3-THET1) + PROD13
      DIFFMS = (EMS3-SAVE1)/SAVE1
      IF((EMS3.LT.1.0) .OR. (EMS3.GT.EMSMAX)) GO TO 13
      IF(ABS (DIFFMS) .LE. 1.0E-4) GO TO 12
C
  11  NCOUNT=NCOUNT+1
      IF(NCOUNT.GT.NCTMAX) GO TO 12
      SAVE1 = EMS3
      R13=AVGF(R1,R3)
      R23=AVGF(R2,R3)
      EMS13=AVGF(EMS1,EMS3)
      EMS23=AVGF(EMS2,EMS3)
      THET13=AVGF(THET1,THET3)
      THET23=AVGF(THET2,THET3)
      ALPH13=ALPHAF(EMS13,GAMMA)
      ALPH23=ALPHAF(EMS23,GAMMA)
      P13=PCOEFF(EMS13,ALPH13)
      P23=PCOEFF(EMS23,ALPH23)
      DIFF13=THET13-ALPH13
      SUM23=THET23+ALPH23
      GO TO 1
C
  12  P3(1) = X3
      P3(2)=R3
      P3(3)=EMS3
      P3(4)=THET3
      IF(NCOUNT .GT. NCTMAX)  WRITE (6,120) NCOUNT,DIFFMS
 120  FORMAT(/, 5X,35H *** CONVERGENCE ERROR IN *FPS*, ( ,I3,2H , ,
     1   E10.3,6H ) ***  /)
      RETURN
C
  13  NERROR=-1
      WRITE (6,14)
  14  FORMAT(//,23X,29H *** ERROR IN *FPS* CALC. ***  //)
      RETURN
      END
```

```
      SUBROUTINE APS (GAMMA,P2,P3,NERROR)
C
C*****AXISYMMETRIC AXIS POINT SUBROUTINE (APS)
C
C     FOR THIS SUBROUTINE, THE UNKNOWN POINT 3 IS ON THE AXIS.
C     THE KNOWN POINT 2 AND THE UNKNOWN POINT 3 ARE ALONG FAMILY II.
C
C     ***VARIABLES***
C
C     GAMMA  = RATIO OF SPECIFIC HEATS.
C     PI(J)  = J-TH FLOW VARIABLE AT THE POINT I WHERE I=1,2,OR 3.
C     P2(J),J=1,4 = FLOW VARIABLES AT KNOWN POINT 2.
C     P3(J),J=1,4 = FLOW VARIABLES AT THE UNKNOWN POINT 3.
C     THE J SUBSCRIPT INDICATES THE FOLLOWING VARIABLES---
C              J=1 CORRESPONDS TO X.
C              J=2 CORRESPONDS TO R.
C              J=3 CORRESPONDS TO MACH STAR (EMS).
C              J=4 CORRESPONDS TO THETA IN RADIANS (THET).
C     NERROR = -1, ERROR IN CALCULATION.
C            = 0, CALCULATION O.K.
C
C
      ALPHAF(EMSTAR,GAMMA)=ATAN (SQRT((1.0 - ((GAMMA-1.0)/(GAMMA+1.0))
     1   *(EMSTAR**2))/(EMSTAR**2-1.0)))
      AVGF(A,B) = (A + B)/2.0
      PCOEFF(EMSTAR,ALPHA)=EMSTAR*TAN (ALPHA)
      QCOEFF(NPOINT,RADIUS,EMSTAR,THETA,ALPHA)=((EMSTAR/RADIUS)*
     1   (TAN (ALPHA)**2)*TAN (THETA))/(TAN (THETA) + ((-1.0)**NPOINT)*
     2   TAN (ALPHA))
C*****NPOINT IN  QCOEFF()  INDICATES THE KNOWN POINT BEING USED--1 OR 2.
      DIMENSION P2(5), P3(5)
C*****ERROR FLAG SET.
      NCOUNT = 0
      NCTMAX=15
      NERROR=0
      EMSMAX=SQRT  ((GAMMA+1.0)/(GAMMA-1.0))
C*****KNOWN INPUT DATA FOR POINTS 2 AND 3.
      X2=P2(1)
      R2=P2(2)
      EMS2=P2(3)
      THET2=P2(4)
      R3=0.0
      THET3=0.0
C*****FOR INITIAL ESTIMATE OF AVERAGE VALUES BETWEEN POINTS 2 AND 3.
      EMS3=EMS2
      R23=AVGF(R2,R3)
      THET23=AVGF(THET2,THET3)
      GO TO 5
C*****ITERATION FOR VARIABLES AT POINT 3.
    1 X3=X2 - (R2/TAN (SUM23))
      EMS3=EMS2 - P23*THET2 - Q23*R2
      DIFFMS = (EMS3-SAVE1)/SAVE1
      IF((EMS3.LT.1.0) .OR. (EMS3.GT.EMSMAX))  GO TO 7
      IF(ABS(DIFFMS) .LE. 1.0E-4)  GO TO 6
C
    5 NCOUNT=NCOUNT+1
      IF(NCOUNT.GT.NCTMAX) GO TO 6
      SAVE1=EMS3
      EMS23=AVGF(EMS2,EMS3)
      ALPH23=ALPHAF(EMS23,GAMMA)
      SUM23=THET23+ALPH23
      P23=PCOEFF(EMS23,ALPH23)
      Q23=QCOEFF(2,R23,EMS23,THET23,ALPH23)
```

```
      GO TO 1                                                           APS  640
C                                                                       APS  650
    6 P3(1)=X3                                                          APS  660
      P3(2)=R3                                                          APS  670
      P3(3)=EMS3                                                        APS  680
      P3(4)=THET3                                                       APS  690
      IF(NCOUNT .GT. NCTMAX)  WRITE (6,60) NCOUNT,DIFFMS                APS  700
   60 FORMAT(/, 5X,35H *** CONVERGENCE ERROR IN *APS*, ( ,I3,2H , ,     APS  710
     1   E10.3,6H ) ***  /)                                             APS  720
      RETURN                                                            APS  730
C                                                                       APS  740
    7 NERROR=-1                                                         APS  750
      WRITE (6,8)                                                       APS  760
    8 FORMAT(//,23X,29H *** ERROR IN *APS* CALC. ***  //)               APS  770
      RETURN                                                            APS  780
      END                                                               APS  790
```

```
      SUBROUTINE CPBS(GAMMA, P1, P2, P3, NERROR)
C
C*****AXISYMMETRIC CONSTANT PRESSURE BOUNDARY SUBROUTINE (CPBS)
C
C     POINTS 2 AND 3 ARE ON THE SAME CONSTANT PRESSURE BOUNDARY.
C     POINTS 1 AND 3 ARE ASSUMED CONNECTED BY FAMILY I.
C
C     ***VARIABLES***
C
C     GAMMA  = RATIO OF SPECIFIC HEATS.
C     PI(J)  = J-TH FLOW VARIABLE AT THE POINT I WHERE I=1,2,OR 3.
C     P1(J) AND P2(J),J=1,4 = FLOW VARIABLES AT KNOWN POINTS 1 AND 2.
C     P3(J),J=1,4 = FLOW VARIABLES AT THE UNKNOWN POINT 3.
C     THE J SUBSCRIPT INDICATES THE FOLLOWING VARIABLES---
C               J=1 CORRESPONDS TO X.
C               J=2 CORRESPONDS TO R.
C               J=3 CORRESPONDS TO MACH STAR (EMS).
C               J=4 CORRESPONDS TO THETA IN RADIANS (THET).
C     NERROR = -1, ERROR IN CALCULATION.
C            = 0, CALCULATION O.K.
C
C
      ALPHAF(EMSTAR,GAMMA)=ATAN (SQRT((1.0 - ((GAMMA-1.0)/(GAMMA+1.0))
     1   *(EMSTAR**2))/(EMSTAR**2-1.0)))
      AVGF(A,B) = (A + B)/2.0
      PCOEFF(EMSTAR,ALPHA)=EMSTAR*TAN (ALPHA)
      HQCOEF (RADIUS,EMSTAR,THETA,ALPHA)=((EMSTAR/RADIUS)*TAN (ALPHA)*
     1     SIN (ALPHA)*SIN (THETA))
      QCOEFF(NPOINT,RADIUS,EMSTAR,THETA,ALPHA)=((EMSTAR/RADIUS)*
     1   (TAN (ALPHA)**2)*TAN (THETA))/(TAN (THETA) + ((-1.0)**NPOINT)*
     2   TAN (ALPHA))
C*****NPOINT IN  QCOEFF()  INDICATES THE KNOWN POINT BEING USED--1 OR 2.
      DIMENSION P1(5), P2(5), P3(5)
C*****ERROR FLAG SET.
      NCOUNT=0
      NCTMAX=15
      NERROR=0
C*****KNOWN INPUT DATA FROM POINTS 1 AND 2.
      X1=P1(1)
      R1=P1(2)
      EMS1=P1(3)
      THET1=P1(4)
C
      X2=P2(1)
      R2=P2(2)
      EMS2=P2(3)
      THET2=P2(4)
C*****FOR INITIAL ESTIMATE OF AVERAGE VALUES BETWEEN POINTS 1-3 AND 2-3.
      R3=AVGF(R1,R2)
      THET3=AVGF(THET1,THET2)
C*****SINCE POINTS 2 AND 3 ARE ON THE SAME CONSTANT PRESSURE BOUNDARY,
      EMS3=EMS2
      EMS13=AVGF(EMS1,EMS3)
      ALPH13=ALPHAF(EMS13,GAMMA)
      P13=PCOEFF(EMS13,ALPH13)
      GO TO 6
C*****ITERATION FOR VARIABLES AT POINT 3.
    1 X3=(R1 - R2 + X2*TAN (THET23) - X1*TAN (DIFF13))/
     1   (TAN (THET23) - TAN (DIFF13))
      R3=(R1 + (X3 - X1)*TAN (DIFF13))
      SIGN = R3*SAVE1
C*****IF SIGN IS NEGATIVE OR ZERO, AN ERROR HAS OCCURRED.
      IF(SIGN) 8,8,2
```

```
C*****TEST AND EVALUATION FOR HORIZONTAL I-CHARACTERISTIC.
C*****FOR I HORIZONTAL.
    2 IF(ABS (DIFF13)-1.0E-3) 3,3,4
    3 PROD13=HQCOEF (R13,EMS13,THET13,ALPH13)*(X3-X1)
      GO TO 5
    4 PROD13=QCOEFF(1,R13,EMS13,THET13,ALPH13)*(R3-R1)
    5 THET3=(THET1 - ((EMS3-EMS1-PROD13)/P13))
      DIFFT=(THET3-SAVE2)/SAVE2
      IF(ABS(DIFFT) .LE. 1.0E-4)  GO TO 7
C
    6 NCOUNT=NCOUNT+1
      IF(NCOUNT.GT.NCTMAX) GO TO 7
      SAVE1=R3
      SAVE2=THET3
      R13=AVGF(R1,R3)
      THET13=AVGF(THET1,THET3)
      DIFF13=THET13-ALPH13
      Q13=QCOEFF(1,R13,EMS13,THET13,ALPH13)
      THET23=AVGF(THET2,THET3)
      GO TO 1
C
    7 P3(1)=X3
      P3(2)=R3
      P3(3)=EMS3
      P3(4)=THET3
      IF(NCOUNT .GT. NCTMAX)  WRITE (6,70) NCOUNT,DIFFT
   70 FORMAT(/, 5X,36H *** CONVERGENCE ERROR IN *CPBS*, ( ,I3,2H , ,
     1   E10.3,6H ) ***  /)
      RETURN
C
    8 NERROR=-1
      WRITE (6,9)
    9 FORMAT(//,23X,30H *** ERROR IN *CPBS* CALC. ***  //)
      RETURN
      END
```

```
      SUBROUTINE OUTPUT(GAMMA,EMS1,PRATIO,BETA,NPRINT,NFLOW)
C
C*****SUBROUTINE PRINTS INPUT AND SOME OUTPUT DATA, AND COL. HEADINGS
C     FOR THE AXISYMMETRIC CONSTANT PRESSURE BOUNDARY SUBPROGRAM.
C
      EMNPRF(PR,GAMMA)=SQRT((2.0/(GAMMA-1.0))*
     1                 (PR**(-(GAMMA-1.0)/GAMMA)-1.0))
      EMSMNF(EMN,GAMMA)=SQRT((0.5*(GAMMA+1.0)*(EMN**2))/
     1                 (1.0+0.5*(GAMMA-1.0)*(EMN**2))  )
      EMNMSF(EMS,GAMMA)=SQRT(((2.0*(EMS**2))/(GAMMA+1.0))/
     1                 (1.0-((GAMMA-1.0)/(GAMMA+1.0))*(EMS**2))  )
C
      IF(NPRINT) 70,70,10
   10 BETAD=57.2957795*BETA
      EMN1 = EMNMSF(EMS1,GAMMA)
      EMN2=EMNPRF(PRATIO,GAMMA)
      EMS2=EMSMNF(EMN2,GAMMA)
      GO TO (20,50), NFLOW
C
   20 IF(ABS (BETA)-1.0E-4) 30,30,40
C
   30 WRITE (6,100)            GAMMA, BETAD, EMN1, PRATIO,
     1                         PRATIO, EMN2, EMS2
  100 FORMAT(1H1, ///, 21X, 31H CONSTANT PRESSURE JET BOUNDARY /,
     1 19X, 36H FOR INITIALLY UNIFORM AXI-SYMMETRIC /,
     2 24X, 25H SUPERSONIC INTERNAL FLOW //,
     3 28X, 17H ***INPUT DATA*** //,
     4 7X, 9H GAMMA = F5.3, 24X, 15H BETA (DEG.) = F10.6 //,
     5 7X, 12H MACH NO. = F9.6, 17X, 8H P/PO = F8.6 //,
     6 22X, 27H ***BOUNDARY OUTPUT DATA*** //,
     7 7X,8H P/PO = F8.6,3X,11H MACH NO. =F9.6,3X,12H MACH STAR =F9.6//,
     8 7X, 2H X, 27X, 2H R, 23X, 13H THETA (DEG.) /)
C
      GO TO 70
C
   40 WRITE (6,101)            GAMMA, BETAD, EMN1, PRATIO,
     1                         PRATIO, EMN2, EMS2
  101 FORMAT(1H1, ///, 21X, 31H CONSTANT PRESSURE JET BOUNDARY /,
     1 19X, 36H FOR INITIALLY CONICAL AXI-SYMMETRIC /,
     2 24X, 25H SUPERSONIC INTERNAL FLOW //,
     3 28X, 17H ***INPUT DATA*** //,
     4 7X, 9H GAMMA = F5.3, 24X, 15H BETA (DEG.) = F10.6 //,
     5 7X, 12H MACH NO. = F9.6, 17X, 8H P/PO = F8.6 //,
     6 22X, 27H ***BOUNDARY OUTPUT DATA*** //,
     7 7X,8H P/PO = F8.6,3X,11H MACH NO. =F9.6,3X,12H MACH STAR =F9.6//,
     8 7X, 2H X, 27X, 2H R, 23X, 13H THETA (DEG.) /)
C
      GO TO 70
C
   50 WRITE (6,102)            GAMMA, BETAD, EMN1, PRATIO,
     1                         PRATIO, EMN2, EMS2
  102 FORMAT(1H1, ///, 21X, 31H CONSTANT PRESSURE JET BOUNDARY /,
     1 19X, 36H FOR INITIALLY UNIFORM AXI-SYMMETRIC /,
     2 24X, 25H SUPERSONIC EXTERNAL FLOW //,
     3 28X, 17H ***INPUT DATA*** //,
     4 7X, 9H GAMMA = F5.3, 24X, 15H BETA (DEG.) = F10.6 //,
     5 7X, 12H MACH NO. = F9.6, 17X, 8H P/PO = F8.6 //,
     6 22X, 27H ***BOUNDARY OUTPUT DATA*** //,
     7 7X,8H P/PO = F8.6,3X,11H MACH NO. =F9.6,3X,12H MACH STAR =F9.6//,
     8 7X, 2H X, 27X, 2H R, 23X, 13H THETA (DEG.) /)
C
   70 RETURN
      END
```

```
      SUBROUTINE TEST(RLMT,NSTMT,NFLOW,N,BPTS)
C
C*****SUBROUTINE STOPS CALCULATIONS AND RETURNS TO THE MASTER IF ---
C         1. THE INTERNAL BOUNDARY RADIUS EXCEEDS RLMT OR IF THE JET
C            BOUNDARY ANGLE CHANGES SIGN.
C         2. THE EXTERNAL BOUNDARY RADIUS IS LESS THAN RLMT.
C
      DIMENSION BPTS(5,30)
C
      GO TO (10,30), NFLOW
C
   10 IF(BPTS(2,N)-RLMT) 20,50,50
C
   20 IF(BPTS(4,N-1)*BPTS(4,N)) 50,50,40
C
   30 IF(BPTS(2,N)-RLMT) 50,50,40
C
   40 NSTMT=1
      GO TO 60
C
   50 NSTMT=2
   60 RETURN
      END
```

```
      SUBROUTINE SLIP(EMS1,THETA1,GAMMA1,EMS2,THETA2,GAMMA2,
     1                  THETAS,NSTOP)
C
C*****THIS SUBROUTINE CALCULATES THE SLIPLINE ANGLE FOR THE OBLIQUE
C      SHOCK RECOMPRESSION SYSTEM WHICH OCCURS AT THE IMPINGEMENT
C      POINT OF TWO SUPERSONIC STREAMS IF IT EXISTS.
C
C      SUBROUTINES REQUIRED---PRSHK
C
C      ***VARIABLES***
C
C      EMS1   = MACH STAR OF STREAM 1.
C      THETA1 = FLOW ANGLE OF STREAM 1 (IN RADIANS).
C      GAMMA1 = RATIO OF SPECIFIC HEATS FOR STREAM 1.
C      EMS2   = MACH STAR OF STREAM 2.
C      THETA2 = FLOW ANGLE OF STREAM 2 (IN RADIANS).
C      GAMMA2 = RATIO OF SPECIFIC HEATS FOR STREAM 2.
C      THETAS = SLIPLINE ANGLE (IN RADIANS).
C      NSTOP  = 1, FOR A SOLUTION.
C             = 3, FOR NO SOLUTION.
C
C      NOTE THAT THETA1 IS ASSUMED LARGER THAN THETA2.
C
C
      EMNMSF(EMS,GAMMA)=SQRT((2.0/(GAMMA+1.0))*(EMS**2)/
     1                  _ (1.0-((GAMMA-1.0)/(GAMMA+1.0))*(EMS**2)))
C*****CALCULATION OF THE MAXIMUM TURNING ANGLE FOR A GIVEN APPROACH
C      MACH NUMBER AND GAMMA (NACA R-1135).
C
      SINWA2 (EMN,GAMMA)=(0.25/(GAMMA*(EMN**2)))*((GAMMA+1.0)*(EMN**2)-
     1      4.0 + SQRT((GAMMA+1.0)*((GAMMA+1.0)*(EMN**4) +
     2      8.0*(GAMMA-1.0)*(EMN**2) + 16.0)))
C*****SINWA2 CALCULATES THE SINE OF THE SHOCK WAVE ANGLE SQUARED
C      FOR MAXIMUM STREAM DEFLECTION BEHIND THE SHOCK (EQN 168).
C
      DELTAM (EMN,GAMMA,SIN2WA)=ATAN ((2.0*SQRT((1.0-SIN2WA)/SIN2WA)*
     1      ((EMN**2)*SIN2WA-1.0))/(2.0+(EMN**2)*
     2      (GAMMA + 1.0 - 2.0*SIN2WA)))
C*****DELTAM CALCULATES THE MAXIMUM TURNING ANGLE GIVEN THE APPROACH
C      MACH NUMBER, GAMMA, AND THE SINE SQUARED OF THE WAVE ANGLE,
C      SIN2WA, FOR THE MAXIMUM DEFLECTION (EQN 139A).
C
      PROSHK (EMN,SIN2WA,GAMMA) = (2.0*GAMMA*(EMN**2)*SIN2WA-GAMMA+1.0)/
     1                            (GAMMA+1.0)
C*****PROSHK CALCULATES THE STATIC PRESSURE RISE FOR AN OBLIQUE SHOCK
C      GIVEN THE APPROACH MACH NUMBER, THE SINE SQUARED OF THE WAVE
C      ANGLE, AND GAMMA (EQN 128).
C
      NIT = 0
      NITMAX = 15
      EMN1=EMNMSF(EMS1,GAMMA1)
      EMN2=EMNMSF(EMS2,GAMMA2)
      PRMAX1 = PROSHK (EMN1,SINWA2 (EMN1,GAMMA1),GAMMA1)
      THET1M=(THETA1-DELTAM (EMN1,GAMMA1,SINWA2 (EMN1,GAMMA1)))
      PRMAX2 = PROSHK (EMN2,SINWA2 (EMN2,GAMMA2),GAMMA2)
      THET2M=(THETA2+DELTAM (EMN2,GAMMA2,SINWA2 (EMN2,GAMMA2)))
C*****DETERMINE THE POSSIBLE SOLUTION RANGE FOR THETAS.
      THET1S=THETA1
      PRSHK1=1.0
      THET2S=THETA2
      PRSHK2=1.0
      IF(THET2M-THET1M) 600,600,100
  100 IF(THETA1-THET2M)  120,120,110
```

```
  110 THET1S=THET2M                                                       SLIP 640
      PRSHK1 = PRSHK(EMS1,-(THETA1-THET1S),GAMMA1)                        SLIP 650
      IF(PRSHK1-1.0)  600,600,120                                         SLIP 660
  120 IF(THETA2-THET1M) 130,200,200                                       SLIP 670
  130 THET2S=THET1M                                                       SLIP 680
      PRSHK2 = PRSHK(EMS2,-(THETA2-THET2S),GAMMA2)                        SLIP 690
      IF(PRSHK2-1.0)  600,600,200                                         SLIP 700
C*****DOES A SOLUTION EXIST WITHIN THE POSSIBLE SOLUTION RANGE.            SLIP 710
  200 IF((PRMAX1.LT.PRSHK2) .OR. (PRMAX2.LT.PRSHK1)) GO TO 600            SLIP 720
  400 NIT=NIT+1                                                           SLIP 730
      IF(NIT .GT. NITMAX) GO TO 530                                       SLIP 740
C*****ITERATION FOR SLIPLINE ANGLE SOLUTION.                               SLIP 750
      THETAS=0.5*(THET1S + THET2S)                                        SLIP 760
      PR1=     PRSHK(EMS1,-(THETA1-THETAS),GAMMA1)                        SLIP 770
      PR2=     PRSHK(EMS2,-(THETA2-THETAS),GAMMA2)                        SLIP 780
      PRDIFF=(PR1-PR2)/((PR1+PR2)/2.0)                                    SLIP 790
      IF(ABS (PRDIFF) - 1.0E-4) 530,530,500                               SLIP 800
  500 IF(PRDIFF) 510,530,520                                              SLIP 810
  510 THET1S=THETAS                                                       SLIP 820
      GO TO 400                                                           SLIP 830
  520 THET2S=THETAS                                                       SLIP 840
      GO TO 400                                                           SLIP 850
  530 NSTOP = 1                                                           SLIP 860
      IF(NIT .GT. NITMAX)  WRITE (6,540) NIT,PRDIFF                       SLIP 870
  540 FORMAT(/,5X,33H ***CONVERGENCE ERROR IN SLIP, ( , I3, 2H , ,        SLIP 880
     1    E10.3, 6H ) ***   /)                                            SLIP 890
      RETURN                                                              SLIP 900
C                                                                         SLIP 910
  600 NSTOP = 3                                                           SLIP 920
      WRITE (6,700)                                                       SLIP 930
  700 FORMAT(15X,48H ***SOLUTION FOR SLIPLINE ANGLE DOESN-T EXIST*** //)SLIP 940
      RETURN                                                              SLIP 950
      END                                                                 SLIP 960
```

```
      FUNCTION PRSHK(EMSTAR, DELTA, GAMMA)
C
C*****OBLIQUE SHOCK FUNCTION (REFERENCE NACA R-1135)
C
C     THIS FUNCTION CALCULATES THE STATIC PRESSURE RATIO ACROSS AN
C     OBLIQUE SHOCK (WEAK SOLUTION) GIVEN THE APPROACH MACH STAR AND
C     THE TURNING ANGLE (IN RADIANS).
C
C     ***VARIABLES***
C
C     EMSTAR = APPROACH MACH STAR (M* = V/C*).
C     DELTA  = TURNING ANGLE (IN RADIANS).
C     GAMMA  = RATIO OF SPECIFIC HEATS.
C     PRSHK  = FINAL TO APPROACH STATIC PRESSURE RATIO.
C
C
C*****EQUATION COEFFICIENT FUNCTIONS.
      CONSTB (EMSQD,DELTA,GAMMA) = -(EMSQD + 2.0)/EMSQD -
     1   GAMMA*(SIN (DELTA)**2)
      CONSTC (EMSQD,DELTA,GAMMA) = (2.0*EMSQD + 1.0)/(EMSQD**2) +
     1 (((GAMMA + 1.0)**2)/4.0 + (GAMMA - 1.0)/EMSQD)*(SIN (DELTA)**2)
      CONSTD (EMSQD,DELTA) = -(COS (DELTA)**2)/(EMSQD**2)
      EMNSQD (EMS,GAMMA)=(2.0/(GAMMA+1.0))*(EMS**2)/(1.0
     1   -((GAMMA-1.0)/(GAMMA+1.0))*(EMS**2))
C
      DIMENSION   Y(3)
      EM2=EMNSQD (EMSTAR,GAMMA)
C*****SOLUTION OF CUBIC EQUATION FOR WAVE ANGLE SQUARED.
      A = (1.0/3.0)*(3.0*CONSTC (EM2,DELTA,GAMMA) -
     1 (CONSTB (EM2,DELTA,GAMMA))**2)
      B = (1.0/27.0)*(2.0*(CONSTB (EM2,DELTA,GAMMA)**3) -
     1 9.0*(CONSTB (EM2,DELTA,GAMMA))*(CONSTC (EM2,DELTA,GAMMA)) +
     2 27.0*CONSTD (EM2,DELTA))
      COSPHI = ( -B/2.0)/SQRT( -(A**3)/27.0)
      IF(ABS (COSPHI) - 1.0) 20,20,10
   10 PRSHK = 0.0
      RETURN
C
   20 PHI = (ATAN (SQRT(1.0 - COSPHI**2)/COSPHI))
      IF (PHI) 1,2,2
    1 PHI = PHI + 3.141593
    2 DO 3 I=1,3
      AI = I
C*****Y(I) IS THE SINE SQUARED OF THE WAVE ANGLE.
    3 Y(I) = 2.0*SQRT(-A/3.0)*COS (PHI/3.0 + (AI-1.0)*2.094395) -
     1       CONSTB (EM2,DELTA,GAMMA)/3.0
C*****THE ROOTS OF THE CUBIC EQN WILL NOW BE ARRANGED IN ASCENDING
C     ORDER, THAT IS, Y(1)  LESS THAN Y(2) LESS THAN Y(3).
C
      DO 6 I=1,2
      N = I + 1
      DO 5 J=N,3
      IF(Y(I)-Y(J)) 5,5,4
    4 SAVE = Y(J)
      Y(J) = Y(I)
      Y(I) = SAVE
    5 CONTINUE
    6 CONTINUE
C*****THE ROOT CORRESPONDING TO THE WEAK SOLUTION IS Y(2) AND
C     THE ROOT CORRESPONDING TO THE STRONG SOLUTION IS Y(3).
C     Y(I) IS THE SQUARE OF THE SINE OF THE SHOCK ANGLE (SIGMA).
C
      I = 2
      PRSHK = (2.0*GAMMA*EM2*Y(I) - (GAMMA - 1.0))/(GAMMA + 1.0)
      RETURN
      END
```

```
      SUBROUTINE TEGRAL(PHID,CSOD,TRBO,EI1J,EI1D,EI3J,EI3D)
C
C*****THIS SUBROUTINE CALCULATES THE TURBULENT JET MIXING INTEGRALS.
C
C     ***VARIABLES***
C
C     PHID = DISCRIMINATING STREAMLINE VELOCITY RATIO.
C     CSOD = FREE-STREAM CROCCO NUMBER SQUARED.
C     TRBO = BASE TO FREE-STREAM STAGNATION TEMPERATURE RATIO.
C     EI1J = MIXING INTEGRAL 1 FOR  J  STREAMLINE.
C     EI1D = MIXING INTEGRAL 1 FOR  D  STREAMLINE.
C     EI3J = MIXING INTEGRAL 3 FOR  J  STREAMLINE.
C     EI3D = MIXING INTEGRAL 3 FOR  D  STREAMLINE.
C
C
      TJM1F(PHI,CSQD,TRO) = PHI/(TRO-CSQD*(PHI**2))
      TJM2F(PHI,CSQD,TRO) = (PHI**2)/(TRO-CSQD*(PHI**2))
      TJM3F(PHI,CSQD,TRO) = (PHI*TRO)/(TRO-CSQD*(PHI**2))
      DIMENSION  TRO(350),EI1(350),EI2(350),EI3(350)
      COMMON  /ERFVP/ PHI(350)
C*****THE ERROR FUNCTION VELOCITY PROFILE, PHI(I), IS INITIALIZED IN
C     *BLOCK DATA* AND STORED IN LABELED COMMON *ERFVP*.  PHI(I) IS
C     GIVEN FOR I=1,350 VALUES OF ETA IN THE RANGE OF ETA=-3.5 TO
C     ETA=3.5 IN INCREMENTS OF DETA=0.02.
C*****INCREMENT SIZE AND INITIAL VALUES AT (ETA RB) ARE SPECIFIED HERE.
      DETA = 0.02
      TRO(1) = TRBO
      EI1(1) = 0.0
      EI2(1) = 0.0
      EI3(1) = 0.0
C*****CALCULATION OF THE MIXING TABLE BY THE TRAPEZOIDAL RULE.
      DO 2 I=1,349
      TRO(I+1) = (TRBO + (1.0-TRBO)*PHI(I+1))
      EI1(I+1) = EI1(I) + 0.5*(TJM1F(PHI(I+1),CSQD,TRO(I+1)) +
     1           TJM1F(PHI(I),CSQD,TRO(I)))*DETA
      EI2(I+1) = EI2(I) + 0.5*(TJM2F(PHI(I+1),CSQD,TRO(I+1)) +
     1           TJM2F(PHI(I),CSQD,TRO(I)))*DETA
      EI3(I+1) = EI3(I) + 0.5*(TJM3F(PHI(I+1),CSQD,TRO(I+1)) +
     1           TJM3F(PHI(I),CSQD,TRO(I)))*DETA
      J = I+1
      IF(PHI(J) .LT. (0.25)) GO TO 2
      IF(ABS(1.0-((EI1(J)-EI2(J))/(EI1(I)-EI2(I)))).LE.1.0E-04) GO TO 3
    2 CONTINUE
C*****DETERMINE THE J- AND D-STREAMLINE VALUES OF THE INTEGRALS.
    3 EI1J = EI1(J) - EI2(J)
C*****TABLE SEARCH AND INTERPOLATION FOR EI3J.
      DO 4 I=1,J
      IF(EI1(I) .GT. EI1J)  GO TO 5
    4 CONTINUE
    5 EI3J = EI3(I-1) + ((EI3(I)-EI3(I-1))/(EI1(I)-EI1(I-1)))*
     1        (EI1J-EI1(I-1))
C*****TABLE SEARCH AND INTERPOLATION FOR EI1D, EI3D.
      DO 6 I=1,J
      IF(PHI(I) .GT. PHID)  GO TO 7
    6 CONTINUE
    7 EI1D = EI1(I-1) + ((EI1(I)-EI1(I-1))/(PHI(I)-PHI(I-1)))*
     1        (PHID-PHI(I-1))
      EI3D = EI3(I-1) + ((EI3(I)-EI3(I-1))/(PHI(I)-PHI(I-1)))*
     1        (PHID-PHI(I-1))
      RETURN
      END
```

```
      BLOCK DATA                                                        BLDA  10
C*****THE ERROR FUNCTION VELOCITY PROFILE, PHI(I), IS INITIALIZED IN    BLDA  20
C     *BLOCK DATA* AND STORED IN LABELED COMMON *ERFVP*.  PHI(I) IS     BLDA  30
C     GIVEN FOR I=1,350 VALUES OF ETA IN THE RANGE OF ETA=-3.5 TO       BLDA  40
C     ETA=3.5 IN INCREMENTS OF DETA=0.02.                               BLDA  50
C                                                                       BLDA  60
      COMMON /ERFVP/ A1(45),A2(45),A3(45),A4(45),A5(45),A6(45),A7(45), BLDA  70
     1   A8(35)                                                         BLDA  80
      DATA  A1                                                          BLDA  90
     * /0.000000 ,  0.000000 ,  0.000000 ,  0.000000 ,  0.000000 ,      BLDA 100
     *  0.000000 ,  0.000001 ,  0.000001 ,  0.000001 ,  0.000001 ,      BLDA 110
     *  0.000001 ,  0.000001 ,  0.000002 ,  0.000002 ,  0.000002 ,      BLDA 120
     *  0.000003 ,  0.000003 ,  0.000004 ,  0.000004 ,  0.000005 ,      BLDA 130
     *  0.000005 ,  0.000006 ,  0.000007 ,  0.000008 ,  0.000009 ,      BLDA 140
     *  0.000011 ,  0.000012 ,  0.000014 ,  0.000016 ,  0.000018 ,      BLDA 150
     *  0.000020 ,  0.000023 ,  0.000026 ,  0.000029 ,  0.000033 ,      BLDA 160
     *  0.000037 ,  0.000042 ,  0.000047 ,  0.000053 ,  0.000059 ,      BLDA 170
     *  0.000067 ,  0.000075 ,  0.000084 ,  0.000094 ,  0.000105 /      BLDA 180
      DATA  A2                                                          BLDA 190
     * /0.000118 ,  0.000131 ,  0.000147 ,  0.000164 ,  0.000182 ,      BLDA 200
     *  0.000203 ,  0.000226 ,  0.000251 ,  0.000279 ,  0.000310 ,      BLDA 210
     *  0.000344 ,  0.000381 ,  0.000422 ,  0.000467 ,  0.000517 ,      BLDA 220
     *  0.000571 ,  0.000631 ,  0.000696 ,  0.000767 ,  0.000845 ,      BLDA 230
     *  0.000931 ,  0.001024 ,  0.001126 ,  0.001237 ,  0.001358 ,      BLDA 240
     *  0.001489 ,  0.001632 ,  0.001788 ,  0.001956 ,  0.002140 ,      BLDA 250
     *  0.002338 ,  0.002553 ,  0.002786 ,  0.003038 ,  0.003310 ,      BLDA 260
     *  0.003604 ,  0.003921 ,  0.004263 ,  0.004631 ,  0.005027 ,      BLDA 270
     *  0.005454 ,  0.005912 ,  0.006404 ,  0.006932 ,  0.007498 /      BLDA 280
      DATA  A3                                                          BLDA 290
     * /0.008104 ,  0.008753 ,  0.009446 ,  0.010188 ,  0.010980 ,      BLDA 300
     *  0.011825 ,  0.012725 ,  0.013685 ,  0.014706 ,  0.015792 ,      BLDA 310
     *  0.016946 ,  0.018172 ,  0.019472 ,  0.020851 ,  0.022311 ,      BLDA 320
     *  0.023857 ,  0.025491 ,  0.027219 ,  0.029043 ,  0.030967 ,      BLDA 330
     *  0.032996 ,  0.035133 ,  0.037382 ,  0.039747 ,  0.042233 ,      BLDA 340
     *  0.044843 ,  0.047582 ,  0.050453 ,  0.053460 ,  0.056607 ,      BLDA 350
     *  0.059899 ,  0.063338 ,  0.066930 ,  0.070677 ,  0.074583 ,      BLDA 360
     *  0.078652 ,  0.082887 ,  0.087291 ,  0.091868 ,  0.096620 ,      BLDA 370
     *  0.101550 ,  0.106661 ,  0.111955 ,  0.117434 ,  0.123101 /      BLDA 380
      DATA  A4                                                          BLDA 390
     * /0.128956 ,  0.135002 ,  0.141239 ,  0.147669 ,  0.154292 ,      BLDA 400
     *  0.161108 ,  0.168118 ,  0.175322 ,  0.182718 ,  0.190305 ,      BLDA 410
     *  0.198084 ,  0.206051 ,  0.214205 ,  0.222544 ,  0.231065 ,      BLDA 420
     *  0.239765 ,  0.248641 ,  0.257688 ,  0.266904 ,  0.276283 ,      BLDA 430
     *  0.285822 ,  0.295514 ,  0.305354 ,  0.315338 ,  0.325457 ,      BLDA 440
     *  0.335708 ,  0.346082 ,  0.356572 ,  0.367173 ,  0.377876 ,      BLDA 450
     *  0.388673 ,  0.399557 ,  0.410519 ,  0.421552 ,  0.432647 ,      BLDA 460
     *  0.443795 ,  0.454988 ,  0.466217 ,  0.477472 ,  0.488746 ,      BLDA 470
     *  0.500029 ,  0.511311 ,  0.522585 ,  0.533840 ,  0.545069 /      BLDA 480
      DATA  A5                                                          BLDA 490
     * /0.556261 ,  0.567409 ,  0.578504 ,  0.589536 ,  0.600498 ,      BLDA 500
     *  0.611382 ,  0.622179 ,  0.632881 ,  0.643480 ,  0.653971 ,      BLDA 510
     *  0.664344 ,  0.674593 ,  0.684712 ,  0.694695 ,  0.704534 ,      BLDA 520
     *  0.714226 ,  0.723763 ,  0.733141 ,  0.742356 ,  0.751403 ,      BLDA 530
     *  0.760278 ,  0.768977 ,  0.777497 ,  0.785834 ,  0.793988 ,      BLDA 540
     *  0.801954 ,  0.809731 ,  0.817317 ,  0.824712 ,  0.831915 ,      BLDA 550
     *  0.838923 ,  0.845739 ,  0.852361 ,  0.858789 ,  0.865026 ,      BLDA 560
     *  0.871070 ,  0.876925 ,  0.882590 ,  0.888068 ,  0.893361 ,      BLDA 570
     *  0.898471 ,  0.903400 ,  0.908151 ,  0.912726 ,  0.917130 /      BLDA 580
      DATA  A6                                                          BLDA 590
     * /0.921364 ,  0.925432 ,  0.929337 ,  0.933083 ,  0.936674 ,      BLDA 600
     *  0.940113 ,  0.943404 ,  0.946550 ,  0.949557 ,  0.952427 ,      BLDA 610
     *  0.955165 ,  0.957774 ,  0.960259 ,  0.962624 ,  0.964873 ,      BLDA 620
     *  0.967009 ,  0.969037 ,  0.970961 ,  0.972785 ,  0.974511 ,      BLDA 630
```

```
     * 0.976146 , 0.977691 , 0.979151 , 0.980529 , 0.981829 ,         BLDA 640
     * 0.983054 , 0.984208 , 0.985293 , 0.986314 , 0.987274 ,         BLDA 650
     * 0.988174 , 0.989018 , 0.989810 , 0.990551 , 0.991245 ,         BLDA 660
     * 0.991894 , 0.992500 , 0.993065 , 0.993593 , 0.994085 ,         BLDA 670
     * 0.994543 , 0.994969 , 0.995365 , 0.995733 , 0.996075 /         BLDA 680
      DATA  A7                                                        BLDA 690
     * /0.996392 , 0.996686 , 0.996958 , 0.997210 , 0.997442 ,        BLDA 700
     * 0.997657 , 0.997856 , 0.998039 , 0.998208 , 0.998363 ,         BLDA 710
     * 0.998506 , 0.998638 , 0.998758 , 0.998869 , 0.998971 ,         BLDA 720
     * 0.999064 , 0.999149 , 0.999227 , 0.999299 , 0.999364 ,         BLDA 730
     * 0.999424 , 0.999478 , 0.999527 , 0.999572 , 0.999613 ,         BLDA 740
     * 0.999651 , 0.999685 , 0.999715 , 0.999743 , 0.999768 ,         BLDA 750
     * 0.999791 , 0.999812 , 0.999831 , 0.999848 , 0.999863 ,         BLDA 760
     * 0.999877 , 0.999889 , 0.999900 , 0.999910 , 0.999919 ,         BLDA 770
     * 0.999927 , 0.999935 , 0.999941 , 0.999947 , 0.999952 /         BLDA 780
      DATA  A8                                                        BLDA 790
     * /0.999957 , 0.999961 , 0.999965 , 0.999968 , 0.999971 ,        BLDA 800
     * 0.999974 , 0.999976 , 0.999978 , 0.999980 , 0.999982 ,         BLDA 810
     * 0.999983 , 0.999984 , 0.999985 , 0.999986 , 0.999987 ,         BLDA 820
     * 0.999988 , 0.999989 , 0.999989 , 0.999990 , 0.999990 ,         BLDA 830
     * 0.999991 , 0.999991 , 0.999991 , 0.999992 , 0.999992 ,         BLDA 840
     * 0.999992 , 0.999992 , 0.999992 , 0.999992 , 0.999993 ,         BLDA 850
     * 0.999993 , 0.999993 , 0.999993 , 0.999993 , 0.999993 /         BLDA 860
      END                                                             BLDA 870
```

APPENDIX B

COMPUTER PROGRAM ORGANIZATION AND SUBROUTINE DESCRIPTION

The names and brief functional descriptions of the subroutines used in the base-pressure program, TSABPP-2, are given in this appendix. The subroutines are ordered on a first-call basis and are sequenced relative to the routine from which they are called.

Additional explanatory C0MMENTS regarding the make-up and operation of this program are contained in the program listing, APPENDIX A.

SEQUENCE NUMBER	NAME	FUNCTION
---	TSABPP-2	Main program in which the various calculation and iteration sequences required in the solution of the isoenergetic or nonisoenergetic base-pressure problem are initialized and controlled.
1.0	IN0UT	Reads and writes the input data to TSABPP-2 and then calculates the working input data for the remainder of the program.
1.1.0	ABTS	Afterbody subprogram which controls the calculation and iteration sequences for analyzing supersonic flow over afterbodies. Subprogram determines the local inviscid flow properties at the afterbody surface and the final II-characteristic through the afterbody terminus.
1.1.1	BTCNST	The constants $[C_1, C_2, C_3]$ in the afterbody profile equations are evaluated here for the given input data.
1.1.2	0UTBT1	Prints input data, some output data, and the afterbody output data headings.
1.1.3	EMSPM	Solves the Prandtl-Meyer function for the Mach Star given a turning angle of $(\theta_2 - \theta_1)$, the approach Mach Star, and the specific heat ratio γ.

SEQUENCE NUMBER	NAME	FUNCTION
1.1.4	ØUTBT2	Prints the local values of $[X,R,M,P/P_E,C_p]$ along the afterbody surface and, finally, the overall afterbody drag coefficient C_D.
1.1.5	MCDATA	*Method of Characteristics* data handling subroutine. This subroutine loads, stores, or shifts data in the *Method of Characteristics* arrays.
1.1.6.0		*Method of Characteristics* subroutines.
1.1.6.1	FPS	Field-point subroutine.
1.1.6.2	BTBPS	Boattail Boundary Point Subroutine.
1.1.7	BTITER	Iteration subroutine for determining the I-characteristic passing through the afterbody terminal point (X_{1E},R_{1E}), Fig. 1.
2.0	ØUT1M	Writes the headings and current data used for the trial inviscid flow-field calculations.
3.0	ACPBS	Calculates the flow field and the constant-pressure boundary for either the internal (nozzle) flow or the external (freestream) flow by the *Method of Characteristics* for irrotational flow.
3.1	ØUTPUT	Writes the headings and input data for the inviscid flow-field calculations.
3.2	UFLØC	Generates the *Method of Characteristics* data along the initial II-characteristic for uniform flow.
3.3	CNFLØC	Generates the *Method of Characteristics* data along the initial II-characteristic for conical-flow nozzles.
3.4.0	PMSBR	Calculates the *Method of Characteristics* data for centered Prandtl-Meyer expansions.
3.4.1	EMSPM	Solves the Prandtl-Meyer expansion function for the value of M_2^* given the approach M_1^*, the turning angle $(\theta_2-\theta_1)$, and the specific heat ratio γ.

SEQUENCE NUMBER	NAME	FUNCTION
3.5	ØUTBDY	Writes (X,R,θ) data along the constant-pressure boundary.
3.6	MCDATA	*Method of Characteristics* data handling subroutine. This subroutine loads, stores, or shifts data in the *Method of Characteristics* arrays.
3.7.0		*Method of Characteristics* Subroutines
3.7.1	FPS	Field-point subroutine.
3.7.2	CPBS	Constant-pressure boundary subroutine.
3.7.3	APS	Axis-point subroutine.
3.8	TEST	Tests for terminating the inviscid flowfield calculations.
4.0	CRØSS	Calculates the impingement point of the "corresponding" inviscid streams, the mixing lengths, and the oblique shock system.
4.1	SLIP	Calculates the slipline angle θ_s for the two impinging supersonic streams.
4.2	PRSHK	Calculates the static pressure ratio across an oblique shock wave given the approach M^*, the turning angle δ, and the specific heat ratio γ. (This routine solves the cubic equation for $(\sin \sigma)^2$ where σ is the shock wave angle; with this solution and the input data, all other oblique shock functions can be found.)
5.0	TJMIX	Calculates the dimensionless mass and energy transport ratios, $\bar{B}$ and $\bar{E}$, due to the turbulent mixing component.
5.1	TEGRAL	Calculates the two-dimensional turbulent mixing integrals.
6.0	ITER	Controls the various iteration sequences by first determining, if possible, the solution interval by incrementing the independent variable. After the solution interval has been determined, the solution is found by iteration using interpolation with acceleration of convergence by Wegstein's method [10].

SEQUENCE NUMBER	NAME	FUNCTION
7.0	ERFVP	BLØCK DATA. The error function velocity profile is stored in this array for ETA=-3.5 to ETA=3.5 in increments of DETA=0.02.

APPENDIX C

PROGRAM ERROR MESSAGES

The informational error messages generated by the TSABPP-2 program and its subroutines are summarized here with an explanation of each error message. The order and sequence numbers of the various routines are the same as in APPENDIX B of this report.

SEQUENCE NUMBER	NAME	MESSAGE/EXPLANATION
--	TSABPP-2	

```
***MAXIMUM NØ. ØF BASE PRESS. ITERATIØNS EXCEEDED***
***BPRL=X.XXXX      BPR=X.XXXX        BPRR=X.XXXX***
*****************************************************
```

If a base-pressure solution is not achieved within IBPR.LE.IBPRMX (currently IBPRMX=20), the current case calculation is terminated and the next case or configuration is considered. At termination, the current values of the base-pressure ratio, BPR = P_B/P_{1E}, as well as the lower and upper bounds on the solution value, BPRL and BPRR, respectively, are also printed.

```
***MAXIMUM NØ. ØF BASE PRESS. ITERATIØNS EXCEEDED***
***BPRL=X.XXXX      BPR=X.XXXX        BPRR=X.XXXX***
***PRØBABLE FLØW SEPARATIØN FØR SPECIFIED DATA*******
*****************************************************
```

This situation is similar to the preceding case; however, the trial value for the base-pressure ratio, BPR, is greater than or approaching the value corresponding to separation of the internal or external flow. The separation-pressure ratio is determined from an empirical expression [4].

SEQUENCE NUMBER	NAME	MESSAGE/EXPLANATION
		::::MAXIMUM NØ. OF NØ-SØLUTIØN TRIALS EXCEEDED:::: No-solution trial cases occur when (i) there is insufficient data to calculate the inviscid boundaries' impingement point, (ii) the boundaries do not impinge, and (iii) the boundaries impinge, but the slipline solution does not exist. In the course of the base-pressure solution iteration, a case calculation is terminated if a total of NØSØLN.GT.NØSMAX (currently NØSMAX=10) no-solution trials occur for a given case. Note that error messages related to (i), (ii), and (iii) are generated by the appropriate subroutines; i.e., (i) and (ii) from CRØSS and (iii) from SLIP.
1.0	INØUT	None
1.1.0	ABTS	None
1.1.1	BTCNST	None
1.1.2	ØUTBT1	None
1.1.3	EMSPM	See message for EMSPM under S/N 3.4.1.
1.1.4	ØUTBT2	None
1.1.5	MCDATA	None
1.1.6.0		*Method of Characteristics* subroutines.
1.1.6.1	FPS	See messages for FPS under S/N 3.7.

SEQUENCE NUMBER	NAME	MESSAGE/EXPLANATION
1.1.6.2	BTBPS	*****CØNVERGENCE ERRØR IN *BTBPS*, (NCØUNT,DIFF)***** Convergence failure in iteration for M^* along the afterbody boundary. Convergence to a normalized difference in M^* between successive trials of .LE. 10^{-4} was not achieved before NCØUNT.GT.NCTMAX occurred (currently NCTMAX=15). (NCØUNT,DIFF) printed are the current iteration number and normalized difference in M^*. *****ERRØR IN *BTBPS* CALC.***** If either ($M^* < 1$) or ($M^* > M^*_{MAX}$) occurs during the iteration for M^* along the solid boundary, the above message is printed and a return is made to ABTS.
1.1.7	BTITER	*****MAX NØ. ITERATIØNS EXCEEDED IN SBR. BTITER. GØ TØ NEXT CASE. The I-characteristic passing through the terminal point of the afterbody could not be determined within the specified number of iterations (currently, 15). Return is made to INØUT and the next configuration is analyzed.
2.0	ØUT1M	None
3.0	ACPBS	None
3.1	ØUTPUT	None
3.2	UFLØC	None
3.3	CNFLØC	None
3.4.0	PMSBR	None

SEQUENCE NUMBER	NAME	MESSAGE/EXPLANATION
3.4.1	EMSPM	*****ERROR IN -EMSPM-***** Message results from the specification of a turning angle, which is either (i) greater than the turning angle corresponding to sonic flow after a *reversible* compression or (ii) greater than the maximum turning angle for a reversible expansion. *****CONVERGENCE ERROR IN EMSPM,(NIT,DIFFO)***** Convergence failure of the iterative procedure used to solve the Prandtl-Meyer function for the Mach Star after the expansion (or compression). The values of NIT, current number of iterations, and DIFFO, the normalized difference between successive values of the Prandtl-Meyer omega function, are printed. Currently, the maximum value of NIT is specified as NITMAX=20.
3.5	OUTBDY	None
3.6	MCDATA	None
3.7	FPS CPBS APS	*Method of Characteristics* subroutines: *****CONVERGENCE ERROR IN **FPS**,(NCOUNT,DIFF)***** **CPBS** **APS** Convergence failure of the *Method of Characteristics* calculations within the specified subroutine. NCOUNT gives the current iteration number (a maximum of fifteen) and DIFF, the current value of the normalized difference function on which the convergence criterion is based.

SEQUENCE NUMBER	NAME	MESSAGE/EXPLANATION

		`*****ERRØR IN *FPS* CALC.*****`
		`*CPBS*`
		`*APS*`
		The Mach Star becomes less than one or a boundary point calculation crosses the axis. The former usually results from wave coalescence and "foldback" while the latter could occur for the external-flow boundary calculations in the vicinity of the axis.

3.8	TEST	None

4.0	CRØSS	`**********IMPINGEMENT ØF THE INTERNAL STREAM ØCCURS BEFØRE SEPARATIØN ØF THE EXTERNAL STREAM**********`
		`IMPINGEMENT ØCCURS AT X =    AND R =`
		`**********IMPINGEMENT ØF THE EXTERNAL STREAM ØCCURS BEFØRE SEPARATIØN ØF THE INTERNAL STREAM**********`
		`IMPINGEMENT ØCCURS AT X =    AND R =`
		The inviscid internal and external streams do not impinge downstream of their separation points, but rather one of the streams would impinge on a solid boundary prior to the separation of the other stream. These cases are considered to be no-solution trials.
		`*****IMPINGEMENT DØES NØT ØCCUR WITHIN THE RANGE ØF CØNSTANT-PRESSURE BØUNDARY DATA*****`
		Insufficient external or internal boundary data are available to determine an impingement point between the flows. These cases are also considered to be no-solution trials.

4.1	SLIP	`*****CØNVERGENCE ERRØR IN SLIP,(NIT,PRDIFF)*****` Convergence to the slipline solution was not achieved within the maximum number of iterations specified (currently NITMAX=15). NIT is the current iteration trial and PRDIFF is the normalized pressure ratio difference function.

SEQUENCE NUMBER	NAME	MESSAGE/EXPLANATION
		*****SØLUTIØN FØR SLIPLINE ANGLE DØESN'T EXIST***** A regular slipline solution with weak shocks does not exist for the trial impingement data. This case is considered as a no-solution trial.
4.2	PRSHK	None
5.0	TJMIX	None
5.1	TEGRAL	None
6.0	ITER	None
7.0	ERFVP (BLØCK DATA)	None

APPENDIX D

MODIFICATIONS FOR OPERATION OF TSABPP-2
ON AN IBM 7094 FØRTRAN IV IBJOB SYSTEM

APPENDIX D IS DIVIDED INTO THREE PARTS. THEY ARE AS FOLLOWS:

- I. MODIFICATIONS IN TSABPP-2 REQUIRED FOR IBM 7094 OPERATION
- II. TSABPP-2 INPUT DATA FORMAT FOR THE IBM 7094 VERSION
- III. CONTROL CARDS FOR OPERATING TSABPP-2 ON AN IBM 7094 UNDER IBJOB CONTROL

MODIFICATIONS IN TSABPP-2 REQUIRED FOR IBM 7094 OPERATION
(SEE *NOTE* ON PAGE 127 BEFORE CHANGING PROGRAM)

```
C*****VERSION --- FOR IBM 7094, WITH *NDEFLT OPTION* ADDED TO PROGRAM.  MAIN  64
C                                                                       MAIN  66
     4                  NPUNCH,PROEOI,PROIE,POIEOI,NSHAPE,NPTSE,PRIIIE, MAIN 450
     5                  NDEFLT                                          MAIN 455
      NDEFLT = 0                                                        MAIN 465


C      INOPT  = 1, INPUT BY NAMELIST /DATAIN/ ONLY.  THE DEFAULT        INOU 220
C                  CARDS FOLLOWING THE FIRST CARD--- $DATAIN INOPT=2 $  INOU 250
C             = 3, INPUT SPECIFIED BY NAMELIST /DATAIN/ FOR CALCULATION INOU 260
C             = 4, INPUT SPECIFIED BY NAMELIST /DATAIN/ FOR CALCULATION INOU 280
C      NDEFLT = 0, THE VARIABLES ARE RESET TO THE *DEFAULT CONFIGURATION*INOU 351
C                  AFTER THE CASE (SET OF PRESSURE RATIOS) IS COMPLETED. INOU 352
C             = 1, THE VARIABLES WILL NOT BE RESET AT UPON COMPLETION   INOU 353
C                  OF THE CASE.                                         INOU 354
C      NOTE --- CHANGING THE VALUE OF *NEDFLT* WILL FIRST AFFECT THE    INOU 355
C               CASE SUCCEEDING THE CASE IN WHICH IT IS CHANGED.        INOU 356
C      **CARD 1**    ANY ALPHANUMERIC HEADING IN COLUMNS 1 TO 80.       INOU 755
C      FOLLOWING CARDS CONTAIN *NAMELIST* DATA SPECIFIED BELOW---       INOU 756
C                                                                       INOU 757
C       $DATAIN  X1I=,R1I=,BETD1I=,GCI=,GAMMAI=,EMN1I=,TROEI=,RECOMP=,  INOU 760
C       NSHAPE=,X2E=,R2E=,BETD2E=,X1E=,R1E=,GCE=,GAMMAE=,EMNE=,INOPT=,  INOU 770
C       NPRINT=,NPUNCH=,KPRESR=,NCASE=,PR=,BRO=,ERO=,NDEFLT=,  $        INOU 780
C      **CARD 1**    ANY ALPHANUMERIC HEADING IN COLUMNS 1 TO 80.       INOU 850
C      FOLLOWING CARDS CONTAIN *NAMELIST* DATA SPECIFIED BELOW---       INOU 855
C                                                                       INOU 860
C      IF NSHAPE=0 (DEFAULT VALUE)                                      INOU 870
C       $DATAIN  R1I=,EMN1I=,EMNE=,NCASE=,PR=-,-,...,NDEFLT=,  $        INOU 880
C                                                                       INOU 890
C      IF NSHAPE=1,2,3 (SPECIFIED BELOW)                                INOU 900
C       $DATAIN  R1I=,EMN1I=,NSHAPE=,BETD2E=,X1E=,R1E=,EMNE=,NCASE=,    INOU 910
C       PR=-,-,...,NDEFLT=,  $                                          INOU 920
C      **CARD 0**   DUMMY CARD.  CONTENT IS IGNORED.                    INOU 955
C      **CARD 1**      $DATAIN  INOPT=2  $                              INOU 960
C      NOTE THAT THERE ARE (7+NCASE) DATA CARDS PER CASE.               INOU1160
C      **CARD 0**   DUMMY CARD.  CONTENT IS IGNORED.                    INOU1192
C      **CARD 1**    ANY ALPHANUMERIC HEADING IN COLUMNS 1 TO 80.       INOU1194
C      FOLLOWING CARDS CONTAIN *NAMELIST* DATA SPECIFIED BELOW---       INOU1196
C                                                                       INOU1198
C       $DATAIN  INOPT=3,EMN1I=,BETD1I=,R1I=,NCASE=,PR=-,-,...,GAMMAE=, INOU1200
C       NDEFLT=,  $                                                     INOU1210
C      **CARD 0**   DUMMY CARD.  CONTENT IS IGNORED.                    INOU1252
C      **CARD 1**    ANY ALPHANUMERIC HEADING IN COLUMNS 1 TO 80.       INOU1254
C      FOLLOWING CARDS CONTAIN *NAMELIST* DATA SPECIFIED BELOW---       INOU1256
C                                                                       INOU1258
C       $DATAIN  INOPT=4,NCASE=,EMNE=,NSHAPE=,BETD2E=,R2E=,X1E=,R1E=,   INOU1260
C       PR=-,-,...,GAMMAE=,NDEFLT=,  $                                  INOU1270
     4                  NPUNCH,PROEOI,PROIE,POIEOI,NSHAPE,NPTSE,PRIIIE, INOU1420
     5                  NDEFLT                                          INOU1425
      NAMELIST /DATAIN/ X1I,R1I,BETD1I,GCI,GAMMAI,EMN1I,NSHAPE,X2E,R2E, INOU1450
     1                  BETD2E,X1E,R1E,GCE,GAMMAE,EMNE,TROEI,RECOMP,    INOU1460
     2                  INOPT,NPRINT,NCASE,NPUNCH,KPRESR,PR,BRO,ERO,    INOU1470
     3                  NDEFLT                                          INOU1475
C*****SKIP *DEFAULT CONFIGURATION* DEFINITION IF NDEFLT=1.              INOU1493
      IF (NDEFLT.NE.0)  GO TO 9                                         INOU1497
C*****READ HEADING CARD.                                                INOU1830
    9 READ (5,68)   A                                                   INOU1835
C*****READ INPUT DATA BY NAMELIST /DATAIN/ .                            INOU1840
      READ (5,DATAIN)                                                   INOU1845
```

TSABPP-2 INPUT DATA FORMAT FOR THE IBM 7094 VERSION

```
C*****COMPLETE INPUT DATA FOR DEFAULT OPTION (INOPT=1).                 INOU 740
C                                                                       INOU 750
C      **CARD 1**     ANY ALPHANUMERIC HEADING IN COLUMNS 1 TO 80.      INOU 755
C      FOLLOWING CARDS CONTAIN *NAMELIST* DATA SPECIFIED BELOW---       INOU 756
C                                                                       INOU 757
C       $DATAIN  X1I=,R1I=,BETD1I=,GCI=,GAMMAI=,EMN1I=,TROEI=,RECOMP=,  INOU 760
C       NSHAPE=,X2E=,R2E=,BETD2E=,X1E=,R1E=,GCE=,GAMMAE=,EMNE=,INOPT=,  INOU 770
C       NPRINT=,NPUNCH=,KPRESR=,NCASE=,PR=,BRO=,ERO=,NDEFLT=,  $        INOU 780
C                                                                       INOU 790
C      IT IS NOT NECESSARY TO SPECIFY ALL OF THE VARIABLES SINCE ALL OR INOU 800
C      PART OF THE DEFAULT CONFIGURATION CAN BE USED.  HOWEVER, THE     INOU 810
C      FOLLOWING  MINIMUM DATA MUST BE SPECIFIED FOR EACH CONFIGURATION INOU 820
C      (SEE  TABLE I, RD-TR-69-14).                                     INOU 830
C                                                                       INOU 840
C      **CARD 1**     ANY ALPHANUMERIC HEADING IN COLUMNS 1 TO 80.      INOU 850
C      FOLLOWING CARDS CONTAIN *NAMELIST* DATA SPECIFIED BELOW---       INOU 855
C                                                                       INOU 860
C      IF NSHAPE=0 (DEFAULT VALUE)                                      INOU 870
C       $DATAIN  R1I=,EMN1I=,EMNE=,NCASE=,PR=-,-,...,NDEFLT=,  $        INOU 880
C                                                                       INOU 890
C      IF NSHAPE=1,2,3 (SPECIFIED BELOW)                                INOU 900
C       $DATAIN  R1I=,EMN1I=,NSHAPE=,BETD2E=,X1E=,R1E=,EMNE=,NCASE=,    INOU 910
C       PR=-,-,...,NDEFLT=,  $                                          INOU 920
C                                                                       INOU 930
C*****INPUT DATA AND FORMATS FOR OPTION 2 (INOPT=2).                    INOU 940
C                                                                       INOU 950
C      **CARD 0**   DUMMY CARD.  CONTENT IS IGNORED.                    INOU 955
C      **CARD 1**      $DATAIN  INOPT=2  $                              INOU 960
C      **CARD 2**   ANY ALPHANUMERIC HEADING IN COLUMNS 1 TO 80.        INOU 970
C      **CARD 3**   X1I, R1I, BETD1I, GCI, GAMMAI, EMN1I,               INOU 980
C                   NSHAPE                               (6F10.6,I1)    INOU 990
C      IF NSHAPE = 0, CARD NO. 4 IS--                                   INOU1000
C      **CARD 4**   X1E, R1E, GCE, GAMMAE, EMNE           (5F10.6)      INOU1010
C                                                                       INOU1020
C      IF NSHAPE = 1,2, OR 3, CARD NO. 4 IS--                           INOU1030
C      **CARD 4**   X2E, R2E, BETD2E, X1E, R1E, GCE,                    INOU1040
C                   GAMMAE, EMNE                          (8F10.6)      INOU1050
C                                                                       INOU1060
C      **CARD 5**   TROEI, RECOMP                                       INOU1070
C      **CARD 6**   NPRINT, NCASE, NPUNCH, KPRESR         (I2,I3,2I1)   INOU1080
C                                                                       INOU1090
C      IF KPRESR = 0, CARD NO. 7 AND FOLLOWING ARE--                    INOU1100
C      **CARD 7 AND FOLLOWING**   PR1IE, BLDRO, ENGRO     (3F10.6)      INOU1110
C                                                                       INOU1120
C      IF KPRESR = 1, CARD NO. 7 AND FOLLOWING ARE--                    INOU1130
C      **CARD 7 AND FOLLOWING**   PROIE, BLDRO, ENGRO     (3F10.6)      INOU1140
C                                                                       INOU1150
C      NOTE THAT THERE ARE (7+NCASE) DATA CARDS PER CASE.               INOU1160
C                                                                       INOU1170
C*****INPUT FOR INTERNAL-FLOW CONSTANT-PRESSURE BOUNDARIES (INOPT=3)    INOU1180
C                                                                       INOU1190
C      **CARD 1**     ANY ALPHANUMERIC HEADING IN COLUMNS 1 TO 80.      INOU1194
C      FOLLOWING CARDS CONTAIN *NAMELIST* DATA SPECIFIED BELOW---       INOU1196
C                                                                       INOU1198
C       $DATAIN  INOPT=3,EMN1I=,BETD1I=,R1I=,NCASE=,PR=-,-,...,GAMMAE=, INOU1200
C       NDEFLT=,  $                                                     INOU1210
C                                                                       INOU1220
C*****INPUT FOR EXTERNAL-FLOW AFTERBODY AND/OR CONSTANT-PRESSURE        INOU1230
C      BOUNDARIES (INOPT=4)                                             INOU1240
C                                                                       INOU1250
C      **CARD 1**     ANY ALPHANUMERIC HEADING IN COLUMNS 1 TO 80.      INOU1254
C      FOLLOWING CARDS CONTAIN *NAMELIST* DATA SPECIFIED BELOW---       INOU1256
C                                                                       INOU1258
C       $DATAIN  INOPT=4,NCASE=,EMNE=,NSHAPE=,BETD2E=,R2E=,X1E=,R1E=,   INOU1260
C       PR=-,-,...,GAMMAE=,NDEFLT=,  $                                  INOU1270
```

CONTROL CARDS FOR OPERATING TSABPP-2 ON AN IBM 7094 UNDER IBJOB CONTROL

```
$ID              IBJOB    SPRUELL.BASE PRESSURE PROGRAM
$JOBOP MAP,DLOGIC,ALTIO

$IBFTC MAIN
$IBFTC INOUTX
$IBFTC OUT1MX
$IBFTC ACPBSX
$IBFTC CROSSX
$IBFTC TJMIXX
$IBFTC OUT2MX
$IBFTC ITERX
$IBFTC ABTSX
$IBFTC BTCNSX
$IBFTC OTBT1X
$IBFTC BTBPSX
$IBFTC OTBT2X
$IBFTC BTITEX
$IBFTC UFLOCX
$IBFTC CNFLOX
$IBFTC PMSBRX
$IBFTC EMSPMX
$IBFTC OUTBYX
$IBFTC MCDATX
$IBFTC FPSX
$IBFTC APSX
$IBFTC CPBSX
$IBFTC OUTPTX
$IBFTC TESTX
$IBFTC SLIPX
$IBFTC PRSHKX
$IBFTC TEGRLX
$IBFTC BLDATA

$DATA
```

APPENDIX E

MODIFICATION OF TSABPP-2 TO SIMPLIFY INPUT FOR PARAMETRIC STUDIES

THE NDEFLT OPTION PERMITS SIMPLIFIED DATA INPUT IN PARAMETRIC VARIATION STUDIES. I.E.. WHEN A LARGE NUMBER OF CASES ARE RUN WITH ONLY ONE OR TWO PARAMETERS CHANGED IN EACH CASE. THIS OPTION CAN ONLY BE USED WITH INPUT OPTIONS 1.3. AND 4 (INOPT=1.3. OR 4). TO USE THE OPTION. THE CARDS LISTED BELOW MUST BE ADDED TO TSABPP-2.

IN THE FIRST CASE OF THE SERIES. SET NDEFLT=1 AND DEFINE THE CONFIGURATION. (THE DEFAULT CONFIGURATION IS AVAILABLE AT THIS POINT). IN EACH SUCCEEDING CASE. ONLY PARAMETERS WHICH DIFFER FROM THE PREVIOUS CASE NEED TO BE SPECIFIED IN THE INPUT FOR THAT CASE. IN OTHER WORDS. WITH NDEFLT=1. THE INPUT PARAMETERS FOR EACH CASE ARE NOT RESET TO THE VALUES SPECIFIED BY THE DEFAULT CONFIGURATION. (SEE PAGES 28. 30 AND 31 FOR THE DEFAULT CONFIGURATION WHEN INOPT=1.3. OR 4. RESPECTIVELY) NORMAL OPERATION OF THE PROGRAM CAN BE RESUMED BY SPECIFYING NDEFLT=0 IN THE LAST CASE OF THE PARAMETRIC VARIATION. WHEN NDEFLT=0. THE INPUT PARAMETERS FOR EACH CASE ARE RESET TO THE VALUES SPECIFIED IN THE DEFAULT CONFIGURATION.

A SAMPLE RUN SET FOR THE IBM 7094 IS GIVEN BELOW.

```
PARAMETRIC VARIATION IN EMNE         FEBRUARY 1970        EMNE=3.5
 $DATAIN   KPRESR=0. NDEFLT=1. RII=0.6. EMNII=2.5. EMNE=3.5. INOPT=1. NCASE=7.
 PR(1)=0.5. PR(2)=1.0. PR(3)=4.0. PR(4)=6.0. PR(5)=8.0. PR(6)=10.0. PR(7)=12.0 $
PARAMETRIC VARIATION IN EMNE         FEBRUARY 1970        EMNE=4.0
 $DATAIN   EMNE=4.0        $
PARAMETRIC VARIATION IN EMNE         FEBRUARY 1970        EMNE=5.0
 $DATAIN   EMNE=5.0        $
PARAMETRIC VARIATION IN EMNE         FEBRUARY 1970        EMNE=7.0
 $DATAIN   EMNE=7.0        $
```

MODIFICATIONS IN TSABPP-2 REQUIRED TO ADD THE NDEFLT OPTION

NOTE---CARDS WITH NUMBERS ENDING IN 0 ARE REPLACEMENT CARDS. ALL OTHERS ARE TO BE INSERTED IN NUMERICAL SEQUENCE INTO THE PROPER SUBROUTINE. EXAMPLE. CARD INOU 780 REPLACES THE CARD HAVING THAT NUMBER IN SUBROUTINE INOUT. WHILE CARD INOU 353 IS INSERTED AFTER CARD INOU 350 AND BEFORE CARD INOU 360.

```
C*****VERSION --- *NDEFLT OPTION* ADDED TO PROGRAM.                    MAIN  64
C                                                                      MAIN  66
     4                   NPUNCH,PRUEOI,PROIE,POIFOI,NSHAPE,NPTSE,PRIIIF, MAIN 450
     5                   NDEFLT                                        MAIN 455
      NDEFLT = 0                                                       MAIN 465


C     NDEFLT = 0, THE VARIABLES ARE RESET TO THE *DEFAULT CONFIGURATION*INOU 351
C                  AFTER THE CASE (SET OF PRESSURE RATIOS) IS COMPLETED. INOU 352
C              = 1, THE VARIABLES WILL NOT BE RESET AT UPON COMPLETION   INOU 353
C                  OF THE CASE.                                        INOU 354
C     NOTE --- CHANGING THE VALUE OF *NEDFLT* WILL FIRST AFFECT THE     INOU 355
C                CASE SUCCEEDING THE CASE IN WHICH IT IS CHANGED.       INOU 356
C       INOPT=,NPRINT=,NPUNCH=,KPRESR=,NCASE=,PR=,BRO=,FRO=,NDEFLT=,+END INOU 780
C      GAMMAI=,NDEFLT=,  +END                                          INOU1210
C       RIF=,PR=-,-,...,GAMMAE=,NDEFLT=,   +END                         INOU1270
     4                   NPUNCH,PRUEOI,PROIE,POIFOI,NSHAPE,NPTSE,PRIIIF, INOU1420
     5                   NDEFLT                                        INOU1425
     2                 NPRINT,NCASE,NPUNCH,KPRESR,PR,BRO,FRO,NDEFLT    INOU1470
   9  READ (5,DATA)                                                    INOU1840
C*****SKIP *DEFAULT CONFIGURATION* DEFINITION IF NDEFLT=1.              INOU1493
      IF (NDEFLT.NE.0)  GO TO 9                                        INOU1497
```

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13. ABSTRACT

The computer program presented and discussed in Part 1 of this report for analyzing the axisymmetric base-pressure and base-temperature problem with interacting supersonic free-stream and propulsive-nozzle flows has been improved and generalized to include the analysis of an afterbody upstream of the base region. The afterbody geometries considered are: cylindrical, conical, parabolic, and tangent-ogive boattails and conical flares. The FØRTRAN IV computer-program listing, as well as detailed information on program development, organization, and usage, are included herein. Theoretical afterbody and base-pressure results are presented for parametric variations in afterbody geometry and flow variables. In addition, a limited comparison between theoretical and experimental conical-afterbody and base-pressure data is made.

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