An Experimental Investigation of the Mixing and Combustion of an Underexpanded H_2 Jet in Supersonic Flow

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ABSTRACT

The interaction of an underexpanded hydrogen jet coaxially injected into supersonic flow is investigated experimentally. Experimental results are d scussed and analyzed. Comparisons are made between the experimental results and theoretical predictions computed using an analytical technique. Changes to improve the theory are suggested.

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LIST OF SYMBOLS

C_p	nondimensional specific heat, C_p^*/C_{p_∞}
H	nondimensional total enthalpy, $H^*/C_{p_\infty}T_\infty$
h	Nondimensional static enthalpy, $h^*/C_{p_\infty}T_\infty$
Le	Lewis number
M	Mach number
m_i	molecular weight of $i^{\underline{th}}$ specie, $\frac{kg}{Kmole}$
n	coordinate normal to streamlines
p	nondimensional pressure, $p^*/(\rho_\infty q_\infty^2)$
Pr	Prandtl number
p_{t_2}	pitot pressure, N/m^2
q	nondimensional velocity, q^*/q_∞
Re	freestream Reynolds number, $\frac{\rho_\infty q_\infty r_j}{\mu_\infty}$
r_j	radius of jet at injector's exit (used as reference dimension), 0.3175 cm
s	coordinate along streamlines
S_1, S_2, S_{3_i}	forcing functions defined in text
T	nondimensional temperature, T^*/T_∞
U_1; U_2	nondimensional velocities normal to the shock wave in Rankine-Hugoniot equations, U_1^*/q_∞; U_2/q_∞
V	nondimensional velocity, V^*/q_∞
V_{t_1}; V_{t_2}	nondimensional tangential velocities in Rankine-Hugoniot equations, $V^*_{t_1}/q_\infty$; $V^*_{t_2}/q_\infty$
W	molecular weight of mixture, $\frac{kg}{Kmole}$

$\dot{W}_O$	the production rate of oxygen at 1000 K and the local pressure of $\dot{W}^*_i$
$\dot{W}_i$	nondimensional species production team, $\dot{W}_i/\dot{W}_O$
x/r_j	nondimensional coordinate along nozzles' axis
y/r_j	nondimensional coordinate normal to nozzles' axis
α_i	mass fraction of $i^{\underline{th}}$ specie
γ	ratio of specific heats
θ	flow angle, radians
ρ	nondimensional density, ρ^*/ρ_∞
μ	nondimensional absolute viscosity, μ^*/μ_∞
$\bar{\mu}$	Mach angle, radians
ϕ	equivalence ratio; the ratio of the actual $\dot{m}_{H_2}$ to that required for stoichiometric reaction, $\frac{\dot{m}_{H_2}}{0.029157\ \dot{m}_{air}}$ (The fictitious ϕ's for nitrogen test medium are computed as if the test stream were air.)

Subscripts:

CL	centerline
f	frozen state
i	pertaining to specie i
j	jet
t_0	test stream vessel stagnation condition
∞	freestream nozzle exit conditions

Superscripts:

*	dimensional variable

SUMMARY

An experimental data base for the injection, mixing, and combustion of an underexpanded hydrogen jet in a supersonic test stream has been obtained. Experimental pitot pressure data have been compared with theoretical predictions.

The experimental tests were conducted with both air and nitrogen as test media which led to reacting and nonreacting flows, respectively. Tests were conducted in a free-jet and in a ducted mode. Theoretical values were computed using two different viscosity models and a wide range of Prandtl number (0.7 to 1.4) with a Lewis number of 1.

The comparison of the experimental and theoretical data indicates that the theory is inadequate for predicting the flow field resulting from the injection of an underexpanded (hydrogen) jet into supersonic flow. Suggestions are made for improving the theory.

CHAPTER 1

INTRODUCTION

The hydrogen fueled supersonic combustion ramjet (scramjet) engine is envisioned as the prime candidate to fill the propulsion requirements for future hypersonic aircraft. However, feasible scramjet engines face problems in several technological areas. (Status evaluations of the scramjet concept may be found in references 1, 2, 3, and 4.) Three such areas are of concern in this work. These are the injection, mixing, and combustion of hydrogen. Note that the last two are directly related to the first by the following sequence: injection controls mixing and mixing controls combustion. As a result, fuel injection holds an important position in the total scramjet problem. Thus, it is not surprising that numerous fuel injection schemes have been investigated in both cold and hot supersonic flows. Simplicity in flow field modeling has made parallel coaxial injection the scheme most widely investigated (references 5, 6, and 7 present investigations of this type).

These previous investigations of coaxial injection were limited to cases where injector exit pressure matched the test stream static pressure. These matched pressure cases were selected primarily because the theory available was designed to handle them.

On the other hand, recent theory (see references 8 and 9) is designed to handle the more complex underexpanded (jet pressure greater than the test stream static pressure) injection. The significance of such a theory becomes apparent when one notes that any practical scramjet engine is likely to use hydrogen injection by an underexpanded jet.

In fact, all scramjet engines must be capable of operating with underexpanded injection, although this may not be the primary type of injection. However, a search of the literature indicated that there was very little information on an underexpanded hydrogen jet coaxially injected into supersonic flow. Particular information, such as data on the underexpansion (exit) shock wave's affect on the hydrogen mixing and combustion, is completely lacking. The present investigation was therefore undertaken to experimentally determine some of the fundamental characteristics of the mixing and combustion of an underexpanded hydrogen jet in supersonic flow. In addition, the theory of reference 8 was tested by comparing experimental data with theoretical data computed using the computer program (reference 9) based on the theory of reference 8.

CHAPTER II

APPARATUS AND INSTRUMENTATION

Facility and Test Conditions

The experimental portion of this work was conducted in the Langley 11-Inch Ceramic-Heated Tunnel. This facility, described in reference 10, has a bed of zirconia pebbles which is heated by the combustion products from a propane burner. The products from the burner are passed through the bed until the desired stagnation temperature is reached. The hot test gas is obtained by passing the test medium (air or nitrogen) through the heated pebbles. In this manner, test gas total temperatures up to 2530 K (maximum usage temperature of the zirconia pebbles) can be furnished with a maximum stagnation pressure of 4 MN/m^2.

For the purpose of the present tests, the facility was fitted with the Mach 2 test stream nozzle which is a scaled version of one given in reference 11. This axisymmetric nozzle was constructed of stainless-steel and cooled by about 6 kg/sec of water. The facility was operated in two modes, a free-jet mode and a ducted mode. In the ducted mode, the ducting around the supersonic flow formed a circular combustor. A schematic of the facility (in the ducted mode configuration) is given in figure 1. The free-jet mode configuration is obtained by removing the constant area duct which extends from plane A-A to plane B-B of figure 1. In each configuration, the exit plane of the Mach 2 hydrogen injector nozzle was 0.3175 cm downstream of the exit plane of the test stream nozzle. Tests were conducted with both air and nitrogen as test media,

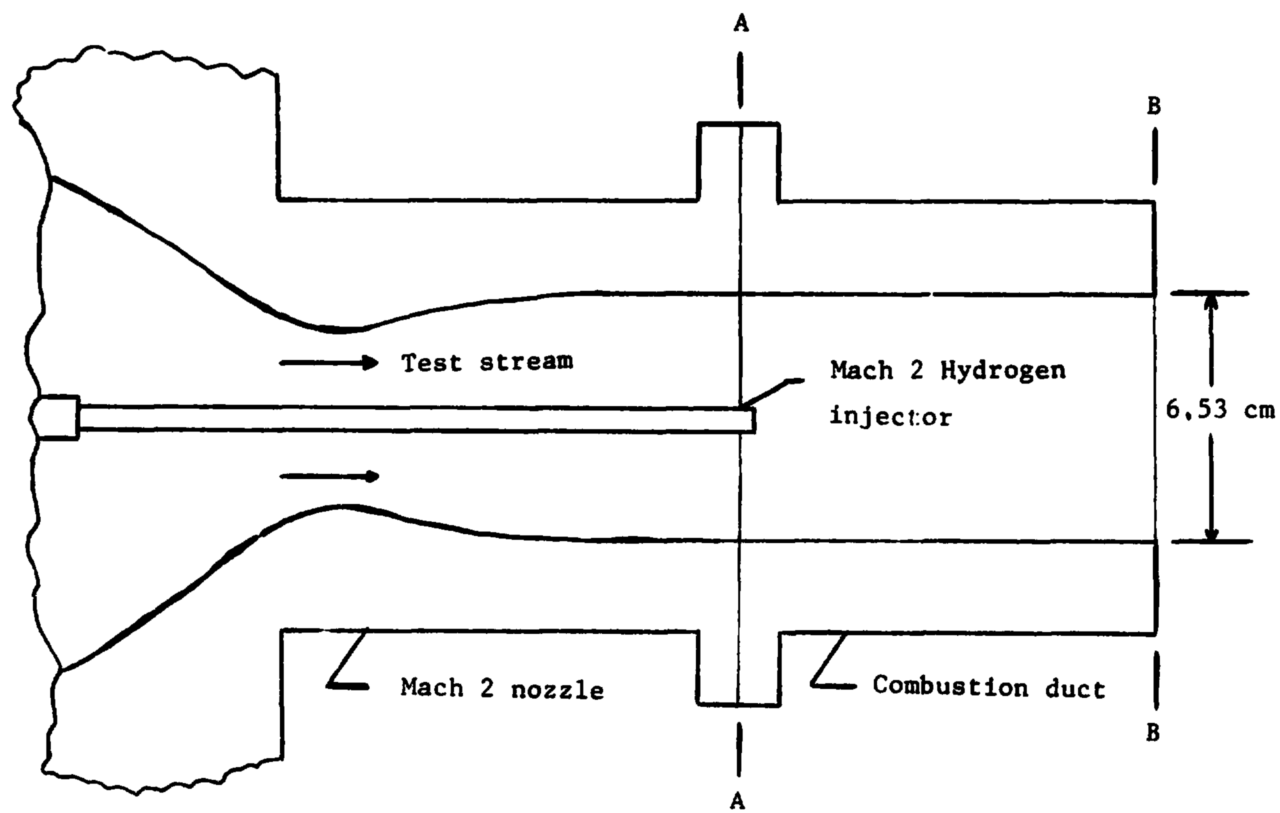


Figure 1.- Schematic of the coaxial supersonic combustion apparatus.

and for all tests the total temperature of the test stream was 2167 K, with a nozzle exit (static) temperature of 1338 K. This temperature was high enough to give ignition without a pilot flame or ignitor. The stagnation pressure ranged from 0.759 to 0.858 MN/m^2, which gave rise to test gas flow rates of 1.23 to 1.39 kg/sec and nozzle exit (static) pressures of 0.099 to 0.112 MN/m^2.

A summary of the test conditions is presented in Table I.

Hydrogen Injector

The hydrogen injector, which was mounted coaxial with the main nozzle, is a 0.953 cm (3/8 in) stainless-steel tube with a 5° conical nozzle at the exit. This nozzle, with a 0.635 cm exit diameter and 0.488 cm throat diameter, gives a nominal exit Mach number of 2. The injector exit lip thickness is 0.159 cm.

This injector lip of finite thickness introduces the problem of wake effects in the base region of the injector. However, it is considered to be a good compromise between the ideal and technically practical nozzle. Ideally, for ease of analysis, the injector should have an infinately thin lip, and parallel flow at its exit. Unfortunately, the contoured nozzle needed to fulfill these ideal conditions cannot be built and a compromise must be sought. If the requirement of parallel flow is dropped, the infinitely thin lip can be approached by at least two designs. One is the boattail conical type nozzle given in figure 2. This design produces two undesirable results. First, the boattail causes the test flow to expand to a lower pressure, and second, the expansion

Table 1

TEST CONDITIONS							
$\frac{x}{r_j}$	P_{t_0} MN/m^2	P_∞ MN/m^2	$\frac{P_j}{P_\infty}$	Re x 10^{-4}	$\dot{m}$ kg/sec	$\dot{m}_{H_2}$ kg/sec	Test Type
1±.5	0.789	0.103	2.03	2.446	1.302	0.015	A-FJ
19	0.794	0.103	2.031	2.460	1.307	0.015	A-FJ
30	0.802	0.104	2.189	2.485	1.320	0.016	A-FJ
40	0.80	0.104	2.138	2.478	1.316	0.016	A-FJ
56	0.817	0.106	2.022	2.531	1.345	0.015	A-FJ
80	0.791	0.103	2.136	2.451	1.302	0.016	A-FJ
1.5±.5	0.792	0.103	2.292	2.452	1.281	0.017	N-FJ
19	0.794	0.103	2.269	2.460	1.285	0.017	N-FJ
30	0.806	0.105	2.356	2.498	1.305	0.018	N-FJ
40	0.782	0.102	2.123	2.425	1.267	0.016	N-FJ
56	0.842	0.11	2.054	2.609	1.363	0.016	N-FJ
80	0.779	0.101	2.205	2.413	1.260	0.016	N-FJ
30	0.817	0.106	2.101	2.530	1.343	0.016	A-D
40	0.812	0.106	1.952	2.517	1.336	0.015	A-D
96	0.811	0.106	1.966	2.511	1.334	0.015	A-D
144	0.819	0.107	2.11	2.538	1.348	0.016	A-D
30	0.759	0.099	2.285	2.352	1.229	0.016	N-D
40	0.833	0.109	2.035	2.582	1.349	0.016	N-D
96	0.781	0.102	1.996	2.422	1.265	0.015	N-D
144	0.858	0.112	2.05	2.657	1.388	0.016	N-D

A - Air FJ - Free Jet N - Nitrogen D - Ducted $\frac{x}{r_j}$ = Duct Length

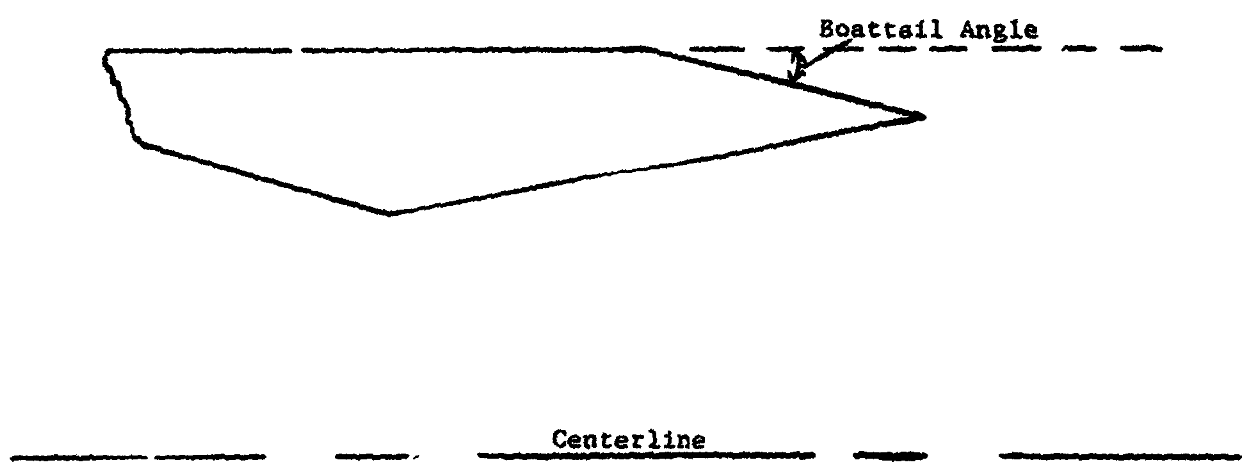


Figure 2.- Half cross section of a nozzle having a very thin lip and boattail.

turns the flow (near the injector) so that it is no longer parallel with the rest of the test stream. The other design is the one of figure 3, where the boattail has been eliminated. Unfortunately, this design suffers from the increased chance of separation of boundary layer on the injector. Such separation of boundary layer would be caused by interaction with the exit shock and the jet flow. If a nozzle of this design is cut off (see figure 3), the resulting nozzle has a finite lip thickness with a base region. Although the wake effects of this region cannot be computed close to the base, the probability of boundary layer separation is reduced. This result is obtained from the fact that the boundary layer can bleed into the wake and the compression effects of the divergent flow are eased. It was felt that the exit thickness (0.159 cm) of the injector chosen was sufficient to prevent separation but small enough to get a far field (several r_j's) solution for the wake region. It is also pointed out that the experimental data of reference 12 indicates that the jet spreads better when injected from a blunt body of this type. Increased spreading (mixing) suggests better burning. This design was therefore adopted for the present investigations.

The cooling needed to protect the injector during each test is provided by the injectant (hydrogen). In the present tests, the hydrogen supplied at ambient temperature was heated to a total temperature of approximately 470 K as it cooled the injector before injection into the stream. With this total temperature, and stagnation pressures ranging from 1.59 to 1.94 MN/m^2, the injector supplied hydrogen mass flow rates of 0.015 to 0.018 kg/sec. The resulting equivalence ratio, based on

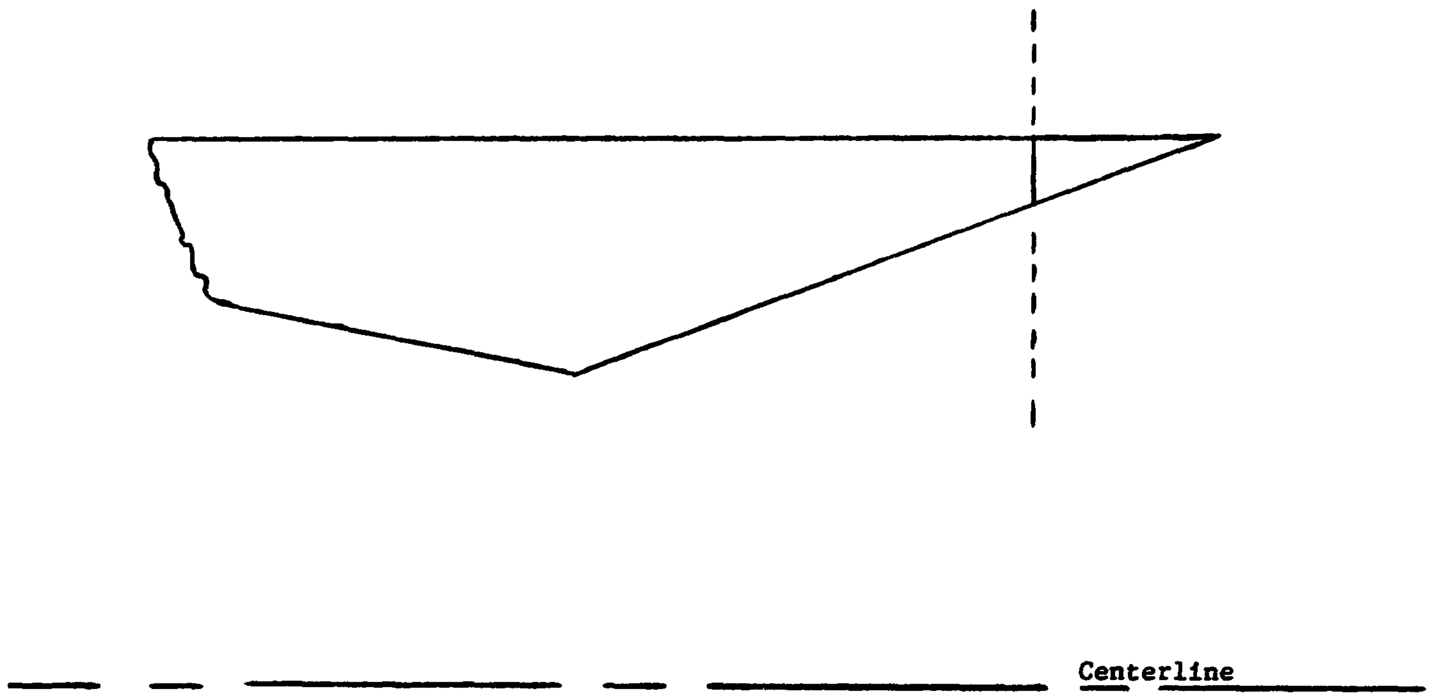


Figure 3.- Half cross section of a nozzle with no boattail but with a very thin lip. (Cutting the tip off this nozzle as indicated by the vertical line produces an injector of the type used in the present work.)

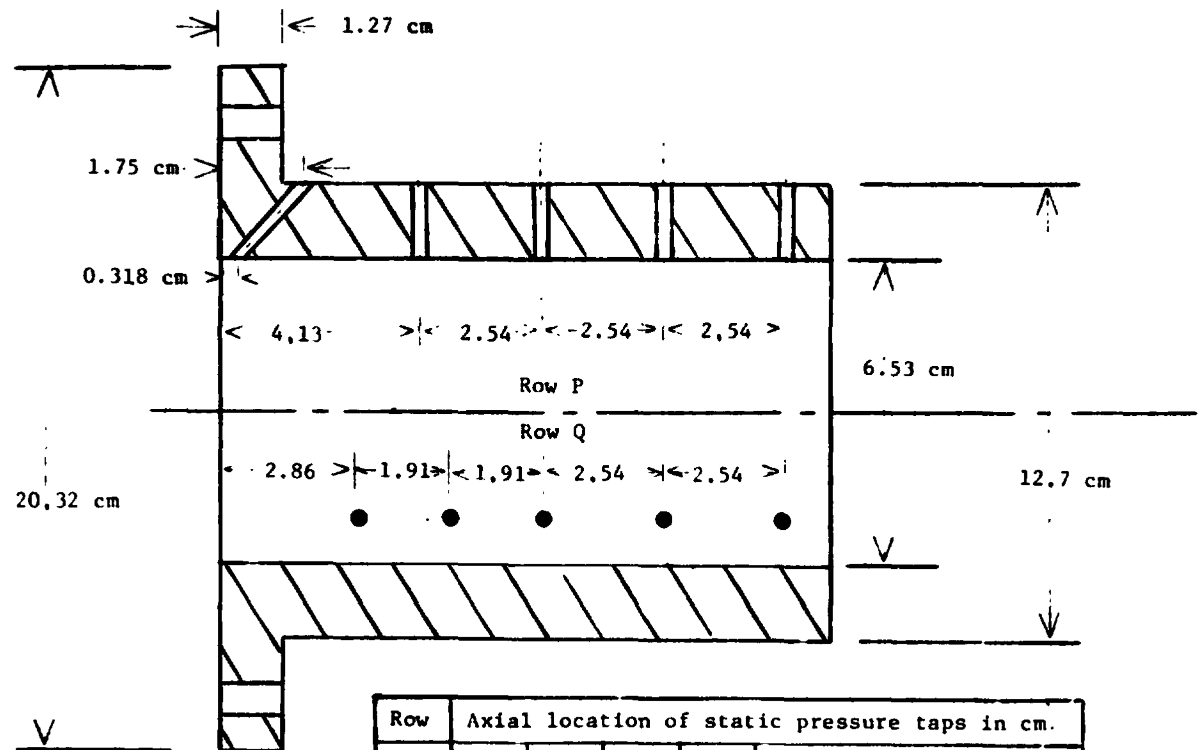
total flow in the test stream nozzle, varied from 0.381 to 0.467 and the exit (static) pressures ranged from 0.203 to 0.248 MN/m^2. The injector exit pressure was therefore about 2 times the test stream static pressure for each test, and the injected hydrogen was thus underexpanded.

Circular Combustor

In the ducted mode, constant area ducts of four different lengths (9.53, 12.70, 30.48, and 45.72 cm) were individually attached to the facility nozzle to form circular combustors. These combustors, constructed of stainless-steel, are uncooled (heat sink) and have numerous pressure orifices for measuring static pressure. The orifices are arranged in three rows (designated P, Q, and R in figure 4) that run axially along the duct with each row spaced 120° apart. A schematic of the 12.7 cm combustor, accompanied by a table summarizing the orifice locations for all four ducts, is given in figure 4.

Pitot Probes

The pitot probes used in the present tests were of two different designs. One design is a modified version of a probe developed by the Applied Physics Laboratory of Johns Hopkins University and reported in reference 13. It has an outside diameter of 0.635 cm and a tip half-angle of 30° (see figure 5 for details of probe tip). The other design is a slightly modified version of a probe described in reference 14. It has an outside tip of 0.914 cm and a tip half-angle of 20° (see figure 6 for details of probe).



Row	Axial location of static pressure taps in cm.				
P	1.75*	4.13	6.67	9.21	Spaced at 2.54 cm intervals from previous locations to the duct exit.
Q	2.86	4.76	6.67	9.21	
R	3.49	5.40	-	9.21	

*This tap drilled at an angle so that it opens into the duct at an axial location of 0.3175 cm.

Figure 4.- Half section of 12.7 cm length duct (' ken in the plane bisecting the pressure taps of Row P) with axial locations for all four ducts.

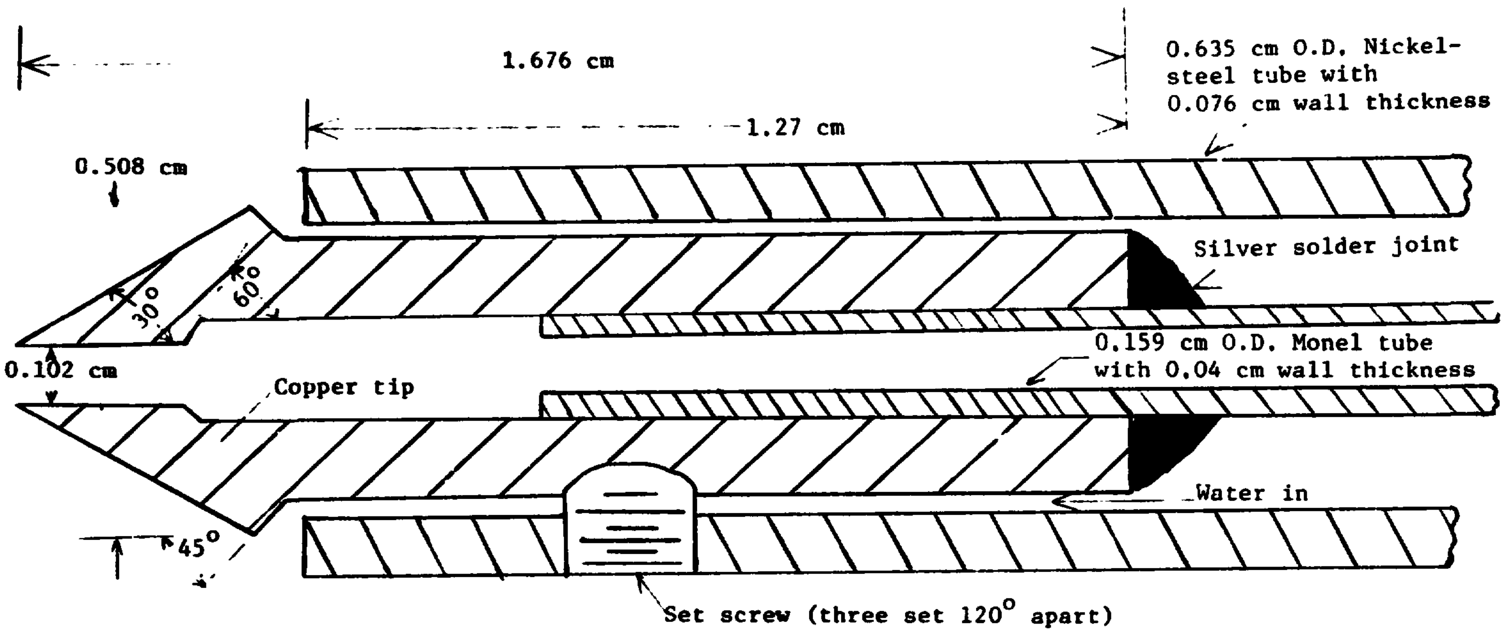


Figure 5.- Cross section of the modified Johns Hopkins' probe.

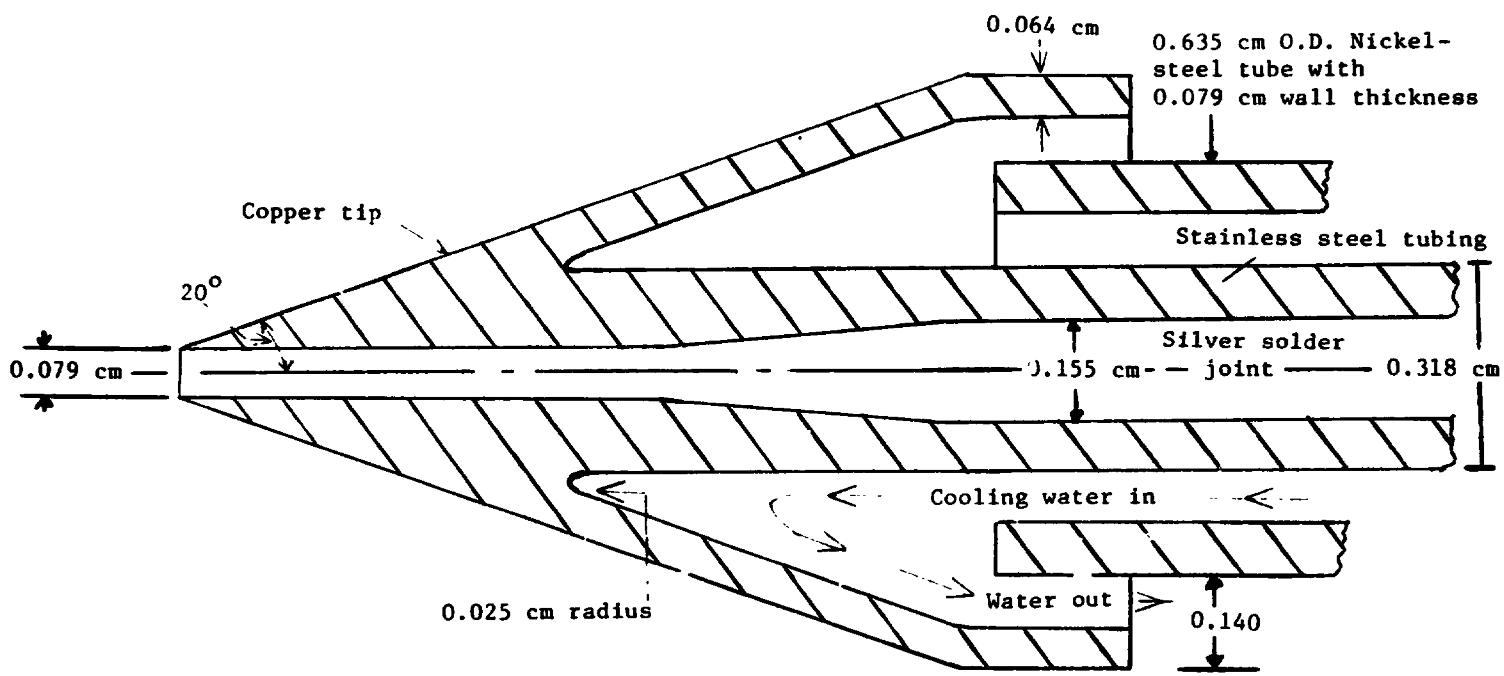


Figure 6.- Half-section of the modified Eggers' probe.

Probes of both designs were water-cooled by a no return method. In this method, water is supplied through a single passage in the main body of the probe, sprayed against the rear of the probe tip, and then injected into the test stream at a location behind the pressure sensing region. Once in the test stream, the water is swept downstream over the probe body furnishing further cooling.

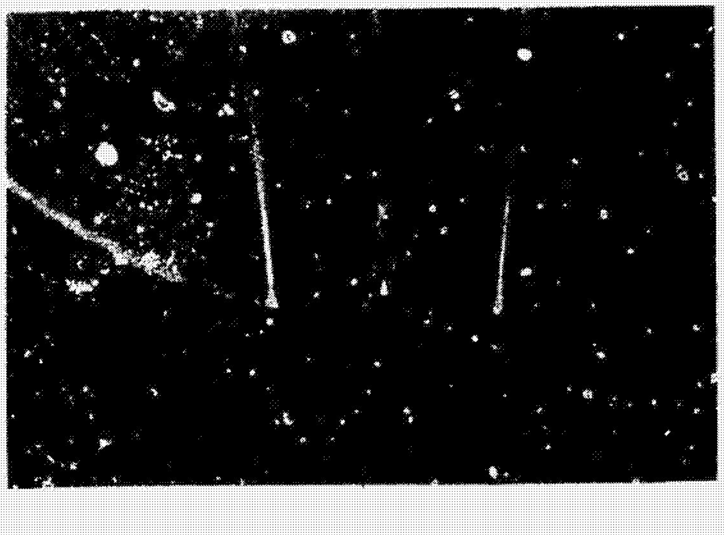
Pitot-pressure profiles were obtained with a single moving probe which was driven perpendicularly across the flow field at a rate of approximately 0.5 cm/sec by a dc motor. Comparisons of pitot pressures taken at the same points with the probe moving and stationary indicated that response of the pressure transducer was sufficient to give accurate measurements while moving. In addition, probes of either design gave the same results for identical test conditions.

Photographs and Shadowgraphs

Data obtained in the form of photographic records were of two types: black and white movies, and shadowgraphs. The movies were taken at a frame rate that varied from 20 to 64 frames/sec. They were used to check the pitot probe alinement and vibration. The shadowgraphs were taken at a constant frame rate of 24 frames/sec. They were used to define the flow quality and are quite valuable for analyzing the flow field.

Photographic records of both types were obtained on 16 mm black and white movie film with an ASA number of 400 (Din number of 27). The total photographic records will not be included in this work. However, an example of the shadowgraphs are given in figure 7.

(a) Test stream and jet.



(b) Blow-up of wave structure.

Figure 7.- Shadowgraph of the test stream and jet in the free-jet mode with combustion.

Example of Pitot Test Data

Although the majority of the test data is to be presented in Chapter IV, the exit pitot surveys are introduced here to provide a feel for the experimental data. In figures 8 and 9, radial exit pitot pressure profiles for the free-jet reacting and nonreacting cases are given respectively. Both profiles have the same general shape, however their peak (centerline) values are not equal. The nonreacting peak value is less than the reacting, since it is taken at an axial location slightly downstream of the axial location of the reacting case. The solid line of both figures is a straight line connection of adjacent data points intended as a guide to the data trend.

Since both cases have the same shape, only one discussion will be offered. This discussion uses the letters common to both of these figures, and the flow schematic of figure 10. The pitot pressure varies radially in the following manner. The pressure decrease in going from points a to b is due partly to the radial travel across the conical jet flow field, and partly to an expansion fan from the injector lip. Both processes result in higher Mach numbers, and thus lower pitot pressures. The small peak at c is the result of the shock wave which terminates the expansion fan. The decrease in pressure from c to d is due to the shock wave indicated at c and the fact that d is in the base region of the injector. The shock indicated at c is a curved shock which extends from the injector lip at the exit to the centerline at a slightly downstream location. Thus, much of the region c to d is behind the curved shock, whose strength varies from a minimum near the

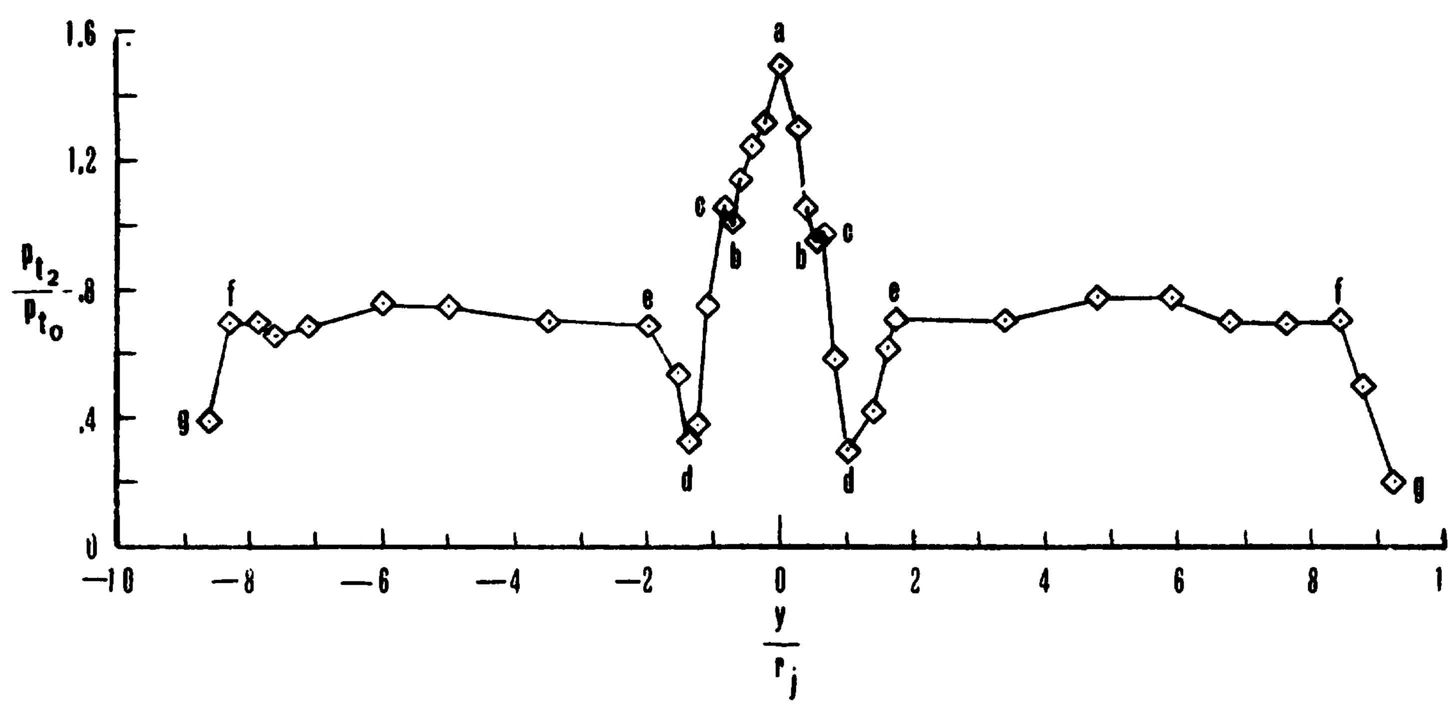


Figure 8.-- Pitot profile at exit of injector ($x/r_j = 1 \pm .5$) with air test medium.

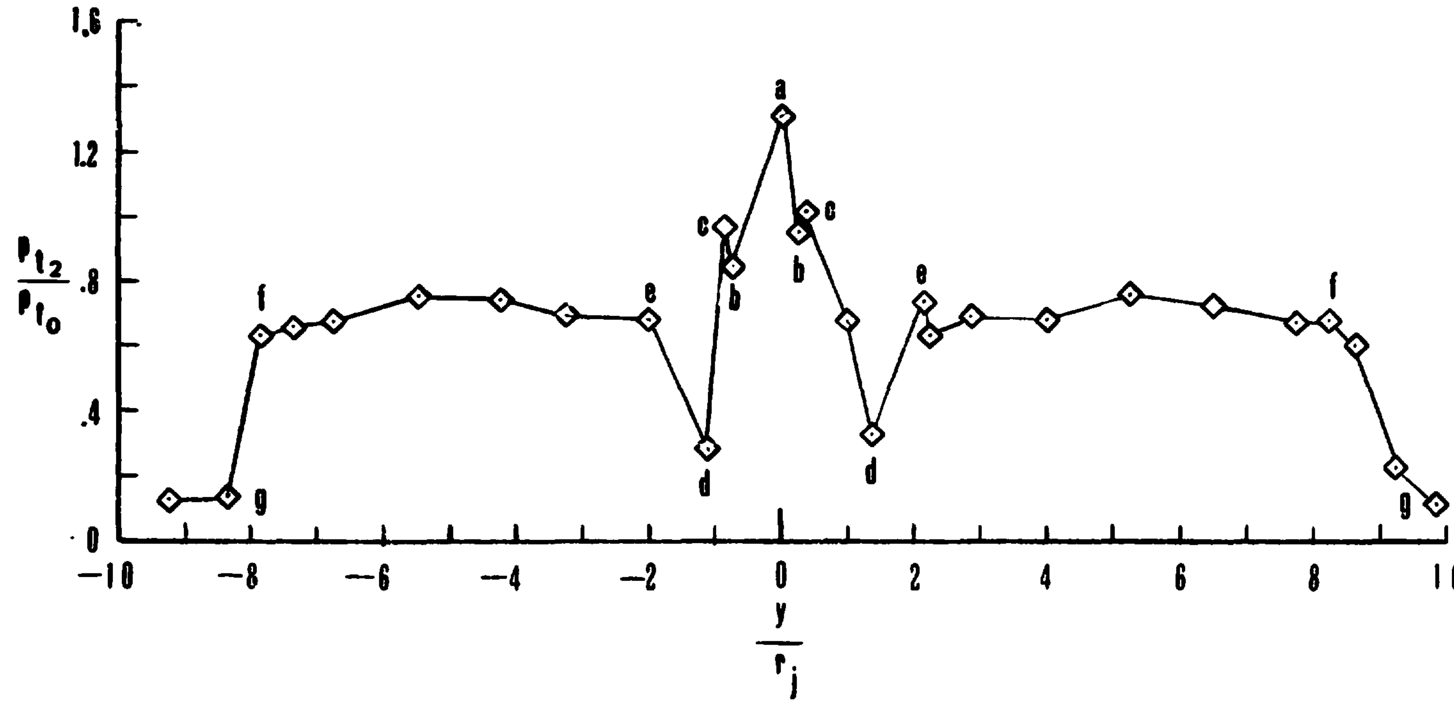


Figure 9.- Pitot profile at exit of injector ($x/r_j = 1.5 \pm .5$) with nitrogen test medium.

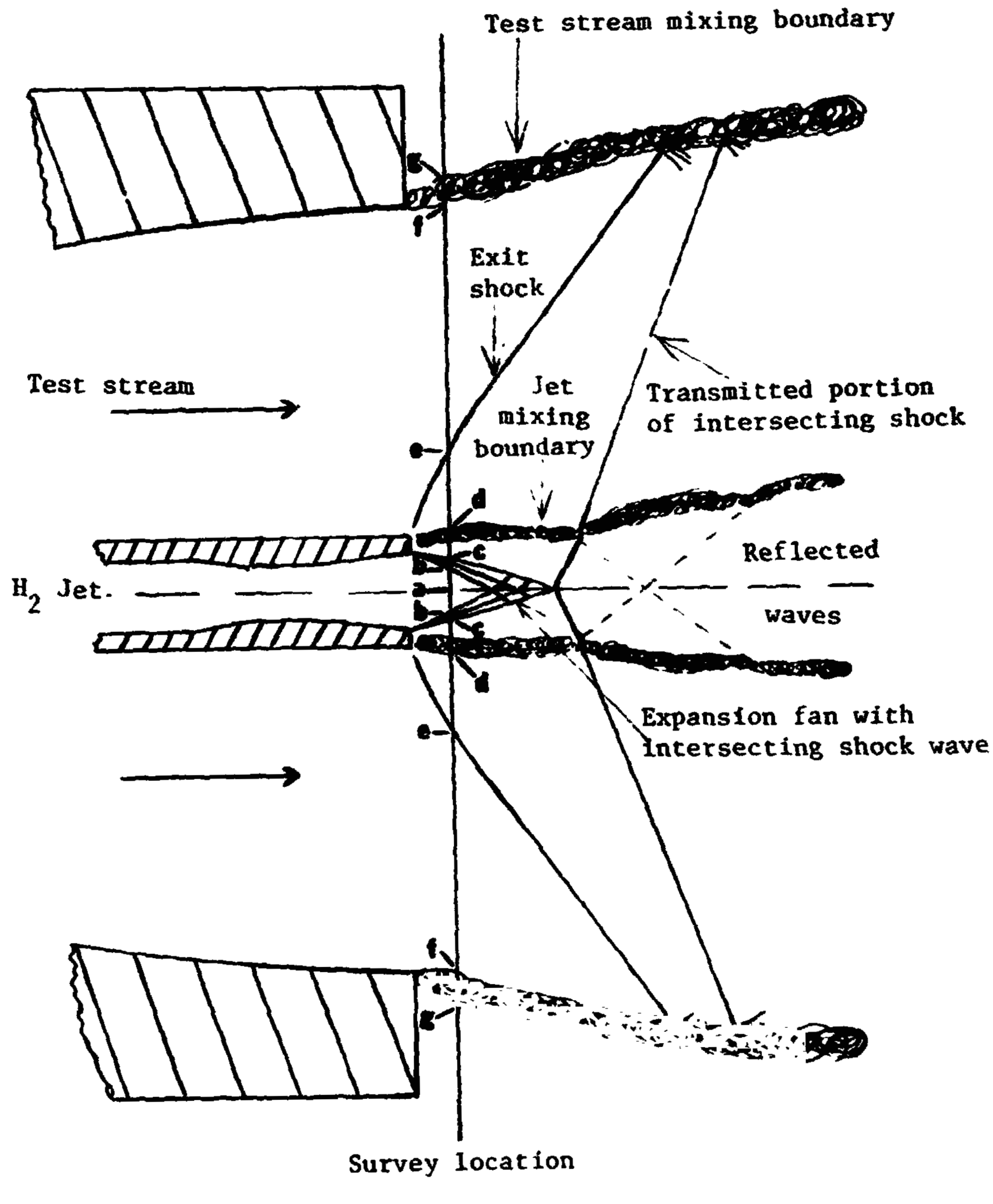


Figure 10.- A schematic of the free-jet flow field with various prominent features at the survey location labeled.

injector lip to a maximum at the centerline. The strength variation in this region produces a radial pitot pressure profile which varies in the same direction (minimum to maximum), whereas the radial Mach number profile varies in the opposite direction. In idealized flow, d would be the location of a slip line separating the test stream and jet flow. In the present work, the radial region near d is probably a mixing boundary. Point e is the underexpansion or exit shock wave which extends from the injector's outer lip to the test stream boundary, where it is reflected as an expansion fan. Therefore, the region d to e is similar but in opposite sense to the region c to d. The region from e to f is the test stream without any interaction. The dip from f to g is an indication of the free-jet test stream interacting with the ambient air.

It may be surmised from the above discussion that the flow field resulting from the underexpanded injection of hydrogen into supersonic flow is quite complex. As a consequence, the theoretical treatment by necessity must be rather sophisticated. The theory used for comparison in this work is that of reference 8, and is outlined in the next chapter.

CHAPTER III

THEORY

General Governing Equations

The basic governing equations are the well known "viscous-inviscid" equations used in higher order boundary layer and viscous flow field analysis with the finite rate chemistry terms included. These "viscous-inviscid" equations are supplemented by the Rankine-Hugoniot and Prandtl-Meyer relations to facilitate the computation of shock and expansion conditions respectively. The basic equations are given in Appendix A along with a limited discussion of how they are applied. The reader interested in a more thorough delineation of the equations and the numerical application may consult references 15, 16, and 17.

Viscosity Models

The program as published in reference 9 had a turbulent eddy viscosity model referred to as the "Ferri-Kleinstein" model. This model, which was developed in references 18 and 19, has viscosity variation in the axial direction only. However, it was felt that Eggers' viscosity model (see reference 20), which varies both axially and radially, may be more accurate. Thus, it was decided that the program would be run with both models individually incorporated.

Ferri-Kleinstein Model

In this model, the turbulent eddy viscosity undergoes an axial variation from the jet exit to the end of the potential core. The length of the potential core is defined as: the distance χ from the jet exit to the downstream location where the mass fraction of hydrogen on the centerline becomes less than 0.99. The viscosity is then assumed to be constant for all locations downstream of the potential core length χ.

The viscosity is computed, for stream locations (x/r_j) less than χ, with the nondimensional equation,

$$\mu = K_1 Re \left((\rho q)_{max} - (\rho q)_{min} \right) (x/r_j + K_3 \qquad (1)$$

where, $K_1 = 7.5 \times 10^{-4}$ and $K_3 = 100$.

For stream locations equal to or greater than χ

$$\mu = K_1 Re \left((\rho q)_{max} - (\rho q)_{min} \right) \chi + K_3 \qquad (2)$$

and since μ is constant downstream of the length χ, eq ation 2 is executed once. The resulting value of μ is stored for a l future downstream calculations.

Eggers' Model

There are two viscosity models generally referred to as Eggers' model, thus one must be careful to specify the model intended. The two models, which are similar in mathematical structure, are called Z-difference and kinematic Z-difference models by Eggers (reference 6). In the Z-difference model (see reference 20) the absolute viscosity varies axially only and is computed using the nondimensional equation,

$$\mu = KZ \; (\rho q)_{CL} \qquad (3)$$

In the kinematic Z-difference model, the kinematic viscosity varies axially and is computed using the nondimensional equation,

$$\varepsilon = KZ\ (q)_{CL} \tag{4}$$

The absolute viscosity is obtained by multiplying the kinematic viscosity (of equation 4) by the local density which varies radially. Thus, the absolute viscosity varies both axially and radially, and is computed with the equation,

$$\mu = \rho local\ KZ\ (q)_{CL} \tag{5}$$

In all three equations (3-5), the empirical constant K has a value of 0.01. The quantity Z is defined as the radial distance between the points where the local velocities are U_1 and U_2 as given by the equations,

$$U_1 = U_a + 0.95\ (U_{CL} - U_a) \tag{6}$$

and,

$$U_2 = U_a + 0.5\ (U_{CL} - U_a) \tag{7}$$

where U_a equal the stream velocity external to the jet.

It is the model computed by use of equation 5 that is referred to as the Eggers' model in this work.

CHAPTER IV

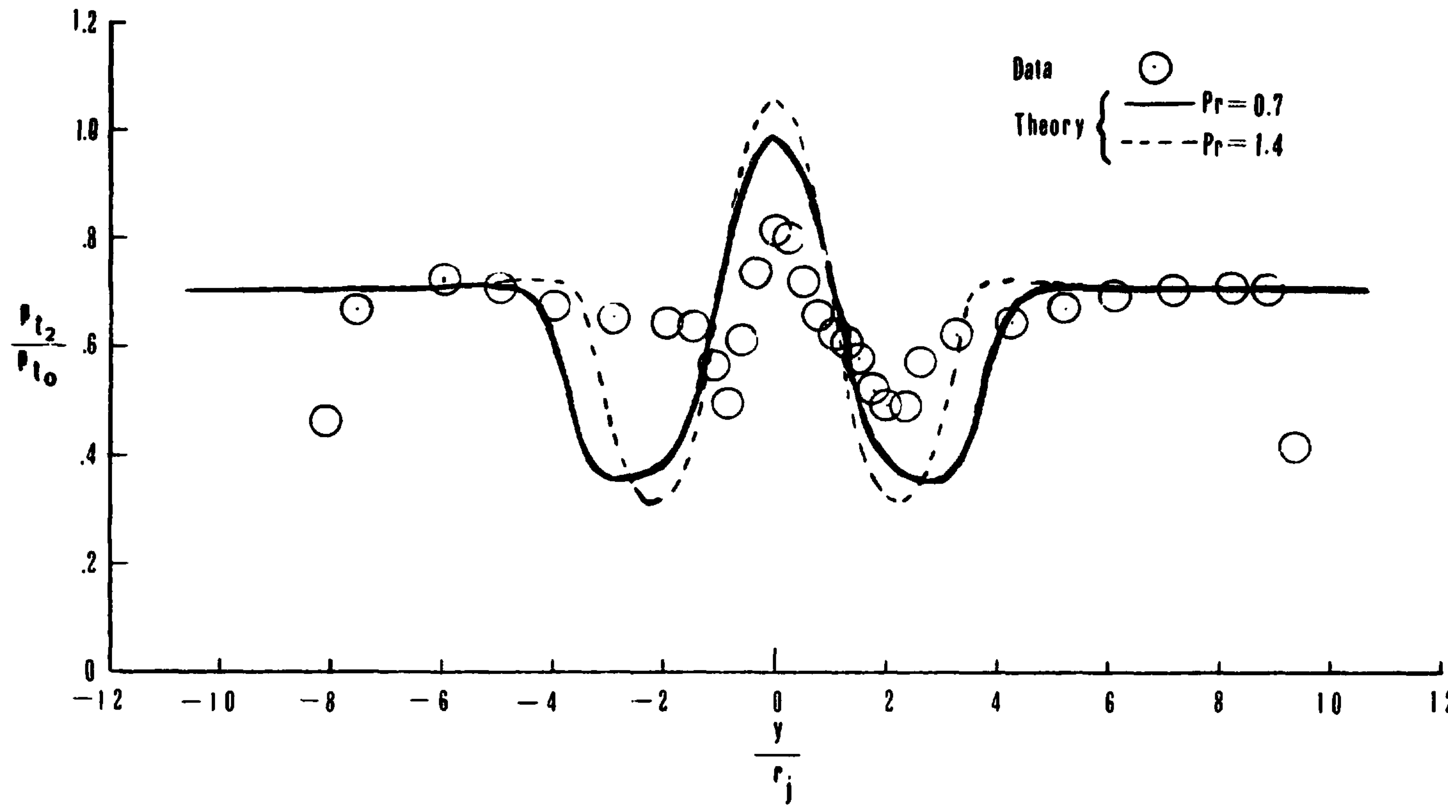
RESULTS AND DISCUSSION

The experimental data and theoretical predictions of the present study are presented in dimensionless form. All pressures are nondimensionalized by dividing by the test stream stagnation pressure (P_{t_o}). Similarly, dimensionless coordinates and lengths are obtained by division by the hydrogen jet radius (r_j) at the exit of the injector. It is also noted that all theoretical calculations were performed with a Lewis number of 1.

Free-jet Data

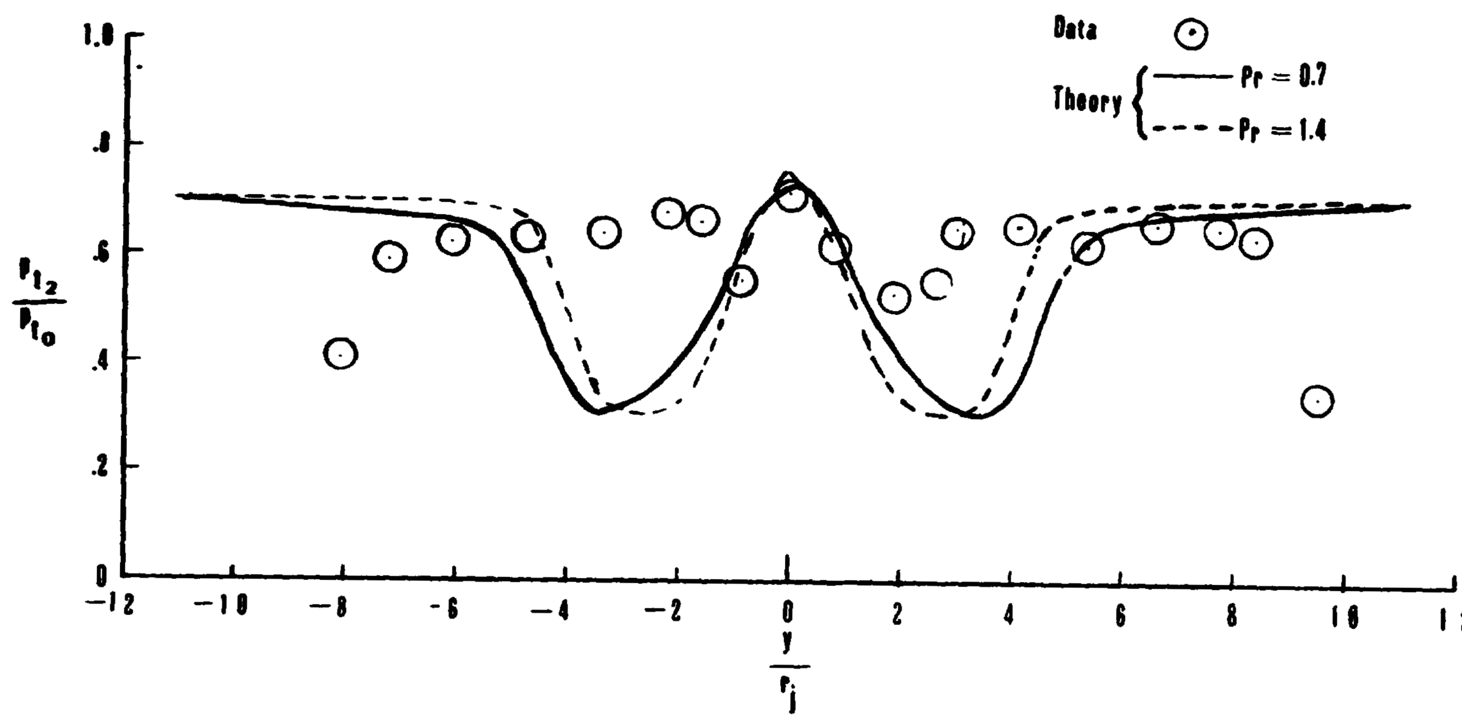
Radial pitot pressure surveys were taken at several axial stations for the free-jet mode and at the end of the ducts when operating in the ducted mode. The pitot pressure data (surveys) for each mode of operation can be subdivided into reacting and nonreacting cases. In the reacting cases, the test stream is air, and in the nonreacting cases the test stream is nitrogen.

The data for the free-jet reacting cases given in figure 11 are typical and will be discussed. The pitot surveys were made at axial locations (x/r_j) of 1, 19, 30, 40, 56, and 80. The data for the axial location x/r_j equal one were previously presented in figure 8, and will not be covered here. The prominent features, such as high jet centerline pressure bounded by jet mixing boundaries, present at the $x/r_j = 1$ location extend downstream. In fact, the high centerline pressure is present for the $x/r_j = 19$, 30, and 40 locations. However, the mixing



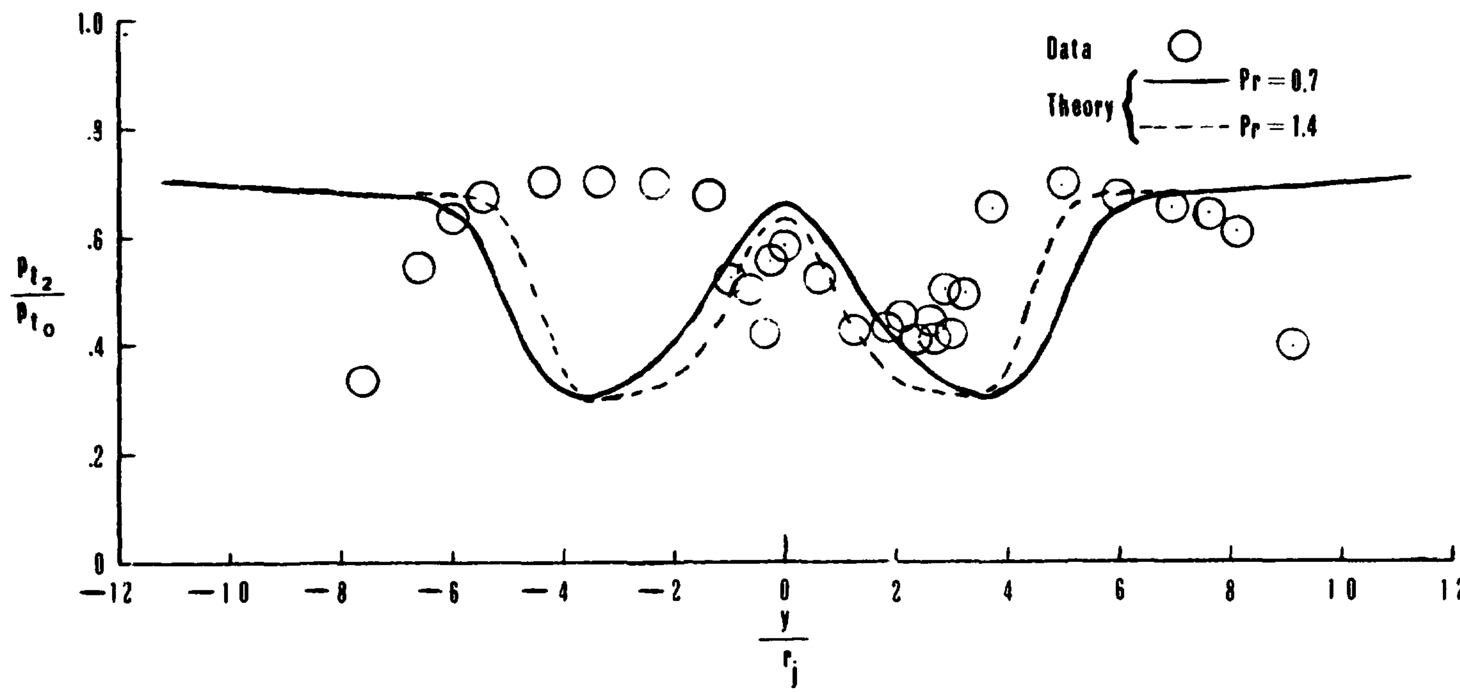
(a) $x/r_j = 19$

Figure 11.- Experimental and theoretical pitot profiles at various axial locations for the reacting free-jet mode (Ferri-Kleinstein viscosity model).



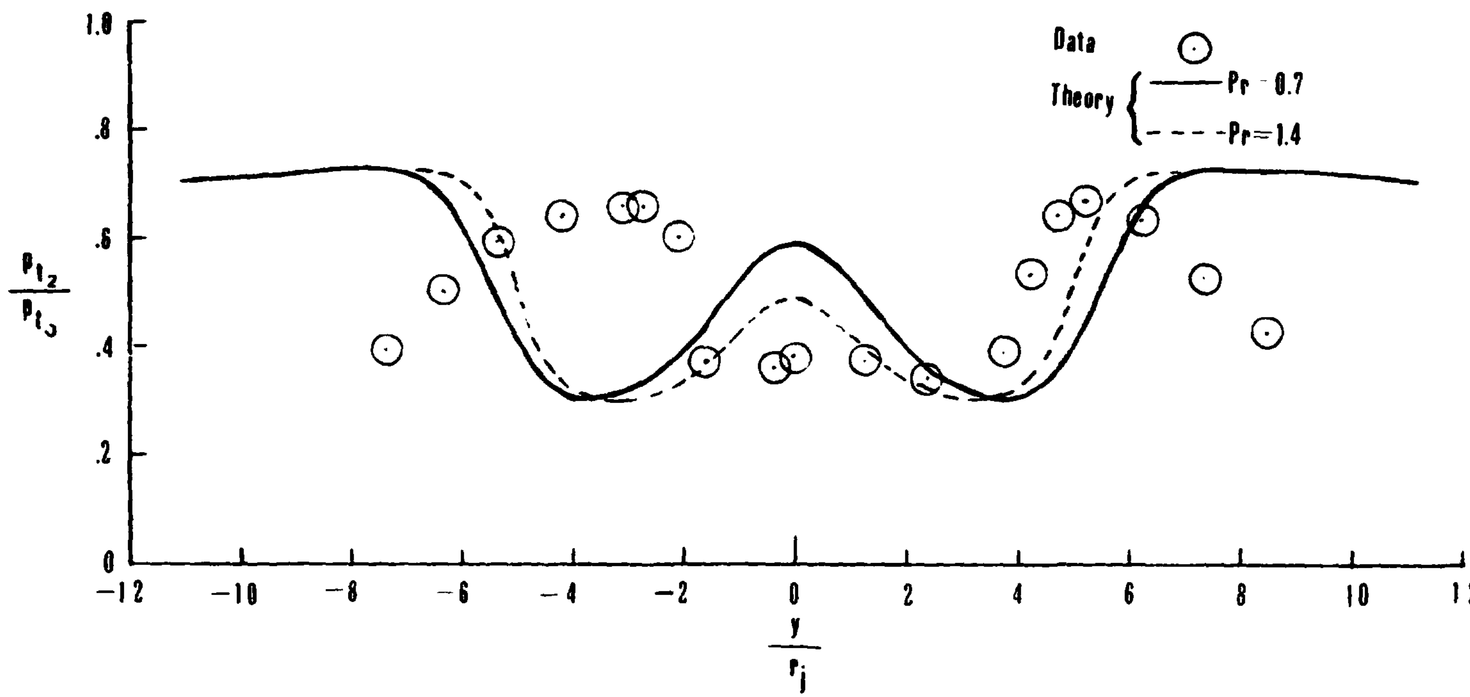
(b) $x/r_j = 30$

Figure 11.- Continued.



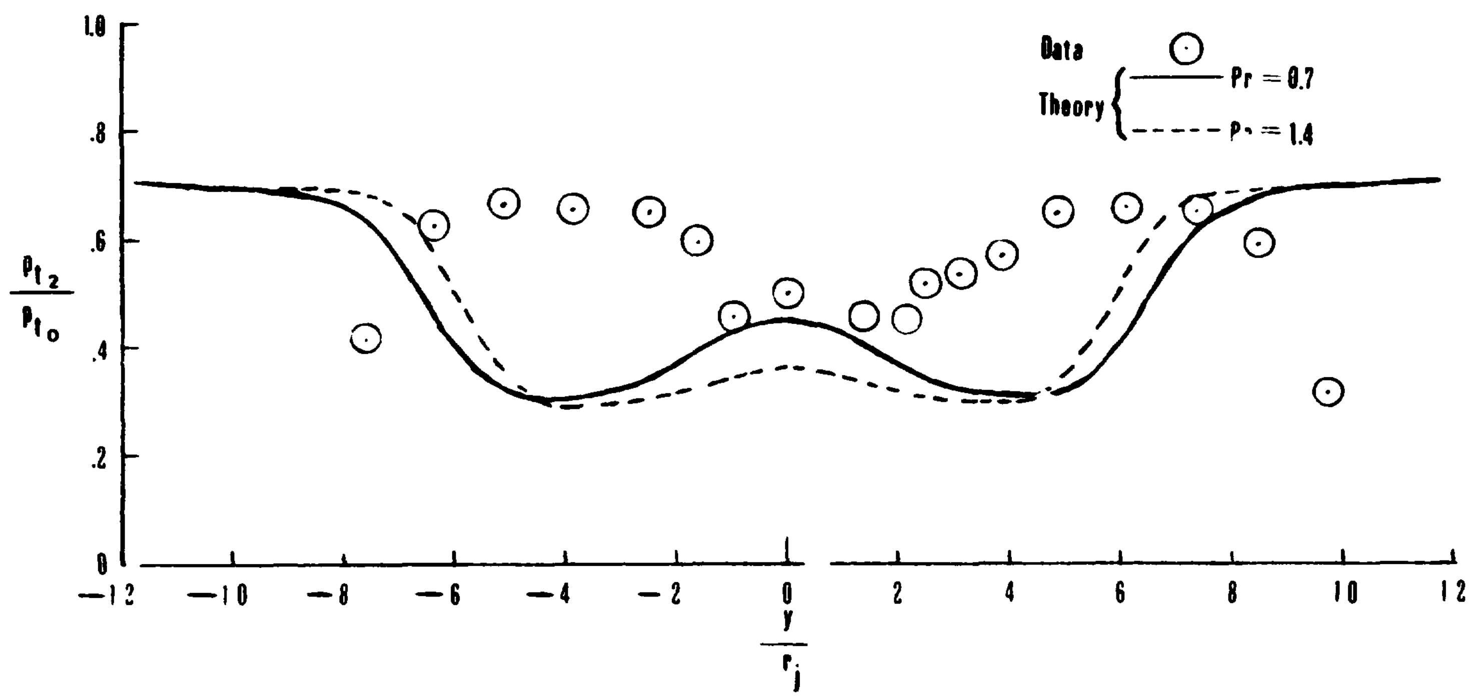
(c) $x/r_j = 40$

Figure 11.- Continued.



(d) $x/r_j = 56$

Figure 11.- Continued.



(e) $x/r_j = 80$

Figure 11.- Concluded

region has engulfed the centerline at the $x/r_j = 56$ location and the centerline is not discernible. The regions of no interaction, previously discussed in the section on the pitot sample, have become tenuous at the $x/r_j = 56$ location. This demise of these regions is attributed to the fact that free-jet test mixing boundary spreads inward to meet the jet-test-stream mixing region which spreads outward.

Other details of the data are given in the following discussion, in which theoretical predictions are compared with the data.

The theoretical calculations at the free-jet test stream boundary were not expected to agree with the experimental data, since the program does not have the necessary theory for handling the test stream mixing boundary. The program takes a constant pressure boundary approach which is sufficient for mathematical consistence, but improper for actual boundary conditions. This approach does not affect the accuracy of the calculations performed for the region inside the test stream mixing boundary since this region is supersonic. Thus, the boundary disturbances cannot be transmitted to the internal region of interest, and the calculations should be in agreement with the experimental data. Unfortunately, an actual comparison of the theoretical calculations and the experimental data does not show such agreement. In figure 11, for example, there is a comparison of the experimental pitot pressure data to theoretical calculations performed with the Ferri-Kleinstein viscosity model. The test stream is air, and the theoretical data are for Prandtl numbers of 0.7 and 1.4. As expected, there is no agreement in the region of the test stream mixing boundary. For axial locations $x/r_j = 19$ and 30 where there is a region of test stream not affected by the mixing boundary or jet interaction, the agreement is excellent. (At $x/r_j = 19$ these regions extend from $y/r_j = -7.5$ to -4 and from $y/r_j = 4$ to 9.) This agreement indicates that the constant pressure boundary approach does not affect the accurary of the program for the region internal to the test stream mixing boundary. However, the only other semblance of agreement is at the centerline region $y/r_j = \pm 1$ and that is not complete. For example, the centerline differences between the experimental and theoretical values $Pr = 0.7$ are given in Table 2.

Table 2

x/r_j	% Difference @ ℄
19	21
30	0
40	13
56	56
80	10

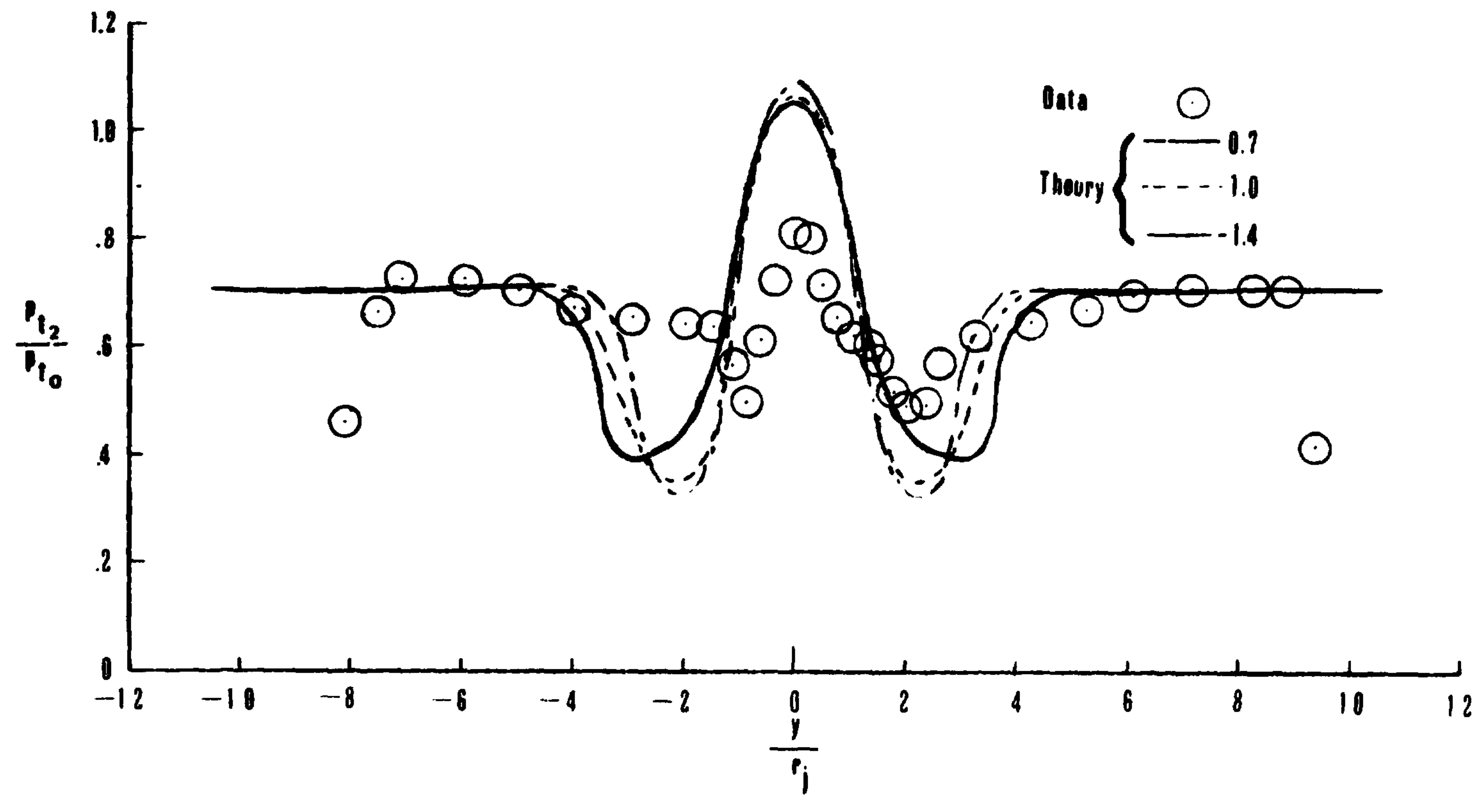
This erratic agreement on the centerline suggests that the analytical technique does not handle the wave structure internal to the jet (see figure 7).

Theoretical jet mixing (spreading) effects, as indicated by pitot pressure, are much too large at all the axial locations (this may be observed by comparing the theoretical and experimental widths of the region of interaction in figure 11).

In figure 12, the theoretical data computed using the Eggers' viscosity model (and Prandtl number of 0.7, 1., and 1.4) are compared to the same experimental data given in figure 11. As can be seen, the agreement with this viscosity model is about the same as that of the Ferri-Kleinstein model. Likewise, the discussion of figure 11 is in general true of figure 12.

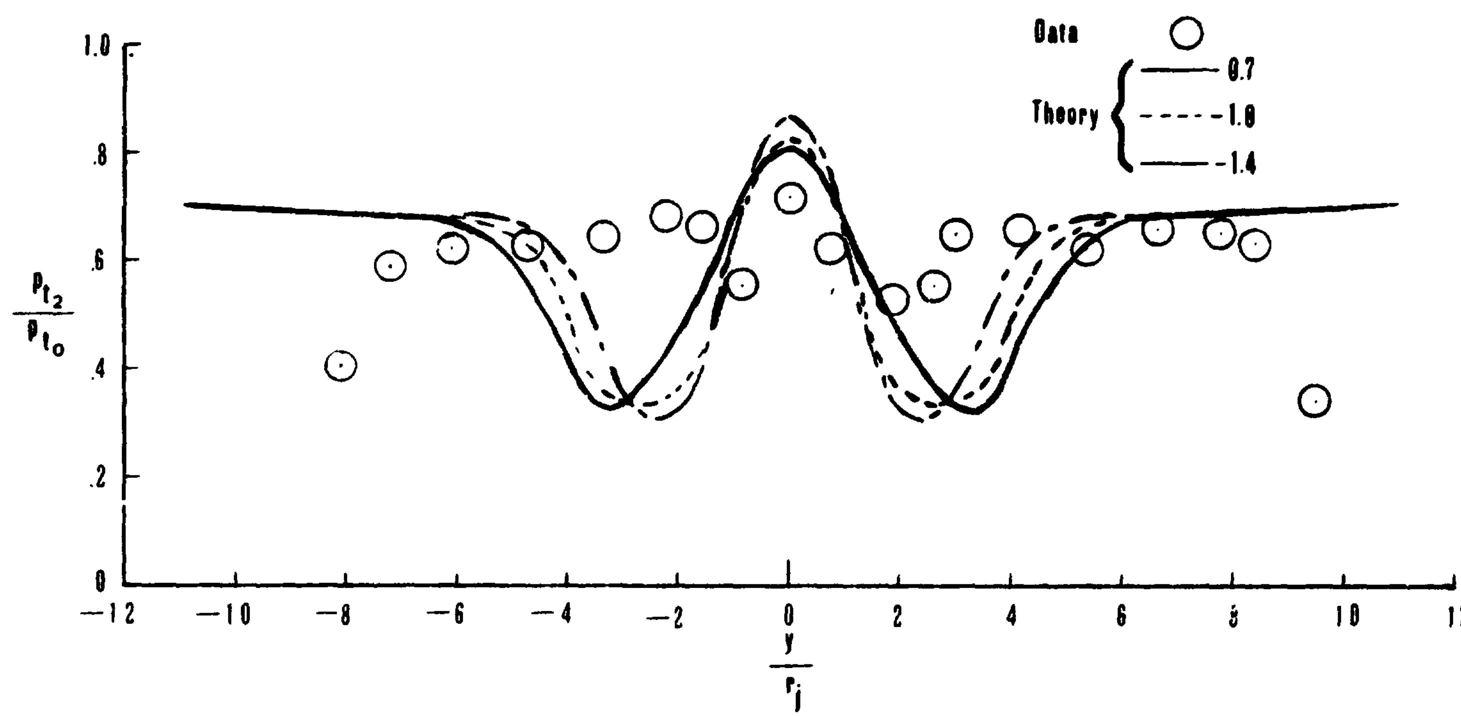
The nonreacting free-jet case, resulting from the use of nitrogen as the test medium, is presented in figure 13. The theoretical results obtained with each of the viscosity models are so close together that only the theoretical results obtained with Eggers' model will be presented. In this figure, only the theoretical results obtained with a Prandtl number of 1 are offered since this gives the best agreement. At an axial location of $x/r_j = 19$ theoretical and experimental results have the same general shapes. The numerical agreement, however, is quite poor in the near centerline region $y/r_j = \pm 1.5$. In addition, the shape agreement is short lived and disappears by the time an axial location of 40 is reached. For all values of $x/r_j \geq 40$ the experimental data have a minimum at the centerline and the theoretical have a maximum. That is, the theoretical data exhibit a valley in the near centerline region. These results indicate that the theoretical near centerline Mach numbers are too low, thus producing pitot pressures which are too high. This contrary behavior of the theoretical predictions is probably due to improper handling of the jet wave structure.

The expected disagreement for the test stream mixing boundary is also present. Furthermore, the region of no test stream interaction (for



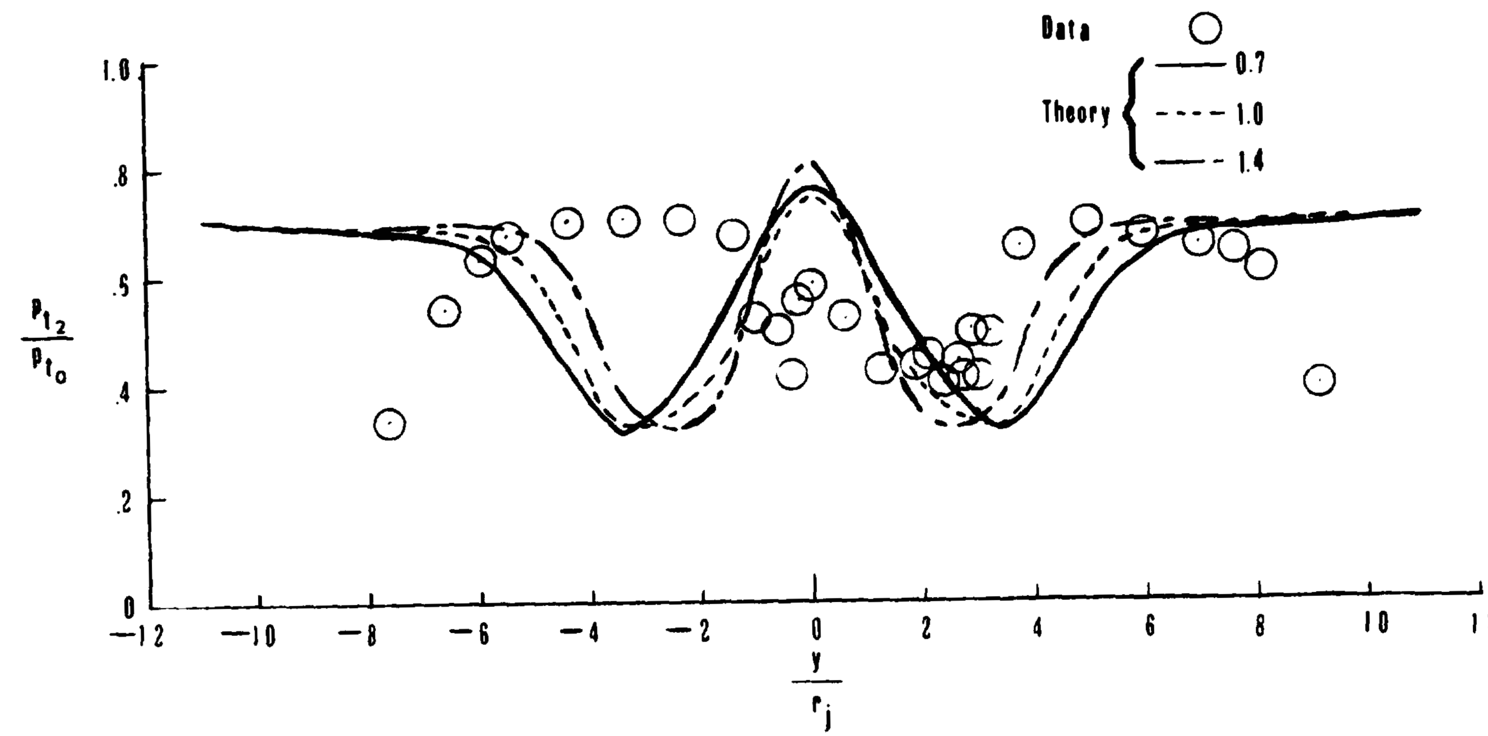
(a) $x/r_j = 19$

Figure 12.- Experimental and theoretical pitot profiles at various axial locations for the reacting free-jet (Eggers' viscosity model).



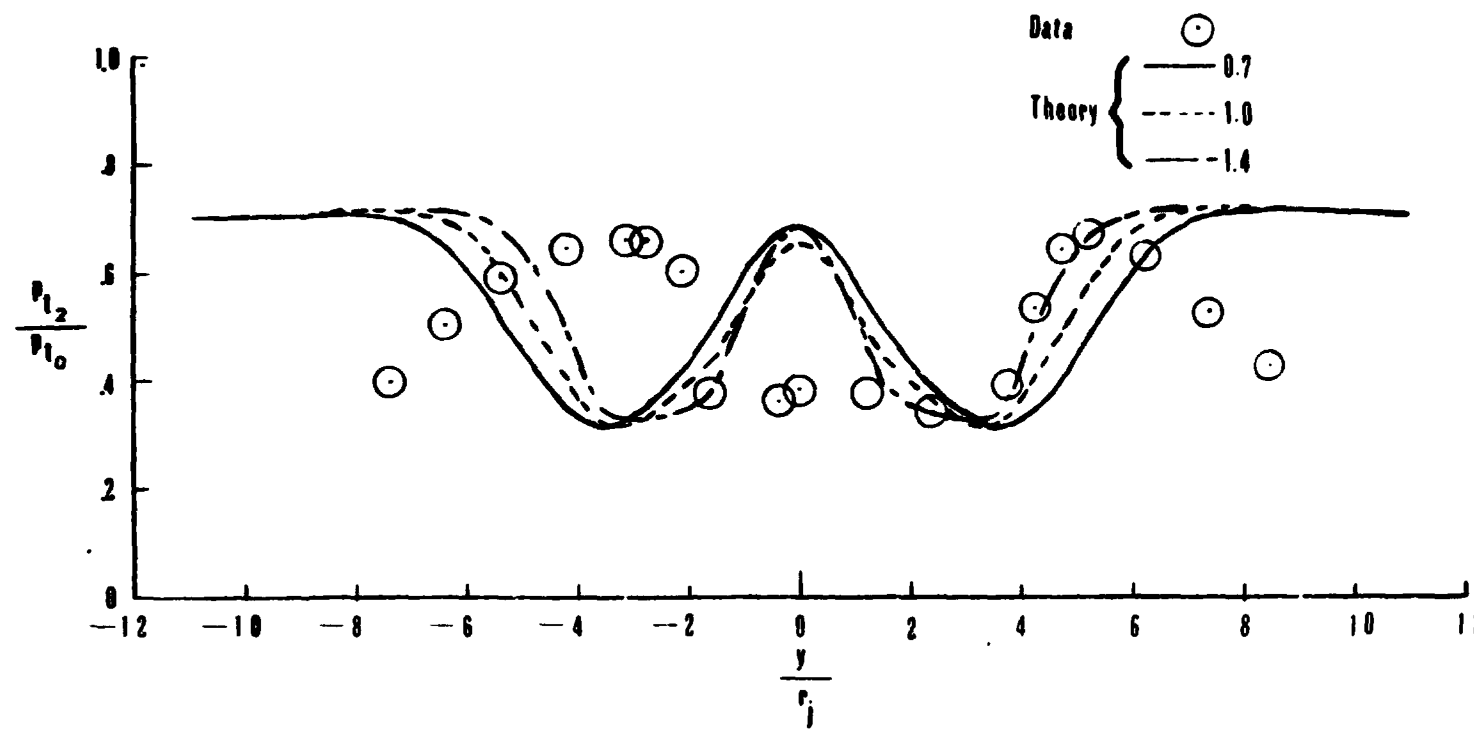
(b) $x/r_j = 30$

Figure 12.- Continued.



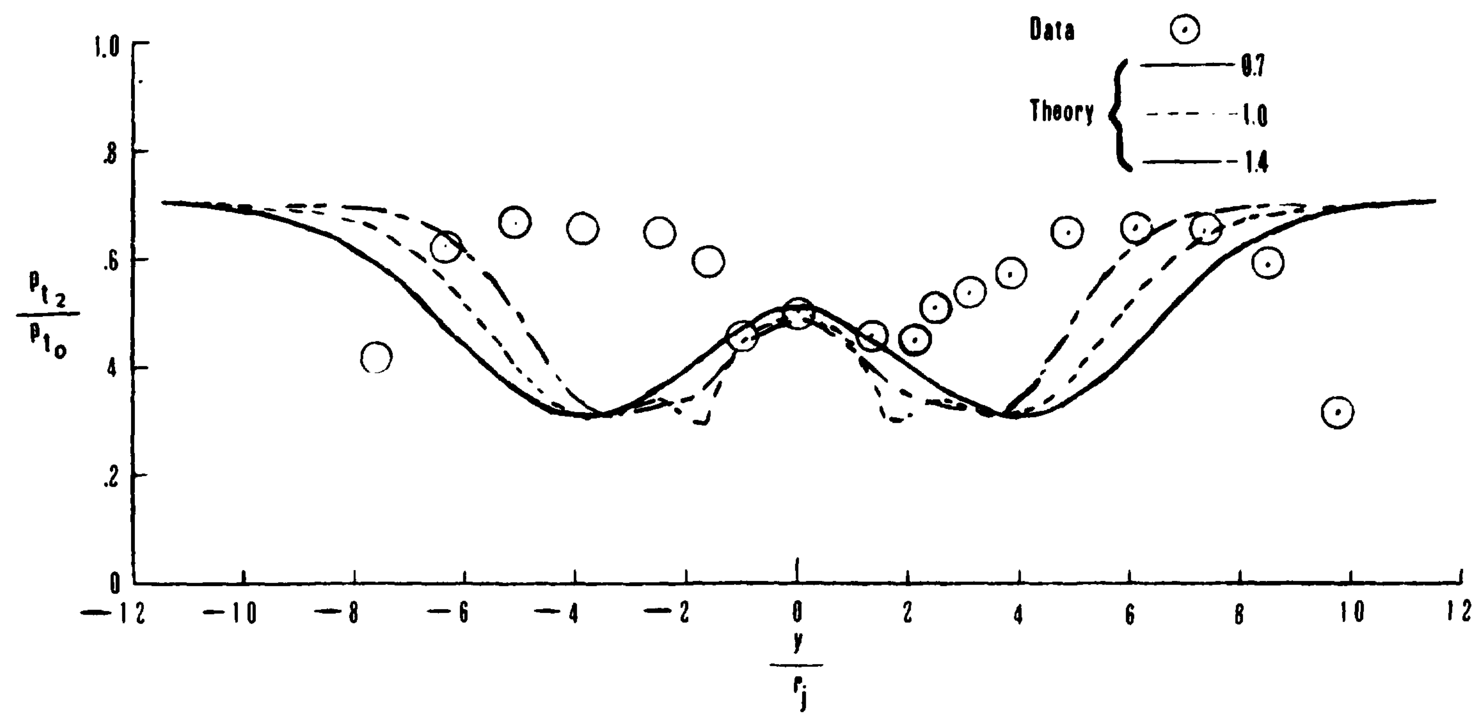
(c) $x/r_j = 40$

Figure 12.- Continued.



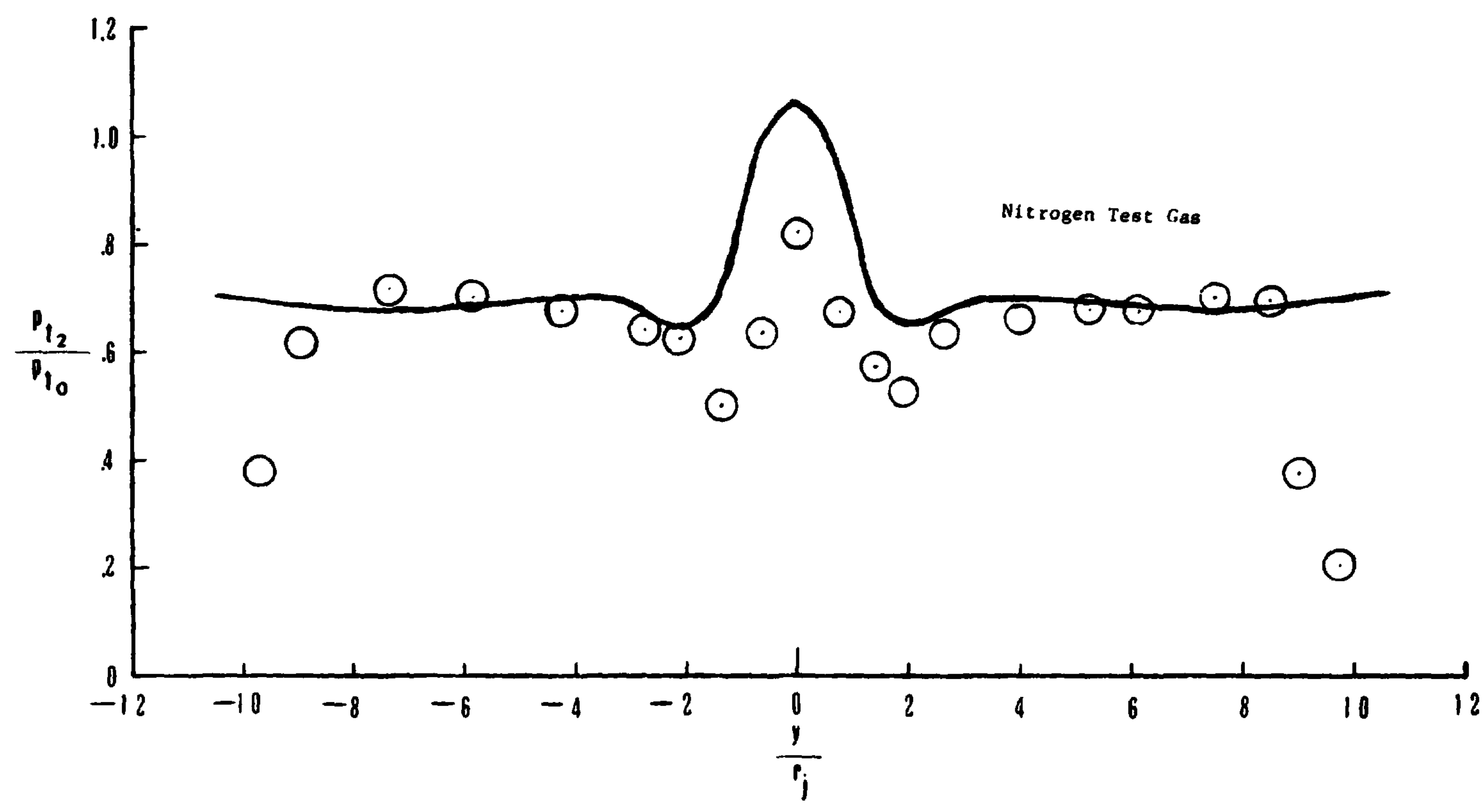
(d) $x/r_j = 56$

Figure 12.- Continued.



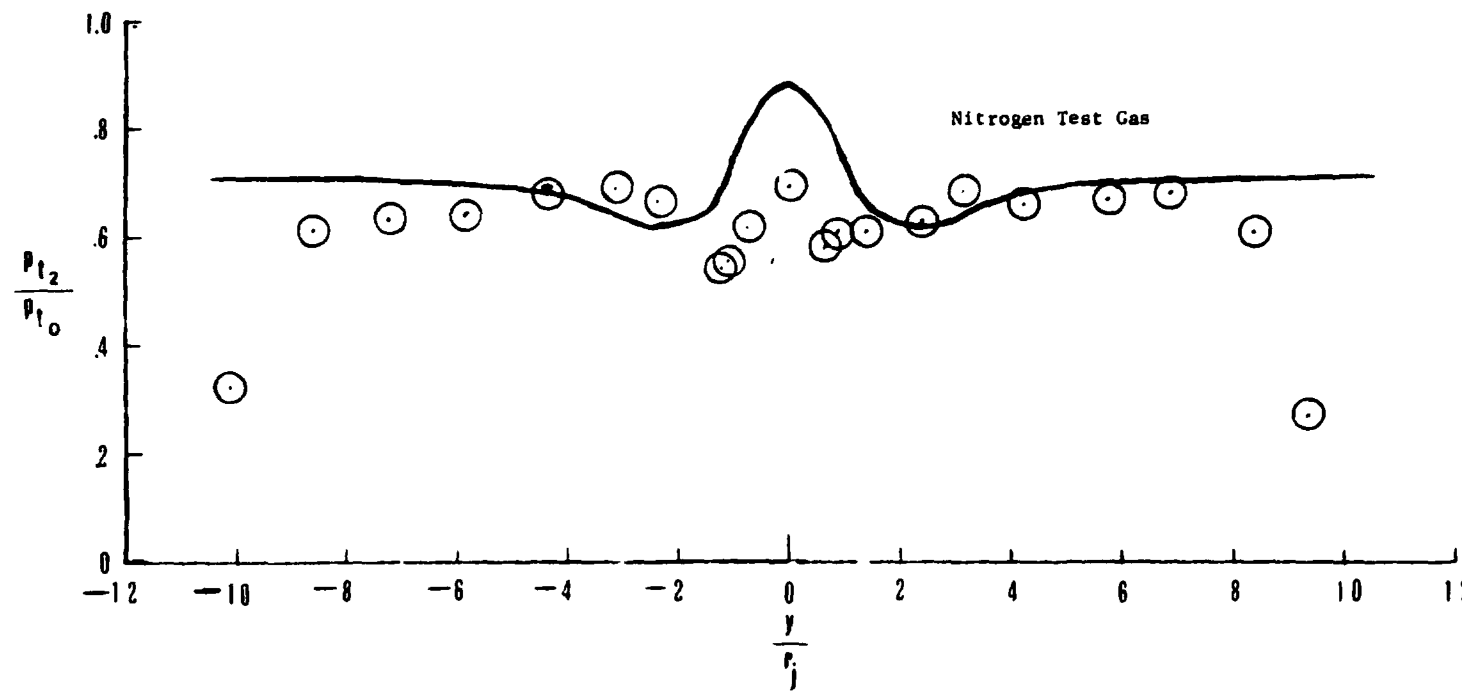
(e) $x/r_j = 80$

Figure 12.- Concluded.



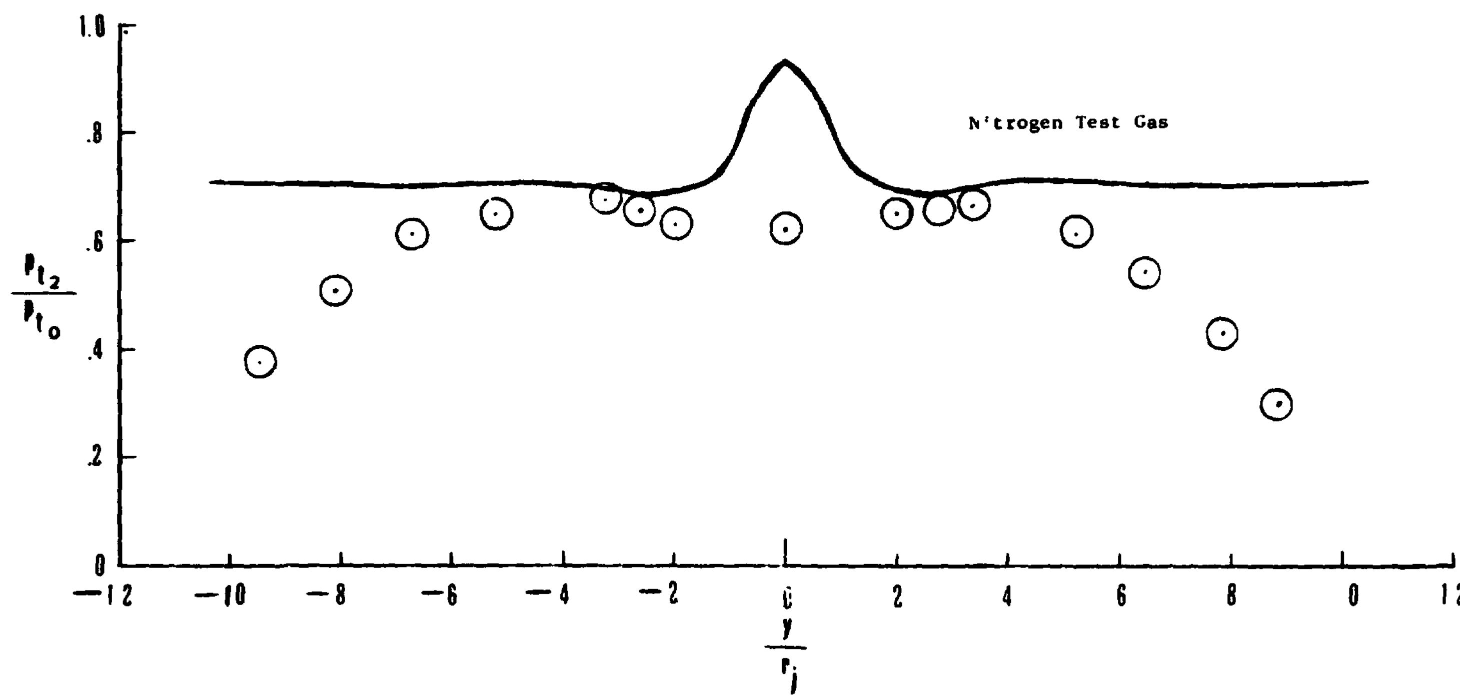
(a) $x/r_j = 19$

Figure 13.- Nonreacting free-jet pitot profiles at various axial locations. (Theoretical curve represents both viscosity models, and a Prandtl number of 1.)



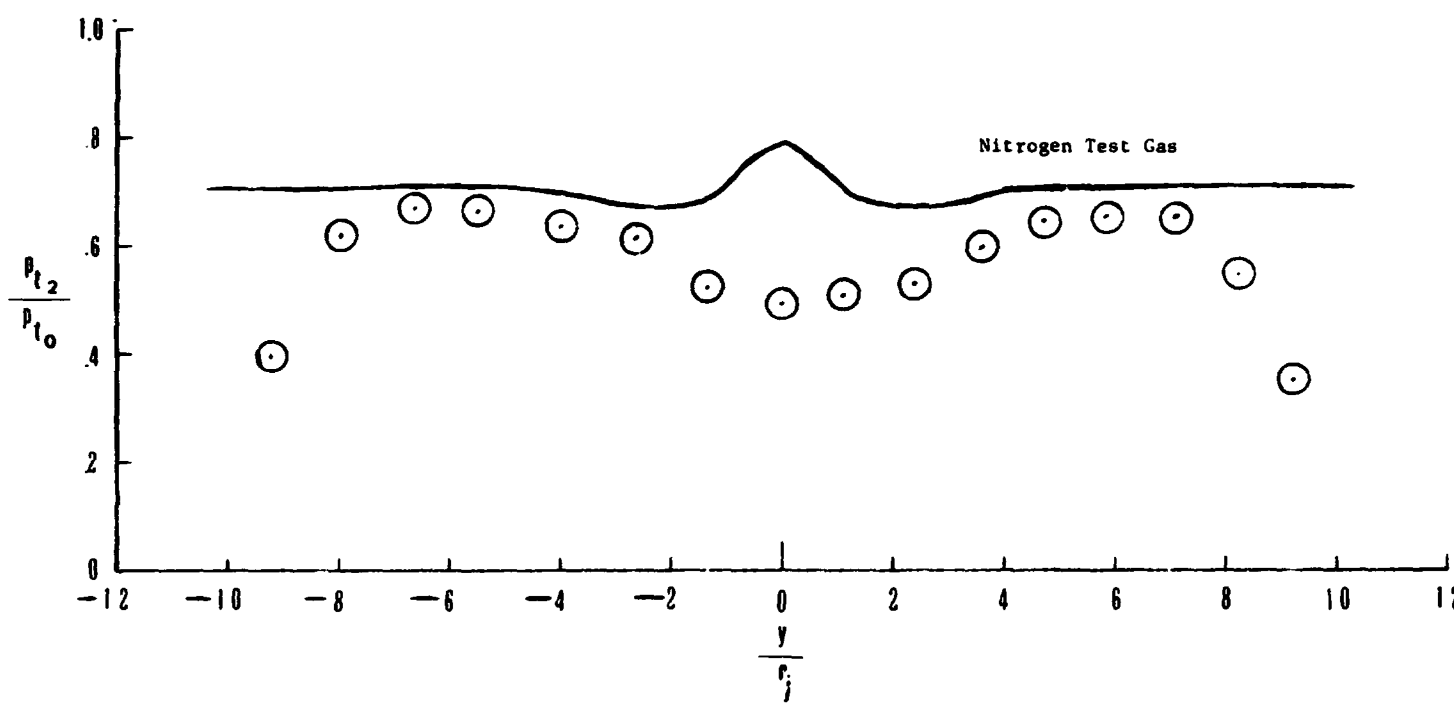
(b) $x/r_j = 30$

Figure 13.- Continued.



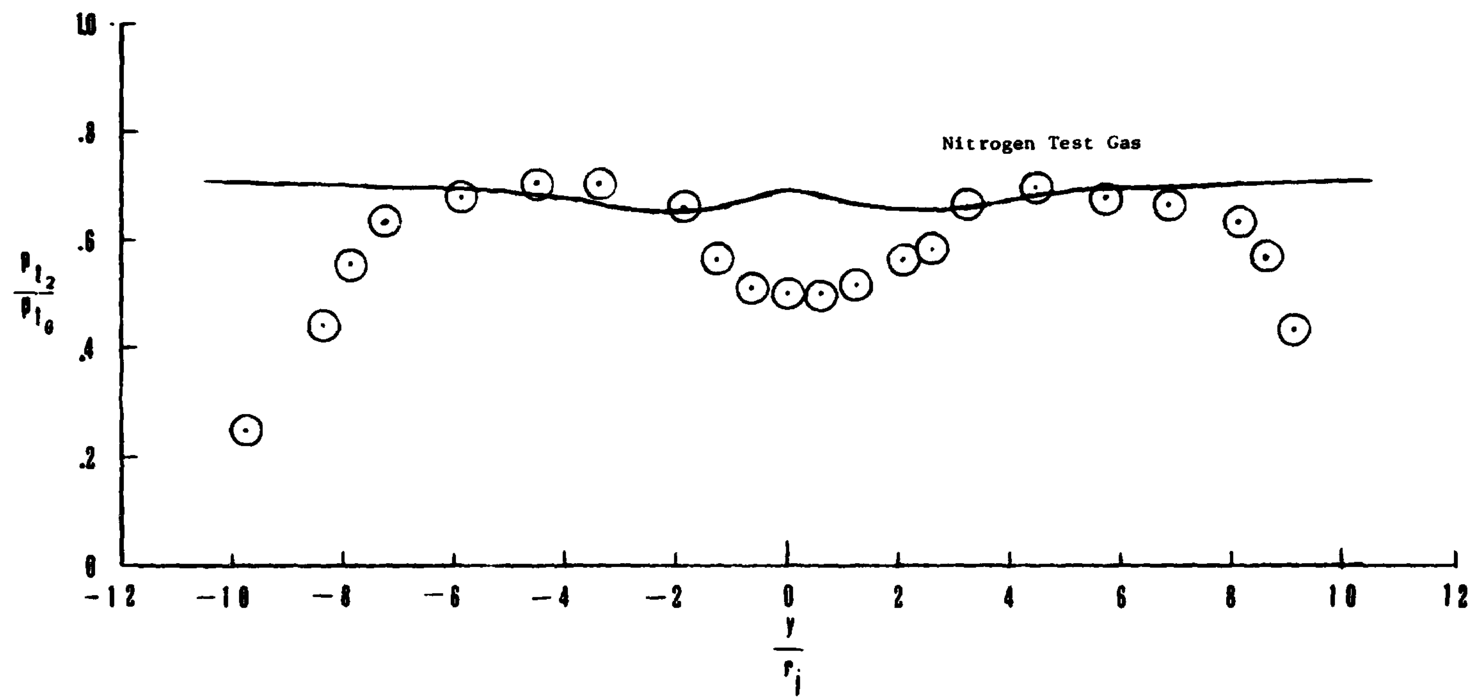
(c) $x/r_j = 40$

Figure 13.- Continued.



(d) $x/r_j \approx 56$

Figure 13.- Continued.



(e) $x/r_j = 80$

Figure 13.- Concluded.

example at $x/r_j = \pm$ 7. to $\pm$ 2.) gives excellent agreement between the experimental and theoretical values of pitot pressures.

Ducted Data (Circular Combustors)

The experimental data for the ducted case are presented in figures 14, 15, and 16. Figure 14 presents the pitot surveys made at the exit of the four ducts using air test medium (reacting case). Figure 15 gives similar data for the nonreacting case (nitrogen test medium). Figure 16 gives the static pressures measured along the various ducts. The static pressure measurements and exit pitot profiles were made simultaneously for each duct. The same technique was used for both air and nitrogen test gas.

The program was unable to calculate the flow field for even the shortest (length = 30 r_j) duct, therefore a comparison between the experimental and theoretical data cannot be made. The inability of the program to compute the flow field for the ducted cases stemmed from the fact that the underexpansion shock wave, which reflects from the duct wall, is unable to traverse the region of test stream jet interaction. The flow angle computed for the jet and its interaction with the test stream are inconsistent with the shock wave and the rest of the flow field. The reflected shock is not suspect since it is fully compatible with the portion of the test stream which has not interacted with the jet.

An Evaluation of the Analytical Tool

The utility of the analytical tool as applied here appears quite limited with either of the two viscosity models employed. This is not

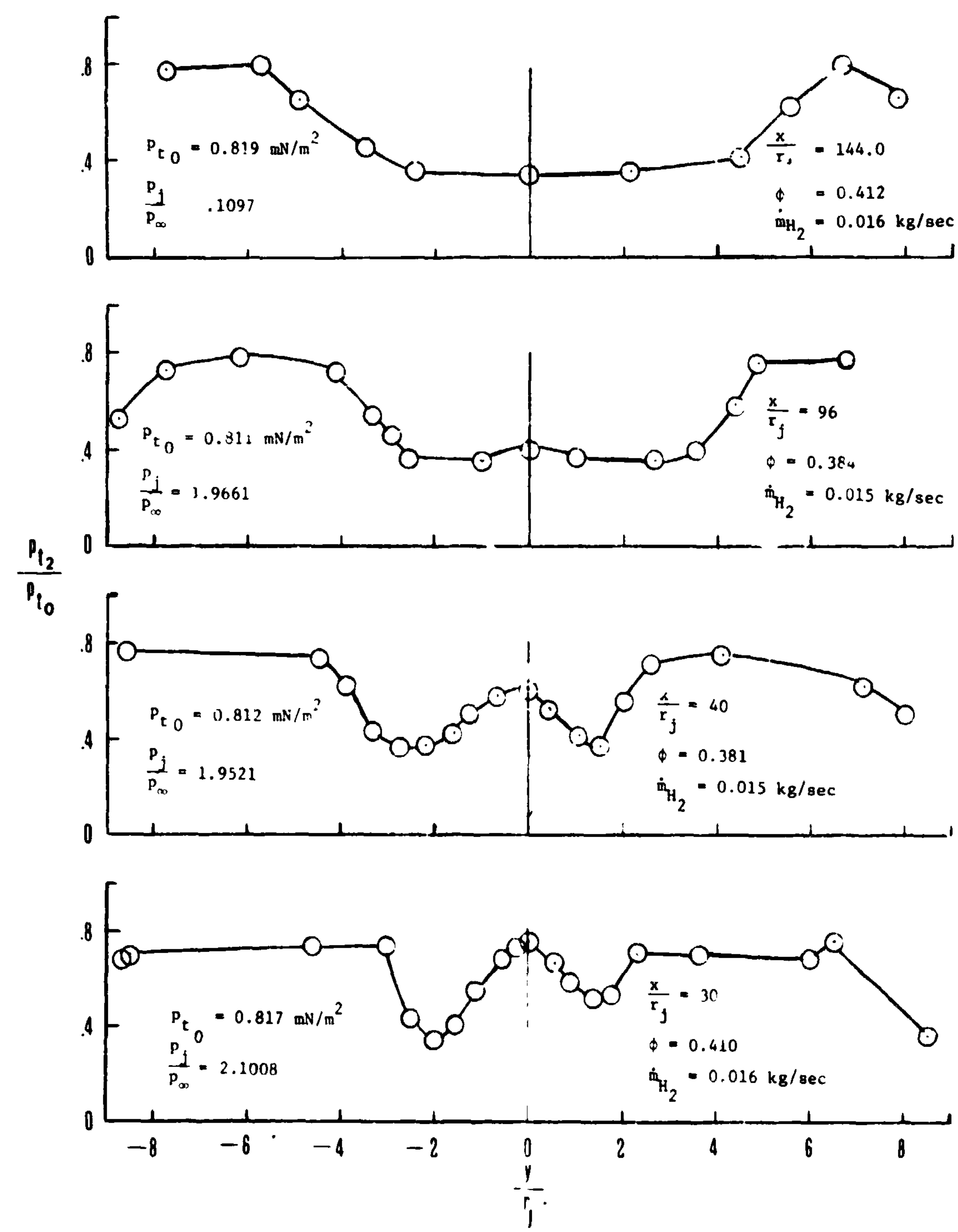


Figure 14.- Lateral pitot pressure distributions at the exits of the four ducts. (Test medium, Air)

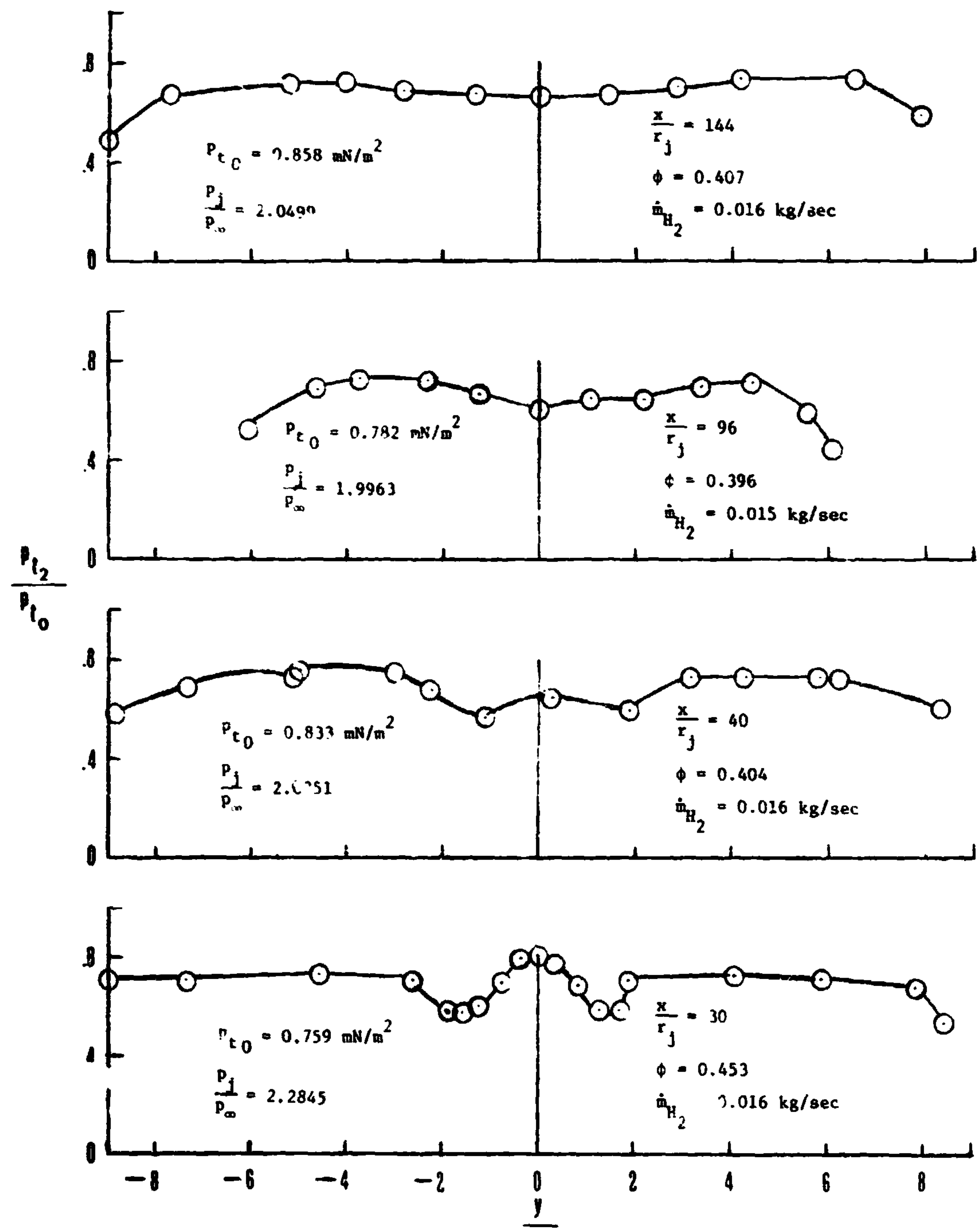


Figure 15.- Lateral pitot pressure distributions at the exits of the four ducts. (Test medium, Nitrogen)

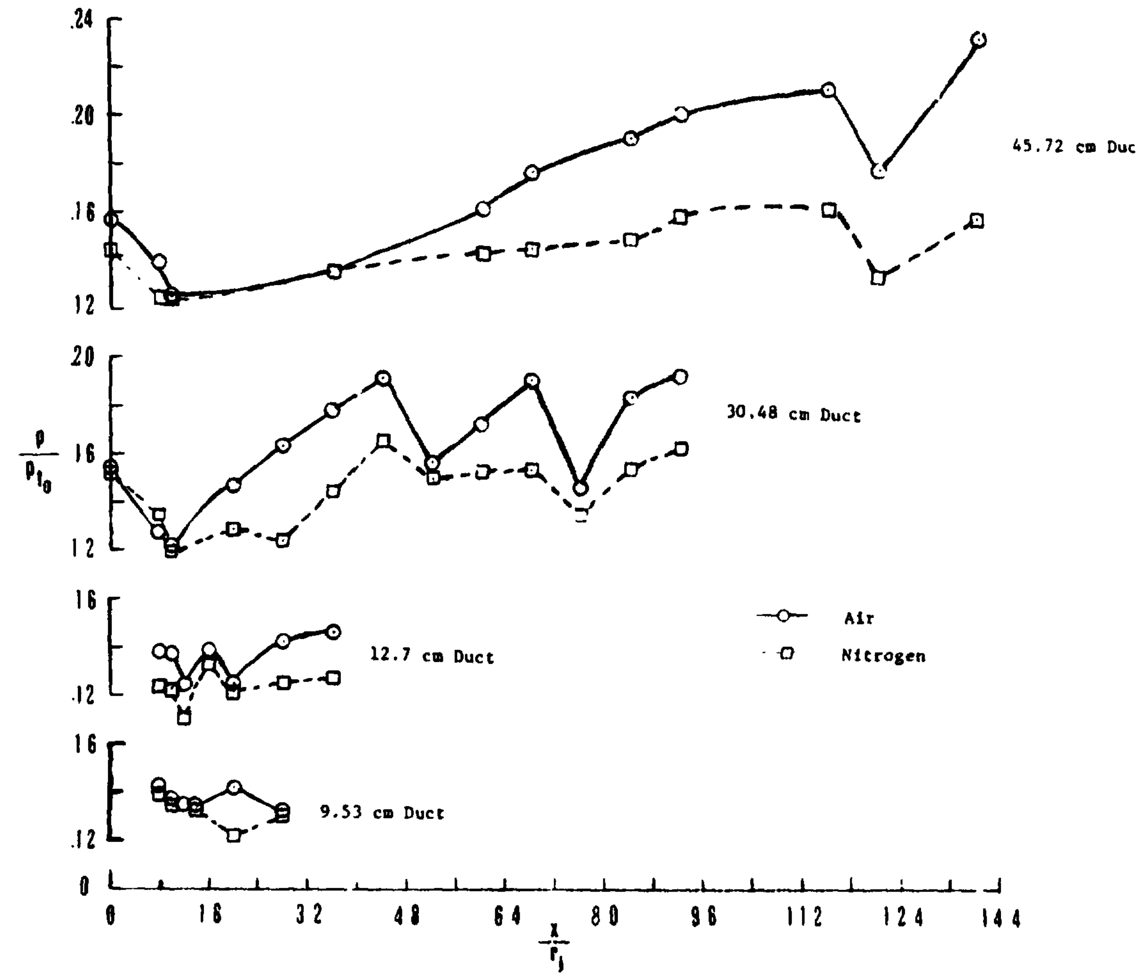


Figure 16.- Static pressures along the duct wall.

to imply that the inadequacy of the program is due to the viscosity models employed. In fact, the similar results obtained with the two different models indicate that the fault lies in handling the internal (jet) flow, and its interaction with the test stream. This hypothesis is further supported by the fact that the spreading as indicated by theoretical pitot pressure is excessive for the reacting case (see figures 11 and 12). Similarly, pitot pressure was consistently overpredicted by the program for the nonreacting case, particularly in the near centerline region which is highly dependent on the jet flow.

Another failing of the program is that it did not detect the fact that the expansion fan is terminated by an intersecting shock front. A discussion of why there is an intersecting shock terminating the fan can be found in reference 21, and one may refer to the discussion of figures 7 and 8 for the location of the shock. The program has incorporated in it a subprogram which checks the entire flow field at one axial location before each downstream marching step is taken, to see if a pressure gradient exists. If a pressure gradient of sufficient strength is encountered, it inserts an embedded shock wave. Thus, it must be concluded that the computed jet flow did not produce the pressure gradient necessary for shock wave insertion.

It should be noted that all of the shortcomings of the analytical approach, detected by the present work, are associated with the divergent internal (conical jet) flow and its interaction with the test stream. Thus, there is the possibility that it can be successfully applied to the case of underexpanded jets whose flow divergence is small at the injector exit.

It is felt that the analytical predictions can be improved by replacing the present method of handling the jet flow with a characteristic expansion network. This network, which would require considerable effort to implement, would be terminated by an intersecting shock front. The intersecting shock may require little additional effort since the subprogram previously mentioned may insert the required shock once the proper jet flow is computed by means of an expansion network. An improved program, which correctly handles the jet flow by an expansion network, would be very useful and probably effective in analyzing underexpanded jets.

CHAPTER V

CONCLUDING REMARKS

One of the major technological problems facing the scramjet engine concept is the ability to successfully predict the flow field resulting from the injection, mixing, and combustion of hydrogen fuel. Such predictions are necessary for good design of major components of the engine (i.e. fuel injectors, the combustor, and the exit nozzle). Of particular importance here is the ability to predict the flow field resulting from underexpanded injection of hydrogen. More fundamental, however, is the need for experimental data on an underexpanded H_2 jet in a supersonic flow.

The present work has accomplished the task of furnishing a small data base on the coaxial injection of an underexpanded H_2 jet into supersonic flow. The data obtained are for a Mach 2 test stream of air or nitrogen, and a Mach 2 hydrogen jet whose exit pressure is approximately twice the test stream static pressure. Since the air or nitrogen test stream has a static temperature of 1338 K, data with and without combustion is provided. In addition, the facility was operated in a free-jet mode and in a ducted mode furnishing data for four different duct lengths. The free-jet data consist of radial pitot profiles at various axial locations. The ducted data consist of radial pitot profiles at the duct ends and static pressures measured along the duct walls. In addition, the present work tested the utility of an analytical technique designed to predict the flow field resulting from the injection of an underexpanded jet into supersonic flow. The theory is tested by comparing experimental data with theoretical predictions. The theoretical calculations, which cover a wide range of Prandtl number (0.7 to 1.4), were unable to correctly predict the experimental results.

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APPENDIX A

THEORY

General Governing Equations

The basic governing equations are the well known "viscous-inviscid" equations used in higher order boundary layer and viscous flow field analysis (see references 15, 16, and 17) with the finite rate chemistry terms included. These equations are evolved from the full Navier-Stokes equations by assuming that the transport effects depend only on gradients normal to the streamlines. (The normal momentum equations are kept in the inviscid form.)

These equations, written in nondimensional form for an intrinsic coordinate system (with s along the streamlines and n normal to the streamlines), are as follows for axisymmetric flow.

Gloval Continuity:

$$\frac{\partial(\rho q)}{\partial s} + \rho q \frac{\partial \Theta}{\partial n} + \frac{\rho q}{y} \sin \Theta = 0 \tag{A1}$$

S-Momentum:

$$\rho q \frac{\partial q}{\partial s} + \frac{\partial p}{\partial s} = S_1 \tag{A2}$$

where,

$$S_1 = \frac{1}{Re} \left[\frac{\partial}{\partial n}\left(\mu \frac{\partial q}{\partial n}\right) + \frac{\mu (\cos \Theta)}{y} \frac{\partial q}{\partial n}\right]$$

N-Momentum:

$$\rho q^2 \frac{\partial \Theta}{\partial s} + \frac{\partial p}{\partial n} = 0 \tag{A3}$$

Energy:

$$\rho q \, (C_p) \, \frac{\partial T}{\partial s} - q \, \frac{\partial p}{\partial \sigma} = S_2 - \Sigma \, W_i \, h_i \tag{A4}$$

where,

$$S_2 = \frac{1}{Re \; (\gamma_\infty - 1) \; M_\infty^2} \left[\frac{\partial}{\partial n} \left(\frac{\mu \; C_p}{Pr} \frac{\partial T}{\partial n} \right) + \frac{\mu \; C_p \; (\cos \Theta)}{y \; Pr} \; \frac{\partial T}{\partial n} + \right.$$

$$\left. \frac{\mu \; (Le)}{Pr} \frac{\partial T}{\partial n} \Sigma \; C_{p_i} \frac{\partial \alpha i}{\partial n} + (\gamma_\infty - 1) \; M_\infty^2 \; \mu \; \left(\frac{\partial q}{\partial n} \right)^2 \right]$$

Species Conservation:

$$\rho q \, \frac{\partial \alpha i}{\partial s} = S_{3_i} + W_i \tag{A5}$$

where,

$$S_{3_i} = \frac{1}{Re} \left[\frac{\partial}{\partial n} \left(\frac{Le \; \mu}{Pr} \frac{\partial \alpha i}{\partial n} \right) + \frac{\mu \; Le \; \cos \Theta}{y \; Pr} \frac{\partial \alpha i}{\partial n} \right]$$

State:

$$p = \frac{W_o \rho T}{\gamma_o M^2 W} \tag{A6}$$

where,

$$w = \left[\Sigma \, \frac{\alpha i}{m_i} \right]^{-1}$$

For supersonic flow fields, the above equations (A1 to A6) have a dual mathematical nature (see reference 15). That is, they exhibit features of both hyperbolic and parabolic systems. The analytical tool of reference 9, therefore, uses a numerical scheme employing a characteristic network in conjunction with a boundary layer type network to yield a coupled solution. This scheme is thoroughly discussed in reference 17, and will not be fully covered here. However, the following description of the approach used by the scheme is offered.

Essentially, the approach finds a characteristic solution which feels the effects of diffusion and finite rate chemistry. This is done by treating the diffusive and chemistry terms as forcing functions in the "compatability relation" along characteristics. Treating these terms as forcing functions results in the characteristic directions of the viscous system being exactly those of the inviscid system. Namely, the frozen Mach line (C±)

$$\frac{dy}{dx} = \tan\left(\Theta \pm \bar{\mu}_f\right) \tag{A7}$$

and thus the streamlines are defined by the equation

$$\frac{dy}{dx} = \tan\Theta \tag{A8}$$

The compatibility relation can be shown to be (see reference 17 for an excellent derivation)

$$\begin{aligned} &\frac{\sin\bar{\mu}_f \cos\bar{\mu}_f}{\gamma_\infty p}\, dp \pm d\Theta + \Bigg[\frac{\sin\Theta}{y} + \frac{S_1}{\rho q^2} - \\ &\frac{(\gamma_f - 1)}{\gamma_\infty p} S_2 + \frac{(\gamma_f - 1)}{\gamma_f\,(\gamma_\infty - 1)\, M_\infty^2\, pq} \Sigma\, W_i\, h_i - \\ &\frac{W}{\rho q}\, \Sigma \left(\frac{S_{3_i}}{m_i} + \frac{w_i}{m_i}\right)\Bigg] \frac{\sin\bar{\mu}_f}{\cos\left(\Theta \pm \bar{\mu}_f\right)}\, dx = 0 \end{aligned} \tag{A9}$$

The program of reference 9 is designed to analyze the mixing and combustion of an underexpanded H_2 jet; therefore, it is apparent that the equations previously presented are not sufficient. Since the jet is underexpanded, it has an exit pressure greater than the test stream static pressure and must expand into the test stream. The expanded jet, however, is seen by the test stream as an obstruction and an exit shock wave is generated. In addition, embedded shocks caused by combustion compression are possible downstream. The equations required to perform the expansion and shock calculations are also incorporated into the program (reference 9).

The expansion was assumed to be isentropic, two dimensional, and inviscid in the limit of vanishing radial distance with respect to the injector lip. These assumptions allowed the use of the following isentropic relations (Prandtl-Meyer expansion) near the injector's lip.

1. State P/ρ^{γ} = constant (A10)

2. Energy $h + 1/2\ V^2$ = constant (A11)

3. Momentum $\frac{dp}{\rho} + 1/2\ d(V^2) = 0$ (A12)

4. Compatibility $\frac{1}{\gamma}\ d(\ell nP) \pm \frac{d\Theta}{\cos\mu \sin\mu} = 0$ (A13)

In the case of the shock wave, it was assumed that the chemistry was frozen across the shock and that it was two dimensional (the 2-D shock is an exact solution for the conical shock if there is no angle of attack). Thus, the following Rankine-Hugoniot relations were incorporated into the program. They are:

1. Continuity $\rho_1 U_1 = \rho_2 U_2$ (A14)

2. Normal Momentum $p_1 + \rho_1 (U_1)^2 = p_2 + \rho_2 (U_2)^2$ (A15)

3. Tangential Momentum $V_{t_1} = V_{t_2}$ (A16)

4. Energy $H = h + (1/2)V^2$ = constant (A17)

where, $h = \Sigma\ \alpha_i h_i(T)$

5. State $\rho = \rho(p,T,\alpha_i)$ (A18)

Exit (Underexpansion) Shock

As previously stated, when the jet expands into the test stream an exit (underexpansion) shock wave is generated. The idealized flow resulting from such an interaction is depicted in figure A1.

Although it can easily be deduced that the pressures (p's), and flow angles (Θ's) are equal on either side of the slip line separating the regions 1 and 2 of this figure, it is not possible to calculate them by a direct method. Fortunately, the downstream conditions can be calculated by the iterative process that follows. A shock angle is chosen (an angle slightly larger than $\sin^{-1}(1/M_\infty)$ is a good choice) and the downstream properties (P_1, T_1, Θ_1, etc.) are computed. The jet is then expanded from its exit pressure to the pressure $p_2 = p_1$. If the flow angle Θ_2 associated with this pressure does not equal the flow angle Θ_1 downstream of the shock wave, a new shock angle is selected and the above procedure is repeated until convergence is obtained. The stream properties (p, Θ) for which convergence is obtained are the properties existing across the slip line of figure A1.

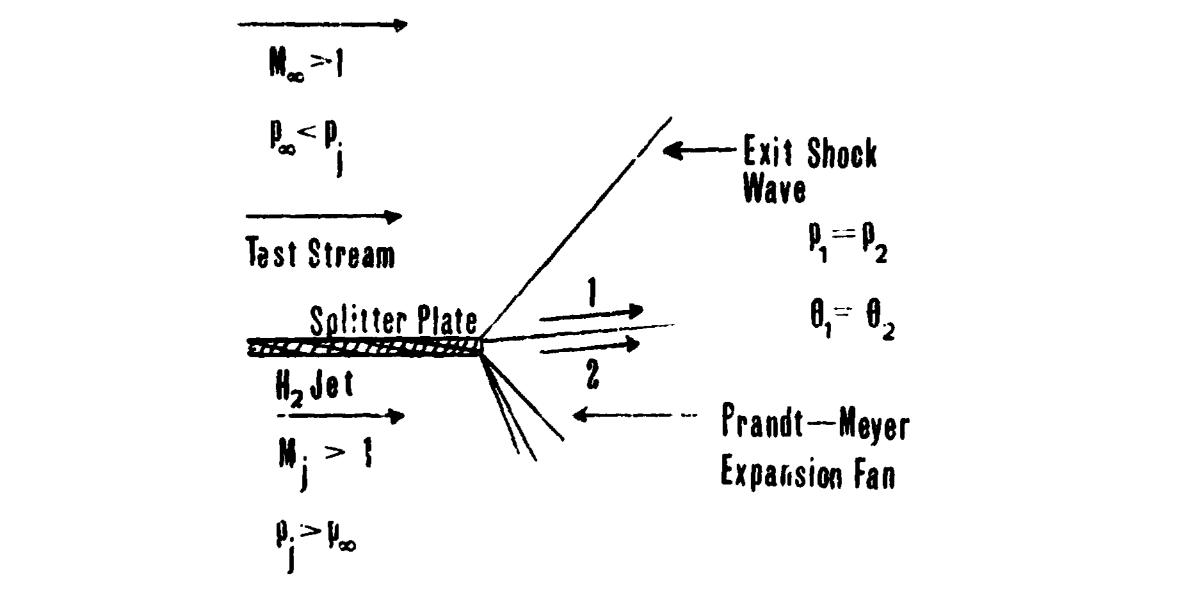

Figure A1.- A schematic of the flow field resulting from the interaction of the test stream and the underexpanded jet.

APPENDIX B

MODIFIED COMPUTER PROGRAM

The original program of reference 9 has been streamlined and modified to the extent that it is not readily recognized as essentially the same program. Numerically, both old and new versions give the same mathematical results for the cases they are both able to handle. (The original program was not able to handle shock waves which ran from the outer boundary toward the centerline, and various other subtleties.) The version given here has the Ferri-Kleinstein viscosity model as did the original of reference 9.

A3977

```
      PROGRAM CHAR(INPUT,OUTPUT,TAPE7,TAPE5=INPUT,TAPE6=OUTPUT)
C     MAIN PROGRAM FOR CHARACTERISTICS WITH SHEAR
      COMMON/AB/EPP,EPC,EPT
      COMMON/AC/IBOD,FIN
      COMMON/AL/GAR,GEW
      COMMON/AX/JSUBL,JSUBU
      COMMON/BA/ALP(7,55),EMINF,WINF
      COMMON/BC/IOCHEM
      COMMON/BC/XMASS(55)
      COMMON/CG/AUP,BUP,CUP,DTSPRI(55),DUP,EUP,JCONV,THPRI(55),YPRI(55)
      COMMON/CK/WTMOLE(7)
      COMMON/DB/BETB(4),IS(4)
      COMMON/DE/MM
      COMMON/DP/YN(55)
      COMMON/ED/CPIN,RC
      COMMON/EF/EM(55),GAM(55),P(55),TH(55),Y(55)
      COMMON/EG/EIN,PR,XLE
      COMMON/EF/GAMINF,H1(7),PINF
      COMMON/FE/DEL
      COMMON/GE/RAD,ROC,UIN,VISINF
      COMMON/GF/DELY,CVISA,KOUNTO,VISA
      COMMON/GK/DELX
      COMMON/HJ/KOUNT,LL,NPT
      COMMON/HL/ALPHA,BETA
      COMMON/HM/ALPN(7,55),CPN(7,55),CPXN(55),EMN(55),GAMN(55),HN(7,55),
     1L,PN(55),CN(55),RHON(55),RN(55),THN(55),TN(55),WN(55),XMUN(55)
      COMMON/HP/BETAN(4),IEMBED
      COMMON/CF/ALPB(7),PHI(55)
      COMMON/FC/W(55),X(55)
      COMMON/PC/ALPHN(7),IFUEL,PRES
      COMMON/PQ/JCHEM,NSP,T(55)
      COMMON/QA/H(7,55),Q(55),RHO(55),XMU(55)
      COMMON/QS/RHOP(2),WDOT(7,55),WDOTC(7),WP(2),XMUP(2)
      COMMON/RC/AP0,AP1,AP2
      COMMON/RS/GPMS,PS,THS,THSL,THSU
      COMMON/ST/I13,IREGI,K ,KFIRST,KKKQ,PSTAR
      COMMON/TS/DVISB,DVISC,IFS,MMM,VISB,VISC
      COMMON/UV/II11,IERR,IPRESS,IPRESU,ISUB
      COMMON/VT/DACH(7,55),DTCH(55),DVISD,VISD
      COMMON/VW/ICONT,IEND,KT,THBPN,XBPN
      COMMON/WV/NPTS,RE,XBP,XJ
      COMMON/XQ/X00
      COMMON/YX/ABODS,EPRESS,CPRESS
      COMMON/YZ/BPRESU,CHEMFC,CPRESU,EMSUB,RTH,XSTEP
      COMMON/ZY/ABOD,BBOD,CBOD,EBOD,FBOD,GBOD,IAVE,IPUNCH,JBOD,KKKKK
      DIMENSION XS(7),PITOT(55)
      DATA II11/0/
C     ********************************  BEGIN INPUTTING PARAMETERS
```

```
      WRITE(6,400)
  112 FORMAT(I5,5X,9E13.5)
  400 FORMAT(1H1)
C     J=0 TWC DIMENSIONAL
C     J=1 AXISYMMETRIC
C     SPECIES 1 IS H
C     SPECIES 2 IS O
C     SPECIES 3 IS H2O
C     SPECIES 4 IS H2
C     SPECIES 5 IS O2
C     SPECIES 6 IS OH
C     SPECIES 7 IS N2
      WTMOLE(1)=1.008
      WTMOLE(2)=16.
      WTMOLE(3)=18.016
      WTMOLE(4)=2.016
      WTMOLE(5)=32.0
      WTMOLE(6)=17.008
      WTMOLE(7)=28.014
      FAS=WTMCLE(4)/16.
      J22=0
      X00=0.
      IDG=0
      DEL=0.
      DO 8220 I=1,4
      BETAN(I)=0.
      BETB(I)=0.
      IS(I)=0
 8220 CONTINUE
      IFS=0
      NSP=7
      RO=1.987
      ROO=RO*3.087*32.2/2.205*1000.
      EPP=1.E-10
      EPTH=1.E-10
      EPQ=1.E-10
      EPT=1.E-10
      IOCHEM=1
      MM=6
      EXXX=1.E-06
      I13=0
      KFIRST=-1
      KKKQ=10000
      JCONV=0
      INPTSH=0
  363 CONTINUE
      CALL INDATA
C     ************************************     MAKE INITIAL SHEAR
      VISO=XVIS(XBP)
```

```
      CFF=0.
      CALL SHEAR1(CFF,VISD)
 6789 CONTINUE
      CALL EMBEC
      VTS=VISD=VISC=VISB=VISA=XVIS(XBP)
      DVISD=DVISC=DVISB=DVISA=0.
      DC 7188 K=1,NPTS
      DO 7199 J=1,NSP
 7199 XS(J)=W(K)*ALP(J,K)/WTMOLE(J)
      FUAIR=1.008*(XS(1)+2.*XS(4)+2.*XS(3)+XS(6))/(16.*(XS(2)+XS(3)
     1+2.*XS(5)+XS(6))+28.014*XS(7))
      PHI(K)=FUAIR/.029161
 7188 CONTINUE
      IF(KOUNT.EQ.KKKKK) GO TO 407
      IF(II11.EC.1) GO TO 407
      IF(KOUNT.EQ.KOUNTO) GO TO 407
      IF(((KCUNT/LL)*LL).NE.KOUNT)GO TO 179
  407 WRITE(6,408)KOUNT
  408 FORMAT(7H1KOUNT=I5)
      WRITE(6,5206) X(1)
 5206 FORMAT(/5H X = E13.5)
      DO 8485 I23=1,4
      IF(BETB(I23).EQ.0.) GO TO 8485
      IF(I23.LT.3)
     1WRITE(6,8484) I23,BETB(I23)
 8484 FORMAT(/5X,20HEMBEDDED SHOCK TYPE  ,I1,10X,7HBETA = ,E11.3)
      IF(I23.GE.3)
     1WRITE(6,2331) I23,BETB(I23)
 2331 FORMAT(/14X,11HSHOCK TYPE  ,I1,10X,7HBETA = ,E11.3)
 8485 CONTINUE
      VISW=VISA*VISINF
      WRITE(6,7222)      VISW
 7222 FORMAT(/5X,11HVISCOSITY =E13.5,15H (LB*SEC/FT**2))
      WRITE(6,5207)
 5207 FORMAT(/3X,3HPT.,11X,1HY,12X,1HQ,12X,1HT,12X,1HP,11X,2HTH,11X,
     12HEM11X3HRHO10X3HGAM9X5HPITOT)
      DO 70 I=1,NPTS
      P(I)=P(I)/PIN
   70 PITOT(I)=P(I)*PRES*((GAM(I)+1.)*.5*EM(I)**2)**(GAM(I)/(GAM(I)-1.))
     A*(2.*GAM(I)/(GAM(I)+1.)*EM(I)**2-((GAM(I)-1.)/(GAM(I)+1.)))**(1./(
     81.-GAM(I)))
      WRITE(6,112)(I,Y(I),Q(I),T(I),P(I),TH(I),EM(I),RHO(I),GAM(I),PITOT
     1(I),I=1,NPTS)
      DO 71 I=1,NPTS
   71 P(I)=P(I)*PIN
      WRITE(6,160)
  160 FORMAT(/////3X,3HPT.,8X,         6HALP(1),7X,6HALP(2),7X,
     26HALP(3),7X,6HALP(4),7X,6HALP(5),7X,6HALP(6),7X,6HALP(7),9X,3HPHI
     2,11X,1HW)
```

```
      WRITE(6,112)(I,(ALP(J,I),J=1,7),PHI(I),W(I),I=1,NPTS)
  179 CONTINUE
      IF(KOUNT.GE.KKKKK)GO TO 1572
      IF(II11.EQ.1) GO TO 1572
      ALPHA=1.0
      BETA=C.0
      CALL STEP(VIS)
      IF(II11.EQ.1) GO TO 407
      IF(KOUNT.NE.KFIRST.OR.I13.NE.1) GC TO 300
      CALL PUNCH
      DO 301 I=JSUBL,JSUBU
      Y PRI(I)=Y (I)
      THPRI(I)=TH(I)
  3C1 CONTINUE
  3C0 CONTINUE
      CALL CHEM(FAS)
 8282 CONTINUE
      ICONT=0
      IEND=C
      K=1
      L=2
  887 IF(L.GE.JSUBL.AND.L.LE.JSUBU) GO TO 9C0
  888 K=L
      KT=L-1
      IF(L.EQ.NPTS)GOTO 612
      IF(L.EQ.JSUBU.AND.ICONT.EQ.1) GO TO 1622
      IF(BETB(1).EQ.0..AND.BETB(2).EQ.0..AND.BETB(3).EQ.0..AND.BETB(4).
     AEQ.0.)GO TO 777
      IF(BETB(1).GT.0..OR.BETB(3).GT.0.)777,776
  777 IF(K.EQ.IS(2).OR.K.EQ.IS(4))GO TC 8230
      IF(K.NE.IS(1)-1)8231,775
 8231 IF(K.NE.IS(3)-1)8234,773
  776 IF(K.NE.IS(1)-1)GO TO 11
  775 MMM=1
      K=IS(1)
      KT=K
      GO TO 8232
   11 IF(K.NE.IS(3)-1)GC TO 22
  773 MMM=3
      K=IS(3)
      KT=K
      GO TO 8232
   22 IF(K.NE.IS(2))GO TO 33
      MMM=2
      GO TO 8232
   33 IF(K.NE.IS(4))GO TO 44
      MMM=4
      GO TO 8232
   44 IF(K.EQ.IS(2)+1.OR.K.EQ.IS(4)+1)88888,8234
```

```
88888 K=K+1
      L=K
      KT=L-1
      GO TO 8234
 8232 L=K
 8230 IFS=1
      IPOI=1
      ALSV=ALPHA
      BESV=BETA
      IF(BETB(1).EQ.0..AND.BETB(2).EQ.0..AND.BETB(3).EQ.0..AND.BETB(4).
     AEQ.0.)GO TO 772
      IF(BETB(1).GT.0..OR.BETB(3).GT.0.)GO TO 772
      KTSAV=KT
  772 CALL CPOINT
      THDE=THN(K)
      ALPHA=.5
      BETA=.5
      IF(BETB(1).EQ.0..AND.BETB(2).EQ.0..AND.BETB(3).EQ.0..AND.BETB(4).
     AEQ.0.)GO TO 2194
      IF(BETB(1).GT.0..OR.BETB(3).GT.0.)GO TO 2194
      K[illegible]=KTSAV
 215[illegible] CALL [illegible]POINT
      I[illegible] = [illegible] 1
      IF[illegible].LT.20)GO TO 2195
      WRITE(6,9191)
      WRITE(6,2196)
 2196 FORMAT(44H ERROR IN CPOINT ITERATION FOR SHOCK IN CHAR)
      STOP
 2195 ERTHD=ABS(THDE-THN(K))
      THDE=THN(K)
      IF(BETB(1).EQ.0..AND.BETB(2).EQ.0..AND.BETB(3).EQ.0..AND.BETB(4).
     AEQ.0.)GO TO 771
      IF(BETB(1).GT.0..OR.BETB(3).GT.0.)GO TO 771
      KT=KTSAV
  771 IF(ERTHD.GT.EXXX)GO TO 2194
      ALPHA=ALSV
      BETA=BESV
      IF(K.EQ.IS(2)) MMM=2
      IF(K.EQ.IS(4)) MMM=4
      IFS=2
      CALL HSHOCK(MMM)
      IFS=0
      K=K+1
      L=L+1
      GO TO 887
 8234 CONTINUE
      IPOI=1
      ALSV=ALPHA
      BESV=BETA
```

```
      CALL CPOINT
      KT=L-1
      THDE=THN(K)
      ALPHA=.5
      BETA=.5
 2601 CALL CPOINT
      KT=L-1
      IPOI=IPOI+1
      IF(IPOI.LT.20)GO TO 2602
      WRITE(6,9191)
 9191 FORMAT(1H1)
      WRITE(6,2197) K
 2197 FORMAT(53H ERROR IN STANDARD CPOINT ITERATION IN CHAR AT POINT I2)
      STOP
 2602 ERTHD=ABS(THDE-THN(K))
      THDE=THN(K)
      IF(ERTHD.GT.EXXX) GO TO 2601
      ALPHA=ALSV
      BETA=BESV
C     ************************  INCREMENT COUNTERS  DO NEXT C POINT
  900 CONTINUE
      K=K+1
      IF(L.EQ.NPTS) GO TO 7676
      L=L+1
      IF(ICONT.EQ.1) GO TO 888
      GO TO 887
C   NOZZLE WALL CALCULATION
  612 CONTINUE
      IPOI=1
      ALSV=ALPHA
      BESV=BETA
      CALL LPOINT(NPTS,1.)
      K=NPTS
      THDE=THN(K)
      IF(               IPRESU.EQ.0) THDE=PN(K)
      ALPHA=.5
      BETA=.5
 2607 CALL LPOINT(NPTS,1.)
      K=NPTS
      IPOI=IPOI+1
      IF(IPOI.LT.20)GO TO 2608
      WRITE(6,9191)
      WRITE(6,2198)
 2198 FORMAT(51H ERROR IN NOZZLE WALL CALCULATION ITERATION IN CHAR)
      STOP
 2608 ERTHD=ABS(THDE-THN(K))
      IF(               IPRESU.EQ.0) ERTHD=ABS(1.-THDE/PN(K))
      THDE=THN(K)
      IF(               IPRESU.EQ.0) THDE=PN(K)
```

```
      IF(ERTHD.GT.EXXX) GO TO 2607
      ALPHA=ALSV
      BETA=BESV
C     COMPLETE FIRST POINT
 7676 CONTINUE
      IF(JSUBL.EQ.1) GO TO 180C
      CALL LPCINT(1,0.)
      K=1
      IPOI=1
      ALSV=ALPHA
      BESV=BETA
      THDE=THN(K)
      IF(IPRESS.EQ.C                       ) THDE=PN(K)
      ALPHA=.5
      BETA=.5
 2609 CALL LPCINT(1,0.)
      K=1
      IPOI=IPOI+1
      IF(IPOI.LT.20)GO TO 2610
      WRITE(6,9191)
      WRITE(6,2199)
 2199 FORMAT(39H ERROR IN FIRST POINT ITERATICN IN CHAR)
      STOP
 2610 ERTHD=ABS(THDE-THN(K))
      IF(IPRESS.EQ.C                       ) ERTHD=ABS(1.-THDE/PN(K))
      THDE=THN(K)
      IF(IPRESS.EQ.0                       ) THDE=PN(K)
      IF(ERTHD.GT.EXXX) GO TO 2609
      ALPHA=ALSV
      BETA=BESV
C     SUBSONIC PRESSURE ITERATION
 1800 CONTINUE
      IF(ISUB.EQ.0) GO TO 1622
      IF(ICCNT.EQ.1) GO TO 1622
      IF(I13.NE.1.OR.KOUNT.NE.KFIRST) GO TO 1777
      CALL DPDTH(THS,JSUBU)
      CALL DPDTH(THSU,JSUBU+1)
      CALL DPDTH(THSL,JSUBU-1)
      CALL THSSS(THSS)
      AUP=Y(JSUBU)
      BUP=TAN(TH(JSUBU))
      IF(IREGI.NE.0.AND.JSUBU.EQ.J22) GO TO 8375
      CUP=THS/COS(TH(JSUBU))**3
      DUP=(THSS+3.*TAN(TH(JSUBU))*THS*THS)/COS(TH(JSUBU))**4
      EUP=-4.095
      GO TO 8376
 8375 CONTINUE
      CUP=0.
      DUP=-1.
```

ORIGINAL PAGE IS
OF POOR QUALITY

```
      EUP=0.
 8376 CONTINUE
      DO 381 I=JSUBL,JSUBU
  381 CALL OPCTH(DTSPRI(I),I)
 1777 CONTINUE
      CALL SSCNIC(IDG)
      IF(IDG.EQ.0) GO TO 1622
      II11=1
      IPUNCH=1
      GO TO 497
 1622 CONTINUE
      IF(ISUB.EQ.0) GO TO 359
      IF(JCCNV.EQ.1) GO TO 360
      IF(KOUNT.NE.KKKQ-1) GO TO 361
      IF(INPTSH.EQ.0) NPTSH=NPTS
      INPTSH=1
      REWIND 7
      GO TO 363
  360 NPTS=NPTSH
      INPTSH=0
  359 DO 357 I=1,NPTS
      II=NPTS-I+1
      IF(EMN(II).GT.EMSU3) GO TO 357
      IF(ISUB.EQ.1) GO TO 355
      ISUB=1
      WRITE(6,354)
  354 FORMAT(37H1          SUBSONIC REGION ENCOUNTERED)
      EMST=EMSUB
      EMSUB=1.15
      AP1=0.
      IREGI=0
      GO TO 359
  355 K=II+1
      IF(IREGI.EQ.1) K=JSUBU
      GO TO 358
  357 CONTINUE
      IREGI=2
      GO TO 361
  358 CONTINUE
      IF(JCCNV.EQ.0) GO TO 1417
      JCCNV=0
      DO 1418 I=1,NPTS
      II=NPTS-I+1
      IF(EMN(II).GT.EMST) GO TO 1418
      GO TO 1417
 1418 CONTINUE
      IREGI=2
      I13=0
      EMSUB=EMST
```

```
      X00=XBPN
      ABOD=YN(1)
      ABODS=YN(1)
      BBOD=TAN(THN(1))
      CBOD=C.
      GO TO 361
 1417 CONTINUE
      APC=PN(1)
      AP2=(PN(K)-PN(1)-AP1*(YN(K)-YN(1)))/(YN(K)-YN(1))**2
      DO 356 I=1,K
      PN(I)=AP0+AP1*(YN(I)-YN(1))+AP2*(YN(I)-YN(1))**2
      RHON(I)=GEW*WN(I)*PN(I)/TN(I)
      IF(I.EQ.1) GO TO 356
      XJ1=1.+XJ
      I1=I-1
      YFUN=(YN(I)**XJ1-YN(I1)**XJ1)/XJ1
      TERM=(RHCN(I)*QN(I)*COS(THN(I))+RHCN(I1)*QN(I1)*COS(THN(I1)))/2.
      XMASS(I)=XMASS(I1)+TERM*YFUN
  356 CONTINUE
      DS=2.*DELX/(COS(TH(K))+COS(THN(K)))
      PS=(PN(K)-P(K))/DS
      GPMS=(GAMN(K)*PN(K)*EMN(K)**2-GAM(K)*P(K)*EM(K)**2)/DS
      DS=2.*DELX/(COS(THN(1))+COS(TH(1)))
  361 CONTINUE
C     COMPUTE SHEAR
      VISE=XVIS(XBPN)
      CFF=0.
      CALL SHEAR2(CFF,VISE)
C     ***********************************   RESET ALPHA AND BETA
      IF(IAVE.EQ.0) GO TO 8396
      IF(BETA.GT.C.0)GO TO 8396
      ALPHA=0.5
      BETA=C.5
      GO TO 8282
 8396 CONTINUE
C     ****************************************** STEP TAKEN   OUTPUT
      J22=JSUBU
      CALL RSET
      DO 1431 I=1,4
 1431 BETB(I)=BETAN(I)
      KOUNT=KCUNT+1
      GO TO 6789
 1572 IF(IPUNCH.EQ.0)CALL EXIT
      CALL PUNCH
      CALL EXIT
      END
      SUBROUTINE EMBED
      COMMON/AC/IBOD,PIN
      COMMON/AL/GAR,GEW
```

```
      COMMON/AX/JSUBL,JSUBU
      COMMON/BA/ALP(7,55),EMINF,WINF
      COMMON/BC/XMASS(55)
      COMMON/CJ/CP(7,55),CP1(7),CPX(55)
      COMMON/CK/WTMOLE(7)
      COMMON/DB/BETB(4),IS(4)
      COMMON/EC/CPIN,RC
      COMMON/EF/EM(55),GAM(55),P(55),TH(55),Y(55)
      COMMON/EF/GAMINF,H1(7),RINF
      COMMON/GK/DELX
      COMMON/HL/ALPHA,BETA
      COMMON/HM/ALPN(7,55),CPN(7,55),CPXN(55),EMN(55),GAMN(55),HN(7,55),
     1L,PN(55),QN(55),RHON(55),PN(55),THN(55),TN(55),WN(55),XMUN(55)
      COMMON/HF/BETAN(4),IEMBED
      COMMON/FC/W(55),X(55)
      COMMON/PC/JCHEM,NSP,T(55)
      COMMON/QA/H(7,55),Q(55),RHO(55),XMU(55)
      COMMON/RC/R(55)
      COMMON/TL/BQ(55),DALP(7,55),DBQ(55),DCPX(55),DDALP(7,55),DTAU(55),
     1TAU(55)
      COMMON/WV/NPTS,RF,XBP,XJ
      DATA EPPRES/1.E-04/
      IEMBED=0
      ALPHA=1.
      BETA=0.
      ALPH=1.
      BET=0.
      DELX=1.
      DO 500 M=1,2
      IF(IS(M).NE.0) GO TO 500
      IM=NPTS-2
      DO 1 I=2,IM
      IF(I.GE.JSUBL.AND.I.LT.JSUBU) GO TO 1
      I2=I
      I1=I2-1
      I3=I2+1
      I4=I2+2
      T10=Y(I1)-Y(I2)
      T11=Y(I2)-Y(I3)
      T12=Y(I3)-Y(I4)
      IF(T10.LT.1.E-04.OR.T11.LT.1.E-04.OR.T12.LT.1.E-04) GO TO 1
      DZ=Y(I+1)  -Y(I)
      IF((M/2)*2.EQ.M) GO TO 200
      XP2=XM1(ALPH ,BET ,TH(I+1),XMU(I+1),0.,0.)
      XP1=XM1(ALPH ,BET ,TH(I  ),XMU(I  ),0.,0.)
      GO TO 201
  200 CONTINUE
      XP2=XM2(ALPH ,BET ,TH(I+1),XMU(I+1),0.,0.)
      XP1=XM2(ALPH ,BET ,TH(I  ),XMU(I  ),0.,0.)
```

```
201 DZLAM=XP1-XP2
    IF(DZLAM.LT.1.E-10) GO TO 1
    DI=DZ/DZLAM
    IF(DI) 1,1,7
  7 IF(DI.GT.10.*DELX) GO TO 1
    P1S=P(I1)*P(I1)
    P2S=P(I2)*P(I2)
    P3S=P(I3)*P(I3)
    P4S=P(I4)*P(I4)
    T1=P(I1)-P(I2)
    T2=P(I2)-P(I3)
    T3=P(I3)-P(I4)
    T4=P1S-P2S
    T5=P2S-P3S
    T6=P3S-P4S
    T7=P1S*P(I1)-P2S*P(I2)
    T8=P2S*P(I2)-P3S*P(I3)
    T9=P3S*P(I3)-P4S*P(I4)
    CALL  SOLVE(T1 ,T2 ,T3 ,T4 ,T5 ,T6 ,T7 ,T8 ,T9 ,E )
    CALL  SOLVE(T10,T11,T12,T4 ,T5 ,T6 ,T7 ,T8 ,T9 ,DB)
    CALL  SOLVE(T1 ,T2 ,T3 ,T10,T11,T12,T7 ,T8 ,T9 ,DC)
    CALL  SOLVE(T1 ,T2 ,T3 ,T4 ,T5 ,T6 ,T10,T11,T12,DD)
    B=DB/E
    C=DC/E
    D=DD/E
    A=Y(I1)+P(I1)*(-B+P(I1)*(-C-D*P(I1)))
    TRE=1./3.
    CD=1./27.
    YST=A-C*B*TRE/D+2.*C *3*CD/D**2
    IF(YST.LE.Y(I).OR.YST.GE.Y(I+1)) GO  TO 1
    YSTP=B-C*C*TRE/D
    IF(YSTP.GE.EPPRES) GO TO 1
    IS(M)  =I+1
    IF((M/2)*2.EQ.M) IS(M)=I
    XP5=XP1
    XP6=XP2
    GO TO 501
  1 CONTINUE
    GO TO 500
501 ISM=IS(M)
    BETB(M)=(ATAN(XP5)+ATAN(XP6))/2.
    WRITE(6,506)M
506 FORMAT(1H1,20X,19HEMBEDDED SHOCK TYPE  I2//13X,2HIS ,5X,4HBETA )
    WRITE(6,508) IS(M),BETB(M)
508 FORMAT(10X,I5,E11.3)
    L=1
    IF((M/2)*2.EQ.M) L=-1
    ISMM=ISM-L
    ISP=ISM+L
```

```
      RAT=((Y(ISM)+Y(ISMH))/2.-Y(ISP))/(Y(ISM)-Y(ISP))
      X      (ISM)=X      (ISP)+RAT*(X      (ISM)-X      (ISP))
      Y      (ISM)=Y      (ISP)+RAT*(Y      (ISM)-Y      (ISP))
      Q      (ISM)=Q      (ISP)+RAT*(Q      (ISM)-Q      (ISP))
      P      (ISM)=P      (ISP)+RAT*(P      (ISM)-P      (ISP))
      T      (ISM)=T      (ISP)+RAT*(T      (ISM)-T      (ISP))
      TH     (ISM)=TH     (ISP)+RAT*(TH     (ISM)-TH     (ISP))
      BQ     (ISM)=BQ     (ISP)+RAT*(BQ     (ISM)-BQ     (ISP))
      TAU    (ISM)=TAU    (ISP)+RAT*(TAU    (ISM)-TAU    (ISP))
      DBQ    (ISM)=DBQ    (ISP)+RAT*(DBQ    (ISM)-DBQ    (ISP))
      DCPX   (ISM)=[illegible] ISP)+RAT*(DCPX   (ISM)-DCPX   (ISP))
      DTAU   (ISM)=[illegible] (ISP)+RAT*(DTAU   (ISM)-DTAU   (ISP))
      XMASS  (ISM [illegible] (ISP)+RAT*(XMASS  (ISM)-XMASS  (ISP))
      CPX(ISM)=0.
      W(ISM)=0.
      CALL THERMO(T(ISM),H1,CP1)
      DO 100 KI=1,NSP
      J=KI
      ALP   (KI,ISM)=ALP   (KI,ISP)+RAT*(ALP   (KI,ISM)-ALP   (KI,ISP))
      DALP  (KI,ISM)=DALP  (KI,ISP)+RAT*(DALP  (KI,ISM)-DALP  (KI,ISP))
      DDALP(KI,ISM)=DDALP(KI,ISP)+RAT*(DDALP(KI,ISM)-DDALP(KI,ISP))
      H(J,ISM)=H1(J)
      CP(J,ISM)=CP1(J)
      W(ISM)=W(ISM)+ALP(J,ISM)/WTMOLE(J)
      CPX(ISM)=CPX(ISM)+ALP(J,ISM)*CP(J,ISM)
      H  N(KI,ISM)=H   (KI,ISM)
      ALFN(KI,ISM)=ALP(KI,ISM)
  100 CONTINUE
      W(ISM)=1./W(ISM)
      R(ISM)=RC/W(ISM)
      GAM(ISM)=CPX(ISM)/(CPX(ISM)-R(ISM)/CPIN)
      RHO(ISM)=P(ISM)*W(ISM)*GEW/T(ISM)
      RI=1./R(ISM)
      EM(ISM)=Q(ISM)*EMINF*SQRT(GAR/GAM(ISM)*RI/T(ISM))
      XMU(ISM)=ZMU(EM(ISM))
      Q   N(ISM)=Q   (ISM)
      R   N(ISM)=R   (ISM)
      T   N(ISM)=T   (ISM)
      P   N(ISM)=P   (ISM)
      W   N(ISM)=W   (ISM)
      TH  N(ISM)=TH  (ISM)
      RHO N(ISM)=RHO (ISM)
      GAM N(ISM)=GAM(ISM)
      IF(JSUBL.GT.IS(M)) JSUBL=JSUBL+1
      IF(JSUBU.GT.IS(M)) JSUBU=JSUBU+1
      DO 101 KK=1,4
      IF(IS(KK).GT.IS(M)) IS(KK)=IS(KK)+1
  101 CONTINUE
      IEMBED=1
```

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```
      CALL HSHOCK(M)
      IEMBED=0
      X(ISMM)=X(ISM)
      Y(ISMM)=Y(ISM)
      XMASS(ISMM)=XMASS(IS:
      W  (ISMM)=W  N(ISMM)
      P  (ISMM)=P  N(ISMM)
      Q  (ISMM)=Q  N(ISMM)
      T  (ISMM)=T  N(ISMM)
      R  (ISMM)=R  N(ISMM)
      TH (ISMM)=TH N(ISMM)
      EM (ISMM)=EM N(ISMM)
      RHO(ISMM)=RHON(ISMM)
      CPX(ISMM)=CPXN(ISMM)
      GAM(ISMM)=GAMN(ISMM)
      XMU(ISMM)=XMUN(ISMM)
      DO 1313 KI=1,NSP
      M  (KI,ISMM)=M  N(KI,ISMM)
      CP (KI,ISMM)=CP N(KI,ISMM)
      ALP(KI,ISMM)=ALPN(KI,ISMM)
 1313 CONTINUE
      IBOD=0.
      RE=0.
      XBP=0.
      CALL SHEAR1(0.,0.)
  500 CONTINUE
      RETURN
      END
      SUBROUTINE SOLVE(A11,A12,A13,A21,A22,A23,A31,A32,A33,DET)
      DET=A11*(A22*A33-A32*A23)-A12*(A21*A33-A31*A23)+A13*(A21*A32-A22*A
     131)
      RETURN
      END
      SUBROUTINE HSHOCK(K)
      COMMON/AL/GAR,GEW
      COMMON/BA/ LP(7,55),EMINF,HINF
      COMMON/BB/S1A,S2A,S3AT
      COMMON/BC/GAMB,PB,QB,RHOB,THB,WB,XMUB,YB
      COMMON/CA/WDOTN(7,55),XN(55)
      COMMON/CJ/CP(7,55),CP1(7),CPX(55)
      COMMON/DB/BETB(4),IS(4)
      COMMON/LP/YN(55)
      COMMON/ED/CPIN,RO
      COMMON/EF/EM(55),GAM(55),P(55),TH(55),Y(55)
      COMMON/EG/FIN,PR,XLE
      COMMON/EP/GAMINF,H1(7),RINF
      COMMON/FE/DEI
      COMMON/GK/DELX
      COMMON/HL/ALPHA,BETA
```

```
      COMMON/HN/ALPN(7,55),CPN(7,55),CPXN(55),EMN(55),GAMN(55),HN(7,55),
     1LS,PN(55),QN(55),RHON(55),RN(55),THN(55),TN(55),WN(55),XMUN(55)
      COMMON/HP/BETAN(4), EMBED
      COMMON/FQ/JCHEM,NSP,T(55)
      COMMON/QA/H(7,55),Q(55),RHO(55),XMU(55)
      COMMON/CS/RHOP(2),WDOT(7,55),WDOTC(7),WP(2),XMUP(2)
      COMMON/SC/BQN(55),DALPN(7,55),DBQN(55),DCPXN(55),DDALPN(7,55),
     1DTAUN(55),TAUN(55)
      COMMON/ST/I13,IRECI,KS,KFIRST,KKKQ,PSTAR
      COMMON/TS/DVISB,CVISC,IFS,MMM,VISB,VISC
      COMMON/TU/BQ(55),DALP(7,55),DBQ(55),DCPX(55),DDALP(7,55),DTAU(55),
     1TAU(55)
      COMMON/TV/ALPP(7,2),BET,BQP(2),DACHP(7,2),DALPP(7,2),DBQP(2),
     1DCPXP(2),DDALPP(7,2),DTAUP(2),DTCHP(2),GAMP(2),PP(2),QP(2),
     2TAUP(2),THP(2),TP(2),YP(2)
      COMMON/VW/ICONT,IEND,KT,THBPN,XBPN
      DIMENSION DUMM(7)
      I=IS(K)
      IT1=1
      BET=BETB(K)
      IT11=1
      XXX=1.
      ICCC=0
      L=1
      IF((K/2)*2.NE.K) L=-1
      M=IS(K)   +L
      IF(BETA.NE.0.) GO TO 8210
      TAUN(M)=TAU(M)
      BQN(M)=BQ(M)
      DCPXN(M)=DCPX(M)
      DTAUN(M)=DTAU(M)
      DBQN(M)=DBQ(M)
      CPXN(M)=CPX(M)
      DO 8211 J=1,NSP
      DALPN(J,M)=DALP(J,M)
      DDALPN(J,M)=DDALP(J,M)
      ALPN(J,M)=ALP(J,I)
      WDOTC(J)=0.
      WDOTN(J,M)=0.
      WN(M)=WN(I)
 8211 CONTINUE
 8210 CONTINUE
      IF(BETA.GT.0.)BET=BETAN(K)
    4 IT=1
      CA=1.
      SA=0.
      VT=QN(I)   *COS(BET-THN(I))
      U1=QN(I)                        *CA*SIN(BET-THN(I))
      U1=ABS(U1)
```

```
      XMS=RHON(I)   *U1
      GN=GAMN(I)
      GP1=(GN+1.)
      GM1=GN-1.
      RNI=1./RN(I)
      XM1=U1**2*EMINF**2*(GAR/GAMN(I)*RNI/TN(I))
      OXM=1./XM1
      IF(IT.EQ.1)U2=U1*(GM1*XM1+2.)/GP1*OXM
    5 RH2P=XMS/U2
      P2H=XMS*(U1-U2)+PN(I)
      V2=VT**2
      V1=V2+U1**2
      V2=V2+U2**2
      H6=0.
      DO 1400 J=1,NSP
 1400 H6=HN(J,I)*ALPN(J,I)+H6
      H2=H6+(V1-V2)/2.*EIN
      IIT1=1
      T1=TN(I)
      IF(IIT1.EQ.1)T2=T1*(2.*GN*XM1-GM1)*(GM1*XM1+2.)/(2.*GP1)*OXM
 8200 CALL THERMO(T2,H1,CP1)
      H2P=0.
      DO 8201 J=1,NSP
 8201 H2P=H2P+ALPN(J,M)*H1(J)
      ERR1=(H2-H2P)/H6
      IF(ABS(ERR1).LT.1.E-08) GO TO 8202
      IIT1=IIT1+1
      IF(IIT1.GT.15) GO TO 8203
      IF(IIT1.GT.2) GO TO 8204
      ERR2=ERR1
      T22=T2
      T2=T2*1.01
      GO TO 8200
 8203 WRITE(6,9191)
 9191 FORMAT(1H1)
      WRITE(6,8205)
 8205 FORMAT(* ERROR IN TEMPERATURE LOOP IN HSHOCK*)
      STOP
 8204 DUM=T22-ERR2*(T2-T22)/(ERR1-ERR2)
      ERR2=ERR1
      T22=T2
      T2=DUM
      GO TO 8200
 8202 CONTINUE
      RH2=P2H*WN(M)*GEM/T2
      ER=(RH2-RH2P)/RHO (I)
      IF(ABS(ER).LT.1.E-8)GO TO 7
      IT=IT+1
      IF(IT.GT.15)GO TO 100
```

```
      IF(IT.GT.2)GO TO 6
      ER2=ER
      U22=U2
      U2=U2*.99
      GO TO 5
  100 WRITE(6,9191)
      WRITE(6,200)
  200 FORMAT(* ERROR IN HUGONIOT LOOP IN HSHOCK*)
      STOP
    6 DUM=U22-ER2*(U2-U22)/(ER-ER2)
      ER2=ER
      U22=U2
      U2=DUM
      GO TO 5
    7 CONTINUE
      CB=COS(BET)
      SB=SIN(BET)
      IF((K/2)*2.EQ.K)U2=-U2
      QN2P=-U2*CA
      UV=VT*CB-QN2P*SB
      WV=VT*SB+QN2P*CB
      PHE2=ATAN(WV/UV)
      Q2=SQRT(UV*UV+WV*WV)
      IF(IFMBEC.EQ.1) GO TO 3535
      YN(M)  =Y(M)  +.5*(TAN(BETB(K)  )+TAN(BET))*DELX
      DEL=1.
      IF(BETB(1).EQ.0..AND.BETB(2).EQ.0..AND.BETB(3).EQ.0..AND.BETB(4).
     AEQ.0.)GO TO 777
      IF(BETB(1).GT.0..OR.BETB(3).GT.0.)777,776
  777 CALL LPOINT(M,1.)
      GO TO 775
  776 IF(MMM/2*2.EQ.MMM)CALL LPOINT(M,0.)
  775 DEL=0.
      S1A=0.
      S2A=0.
      S3AT=0.
      GAMB=GAMP(1)
      PB=PP(1)
      QB=QP(1)
      RHOB=RHOP(1)
      THB=THP(1)
      WB=WP(1)
      XMUB=XMUP(1)
      YB=YP(1)
      A1=F1(M)
      A2=F2(M,S1A,S2A,S3AT)
      IF(JCHEM.EQ.1) GO TO 7254
      A3=0.
      GO TO 7257
```

```
7254 TP1=(TP(1)+T2)/2.
     DTCHP(1)=DTCHP(1)/2.
     DO 1552 J=1,NSP
1552 DUMM(J)=CACHP(J,1)/2.
     A3=F3(TP1,DTCHP(1),TP(1),T2,THP(1),PHE2,DUMM,WP(1),WN(M))
7257 CONTINUE
     OPT=-1.
     IF((K/2)*2.EQ.K) OPT=1.
     A4=F4(BETA,-OPT,XMUP(1),THP(1),XMUN(M),THN(M))
     A2=(A2+A3)*A4
     PSH=PP(1)+(OPT*(PHE2-THP(1))-A2*DELX)/A1
     ER3=(PSH-P2H)/P(M)
     IF(ABS(ER3).LT.1.E-3)GO TO 19
     IT1=IT1+1
     IF(IT1.GT.15)GO TO 103
     IT11=IT11+1
     IF(IT1.EQ.2) GO TO 1430
     IF(ER1*ER3.LT.0.) GO TO 14
     IF(ABS(ER1-ER3).LT.5.E-06) GO TO 1492
     IF(ABS(ER1).GT.ABS(ER3)) GO TO 1430
     IF(ICCC.EQ.1) GO TO 103
     XXX=-1.
     ICCC=1
     IT11=IT11-1
1430 ER1=ER3
     BET1=BET
     BET=BET+.01*(IT11-1)*BET*XXX
     GO TO 15
1492 BET2=(BET-BET1 )*20.
     ER1=ER3
     BET1=BET
     BET=BET+BET2
     GO TO 15
 103 WRITE(6,9191)
     WRITE(6,220)
 220 FORMAT(* ERROR IN SHOCK ANGLE IN HSHOCK*)
     STOP
  14 DUM=BET1-ER1*(BET-BET1)/(ER3-ER1)
     ER1=ER3
     BET1=BET
     BET=DUM
  15 YN(M)  =Y(M)   +.5*(TAN(BETB(K)   )+TAN(BET))*DELX
     I5=IS(K)
     YN(I5)  =YN(M)
     KS=IS(K)
     LS=KS
     KT=KS
     IF(K.EQ.2.OR.K.EQ.4) KT=KT-1
     CALL CPCINT
```

```
      GO TO 4
   19 BETAN(K)   =BE
      YN(M)   =.5*(TAN(BETB(K)   )+TAN(BETAN(K)   ))*DELX+Y(M)
      I5=IS(K)
      YN(I5)   =YN(M)
 3535 CONTINUE
      PN(M)   =P2H
      QN(M)   =Q2
      THN(M)    =PHE2
      RHON(M)   =RH2
      TN(M)=T2
      RN(M)=RC/WN(M)
      CPXN(M)=0.
      DO 1401 J=1,NSP
      HN(J,M)=H1(J)
      CPN(J,M)=CP1(J)
 1401 CPXN(M)=CPXN(M)+ALPN(J,M)*CPN(J,M)
      GAMN(M)=CPXN(M)/(CPXN(M)-RN(M)/CPIN)
      ORM=1./RN(M)
      EMN(M)=QN(M)*EMINF*SQRT(GAR/GAMN(M)*ORM/TN(M))
      IF(EMN(M).LT.1.0001) GO TO 1402
      XMUN(M)=ZMU(EMN(M))
 1402 CONTINUE
      RETURN
      END
      SUBROUTINE SWITCH(J,K)
      COMMON/BA/ALP(7,55),EMINF,WINF
      COMMON/BD/XMASS(55)
      COMMON/CJ/CP(7,55),CP1(7),CPX(55)
      COMMON/FF/EM(55),GAM(55),P(55),TH(55),Y(55)
      COMMON/FC/W(55),X(55)
      COMMON/PQ/JCHEM,NSP,T(55)
      COMMON/QA/H(7,55),Q(55),RHO(55),XMU(55)
      COMMON/RC/R(55)
      COMMON/TL/BQ(55),DALP(7,55),DBQ(55),DCPX(55),DDALP(7,55),DTAU(55),
     1TAU(55)
      X     (J)=X     (K)
      Y     (J)=Y     (K)
      Q     (J)=Q     (K)
      P     (J)=P     (K)
      T     (J)=T     (K)
      W     (J)=W     (K)
      R     (J)=R     (K)
      EM    (J)=EM    (K)
      TH    (J)=TH    (K)
      BQ    (J)=BQ    (K)
      TAU   (J)=TAU   (K)
      DBQ   (J)=DBQ   (K)
      GAM   (J)=GAM   (K)
```

```
      RHC   (J)=RHO   (K)
      XMU   (J)=XMU   (K)
      CPX   (J)=CPX   (K)
      DCPX  (J)=CCPX  (K)
      DTAU  (J)=DTAU  (K)
      XMASS(J)=XMASS(K)
      DO 108 JJ=1,NSP
      H     (JJ,J)=H     (JJ,K)
      CP    (JJ,J)=CP    (JJ,K)
      ALP   (JJ,J)=ALP   (JJ,K)
      DALP  (JJ,J)=DALP  (JJ,K)
      CDALP(JJ,J)=DDALP(JJ,K)
  108 CONTINUE
      RETURN
      END
      SUBROUTINE PM(M,L,IFAN,K,OPT,KCPT)
      COMMON/AL   AR,GEW
      COMMON/BA   LP(7,55),EMINF,WINF
      COMMON/CJ/CP(7,55),CP1(7),CPX(55)
      COMMON/CK/WTMOLE(7)
      COMMON/FC/CPIN,RC
      COMMON/EF/EM(55),GAM(55),P(55),TH(55),Y(55)
      COMMON/FC/EIN,PR,XLE
      COMMON/F /GAMINF,H1(7),RINF
      COMMON/ /W(55),X(55)
      COMMON/PC/JCHEM,NSP,T(55)
      COMMON/CA/H(7,55),Q(55),RHO(55),XMU(55)
      COMMON/RC/R(55)
      II=L+KCPT
      DP=ALOG(P(M)/P(II))/FLOAT(IFAN-1)
      IFF=IFAN
      H6=0.
      DO 2 J=1,NSP
    2 H6=H6+H(J,M)*ALP(J, )
      DO 1 LL=2,IFF
      N=LL-1+M
      IF((M/2)*2.EQ.K) N=M-LL+1
      KK=N-1
      IF((K/2)*2.EQ.K) KK=N+1
      X(N)=X(KK)
      P(N)=P(KK)/EXP(DP)
      ALNR=DP/GAM(KK)
      RHO(N)=RHC(KK)/EXP(ALNR)
      G=2.*GAM(KK)/(GAM(KK)-1.)
      QQ=-G*(P(N)/RHO(N)-P(KK)/RHO(KK))
      Q(N)=Q(KK)*Q(KK)+QQ
      Q(N)=SQRT(Q(N))
      H2=H6-QQ/2.*EIN
      IIT1=1
```

```
      T1=T(KK)
      IF(IIT1.EQ.1) T2=T1*.99
8200  CALL THE' D(T2,H1,CP1)
      H2P=0.
      DO 4 J=1,NSP
      ALP(J,N)=ALP(J,KK)
    4 H2P=H2P+ALP(J,N)*H1(J)
      ERR1=(H2-H2P)/H6
      IF(ABS(ERR1).LT.1.E-08) GO TO 8202
      IIT1=IIT1+1
      IF(IIT1.GT.15) GO TO 8203
      IF(IIT1.GT.2) GO TO 8204
      ERR2=ERR1
      T22=T2
      T2=T2*.99
      GO TO 8200
8203  WRITE(6,9191)
9191  FORMAT(1H1)
      WRITE(6,8205)
8205  FORMAT(* ERROR IN TEMPERATURE LOOP IN PM*)
      STOP
8204  DUM=T22-ERR2*(T2-T22)/(ERR1-ERR2)
      ERR2=ERR1
      T22=T2
      T2=DUM
      GO TO 8200
8202  CONTINUE
      T(N)=T2
      W(N)=0.
      CPX(N)=0.
      DO 5 J=1,NSP
      CP(J,N)=CP1(J)
      H(J,N)=H1(J)
      CPX(N)=CPX(N)+ALP(J,N)*CP1(J)
    5 W(N)=W(N)+ALP(J,N)/WTMOLE(J)
      W(N)=1./W(N)
      R(N)=RO/W(N)
      GAM(N)=CPX(N)/(CPX(N)-R(N)/CPIN
      ORN=1./R(N)
      EM(N)=Q(N)*EMINF*SQRT(GAR GAM(N) ORN/T(N))
      XMU(N)=ZMU(EM(N))
      TH(N)=TH(KK)-OPT*ALNP*(COS(XMU(KK ,*SIN(XMU(KK))+COS(XMU(N))*SI
     IN(XMU(N)))*.5
      H6=H2
    1 CONTINUE
      RETURN
      END
      SUBROUTINE CHEM(FAS)
      COMMON/BA/ALP(7,55),EMINF,WINF
```

```
      COMMON/CA/WDOTN(7,55),XN(55)
      COMMON/CB/BETB(4),IS(4)
      COMMON/DF/YN(55)
      COMMON/EF/EM(55),GAM(55),P(55),TH(55),Y(55)
       COMMON/HI/DALCH(7),DTCHEM
      COMMON/OP/ALPB(7),PHI(55)
      COMMON/PC/W(55),X(55)
      COMMON/PQ/JCHEM,NSP,T(55)
      COMMON/QA/H(7,55),Q(55),RHO(55),XMU(55)
      COMMON/QS/RHOP(2),WDOT(7,55),WDOTC(7),WP(2),XMUP(2)
      COMMON/VT/DACH(7,55),DTCH(55),DVISO,VISO
      COMMON/WV/NPTS,RE,X9P,XJ
      COMMON/YZ/BPRESU,CHEMFC,CPRESU,EMSUB,RTH,XSTEP
      IF(JCHEM.EQ.0) GO TO 8351
C          **********  CHEMISTRY PACKAGE  **********
      DO 8355 L=1,NPTS
      DO 89 M=1,4
      IF(IS(M).EQ.0) GO TO 89
      ITEST=IS(M)-1
      IF((M/2)*2.EQ.M) ITEST=IS(M)
      IF(L.EQ.ITEST.OR.L.EQ.ITEST+1) GO TO 8398
   89 CONTINUE
      FAT=ABS(PHI(L))
      IF((FAT.LT..01).OR.(FAT.GT.100.)) GO TO 8398
      K=L
      DX=SQRT((XN(L)-X(K))**2+(YN(L)-Y(K))**2)*RTH
      DO 8350 J=1,NSP
 8350 ALPB(J)=ALP(J,K)
      CALL MOCLS(T(K),P(K),Q(K),RHO(K),ALPB,DX,L)
      DO 8301 J=1,NSP
 8301 DACH(J,L)=DALCH(J)
      DTCH(L)=DTCHEM
      GO TO 8355
 8398 DTCH(L)=0.
      DO 8399 J=1,NSP
      WDOT(J,L)=0.
      WDOTN(J,L)=0.
 8399 DACH(J,L)=0.
 8355 CONTINUE
      GO TO 4000
 8351 DO 6100 L=1,NPTS
      DTCH(L)=0.
      DO 8302 J=1,NSP
      WDOT(J,L)=0.
      WDOTN(J,L)=0.
 8302 DACH(J,L)=0.
 6100 CONTINUE
 4000 CONTINUE
      RETURN
```

```
      END
      SUBROUTINE SHEAR(I,ASHEAR)
      COMMON/CJ/CP(7,55),CP1(7),CPX(55)
      COMMON/CK/WTMOLE(7)
      COMMON/EF/EM(55),GAM(55),P(55),TH(55),Y(55)
      COMMON/GK/DELX
      COMMON/PC/W(55),X(55)
      COMMON/PG/JCHEM,NSP,T(55)
      COMMON/GA/H(7,55),Q(55),RHO(55),XMU(55)
      COMMON/SS/AL1,AL2,BQ1,BQ2,C1,C2,CH1,CH2,DB1,DB2,DD1,DD2,DT1,DT2,DV
     A1,DV2,PX1,PX2,TA1,TA2,TH1,TH2,V1,V2,Y1,Y2
      COMMON/ST/I13,IREGI,K ,KFIRST,KKKQ,PSTAR
      COMMON/TU/BQ(55),DALP(7,55),DBQ(55),DCPX(55),DDALP(7,55),DTAU(55),
     1TAU(55)
      COMMON/VT/DACH(7,55),DTCH(55),DVISD,VISD
      COMMON/WV/NPTS,PE,XBP,XJ
      DIMENSION S3D(7)
      K=I
      V1=V2=VISD
      DV1=DV2=DVISD
      TA1=TA2=TAU(K)
      DT1=DT2=DTAU(K)
      Y1=Y2=Y(K)
      TH1=TH2=TH(K)
      S1D=S1(XJ,RE)
      CH2D=0.
      DO 10 J=1,NSP
   10 CH2D=CH2D+DALP(J,K)*CP(J,K)
      BQ1=BQ2=BQ(K)
      C1=C2=CPX(K)
      DB1=DB2=DBQ(K)
      PX1=PX2=DCPX(K)
      CH1=CH2=CH2D
      S2D=S2(XJ,RE)
      S3DT=0.
      DO 20 J=1,NSP
      AL1=AL2=DALP(J,K)
      DD1=DD2=DDALP(J,K)
      S3D(J)=S3(XJ,RE)
   20 S3DT=S3DT+S3D(J)/WTMOLE(J)
      PK=1./P(K)
      SH1=S1D/GAM(K)*PK/EM(K)**2
      QK=1./Q(K)
      SH2=-(GAM(K)-1.)*S2D/GAM(K)*PK*QK
      SH3=-W(K)*S3DT/RHO(K)*QK
      IF(XJ.EQ.0) SH4=0.
      IF(XJ.EQ.0) GO TO 40
      IF(K.NE.1.OR.Y(K).GT.1.E-6) GO TO 30
      SH4=TH(2)/Y(2)
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      GO TO 40
   30 SH4=SIN(TH(K))/Y(K)
   40 CONTINUE
      OD=1./DELX
      SH5=-DTCH(K)/T(K)*OD*COS(TH(K))
      DUM=0.
      DO 50 J=1,NSP
   50 DUM=DUM+CACH(J,K)/WTMOLE(J)
      SH6=-W(K)*DUM/DELX*COS(TH(K))
      SH=SH1+SH2+SH3+SH4+SH5+SH6
      ASHEAR=-GAM(K)*P(K)*EM(K)**2*SH
      RETURN
      END
      SUBROUTINE PRESS(X,P,TH,THN)
      COMMON/AC/IBOD,PIN
      COMMON/WX/APRESS,APRESU
      COMMON/YX/ABODS,BPRESS,CPRESS
      P=APRESS+X*(BPRESS+CPRESS*X)
      P=P*PIN
      THN=TH
      RETURN
      END
      FUNCTION XVIS(A)
      COMMON/BA/ALP(7,55),EMINF,WINF
      COMMON/DB/BETB(4),IS(4)
      COMMON/FH/XK1,XK3,XPOT
      COMMON/QA/H(7,55),Q(55),RHO(55),XMU(55)
      COMMON/WV/NPTS,RE,XBP,XJ
      DATA IVIS 0/
      IDUM=NPTS
      IDD=1
      IF(IS(4).LT.0)IDD=IS(4)+1
      IF(IS(3).GT.0) IDUM=IS(3)-1
      DUM1=0.
      RU=RHO(IDD)*Q(IDD)
      IDE=IDD+1
      DO 10 I=IDE,IDUM
      DUM=ABS(RHO(I)*Q(I)-RU)
      IF(DUM.LT.DUM1) GO TO 10
      DUM1=DUM
   10 CONTINUE
      IF(ALP(4,1).GT..99 ) GO TO 30
      IF(ALP(4,1).LT.1.E-09.AND.XBP.LT.XPOT) GO TO 30
      IF(IVIS.EQ.0) XVIS1=XK1*RE*XBP*DUM1+XK3
      IF(IVIS.EQ. 0)
     1WRITE(6,9696) XBP,XVIS1
 9696 FORMAT(32H VISCOSITY MODEL SWITCHED AT X =E10.3,14H  VISCOSITY = ,
     1F13.5)
      IVIS=1
```

```
      XVIS=XVIS1
      GO TO 40
   30 CONTINUE
      XVIS=XK1*RE*XBP*DUM1+XK3
   40 CONTINUE
      RETURN
      END
      SUBROUTINE COWL
      COMMON/BA/ALP(7,55),EMINF,WINF
      COMMON/CJ/CP(7,55),CP1(7),CPX(55)
      COMMON/DB/BETR(4),IS(4)
      COMMON/DE/MM
      COMMON/EF/EM(55),GAM(55),P(55),TH(55),Y(55)
      COMMON/HJ/KOUNT,LZ,NPT
      COMMON/HL/ALPHA,BETA
      COMMON/HM/ALPN(7,55),CPN(7,55),CPXN(55),EMN(55),GAMN(55),HN(7,55),
     1LS,PN(55),QN(55),RHON(55),RN(55),THN(55),TN(55),WN(55),XMUN(55)
      COMMON/HP/BETAN(4),IEMBED
      COMMON/PC/W(55),X(55)
      COMMON/PC/JCHEM,NSP,T(55)
      COMMON/QA/H(7,55),Q(55),RHO(55),XMU(55)
      COMMON/RC/R(55)
      COMMON/TU/BQ(55),DALP(7,55),DBQ(55),DCPX(55),DDALP(7,55),DTAU(55),
     1TAU(55)
      COMMON/WV/NPTS,RE,XBP,XJ
      ALPHA=1.
      BETA=0.
      NPTSSS=NPT
      NPT=NPT-3
      IF(P(NPT+MM)-P(NPT)) 2001,2002,2003
 2002 WRITE(6,9191)
 9191 FORMAT(1H1)
      WRITE(6,2004)
 2004 FORMAT(1H1,67H ERROR IN INPUT DATA - NO PRESSURE DIFFERENCE ACROSS
     1 SPLITTER PLATE/23H SET INPUT - INTACT = 0)
      STOP
 2003 OPT=1.
      K=4
      IS(K)=NPTSSS-1
      L=IS(K)
      M=L+MM
      GO TO 2005
 2001 OPT=-1.
      K=3
      IS(K)=NPT+MM
      M=NPT
      L=M+MM
 2005 IFAN=MM-2
      KOPT=OPT*1.5
```

```
      N13=NPTSSS-2*KOPT
      IF((K/2)*2.EQ.K) N13=NPTSSS
      DO 300 N12=N13,NPTS
      K5=NPTS+N13-N12
      J5=K5+1
      CALL SWITCH(J5,K5)
  300 CONTINUE
      NPTS=NPTS+1
      DO 301 I11=1,4
      IF(I11.EQ.K) GO TO 301
      IF(IS(I11).GT.N13) IS(I11)=IS(I11)+1
  301 CONTINUE
      LL=L+KOPT
      TAU(LL)=0.
      PN(L)=P(L)
      THN(L)=TH(L)
      Q  N(L)=Q  (L)
      T  N(L)=T  (L)
      R  N(L)=R  (L)
      RHON(L)=RHO(L)
      GAMN(L)=GAM(L)
      BQ(LL)=0.
      DCPX(LL)=0.
      DTAU(LL)=0.
      DBQ(LL)=0.
      CPX(LL)=0.
      WN(L)=W(L)
      DO 2006 J=1,NSP
      HN(J,L)=H(J,L)
      DALP(J,LL)=0.
      DDALP(J,LL)=0.
 2006 ALPN(J,L)=ALP(J,L)
      ITT=1
      BETB(K)=(TH(L)-OPT*XMU(L))*1.01
      BET=BETB(K)
 2007 IEMBED=1
      CALL FSHOCK(K)
      IEMBED=0
      KK=LL+KOPT
      P  (LL)=P  N(LL)
      Q  (LL)=Q  N(LL)
      T  (LL)=T  N(LL)
      W  (LL)=W  N(LL)
      R  (LL)=R  N(LL)
      TH (LL)=TH N(LL)
      EM (LL)=EM N(LL)
      XMU(LL)=XMUN(LL)
      GAM(LL)=GAMN(LL)
      RHO(LL)=RHON(LL)
```

```
      CPX(LL)=CPXN(LL)
      P  (KK)=P  N(LL)
      Q  (KK)=Q  N(LL)
      T  (KK)=T  N(LL)
      W  (KK)=W  N(LL)
      R  (KK)=R  N(LL)
      TH (KK)=TH N(LL)
      EM (KK)=EM N(LL)
      XMU(KK)=XMUN(LL)
      GAM(KK)=GAMN(LL)
      RHO(KK)=RHON(LL)
      CPX(KK)=CPXN(LL)
      DO 2008 J=1,NSP
      H  (J,LL)=H  N(J,LL)
      CP (J,LL)=CP N(J,LL)
      ALP(J,LL)=ALPN(J,LL)
      H  (J,KK)=H  N(J,LL)
      CP (J,KK)=CP N(J,LL)
 2008 ALP(J,KK)=ALPN(J,LL)
      X(LL)=X(L)
      X(KK)=X(L)
      THS=TH(KK)
      CALL PM(M,L,IFAN,K,OPT,KOPT)
      NNN=IFAN-1+M
      IF((K/2)*2.EQ.K) NNN=M-IFAN+1
      THPM=TH(NNN)
      ERR=THS-THPM
      IF(ABS(ERR).LT.1.E-04) GO TO 15
      ITT=ITT+1
      IF(ITT.GT.15) GO TO 102
      IF(ITT.GT.2) GO TO 14
      ER1=ERR
      BET1=BET
      BET=1.01*BET
      BETB(K)=BET
      GO TO 2007
  102 WRITE(6,203)
  203 FORMAT(* ERROR IN BETA SHOCK IN COWL*)
      CALL EXIT
   14 DUM1=BET1-ER1*(BET-BET1)/(ERR-ER1)
      ER1=ERR
      BET1=BET
      BET=DUM1
      BETB(K)=BET
      GO TO 2007
   15 CONTINUE
      NPT=NPTSSS
      RETURN
      END
```

ORIGINAL PAGE IS
OF POOR QUALITY

```
      SUBROUTINE DPOINT(K, )
      COMMON/A /GAR,GEM
      COMMON/B/ ALP(7,55),EMINF,WINF
      COMMON/CJ/CP(7,55),CP1(7),CPX(55)
      COMMON/CK/WTMOLE(7)
      COMMON/DP/YN(55)
      COMMON/EF/EM(55),GAM(55),P(55),TH(55),Y(55)
      COMMON/EP/GAMINF,H1(7),RINF
      COMMON/GK/DELX
      COMMON/PD/W(55),X(55)
      COMMON/PG/JCHEM,NSP,T(55)
      COMMON/GA/H(7,55),Q(55),RHO(55),XMU(55)
      COMMON/TU/BQ(55),DALP(7,55),DBQ(55),DCPX(55),DDALP(7,55),DTAU(55),
     1TAU(55)
      COMMCN/TV/ALPP(7,2),BET,BQP(2),DACHP(7,2),DALPP(7,2),DBQP(2),
     1DCPXP(2),DDALPP(7,2),DTAUP(2),DTCHP(2),GAMP(2),PP(2),QP(2),
     2TAUP(2),THP(2),TP(2),YP(2)
      COMMON/VT/DACH(7,55),DTCH(55),DVISD,VISD
      IT=1
      YD=(YP(1)+YP(2))/2.
   16 RAT=(YD-YP(1))/(YP(2)-YP(1))
      ALAMD=TAN(THP(1))+RAT*(TAN(THP(2))-TAN(THP(1)))
      YAT=YN(L)-ALAMD*DELX
      ERR=ABS((YAT-YD)/(YP(2)-YP(1)))
      IF(ERR.LT.1.E-05) GO TO 18
      YD=YAT
      IT=IT+1
      IF(IT.LE.10) GO TO 16
      WRITE(6,9191)
 9191 FORMAT(1H1)
      WRITE(6,202)
  202 FORMAT(* ERROR IN D POINT ITERATION*)
      STOP
   18 Y(K)=YD
      P   (K)=P   P(1)+RAT*(P   P(2)-P   P(1))
      Q   (K)=Q   P(1)+RAT*(Q   P(2)-Q   P(1))
      T   (K)=T   P(1)+RAT*(T   P(2)-T   P(1))
      TH  (K)=TH  P(1)+RAT*(TH  P(2)-TH  P(1))
      BQ  (K)=BQ  P(1)+RAT*(BQ  P(2)-BQ  P(1))
      TAU (K)=TAU P(1)+RAT*(TAU P(2)-TAU P(1))
      DBQ (K)=DBQ P(1)+RAT*(DBQ P(2)-DBQ P(1))
      DCPX(K)=DCPXP(1)+RAT*(DCPXP(2)-DCPXP(1))
      DTAU(K)=DTAUP(1)+RAT*(DTAUP(2)-DTAUP(1))
      DTCH(K)=DTCHP(1)+RAT*(DTCHP(2)-DTCHP(1))
      CPX(K)=0.
      W(K)=0.
      CALL THERMO(T(K),H1,CP1)
      DO 1 J=1,NSP
      H (J,K)=H 1(J)
```

C-2

```
      CP(J,K)=CP1(J)
      ALP   (J,K)=ALP   P(J,1)+RAT*(ALP   P(J,2)-ALP   P(J,1))
      DAL   (J,K)=DALP P(J,1)+RAT*(DALP P(J,2)-DALP P(J,1))
      DACH(J,K)=DACHP(J,1)+RAT*(DACHP(J,2)-DACHP(J,1))
      DDALP(J,K)=DDALPP(J,1)+RAT*(DDALPP(J,2)-DDALPP(J,1))
      CPX(K)=CPX(K)+ALP(J,K)*CP(J,K)
    1 W(K)=W(K)+ALP(J,K)/WTMOLE(J)
      W(K)=1./W(K)
      RHO(K)=P(K)*W(K)*GEW/T(K)
      RETURN
      END
      SUBROUTINE STEP(VIS)
      COMMON/AC/IBOD,FIN
      COMMON/AX/JSUBL,JSUBU
      COMMON/CA/WDOTN(7,55),XN(55)
      COMMON/CB/BETB(4),IS(4)
      COMMON/CP/YN(55)
      COMMON/EF/EM(55),GAM(55),P(55),TH(55),Y(55)
      COMMON/EG/EIN,PR,XLE
      COMMON/GE/RAD,RCO,UIN,VISINF
      COMMON/GK/DELX
      COMMON/HJ/KOUNT,LL,NPT
      COMMON/HP/ALPN(7,55),CPN(7,55),CPXN(55),EMN(55),GAMN(55),HN(7,55),
     1LS,PN(55),QN(55),RHON(55),RN(55),THN(55),TN(55),WN(55),XMUN(55)
      COMMON/QR/THBP,YBP,YBPN
      COMMON/FQ/JCHEM,NSP,T(55)
      COMMON/QA/H(7,55),Q(55),RHO(55),XMU(55)
      COMMON/ST/I13,IREGI,KS,KFIRST,KKKQ,PSTAR
      COMMON/UV/II11,IERR,IPRESS,IPRESU,ISUB
      COMMON/V  ICONT,IEND,KT,THBPN,XBPN
      COMMON/WV/NPTS,PE,XBP,XJ
      COMMON/WX/APRESS,APRESU
      COMMON/YZ/BPRESU,CHEMFC,CPRESU,EMSUB,HTH,XSTEP
      DIMENSION DELLX(55),XW(2),YW(2),THW(2)
      DATA I13/0/
      DATA IREGI/0/
      ISPP=0
      ISPA=0
      NSAVE=2
      XW(1)=0.
      XW(2)=10000.
      YW(1)=10000.
      YW(2)=10000.
      THW(1)=0.
      THW(2)=0.
      ISUB=0
      JSUBL=NPTS+1
      JSUPU=NPTS+1
      DO 910 I=1,NPTS
```

```
      IF(EM(I).GT.EMSUB) GO TO 910
      JSUBL=1
      ISUB=1
      GO TO 800
  910 CONTINUE
      GO TO 801
  800 CONTINUE
      DO 802 I=1,NPTS
      II=NPTS-I+1
      IF(EM(II).GT.EMSUB) GO TO 802
      JSUBU=II+1
      GO TO 801
  802 CONTINUE
  801 CONTINUE
      IF(ISUB.EQ.0) GO TO 10
      I13=1
      KFIRST=KCUNT
   10 CONTINUE
      JDUM=JSUBU-1
      NP2=NPTS-1
      DO 499 K=1,NP2
      DEY=Y(K+1)-Y(K)
      IF(DEY.LT.1.E-08) GO TO 498
      IF(K.GE.JSUBL.AND.K.LE.JDUM) GO TO 498
      EM1=XM1(1.,0.,TH(K),XMU(K),0.,0.)
      EM2=XM2(1.,0.,TH(K+1),XMU(K+1),0.,0.)
      DELLX(K)=(Y(K+1)-Y(K))/(EM1-EM2)
      IF(BETB(1).EQ.0..AND.BETB(2).EQ.0..AND.BETB(3).EQ.0..AND.BETB(4).
     AEQ.0.)GO TO 499
      IF(BETB(1).GT.0..OR.BETB(3).GT.0.)GO TO 499
      IF(K.EQ.IS(1).OR.K.EQ.IS(3))DELLX(K)=DELLX(K-1)
      IF(K.EQ.IS(2).OR.K.EQ.IS(4))DELLX(K-1)=DELLX(K-2)
      GO TO 499
  498 DELLX(K)=1.E+06
  499 CONTINUE
      DELXM=DELLX(1)
      DO 501 K=2,NP2
      IF(DELLX(K).LT.DELXM)DELXM=DELLX(K)
  501 CONTINUE
      IF(BETB(1).EQ.0..AND.BETB(2).EQ.0..AND.BETB(3).EQ.0..AND.BETB(4).
     AEQ.0.)GO TO 777
      IF(BETB(1).GT.0..OR.BETB(3).GT.0.)777,776
  777 DCHAR=DELXM
      GO TO 775
  776 DCHAR=2.*DELXM
  775 IF(XLE.EQ.0..OR.VIS.EQ.0.)GO TO 50
      VI=1./VIS
      DELV=.5*PR*RE*VI/XLE
      GO TO 51
```

```
   50 DELV=0.
   51 DO 502 K=1,NPTS
      DELV1=1.E+10
      IF(K.NE.1) DELY=Y(K)-Y(K-1)
      IF(K.NE.NPTS) DELYY=Y(K+1)-Y(K)
      IF(K.EQ.1) DELY=DELYY
      IF(K.EQ.NPTS) DELYY=DELY
      IF(DELYY.LT.DELY) DELY=DELYY
      IF(DELY.LT.1.E-08) GO TO 502
      DELV1=DELV*RHO(K)*Q(K)*DELY**2*COS(TH(K))
  502 DELLX(K)=DELV1
      DELXM=DELLX(1)
      DO 504 K=2,NPTS
  504 IF(DELLX(K).LT.DELXM)DELXM=DELLX(K)
      DSHEAR=DELXM
      DELX=1./(1./DCHAR+1./DSHEAR)
      DELX=DELX/XSTEP
      IF(ISPA.EQ.1) GO TO 4
      ISPA=1
      CALL SPACE(ISPP)
      IF(II11.EQ.1) RETURN
      IF(ISPP.EQ.1) GO TO 10
    4 CONTINUE
      IF(JCHEM.EQ.0) GO TO 4275
      DO 505 I=1,NPTS
      DTEST=C(I)*UIN*4.E-7/RTH
      DTEST=CHEMFC*DTEST
  505 IF(DELX.GT.DTEST) DELX=DTEST
 4275 CONTINUE
      IF(I13.NE.1.OR.KOUNT.NE.KFIRST) GO TO 4545
      KKKQ=KOUNT+20
 4545 CONTINUE
      IF(EM(JSUBU).LT.1.05) KKKQ=KOUNT+1
      XWT=XBP+DELX
      RA=1./RAC
      IF(XWT.LT.XW(1)) GO TO 741
      IF(XWT.LE.XW(NSAVE)) GO TO 5209
      THBPN=0.
      XBPN=XW(NSAVE)
      YBPN=YW(NSAVE)
      II11=1
      GO TO 5210
 5209 CALL TBL(XWT,THBPN,XW,THW,NSAVE)
      GO TO 5204
  741 THBPN=THBP+DELX/COS(THBP)*RA
 5204 DELX=DELX/COS(THBP)*(COS(THBP)+COS(THBPN))/2.
      XBPN=XWT
      YBPN=YBP+(SIN(THBP)+SIN(THBPN))*.5*DELX/COS(THBP)
 5210 CONTINUE
```

```
      DO 5211 I=1,NPTS
      XN(I)=XBPN
      YN(I)=Y(I)+TAN(TH(I))*DELX
 5211 THN(I)=TH(I)
      IF(IBOD.EQ.1) CALL BODY(XN(1),YN(1),THN(1),0)
      IF(IPRESS.EQ.1) CALL PRESS(XN(1),PN(1),TH(1),THN(1))
      IF(IPRESU.EQ.1) PN(NPTS)=PIN*(APRESU+XN(NPTS)*(BPRESU+CPRESU*
     1XN(NPTS)))
      IF(IPRESU.EQ.1) RETURN
      IF(Y(NPTS).EQ.YBP) GO TO 6211
      CALL BODY(XWT,YN(NPTS),THN(NPTS),1)
      XN(NPTS)=XWT
      RETURN
 6211 XN(NPTS)=XBPN
      YN(NPTS)=YBPN
      THN(NPTS)=THBPN
      RETURN
      END
      SUBROUTINE SSONIC(IDG)
      COMMON/AC/IBOD,FIN
      COMMON/AX/JSUBL,JSUBU
      COMMON/BC/XMASS(55)
      COMMON/CG/AUP,BUP,CUP,DTSPRI(55),DUP,EUP,JCONV,THPRI(55),YPRI(55)
      COMMON/DP/YN(55)
      COMMON/EF/EM(55),GAM(55),P(55),TH(55),Y(55)
      COMMON/GK/DELX
      COMMON/HJ/KOUNT,LL,NPT
      COMMON/HL/ALPHA,BETA
      COMMON/HP/ALPN(7,55),CPN(7,55),CPXN(55),EMN(55),GAMN(55),HN(7,55),
     IL,PN(55),QN(55),RHON(55),RN(55),THN(55),TN(55),WN(55),XMUN(55)
      COMMON/RC/AP0,AP1,AP2
      COMMON/ST/I13,IREGI,K ,KFIRST,KKKQ,PSTAR
      COMMON/UV/II11,IERR,IPRESS,IPRESU,ISUB
      COMMON/VW/ICONT,IEND,KT,THBPN,XBPN
      COMMON/WV/NPTS,RE,XBP,XJ
      DIMENSION EZ(2),ERET(2),ERTHL(2)
      DATA LKIP/1/,LME/1/,LICO/0/,LICK/0/,LIJUMP/0/
      DATA DTHC/0./
      IF(I13.NE.1.OR.KOUNT.NE.KFIRST) GO TO 1777
      XKF=XBP
      CALL OPCTH(THSBOT,JSUBL)
      ATHB=Y(JSUBL)
      BTHB=TAN(TH(JSUBL))
      IF(IREGI.EQ.0)CTHB=THSBCT/COS(TH(JSUBL))**3
      IF(IREGI.NE.0)CTHB=(CTHB+DTHB*XDEL)
      DTHB=DTHO
      XMKF=XMASS(JSUBU)
 1777 CONTINUE
      K=JSUBU
```

```
      DQ=XBPN-XKF
      OS=1./6.
      OQ=1./24.
      YN(K)=AUP+BUP*CQ+CUP*DQ**2*.5+DUP*DQ**3*OS+EUP*DQ**4*OQ
      THN(K)=ATAN(BUP+CUP*DQ+DUP*DQ**2*.5+EUP*DQ**3*OS)
      DS=2.*DELX/(COS(TH(K))+COS(THN(K)))
      THGH=THN(K)
      YGH=YN(K)
      IBOD1=IBCC
      IBOD=1
      IPRES1=IPRESS
      IPRESS=0
      IPRE U1=IPRESU
      IPRESU=0
      ALSV=ALPHA
      BESV=BETA
      CALL LPOINT(JSUBU,0.)
      K=JSUBU
      THN(K)=THGH
      YN(K)=YGH
      ALPHA=.5
      BETA=.5
      CALL LPCINT(JSUBU,0.)
      ALPHA=ALSV
      BETA=BESV
      K=JSUBU
      THN(K)=THGH
      YN(K)=YGH
      IBOD=IBOD1
      IPRESS=IPRES1
      IPRESU=IPREU1
      DS=2.*DELX/(COS(TH(K))+COS(THN(K)))
      PSA=(PN(K)-P(K))/DS
      THSA=(CUP+DUP*CQ+EUP*DQ**2*.5)*COS(THN(K))**3
      PNA=-GAMN(K)*PN(K)*EMN(K)**2*THSA
      PYU=CCS(THN(K))*PNA+SIN(THN(K))*PSA
      K=JSUBL
      DQ=XBPN-XKF
      YN(K)=ATHB+BTHB*CQ+CTHB*DQ**2*.5+DTHB*DQ**3*OS
      THN(K)=ATAN(BTHB+CTHB*DQ+DTHB*DQ**2*.5)
      THSB=(CTHB+DTHB*DQ)*COS(THN(K))**3
      DS=2.*DELX/(COS(TH(K))+COS(THN(K)))
      PYB=AP1
      ITE1=1
      IET=0
 1790 AP2=(PYU-PYB)*.5/(YN(JSUBU)-YN(K))
      AP0=PN(JSUBU)-.5*(PYB+PYU)*(YN(JSUBU)-YN(K))
      AP1=PYB
      PN(K)=AP0
```

```
      ICONT=1
      IEND=0
      KP=K
      L=K
      KT=K
      PSTAR=PN(K)
      YGH=YN(K)
      THGH=THN(K)
      CALL CPCINT
      YN(K)=YGH
      THN(K)=THGH
      PNB=-GAMN(K)*PN(K)*EMN(K)**2*THSB
      PYB2=COS(THN(K))*PNB
      ET=PYB-PYB2
      IF(ABS(ET).LT.1.E-06) GO TO 1789
      IET=IET+1
      IF(IET.LT.20) GO TO 6532
      WRITE(6,6533)
 6533 FORMAT(* ET LOOP IN SSONIC*)
      STOP
 6532 CONTINUE
      ERET(ITE1)=ET
      IF(ITE1.GT.1) GO TO 358
      ITE1=2
      PYB1=PYB
      PYB=PYB2
      GO TO 1790
  358 PYBD=PYB1-ERET(1)*(PYB-PYB1)/(ERET(2)-ERET(1))
      PYB1=PYB
      ERET(1)=ERET(2)
      PYB=PYBD
      GO TO 1790
 1789 CONTINUE
      ICONT=1
      IEND=0
      JSUBL1=JSUBL+1
      JSUBU1=JSUBU-1
      DO 1734 KK=JSUBL1,JSUBU1
      K=JSUBU-KK+1
      THN(K)=TH(K)
      YN(K)=TAN(TH(K))*DELX+Y(K)
      PN(K)=AP0+AP1*(YN(K)-YN(JSUBL))+AP2    *(YN(K)-YN(JSUBL))**2
      KIP=1
      ME=1
      KP=K
      L=K
      KT=K
      PSTAR=PN(K)
      DS=2.*DELX/(COS(TH(K))+COS(THN(K)))
```

```
      YN(K)=Y(K)+.5*(TAN(TH(K))+TAN(THN(K)))*DELX
      YGH=YN(K)
      THGH=THN(K)
      CALL CPCINT
      YN(K)=YGH
      THN(K)=THGH
      YN(K)=Y(K)+.5*(TAN(TH(K))+TAN(THN(K)))*DELX
      KP=K+1
      TERM=(RHCN(K)*QN(K)*COS(THN(K))+RHON(KP)*QN(KP)*COS(THN(KP)))/2.
      XMDUM=XMASS(KP)+TERM*(YN(K)**(1.+XJ)-YN(KP)**(1.+XJ))/(1.+XJ)
      Q1J=1.+XJ
      YN(K)=(YN(KP)**Q1J+Q1J*(XMASS(K)-XMASS(KP))/TERM)**(1./Q1J)
1734  CONTINUE
      IF(KOUNT.NE.KKKQ-1) RETURN
      XMDIFF=XMKF-XMASS(JSUBU)
      JK=JSUBL+1
      DC 347 I=JK,JSUBU
 347  XMASS(I)=XMASS(I)+XMDIFF
      JSU1=JSUBU-1
      WRITE(6,1418)
1418  FORMAT(1CX,*CORRECTED INTERMEDIATE STREAMLINES*/2X,*STREAMLINE NO.
     1*,7X,*X*,12X,*Y*,11X,*TH*)
      DC 386 KK=1,JSU1
      K=JSUBU-KK
      KIP=1
      ME=1
      DTERM=0.
      DYDX=TAN(THPRI(K))
      D2YCX2=CTSPRI(K)/COS(THPRI(K))**3*.5
      IF(K.EQ.1)D2YDX2= CTHB*.5
      XDEL=XBPN-XKF
6030  YSTAR=YPRI(K)+DYDX*XDEL+D2YDX2*XDEL**2+DTERM*XDEL**3*OS
      THSTAR=ATAN(DYDX+2.*D2YDX2*XDEL+DTERM*XDEL**2*.5)
      KP=K+1
      TERM=(RHON(KP)*QN(KP)*COS(THN(KP))+RHON(K)*QN(K)*COS(THSTAR))/2.
      X1J=1.+XJ
      XMDUM=XMASS(KP)+TERM*(YSTAR**X1J-YN(KP)**X1J)/X1J
      EZ(ME)=XMDUM-XMASS(K)
      IF(ABS(EZ(ME)).LT.1.E-06                ) GO TO 6034
      KIP=KIP+1
      GO TO (6041,6C42),ME
6041  ME=2
      DTERM1=DTERM
      DTERM=-.01/XDEL**2
      GO TO 603C
6042  DTERMD=DTERM1-EZ(1)*(DTERM-DTERM1)/(EZ(2)-EZ(1))
      DTERM1=DTERM
      DTERM=DTERMD
      EZ(1)=EZ(2)
```

```
      IF(KIF.LE.20) GO TO 603C
      WRITE(6,6081)
 6081 FORMAT(* TOO MANY ITERATIONS FOR ONE POINT IN SSONIC*)
      STOP
 6034 IF(K.EQ.1) GO TO 6036
      YN(K)=YSTAR
      THN(K)=THSTAR
      XDEL1=XCEL/4.
      DO 1417 I=1,4
      XDE=XDEL1*FLOAT(I)
      XPRNT=XKF+XDE
      YPRNT=YPRI(K)+DYCX*XDE+D2YDX2*XDE**2+DTERM*XDE**3*OS
      THPRNT=ATAN(DYDX+2.*D2YDX2*XDE+DTERM*XDE**2*.5)
      WRITE(6,1419) K,XPRNT,YPRNT,THPRNT
 1419 FORMAT(5X,I5,5X,3E13.5)
 1417 CONTINUE
      GO TO 386
 6036 ERTH=THSTAR-THN(JSURL)
      JCONV=0
      I13=2
      ERTHL(LME)=ERTH
      IF(LIJUMP.EQ.1) GO TO 2501
      IF(ABS(ERTHL(LME)).LT..0C1) GO TO 2501
      LKIP=LKIP+1
      GO TO (2502,2503),LME
 2502 LME=2
      DTHB2=DTHB
      DTHQ=CTHB-.05
      GO TO 2504
 2503 IF(LICG.EQ.1) GO TO 2505
      IF(ERTHL(1)*ERTHL(2).LT.0.) GO TO 2505
      IF(LICK.EQ.1) GO TO 2506
      LICK=1
      RTHL=-.5
      IF(ABS(ERTHL(2)).GT.ABS(ERTHL(1))) RTHL=-RTHL
 2506 IF(ABS(ERTHL(2)).GT.ABS(ERTHL(1)).AND.LKIP.GE.4) GO TO 2507
      DTHB1=DTHB2
      DTHB2=DTHB
      DTHQ=DTHB+RTHL
 2509 ERTHX=ERTHL(1)
      ERTHL(1)=ERTHL(2)
      IF(LKIP.LE.10) GO TO 2504
      WRITE(6,2508)
 2508 FORMAT(* TOO MANY ITERATIONS IN LOWER WALL LOOP IN SSONIC*)
      STOP
 2507 PMB=ERTHL(1)*DTHB**2-ERTHL(2)*DTHB2**2+ERTHL(2)*DTHB1**2-ERTHX*
     1DTHB**2+ERTHX*DTHB2**2-ERTHL(1)*DTHB1**2
      PMC=ERTHL(2)*DTHB2-ERTHL(1)*DTHB+ERTHX*DTHB-ERTHL(2)*DTHB1
     1+ERTHL(1)*DTHB1-ERTHX*DTHB2
```

```
      DTHQ=-PMB/(2.*PMC)
      LIJUMP=1
      GO TO 2504
 2505 LICQ=1
      DTHD=DTHB2-ERTHL(1)*(DTHB-DTHB2)/(ERTHL(2)-ERTHL(1))
      DTHB1=DTHB2
      DTHB2=DTHP
      DTHQ=DTHD
      GO TO 2509
 2501 JCCNV=1
      I13=0
      LKIP=1
      LME=1
      LICQ=0
      LICK=0
      LIJUMP=0
      IREGI=1
      DTHQ=0.
 2504 IF(JCCNV.EQ.0)DTHB=DTHQ
  386 CONTINUE
      RETURN
      END
      SUBROUTINE BODY(X1,Y,TH,ID)
      COMMON/AC/IBOD,PIN
      COMMON/X0/X00
      COMMON/ZY/ABOD,BBOD,CBOD,EBOD,FBOD,GBOD,IAVE,IPUNCH,JBOD,KKKKK
      X=X1
      IF(ID.EQ.1) GO TO 4
      IF(IBOD.EQ.0) GO TO 1
      X=X1-X00
      Y=ABOD+X*(BBOD+X*CBOD)
      TH=ATAN(BBOD+2.*CBOD*X)
      GO TO 2
    1 Y=0.
      TH=0.
      GO TO 2
    4 Y=EBOD+X*(FBOD+X*GBOD)
      TH=ATAN(FBOD+2.*GBOD*X)
    2 RETURN
      END
      SUBROUTINE DPDTH(DTDS,I)
      COMMON/AX/JSUBL,JSUBU
      COMMON/EF/EM(55),GAM(55),P(55),TH(55),Y(55)
      COMMON/RC/AP0,AP1,AP2
      CALL SHEAR(I,ASHEAR)
      ASH=ASHEAR
      PY=AP1+2.*AP2*(Y(I)-Y(JSUBL))
      D2=Y(I+1)-Y(I)
      D1=Y(I)-Y(I-1)
```

```
 SUM=D1+D2
 RAT1=C1/D2
 RAT2=C2/C1
 IF(I.GT.JSUBU) PY=(P(I+1)*RAT1-P(I)*(RAT1-RAT2)-P(I-1)*RAT2)/SUM
 THY=(TH(I+1)*RAT1-TH(I)*(RAT1-RAT2)-TH(I-1)*RAT2)/SUM
 DPDS    =(ASH*COS(TH(I))**2-GAM(I)*P(I)*EM(I)**2*COS(TH(I))*THY
1-SIN(TH(I))*PY)/(EM(I)**2*COS(TH(I))**2-1.)
 DPDN=PY/COS(TH(I))-TAN(TH(I))*DPDS
 GS=1./GAM(I)
 SM=1./EM(I)**2
 DTDS=-DPDN*GS/P(I)*SM
 RETURN
 END
 SUBROUTINE CPCINT
 COMMON/AL/GAR,GEW
 COMMON/BA/ALP(7,55),EMINF,WINF
 COMMON/BC/GAMB,PB,Q3,RHOB,THE,WB,XMUB,YB
 COMMON/CA/WDOTN(7,55),XN(55)
 COMMON/CJ/CP(7,55),CP1(7),CPX(55)
 COMMON/CK/WTMOLE(7)
 COMMON/DB/BETB(4),IS(4)
 COMMON/DP/YN(55)
 COMMON/EC/CPIN,PO
 COMMON/EF/EM(55),GAM(55),P(55),TH(55),Y(55)
 COMMON/EG/EIN,PR,XLE
 COMMON/EP/GAMINF,H1(7),RINF
 COMMON/GF/DELY,DVISA,KOUNTO,VISA
 COMMON/GK/DELX
 COMMON/HL/ALPHA,BETA
 COMMON/HP/ALPN(7,55),CPN(7,55),CPXN(55),EMN(55),GAMN(55),HN(7,55),
1L,PN(55),QN(55),RHON(55),RN(55),THN(55),TN(55),WN(55),XMUN(55)
 COMMON/HN/CHC(2),CPB(7),CPXP(2),DALDIF(7),DALPB(7),DDALPB(7),DELS,
AEMP(2),HB(7),HC(7),RP(2),S3A(7),S3B(7),S3D(7),WDOTB(7),XP(2)
 COMMON/PC/W(55),X(55)
 COMMON/PQ/JCHEM,NSP,T(55)
 COMMON/CA/H(7,55),Q(55),RHO(55),XMU(55)
 COMMON/CS/RHOP(2),WDOT(7,55),WDOTC(7),WP(2),XMUP(2)
 COMMON/SC/BQN(55),DALPN(7,55),DBQN(55),DCPXN(55),DDALPN(7,55),
1DTAUN(55),TAUN(55)
 COMMON/SS/AL1,AL2,BQ1,BQ2,C1,C2,CH1,CH2,DB1,DB2,DD1,DD2,DT1,DT2,DV
A1,DV2,PX1,PX2,TA1,TA2,TH1,TH2,V1,V2,Y1,Y2
 COMMON/ST/I13,IREGI,K ,KFIRST,KKKQ,PSTAR
 COMMON/TS/DVISB,DVISC,IFS,MMM,VISB,VISC
 COMMON/TU/BQ(55),DALP(7,55),DBQ(55),DCPX(55),DDALP(7,55),DTAU(55),
1TAU(55)
 COMMON/TV/ALPP(7,2),BET,BQP(2),DACHP(7,2),DALPP(7,2),DBQP(2),
1DCPXP(2),DDALPP(7,2),DTAUP(2),DTCHP(2),GAMP(2),PP(2),QP(2),
2TAUP(2),THP(2),TP(2),YP(2)
 COMMON/VT/QACH(7,55),DTCH(55),DVISD,VISD
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      COMMON/WW/ICONT,IEND,KT,THBPN,XBPN
      COMMON/WV/NPTS,RE,XBP,XJ
      DIMENSION ALPSS(7),DALPSS(7),DDALPS(7),HSS(7),CPSS(7)
      DIMENSION DUMCHP(7),DACHSS(7)
      IF(IEND.EQ.1) GO TO 601
      EM3=XM3(ALPHA,BETA,TH(K),THN(L))
      XN(L)=XBPN
      IF(IFS.EQ.1.AND.L.EQ.IS(MMM)) EM3=TAN(BETB(MMM))
      IF(IFS.EQ.2.AND.L.EQ.IS(MMM)) EM3=.5*(TAN(BETB(MMM))+TAN(BET))
      YN(L)=Y(K)+DELX*EM3
      IF(ICONT.EQ.1) GO TO 601
      KP=1
      EM2P=XM1(ALPHA,BETA,TH(KT+1),XMU(KT+1),THN(L),XMUN(L))
      EM2L=XM1(ALPHA,BETA,TH(KT),XMU(KT),THN(L),XMUN(L))
  351 EM2K=0.5*(EM2L+EM2P)
      XP(KP)=XBP
      YP(KP)=YN(L)-DELX*EM2K
      KIP2=0
      IF(YP(KP).LT.Y(KT+1)+1.E-05.AND.YP(KP).GT.Y(KT)-1.E-05) GO TO 201
 4150 FORMAT(3I5,6E13.5)
      WRITE(6,9191)
      WRITE(6,4150) KP    ,L,KT,ALPHA,YP(KP),YN(L),THN(L),XMUN(L),PN(L)
      WRITE(6,111) Y(KT),Y(K),DELX,EM2K,XBPN,TH(K),XMU(KT),XMU(KT+1),
     1DELS,THBPN,DELY,Y(KT+1)
      WRITE(6,2000)
 2000 FORMAT(97H Y LOCATION OF CHARACTERISTIC ON ORIGIONAL DATA LINE IS
     1OUTSIDE OF BOUNDING STREAMLINES IN CPOINT           )
      STOP
  201 RATB=(YP(KP)-Y(KT))/(Y(KT+1)-Y(KT))
      EM2=EM2L+RATB*(EM2P-EM2L)
      YBT=YP(KP)
      YP(KP)=YN(L)-DELX*EM2
      IF((ABS(YP(KP)-YBT)/ABS(Y(KT+1)-Y(KT))).LT.0.01)GO TO 202
      KIP2=KIP2+1
      IF(KIP2.LE.20) GO TO 201
      WRITE(6,9191)
 9191 FORMAT(1H1)
      WRITE(6,2001)
 2001 FORMAT(56H UNABLE TO LOCATE Y LOCATION OF CHARACTERISTIC IN CPOINT
     1)
      STOP
  202 RATB=(YP(KP) -Y(KT))/(Y(KT+1)-Y(KT))
      QP(KP)=Q(KT)+RATB*(Q(KT+1)-Q(KT))
      PP(KP)=P(KT)+RATB*(P(KT+1)-P(KT))
      TP(KP) =T(KT)+RATB*(T(KT+1)-T(KT))
      THP(KP)=TH(KT)+RATB*(TH(KT+1)-TH(KT))
      TAUP(KP)=TAU(KT)+RATB*(TAU(KT+1)-TAU(KT))
      BQP(KP)=BQ(KT)+RATB*(BQ(KT+1)-BQ(KT))
      DCPXP(KP)=DCPX(KT)+RATB*(DCPX(KT+1)-DCPX(KT))
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      DTAUP(KP)=DTAU(KT)+RATB*(DTAU(KT+1)-DTAU(KT))
      DBQP(KP)=DBQ(KT)+RATB*(DBQ(KT+1)-DBQ(KT))
      DTCHP(KP)=DTCH(KT)+RATB*(DTCH(KT+1)-DTCH(KT))
      CPXP(KP)=0.0
      WP(KP)=0.0
      CHC(KP)=0.
      CALL THERMO(TP(KP),HR,CPB)
      DO 4020 J=1, NSP
      ALPP(J,KP)=ALP(J, KT)+RATB*(ALP(J, KT+1)-ALP(J, KT))
      DALPP(J,KP)=DALP(J, KT)+RATB*(DALP(J, KT+1)-DALP(J, KT))
      DDALPF(J,KP)=DDALP(J, KT)+RATB*(DDALP(J, KT+1)-DDALP(J, KT))
      CHC(KP)=CHC(KP)+DALPP(J,KP)*CPB(J)
      CPXP(KP)=CPXP(KP)+ALPP(J,KP)*CPB(J)
      WP(KP)=WP(KP)+ ALPP(J,KP)/WTMOLE(J)
      DACHP(J,KP)=DACH(J,KT)+RATB*(DACH(J,KT+1)-DACH(J,KT))
      IF(KP.NE.2)GO TO 4020
      WDOTB(J)=WDOT(J,KT)+RATB*(WDOT(J,KT+1)-WDOT(J,KT))
 4020 CONTINUE
      WP(KP)=1./WP(KP)
      RP(KP)=RC/WP(KP)
      GAMP(KP)=CPXP(KP)/(CPXP(KP)-RP(KP)/CPIN)
      RK=1./RP(KP)
      RHOP(KP)=PP(KP)*WP(KP)*GEW/TP(KP)
      EMP(KP)=CP(KP)*EMINF*SQRT(GAR/GAMP(KP)*RK/TP(KP))
      XMUP(KP)=ZMU(EMP(KP))
      IF(KP.EQ.2) GO TO 601
      KP=2
      IF(IFS.EQ.0) KT=L
      EM2P=XP2(ALPHA,BETA,TH(KT+1),XMU(KT+1),THN(L),XMUN(L))
      EM2L=XP2(ALPHA,BETA,TH(KT),XMU(KT),THN(L),XMUN(L))
      GO TO 351
C     GET ALL THE PROPERTIES AT THE C POINT
  601 CONTINUE
      IF(IFS.EQ.0) GO TO 8600
      Y    SS=Y   (K)
      P    SS=P   (K)
      Q    SS=Q   (K)
      T    SS=T   (K)
      TH   SS=TH  (K)
      BQ   SS=BQ  (K)
      W    SS=W   (K)
      TAU  SS=TAU (K)
      RHO  SS=RHO (K)
      CPX  SS=CPX (K)
      DBQ  SS=DBQ (K)
      DTAUSS=DTAU(K)
      DCPXSS=DCPX(K)
      DTCHSS=DTCH(K)
      DO 1555 J=1,NSP
```

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      CPSS(J)=CP(J,K)
      HSS(J)=H(J,K)
      ALPSS(J)=ALP(J,K)
      DALPSS(J)=DALP(J,K)
      DACHSS(J)=DACH(J,K)
 1555 DDALPS(J)=DDALP(J,K)
      CALL CPCINT(K,L)
      KT=K
 8600 CONTINUE
      CH2D=0.0
      DO 4030 J=1, NSP
      CH2D=CH2C+DALP(J,K)*CP(J,K)
 4030 CONTINUE
      IF(BETA.NE.0.0)GO TO 4036
      TAUN(L)=TAU(K)
      BQN(L)=BQ(K)
      DCPXN(L)=DCPX(K)
      DTAUN(L)=DTAU(K)
      DBQN(L)=DBQ(K)
      THN(L)=TH(K)
      CPXN(L)=CPX(K)
      TN(L)=T(K)+DTCH(K)
      HN(L)=H(K)
      CH2C=CH2C
      DO 4035 J=1, NSP
      DALPN(J,L)=DALP(J,K)
      DDALPN(J,L)=DDALP(J,K)
      HC(J)=H(J,K)
      WDOTC(J)=WDOTN(J,L)
 4035 CONTINUE
 4036 CONTINUE
      IF(BETA.EQ.0.0) GO TO 302
      CH2C=0.
      DO 301 J=1,NSP
      HC(J)=HN(J,K)
      WDOTC(J)=WDOTN(J,L)
  301 CH2C=CH2C+DALPN(J,L)*CPN(J,L)
  302 CONTINUE
      V1=VISA
      V2=VISC
      DV1=DVISA
      DV2=DVISC
      TA1=TAUP(1)
      TA2=TAUN(L)
      DT1=DTAUP(1)
      DT2=DTAUN(L)
      BQ1=BQF(1)
      BQ2=BQN(L)
      Y1=YP(1)
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```
      Y2=YN(L)
      TH1=THP(1)
      TH2=THN(L)
      C1=CPXP(1)
      C2=CPXN(L)
      DB1=DBQP(1)
      DB2=DBQN(L)
      PX1=DCPXP(1)
      PX2=DCPXN(L)
      CH1=CHC(1)
      CH2=CH2C
      IF(ICONT.EQ.1) GO TO 4309
      S1A=S1(XJ,RE)
      S2A=S2(XJ,RE)
4309  V1=VISD
      DV1=DVISD
      TA1=TAU(K)
      DT1=DTAU(K)
      BQ1=BC(K)
      Y1=Y(K)
      TH1=TH(K)
      C1=CPX(K)
      DB1=DBQ(K)
      PX1=DCPX(K)
      CH1=CH2D
      S1D=S1(XJ,RE)
      S2D=S2(XJ,RE)
      IF(ICCNT.EQ.1) GO TO 6427
      IF(L.EQ.NPTS) GO TO 6427
      V1=VISB
      DV1=DVISB
      TA1=TAUP(2)
      DT1=DTAUP(2)
      BQ1=BQP(2)
      Y1=YP(2)
      TH1=THP(2)
      C1=CPXP(2)
      DB1=DBQP(2)
      PX1=DCPXP(2)
      CH1=CHC(2)
      S1B=S1(XJ,RE)
      S2B=S2(XJ,RE)
6427  CONTINUE
      S3AT=0.0
      S3BT=0.0
      S3DT=C.0
      DO 4040 J=1, NSP
      AL2=DALPN(J,L)
      DD2=DDALPN(J,L)
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```
      IF(ICCNT.EQ.1) GO TO 4311
      V1=VISA
      DV1=DVISA
      AL1=DALPP(J,1)
      DD1=DCALPF(J,1)
      BQ1=BQP(1)
      TH1=THP(1)
      Y1=YP(1)
      S3A(J)=S3(XJ,RE)
      S3AT=S3AT+S3A(J)/WTMOLE(J)
4311  AL1=DALP(J,KT)
      DD1=DCALP(J,KT)
      V1=VISC
      DV1=DVISC
      BQ1=BC(KT)
      TH1=TH(KT)
      Y1=Y(KT)
      S3D(J)=S3(XJ,RE)
      S3CT=S3CT+S3D(J)/WTMOLE(J)
      IF(ICCNT.EQ.1)GO TO 4940
      IF(L.EQ.NPTS)GO TC 4049
      V1=VISB
      DV1=DVISB
      AL1=DALPP(J,2)
      DC1=DCALFF(J,2)
      BQ1=BQP(2)
      TH1=THP(2)
      Y1=YP(2)
      S3B(J)=S3(XJ,RE)
      S3BT=S3BT+S3B(J)/WTMOLE(J)
4040  CONTINUE
      IF(ICCNT.FQ.1) GO TO 6429
      GAMB=GAMF(1)
      PB=PP(1)
      QB=QP(1)
      RHOB=RHCF(1)
      THB=THP(1)
      WB=WP(1)
      XMUB=XMUP(1)
      YB=YP(1)
      A1=F1(L)
      A2=F2(L,S1A,S2A,S3AT)
      IF(JCHEM.EQ.1) GO TO 7252
      A3=0.
      GO TO 7255
7252  DO 1712 J=1,NSP
1712  DUMCHP(J)=(DACHP(J,1)+DACH(J,K))/2.
      DTCHP(1)=(DTCHP(1)+DTCH(K))/2.
      TP1=(T(L)+TP(1)+CTCH(L))/2.
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      A3=F3(TF1,DTCHP(1),TP(1),TN(L),THP(1),THN(L),DUMCHP,WP(1),WN(L))
7255  A4=F4(BETA,1.,XMUP(1),THP(1),XMUN(L),THN(L))
      A2=(A2+A3)*A4
      IF(L.EQ.NPTS) GO TO 6429
      GAMB=GAMP(2)
      PB=PP(2)
      QB=QP(2)
      RHOB=RHOP(2)
      THB=THP(2)
      WB=WP(2)
      XMUB=XMUP(2)
      YB=YP(2)
      B1=F1(L)
      B2=F2(L,S1B,S2P,S3BT)
      IF(JCHEM.EQ.1) GO TO 7253
      B3=0.
      GO TO 7256
7253  DO 1713 J=1,NSP
1713  DUMCHP(J)=(DACHP(J,2)+DACH(J,K))/2.
      DTCHP(2)=(DTCHP(2)+DTCH(K))/2.
      TP2=(T(L)+TP(2)+DTCH(L))/2.
      B3=F3(TP2,DTCHP(2),TP(2),TN(L),THP(2),THN(L),DUMCHP,WP(2),WN(L))
7256  B4=F4(BETA,-1.,XMUP(2),THP(2),XMUN(L),THN(L))
      B2=(B2+B3)*B4
6429  CONTINUE
      IF(IEND.EQ.0) GO TO 630
      THN(L)=THBPN
      PN(L)=PP(1)+(THP(1)-THN(NPTS)-A2*(XN(NPTS)-XP(1)))/A1
      GO TO 631
 630  IF(ICCNT.EQ.0)
     1PN(L)=(A1*PP(1)+B1*PP(2)+THP(1)-THP(2)-
     2(A2+B2)*XN(L)+A2*XP(1)+B2*XP(2))/(A1+B1)
      IF(ICCNT.EQ.1)
     1PN(L)=PSTAR
      IF(ICCNT.EQ.0)
     1THN(L)=THP(1)-A1*(PN(L)-PP(1))-A2*(XN(L)-XP(1))
 631  CONTINUE
      DELS=2.*(XN(L)-X(K))/(COS(TH(K))+COS(THN(L)))
      TERM2=RHC(K)*C(K)
      IF(BETA.GT.0.)TERM2=(TERM2+RHON(L)*QN(L))*.5
      OT=1./TERM2
      QN(L)=(S1C*DELS-PN(L)+P(K))*OT+C(K)
      IF(BETA.EQ.0.0)CPXN(L)=CPX(K)
      DTCHEM=DTCH(L)+(PN(L)-P(K))*(QN(L)+Q(K))/(CPX(K)+CPXN(L))*EIN*OT
      DTDIFF=S2D*DELS*EIN*2./(CPX(K)+CPXN(L))*OT
      TN(L)=T(K)+DTCHEM+DTDIFF
      CPXN(L)=0.0
      WN(L)=0.0
      CALL THERMO(TN(L),H1,CP1)
```

```
      DO 4050 J=1, NSP
      DALDIF(J)=S3D(J)*DELS*DT
      ALPN(J, L)=ALP(J,K)            +DALDIF(J)+DACH(J,L)
      HN(J,L)=H1(J)
      CPN(J,L)=CP1(J)
      WN(L)=WN(L)+ALPN(J, L)/WTMOLE(J)
      CPXN(L)=CPXN(L)+ALPN(J, L)*CPN(J, L)
4050  CONTINUE
      WN(L)=1./WN(L)
      RN(L)=RC/WN(L)
      GAMN(L)=CPXN(L)/(CPXN(L)-RN(L)/CPIN)
      ORN=1./RN(L)
      RHON(L)=PN(L)*WN(L)*GEW/TN(L)
      EMN(L)=QN(L)*EMINF*SQRT(GAR/GAMN(L)*ORN/TN(L))
      IF(EMN(L).LT.1.0001) GO TO 900
7360  XMUN(L)=ZPU(EMN(L))
 900  CONTINUE
      IF(IFS.EQ.0) GO TO 1361
      Y    (K)=Y    SS
      P    (K)=P    SS
      Q    (K)=Q    SS
      T    (K)=T    SS
      W    (K)=W    SS
      TH   (K)=TH   SS
      BQ   (K)=BQ   SS
      TAU  (K)=TAU  SS
      DBQ  (K)=DBQ  SS
      CPX  (K)=CPX  SS
      RHO  (K)=RHO  SS
      DCPX(K)=DCPXSS
      DTAU(K)=DTAUSS
      DTCH(K)=DTCHSS
      DO 1556 J=1,NSP
      ALP(J,K)=ALPSS(J)
      DALP(J,K)=DALPSS(J)
      DACH(J,K)=DACHSS(J)
      DDALP(J,K)=DDALPS(J)
      CP(J,K)=CPSS(J)
1556  H(J,K)=HSS(J)
1361  CONTINUE
 111  FORMAT(10X,9E1 .5)
      RETURN
      END
      SUBROUTINE SPACE(ISPP)
      COMMON/AC/IBOD,PIN
      COMMON/AL/GAR,GEW
      COMMON/AX/JSUBL,JSUBU
      COMMON/BA/ALP(7,55),EMINF,WINF
      COMMON/BD/XMASS(55)
```

```
      COMMON/CA/WDOTN(7,55),XN(55)
      COMMON/CJ/CP(7,55),CP1(7),CPX(55)
      COMMON/CK/WTMOLE(7)
      COMMON/DB/BETB(4),IS(4)
      COMMON/DP/YN(55)
      COMMON/ED/GPIN,PC
      COMMON/EF/EM(55),GAM(55),P(55),TH(55),Y(55)
      COMMON/EP/GAMINF,H1(7),RINF
      COMMON/GK/DELX
      COMMON/HP/ALPN(7,55),CPN(7,55),CPXN(55),EMN(55),GAMN(55),HN(7,55),
     1L,PN(55),CN(55),RHON(55),RN(55),THN(55),TN(55),WN(55),XMUN(55)
      COMMON/PC/W(55),X(55)
      COMMON/PG/JCHEM,NSP,T(55)
      COMMON/CA/H(7,55),Q(55),RHO(55),XMU(55)
      COMMON/RC/R(55)
      COMMON/RC/AP0,AP1,AP2
      COMMON/SG/BQN(55),DALPN(7,55),DBQN(55),DCPXN(55),DDALPN(7,55),
     1DTAUN(55),TAUN(55)
      COMMON/ST/I13,IREGI,K ,KFIRST,KKKG,PSTAR
      COMMON/TU/BQ(55),CALP(7,55),DBQ(55),DCPX(55),DDALP(7,55),DTAU(55),
     1TAU(55)
      COMMON/UV/II11,IERR,IPRESS,IPRESU,ISUB
      COMMON/WV/NPTS,RE,XBP,XJ
      COMMON/WX/APRESS,APRESU
      COMMON/XY/APRS,APUS,DELTAY,EBODS,IBODS,INTACT,IPRS,IPUS,ITYP,
     1JBODS,MMAX,RHEAT,XK2,XK4,YBOT,YTP
      COMMON/YX/ABODS,BPRESS,CPRESS
      COMMON/ZY/ABOD,BBOD,CBOD,EBOD,FBOD,GBOD,IAVE,IPUNCH,JBOD,KKKKK
      DIMENSION ISN(4),XMASSN(55)
      XJ2=1.-XJ
      XJ1=1.+XJ
      DY=DELTAY
      DO 1 I=1,4
      IF(IS(I).EQ.0) GO TO 1
      N=-1
      IF((I/2)*2.EQ.I) N=1
      ISI=IS(I)
      DYS=ABS(Y(ISI+N)-Y(ISI+2*N))
      IF(DYS.LT.2.*DY) GO TO 2
C*********  ADD PT ON DOWNSTREAM SIDE OF SHOCK  *****
      ISM=IS(I)-1
      IF((I/2)*2.EQ.I) ISM=IS(I)+2
      DO 3 KK=ISM,NPTS
      K=NPTS+ISM-KK
      J=K+1
      CALL SWITCH(J,K)
    3 CONTINUE
      NPTS=NPTS+1
      ISPP=1
```

```
      IF(JSUBL.GT.IS(I)) JSUBL=JSUBL+1
      IF(JSUBU.GT.IS(I)) JSUBU=JSUBU+1
      DO 4 J=1,4
      IF(IS(J).GT.IS(I)) IS(J)=IS(J)+1
    4 CONTINUE
      IF((I/2)*2.NE.I) IS(I)=IS(I)+1
      L=ISM-1
      M=ISM+1
      K=ISM
      RAT=.5
      P     (K)=P     (L)+RAT*(P     (M)-P     (L))
      TH    (K)=TH    (L)+RAT*(TH    (M)-TH    (L))
      X     (K)=X     (L)+RAT*(X     (M)-X     (L))
      Y     (K)=Y     (L)+RAT*(Y     (M)-Y     (L))
      Q     (K)=Q     (L)+RAT*(Q     (M)-Q     (L))
      T     (K)=T     (L)+RAT*(T     (M)-T     (L))
      BQ    (K)=BQ    (L)+RAT*(BQ    (M)-BQ    (L))
      TAU   (K)=TAU   (L)+RAT*(TAU   (M)-TAU   (L))
      DBQ   (K)=DBQ   (L)+RAT*(DBQ   (M)-DBQ   (L))
      DCPX  (K)=DCPX  (L)+RAT*(DCPX  (M)-DCPX  (L))
      DTAU  (K)=DTAU  (L)+RAT*(DTAU  (M)-DTAU  (L))
      XMASS(K)=XMASS(L)+RAT*(XMASS(M)-XMASS(L))
      CPX(K)=0.
      W(K)=0.
      CALL THERMO(T(K),H1,CP1)
      DO 5 J=1,NSP
      ALP  (J,K)=ALP  (J,L)+RAT*(ALP  (J,M)-ALP  (J,L))
      DALP (J,K)=DALP (J,L)+RAT*(DALP (J,M)-DALP (J,L))
      DDALP(J,K)=DDALP(J,L)+RAT*(DDALP(J,M)-DDALP(J,L))
      H(J,K)=H1(J)
      CP(J,K)=CP1(J)
      W(K)=W(K)+ALP(J,K)/WTMOLE(J)
      CPX(K)=CPX(K)+ALP(J,K)*CP(J,K)
    5 CONTINUE
      W(K)=1./W(K)
      R(K)=RO/W(K)
      GAM(K)=CPX(K)/(CPX(K)-R(K)/CPIN)
      OR=1./R(K)
      RHO(K)=P(K)*W(K)*GEW/T(K)
      EM(K)=Q(K)*EMINF*SQRT(GAR/GAM(K)*OR/T(K))
      XMU(K)=ZMU(EM(K))
    2 CONTINUE
      YSN=Y(ISI)+TAN(BETB(I))*DELX
      IF((I/2)*2.EQ.I) GO TO 6
      J=IS(I)
      K=J+1
      EMP=XM2(1.,0.,TH(K),XMU(K),0.,0.)
      EML=XM2(1.,0.,TH(J),XMU(J),0.,0.)
      EMP1=XM1(1.,0.,TH(K),XMU(K),0.,0.)
```

```
      EML1=XM1(1.,0.,TH(J),XMU(J),0.,0.)
      GO TO 7
    6 J=IS(I)
      K=J-1
      EMP=XM1(1.,0.,TH(J),XMU(J),0.,0.)
      EML=XM1(1.,0.,TH(K),XMU(K),0.,0.)
      EMP1=XM2(1.,0.,TH(J),XMU(J),0.,0.)
      EML1=XM2(1.,0.,TH(K),XMU(K),0.,0.)
    7 EM3=XM3(1.,0.,TH(K),0.)
      YCN=Y(K)+EM3*DELX
      YCT=YCN-DELX*(EMP1+EML1)*.5
      YST=YSN-DELX*(EMP+EML)*.5
      DYT=-N*(YCT-YST)
      IF(BETB(1).EQ.0..AND.BETB(2).EQ.0..AND.BETB(3).EQ.0..AND.BETB(4).
     AEQ.0.)GO TO 777
      IF(BETB(1).GT.0..OR.BETB(3).GT.0.)777,776
  777 IF(DYT/ABS(Y(J)-Y(K)).GT..1)1,775
  776 IF(N*(YSN-YCN).GT.DY*.3)GO TO 1
      ISIMN=IS(I)-N
      IF(ISIMN.EQ.NPTS.OR.ISIMN.EQ.1)GO TO 1
C*********  SUBTRACT PT FROM FREE STREAM SIDE OF SHOCK  ****
  775 L=K+1
      DO 8 K=L,NPTS
      J=K-1
      CALL SWITCH(J,K)
    8 CONTINUE
      NPTS=NPTS-1
      ISPP=1
      IF(JSUBL.GT.IS(I)) JSUBL=JSUBL-1
      IF(JSUBU.GT.IS(I)) JSUBU=JSUBU-1
      DO 9 J=1,4
      IF(IS(J).GT.IS(I)) IS(J)=IS(J)-1
    9 CONTINUE
      IF((I/2)*2.EQ.I) IS(I)=IS(I)-1
    1 CONTINUE
      IF(ITYP.NE.1) GO TO 850
      IF(NPTS.LT.MMAX) GO TO 2121
      II11=1
      IPUNCH=1
      WRITE(6,9191)
 9191 FORMAT(1H1)
      WRITE(6,851)
  851 FORMAT(74H REQUESTED MAXIMUM NUMBER OF FLOW FIELD PTS. EXCEEDED, P
     1UNCH FILE OBTAINED/97H RESUBMIT RUN WITH REDUCED NUMBER OF FLOW FI
     1ELD PTS. OR INCREASE INPUT FOR MAXIMUM NUMBER OF PTS.)
      RETURN
  850 CONTINUE
      IF(Y(1).EQ.YBOT.OR.ITYP.EQ.4) GO TO 2100
      IPRESS=1
```

```
      APRESS=P(1)/PIN
 2100 IF(Y(NPTS).EQ.YTP.OR.ITYP.EQ.3) GO TO 2101
      IPRESU=1
      APRESU=P(NPTS)/PIN
 2101 CONTINUE
      IF(NPTS.LT.MMAX) GO TO 1000
      ISC=0
      DO 700 I=1,4
  700 IF(IS(I).NE.0) ISC=ISC+1
      IF(ITYP.NE.2.OR.ISC.NE.0.OR.ISUB.NE.3.)GO TO 701
      YQ=YTP
      IF(Y(NPTS).LE.YTP-2.*DELTAY)YQ=Y(NPTS)+DELTAY
      IK=1
      IX=1
      NP=NPTS
      IF((NPTS/2)*2.NE.NPTS) GO TO 702
  800 J=NPTS+1
      K=NPTS
      CALL SWITCH(J,K)
      Y(J)=YQ
      NPTS=NPTS+1
      YFUN=(Y(J)*(XJ2+Y(J)*XJ)-Y(K)*(XJ2+Y(K)*XJ))/XJ1
      RQAV=RHO(K)*Q(K)*COS(TH(K))
      XMASS(J)=XMASS(K)+RQAV*YFUN
      TH(NPTS)=0.
      APRESU=P(NPTS)/PIN
      GO TO (702,903),IX
  702 J=1
      DO 703 K=3,NP,2
      J=J+1
      CALL SWITCH(J,K)
  703 CONTINUE
      DELTAY=DELTAY*2.
      IF(IK.EQ.2) GO TO 704
      NPTS=NPTS/2+1
      GO TO 1000
  701 IF(ITYP.NE.3.OR.IS(3).EQ.0.OR.ISUB.NE.0.OR.ISC.NE.1) GO TO 303
      IK=2
      NP=IS(3)-1
      IF((NP/2)*2.NE.NP) GO TO 702
      IQ=1
      IF(Y(1).GE.YBOT+2.*DELTAY+1.E-03) GO TO 706
      YT=YBOT
      GO TO 707
  706 YT=Y(1)-DELTAY
  707 DO 708 KK=1,NPTS
      K=NPTS+1-KK
      J=K+1
      CALL SWITCH(J,K)
```

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OF POOR QUALITY

```
7C8 CONTINUE
    NPTS=NPTS+1
    DO 7C9 I=1,4
7C9 IF(IS(I).NE.0) IS(I)=IS(I)+1
    IF(ISUB.EC.0) GO TO 710
    JSUBL=JSUEL+1
    JSUBU=JSUBU+1
710 Y(1)=YT
    YFUN=(Y(2)*(XJ2+Y(2)*XJ)-Y(1)*(XJ2+Y(1)*XJ))/XJ1
    RQAV=RHO(2)*Q(2)*COS(TH(2))
    XMASS(1)=XMASS(2)-RQAV*YFUN
    TH(1)=0.
    APRESS=P(1)/PIN
    GO TO (711,907),IQ
711 NP=NP+1
    GC TO 7C2
7C4 ISN(3)=NF/2+2
    ID=IS(3)-ISN(3)
    ISS=IS(3)
    IS(3)=ISN(3)
    DO 705 K=ISS,NPTS
    J=K-ID
    CALL SWITCH(J,K)
7C5 CONTINUE
    NPTS=NPTS-ID
    GO TO 1000
303 ICT=ISC
    ITCP=NPTS
    IF(IS(3).NE.0) ITCP=IS(3)-1
    IBOT=1
    IF(IS(4).NE.0) IBOT=IS(4)+1
    DTY=Y(ITCP)-Y(IBCT)
    DELTAY=CTY/FLOAT((MMAX-(NPTS-ITOP)-IS(4))/2-ICT)
    IB=IBOT
    ISN(1)=IS(1)
    ISN(2)=IS(2)
    ISN(3)=IS(3)
    ISN(4)=IS(4)
    JSUBLN=JSUBL
    JSUBUN=JSUBU
    IBB=IB
    IREG=1
    IF(IS(2).EQ.0) GC TO 501
    IT=IS(2)
    GO TC 502
501 IREG=2
    IF(ISUB.EQ.0) GO TO 5C4
    IF(JSUBL.EQ.1) GO TO 503
    IT=JSUBL
```

```
      GO TO 502
  503 CONTINUE
      IB=JSUBU
      IBB=IB
  504 IREG=4
      IF(IS(1).EQ.0) GO TO 505
      IT=IS(1)-1
      GO TO 502
  505 IREG=5
      IF(IS(3).EQ.0) GO TO 506
      IT=IS(3)-1
      GO TO 502
  506 IT=NPTS
  502 MP=(Y(IT)-Y(IB))/DELTAY
      L=IB
      JZ=1
      DEL=(Y(IT)-Y(IB))/FLOAT(MP)
 5932 CONTINUE
      J=IBB
      K=IB
      X    N(J)=X     (K)
      Y    N(J)=Y     (K)
      Q    N(J)=Q     (K)
      P    N(J)=P     (K)
      T    N(J)=T     (K)
      W    N(J)=W     (K)
      R    N(J)=R     (K)
      EM   N(J)=EM    (K)
      TH   N(J)=TH    (K)
      BQ   N(J)=BQ    (K)
      TAU  N(J)=TAU   (K)
      DBQ  N(J)=DBQ   (K)
      GAM  N(J)=GAM   (K)
      RHO  N(J)=RHO   (K)
      XMU  N(J)=XMU   (K)
      CPX  N(J)=CPX   (K)
      DCPXN(J)=DCPX  (K)
      DTAUN(J)=DTAU  (K)
      XMASSN(J)=XMASS(K)
      DO3108 JJ=1,NSP
      H    N(JJ,J)=H     (JJ,K)
      CP   N(JJ,J)=CP    (JJ,K)
      ALP  N(JJ,J)=ALP   (JJ,K)
      DALPN(JJ,J)=DALP  (JJ,K)
      DDALPN(JJ,J)=DDALP(JJ,K)
 3108 CONTINUE
      GO TO (2201,2904),JZ
 2201 DO 600 KK=1,MP
      I=KK+IBB-1
```

```
      YN(I+1)=YN(I)+DEL
  602 IF(YN(I+1).GE.Y(L).AND.YN(I+1).LT.Y(L+1)) GO TO 601
      L=L+1
      GO TO 602
  601 RAT=(YN(I+1)-Y(L))/(Y(L+1)-Y(L))
      IF(IT.EQ.JSUBU) GO TO 1200
      PN(I+1)=P(L)+RAT*(P(L+1)-P(L))
      THN(I+1)=TH(L)+RAT*(TH(L+1)-TH(L))
      GO TO 1201
 1200 CONTINUE
      YY=YN(I+1)
      PN(I+1)=AP0+YY*(AP1+YY*AP2)
      THN(I+1)=0.
 1201 CONTINUE
      M=L+1
      K=I+1
      X   N(K)=X    (L)+RAT*(X    (M)-X    (L))
      Y   N(K)=Y    (L)+RAT*(Y    (M)-Y    (L))
      Q   N(K)=Q    (L)+RAT*(Q    (M)-Q    (L))
      T   N(K)=T    (L)+RAT*(T    (M)-T    (L))
      BQ  N(K)=BQ   (L)+RAT*(BQ   (M)-BQ   (L))
      TAU N(K)=TAU  (L)+RAT*(TAU  (M)-TAU  (L))
      DBQ N(K)=DBQ  (L)+RAT*(DBQ  (M)-DBQ  (L))
      DCPXN(K)=DCPX (L)+RAT*(DCPX (M)-DCPX (L))
      DTAUN(K)=DTAU (L)+RAT*(DTAU (M)-DTAU (L))
      XMASSN(K)=XMASS(L)+RAT*(XMASS(M)-XMASS(L))
      CPXN(K)=0.
      WN(K)=0.
      CALL THERMO(TN(K),H1,CP1)
      DO55 J=1,NSP
      ALP N(J,K)=ALP  (J,L)+RAT*(ALP  (J,M)-ALP  (J,L))
      DALPN(J,K)=DALP (J,L)+RAT*(DALP (J,M)-DALP (J,L))
      DDALPN(J,K)=DDALP(J,L)+RAT*(DDALP(J,M)-DDALP(J,L))
      HN(J,K)=H1(J)
      CPN(J,K)=CP1(J)
      WN(K)=WN(K)+ALPN(J,K)/WTMOLE(J)
      CPXN(K)=CPXN(K)+ALPN(J,K)*CPN(J,K)
   55 CONTINUE
      WN(K)=1./WN(K)
      RN(K)=RC/WN(K)
      GAMN(K)=CPXN(K)/(CPXN(K)-RN(K)/CPIN)
      RK=1./RN(K)
      RHCN(K)=PN(K)*WN(K)*GEW/TN(K)
      EMN(K) QN(K)*EMINF*SQRT(GAR/GAMN(K)*RK/TN(K))
      IF(EMN(K).GT.1.)
     1XMUN(K)=ZMU(EMN(K))
  600 CONTINUE
      GO TO (2200,603,604,605,606),IREG
 2200 ISN(2)=I+1
```

```
      IB=IS(2)+1
      IBB=ISN(2)+1
      GO TO 501
  603 JSUBLN=I+1
      IB=JSUBU
      JSUBUN=JSUBLN+JSUBU-JSUBL
      IBB=JSUBUN
  604 CONTINUE
      GO TO 504
  605 ISN(1)=I+2
      IB=IS(1)
      IBB=ISN(1)
      GO TO 505
  606 IF(IS(3).NE.0) ISN(3)=I+2
      IF(IS(3).EQ.0) NPTS=I+1
      NP=NPTS
      IF(IS(3).EQ.0) GO TO 2203
      ID=IS(3)-ISN(3)
      ISS=IS(3)
      DO 2304 K=ISS,NPTS
      J=K-ID
      CALL SWITCH(J,K)
 2304 CONTINUE
      NPTS=NPTS-ID
      NP=ISN(3)-1
       IF(ISUB.EQ.0) GO TO 2903
      JZ=2
      JZIO=JSUBL-1
      JZI=JSUBLN-1
 2904 JZI=JZI+1
      JZIO=JZIO+1
      IF(JZI.EQ.JSUBUN) GO TO 2903
      IBB=JZI
      IB=JZIO
      GO TO 5932
 2903 CONTINUE
 2203 DO 2204 I=IBOT,NP
      J=I
      K=I
      X     (J)=XN    (K)
      Y     (J)=YN    (K)
      Q     (J)=QN    (K)
      P     (J)=P    N(K)
      T     (J)=T    N(K)
      W     (J)=W    N(K)
      R     (J)=R    N(K)
      EM    (J)=EM   N(K)
      TH    (J)=TH   N(K)
      BQ    (J)=BQ   N(K)
```

```
      TAU   (J)=TAU N(K)
      DBQ   (J)=DBQ :(K)
      GAM   (J)=GAM N(K)
      RHO   (J)=RHO N(K)
      XMU   (J)=XMU N(K)
      CPX   (J)=CPX N(K)
      DCPX  (J)=DCPXN(K)
      DTAU  (J)=DTAUN(K)
      XMASS(J)=XMASSN(K)
      DO4108 JJ=1,NS(
      H     (JJ,J)=H    N(JJ,K)
      CP    (JJ,J)=CP   N(JJ,K)
      ALP   (JJ,J)=ALP N(JJ,K)
      DALP  (JJ,J)=DALPN(JJ,K)
      DDALP(JJ,J)=DDALPN(JJ,K)
 4108 CONTINUE
 2204 CONTINUE
      DO 607 I=1,4
  6C7 IS(I)=ISN(I)
      JSUBL=JSUBLN
      JSUBU=JSUBUN
 1000 CONTINUE
      IF(ITYP.EQ.3) GO TO 903
      IF(Y(NPTS).EQ.YTP) GO TO 903
      YQ=YTP
      IF(Y(NPTS).LE.YTP-1.*DELTAY)YQ=Y(NPTS)+DELTAY
      IX=2
      L=NPTS-1
      M=L-1
      IF(ABS(P(M)-P(L))/P(L)-.001) 9C0,900,830
  9C0 IF(ABS(Q(M)-Q(L))/Q(L)-.C01) 901,9C1,800
  901 IF(ABS(T(M)-T(L))/T(L)-.001) 902,902,800
  902 IF(ABS(ALP(5,M)-ALP(5,L))-.0G1*ALP(5,L)) 9C3,903,80C
  903 IF(Y(1).EQ.YBOT) GO TO 9C7
      IF(ITYP.EC.4) GO TO 907
      L=2
      M=3
      *Q=2
      IF(Y(*).GE.YBOT+DELTAY+1.E-03) GO TO 910
      YT=YBOT
      GO TO 912
  910 YT=Y(1)-DELTAY
  912 IF(ABS(P(M)-P(L))/P(L)-.001) 904,904,7C7
  9C4 IF(ABS(Q(M)-Q(L))/Q(L)-.001) 905,905,707
  905 IF(ABS(T(M)-T(L))/T(L)-.001) 906,906,707
  906 IF(ABS(ALP(4,M)-ALP(4,L))-.001*ALP(4,L)) 9C.,9C7,7C7
  9C7 CONTINUE
      IF(ITYP.EQ.4) GO TO 2102
      IF(Y(1).NE.YBOT) GO TO 2102
```

```
      IBCD=IBCDS
      ABOD=ABCCS
      IPRESS=IPRS
      APPESS=APRS
 2102 IF(ITYP.EQ.3) GO TO 2103
      IF(Y(NPTS).NE.YTP) GO TO 2103
      JBOD=JBCCS
      EBOD=EBCCS
      IPRESU=IPUS
      APPESU=APUS
 2103 CONTINUE
      IF(Y(1).EQ.YBOT.AND.ITYP.EQ.3) ITYP=1
      IF(Y(1).EQ.YBOT.AND.ITYP.EQ.2) ITYP=4
      IF(Y(NPTS).EQ.YTP.AND.ITYP.EQ.4) ITYP=1
      IF(Y(NPTS).EQ.YTP.AND.ITYP.EQ.2) ITYP=3
 2121 CONTINUE
      IF(ISUB.EQ.1) RETURN
      JSUBL=NPTS+1
      JSUBU=NPTS+1
      RETURN
      END
      SUBROUTINE RSET
      COMMON/AL/GAR,GEN
      COMMON/BA/ALP(7,55),EMINF,WINF
      COMMON/BC/XMASS(55)
      COMMON/CJ/CP(7,55),CP1(7),CPX(55)
      COMMON/DP/YN(55)
      COMMON/EC/CPIN,RC
      COMMON/EF/EM(55),GAM(55),P(55),TH(55),Y(55)
      COMMON/EP/GAMINF,H1(7),PINF
      COMMON/HP/ALPN(7,55),CPN(7,55),CPXN(55),EMN(55),GAMN(55),HN(7,55),
     1L,PN(55),QN(55),RHON(55),RN(55),THN(55),TN(55),WN(55),XMUN(55)
      COMMON/CR/THBP,YBP,YBPN
      COMMON/PC/W(55),X(55)
      COMMON/PG/JCHEM,NSP,T(55)
      COMMON/QA/H(7,55),Q(55),RHO(55),XMU(55)
      COMMON/RC/R(55)
      COMMON/SC/BQN(55),DALPN(7,55),DBQN(55),DCPXN(55),DDALPN(7,55),
     1DTAUN(55),TAUN(55)
      COMMON/TU/BQ(55),DALP(7,55),DBQ(55),DCPX(55),DDALP(7,55),DTAU(55),
     1TAU(55)
      COMMON/VH/ICONT,IEND,KT,THBPN,XBPN
      COMMON/WV/NPTS,RE,XBP,XJ
      DO 5110 I=1,NPTS
      TH(I)=THN(I)
      X(I)=XBPN
      Y(I)=YN(I)
      Q(I)=QN(I)
      P(I)=PN(I)
```

```
      T(I)=TN(I)
      RHO(I)=RHON(I)
      EM(I)=EMN(I)
      XMU(I)=XMUN(I)
      TAU(I)=TAUN(I)
      RQ(I)=RQN(I)
      DCPX(I)=DCPXN(I)
      DTAU(I)=DTAUN(I)
      DRQ(I)=DRQN(I)
      DO4090J=1, NSP
      ALP(J, I)=ALPN(J, I)
      DALP(J, I)=DALPN(J, I)
      DDALP(J, I)=DDALPN(J, I)
      CP(J, I)=CPN(J, I)
      H(J, I)=HN(J, I)
 4090 CONTINUE
      W(I)=WN(I)
      R(I)=RN(I)
      GAM(I)=GAMN(I)
      CPX(I)=CPXN(I)
 5110 CONTINUE
      XJ1=1.+XJ
      IF(Y(1).EQ.0.) XMASS(1)=0.
      DO 10 I=2,NPTS
      YFUN=(Y(I)*(1.-XJ+Y(I)*XJ)- Y(I-1)*(1.-XJ+Y(I-1)*XJ))/XJ1
      RQAV=(RHO(I)*Q(I)*COS(TH(I))+ RHO(I-1)*Q(I-1)*COS(TH(I-1)))/2.
      XMASS(I)=XMASS(I-1)+RQAV*YFUN
   10 CONTINUE
      DO 8409 I=1,NPTS
      CPX(I)=0.
      CALL THERMO(T(I),H1,CP1)
      DO 8410 I4=1,NSP
      CP(I4,I)=CP1(I4)
      H(I4,I)=H1(I4)
 8410 CPX(I)=CPX(I)+ALP(I4,I)*CP1(I4)
      RHO(I)=GEW*W(I)*P(I)/T(I)
      GAM(I)=CPX(I)/(CPX(I)-R(I)/CPIN)
      RI=1./R(I)
      EM(I)=Q(I)*EMINF*SQRT(GAR/GAM(I)*RI/T(I))
      IF(EM(I).LT.1.0001) GO TO 8409
      XMU(I)=ZMU(EM(I))
 8409 CONTINUE
      XBP=XBPN
      YBP=Y(NPTS)
      THBP=TH(NPTS)
      IF(YBPN.EQ.YN(NPTS)) RETURN
      YBP=YBPN
      THBP=THBPN
      RETURN
```

```
      END
      SUBROUTINE SHEAR1(CFF,VISO)
      COMMON/AC/IBOD,PIN
      COMMON/BA/ALP(7,55),EMINF,HINF
      COMMON/CJ/CP(7,55),CP1(7),CPX(55)
      COMMON/EF/EM(55),GAM(55),P(55),TH(55),Y(55)
      COMMON/PC/JCHEM,NSP,T(55)
      COMMON/QA/H(7,55),Q(55),RHO(55),XMU(55)
      COMMON/SG/BQN(55),DALPN(7,55),DBQN(55),DCPXN(55),DDALPN(7,55),
     1DTAUN(55),TAUN(55)
      COMMON/TU/BQ(55),DALP(7,55),DBQ(55),DCPX(55),DDALP(7,55),DTAU(55),
     1TAU(55)
      COMMON/WV/NPTS,RE,XBP,XJ
      DIMENSION LOCS(8)
      KKI=0
      DO 100 K=1,8
  100 LOCS(K)=0
      LAST=NPTS
      LAST1=NPTS+1
      LAST2=NPTS-1
      Y (LAST1)=2.*Y (LAST)-Y (LAST2)
      Q (LAST1)=Q (LAST2)
      T (LAST1)=T (LAST2)
      CPX (LAST1)=CPX (LAST2)
      P(LAST1)=P(LAST2)
      TH(LAST1)=TH(LAST2)
      TAU (LAST)=0.
      BQ (LAST)=0.
      DCPX (LAST)=0.
      DO 6290 J=1,NSP
      DALP (J,LAST)=0.
 6290 ALP (J,LAST1)=ALP (J,LAST2)
      DO 6292 K=2,LAST
      DELY2=Y (K+1)-Y (K)
      DELY1=Y (K)-Y (K-1)
      IF(DELY2.LT.1.E-06.OR.DELY1.LT.1.E-06) GO TO 1301
      SUM=DELY1+DELY2
      RATIO1=DELY1/DELY2
      RATIO2=DELY2/DELY1
      SU=1./SUM
      RMR=RATIO1-RATIO2
      TAU(K)=(Q(K+1)*RATIO1-Q(K)*RMR-Q(K-1)*RATIO2)*SU
      OD=1./DELY2
      DTAU(K)=2.*(Q(K+1)*DELY1*SU-Q(K)+Q(K-1)*DELY2*SU)/DELY1*OD
      BQ(K)=(T(K+1)*RATIO1-T(K)*RMR-T(K-1)*RATIO2)*SU
      DBQ(K)=2.*(T(K+1)*DELY1*SU-T(K)+T(K-1)*DELY2*SU)/DELY1*OD
      DCPX(K)=(CPX(K+1)*RATIO1-CPX(K)*RMR-CPX(K-1)*RATIO2)*SU
      DO 6291 J=1,NSP
      DALP(J,K)=(ALP(J,K+1)*RATIO1-ALP(J,K)*RMR-ALP(J,K-1)*RATIO2)*SU
```

```
      DDALP(J,K)=2.*(ALP(J,K+1)*DELY1*SU-ALP(J,K)+ALP(J,K-1)*DELY2*SU)
     1/DELY1*CD
 6291 CONTINUE
      GO TO 6292
 1301 KKI=KKI+1
      LOCS(KKI)=K
 6292 CONTINUE
      TAU (1)=0.0
      DY=Y(2)-Y(1)
      IF(IBCD.EQ.1)TAU(1)=CFF*PE*RHO(1)*Q(1)**2*.5/VISD
      BQ (1)=0.0
      DCPX (1)=0.
      DTAU (1)=(Q (2)-Q (1))*2./(Y (2)-Y (1))**2
      IF(IBCD.EQ.1) DTAU(1)=4.*(Q(2)-Q(1))/DY**2-2.*(TAU(1)+TAU(2))/DY+
     1DTAU(2)
      DBQ (1)=(T (2)-T (1))*2./(Y (2)-Y (1))**2
      IF(IBCD.EQ.1) DBQ(1)=4.*(T(2)-T(1))/DY**2-2.*BQ(2)/DY+DBQ(2)
      DO6293J=1, NSP
      DALP (J, 1)=0.0
      DDALP (J, 1)=2.*(ALP (J, 2)-ALP (J, 1))/(Y (2)-
     1Y (1))**2
      IF(IBCD.EQ.1) DDALP(J,1)=4.*(ALP(J,2)-ALP(J,1))/DY**2-2.*DALP(J,2
     1)/DY+DDALP(J,2)
 6293 CONTINUE
      DO 101 M=1,8
      IF(LOCS(M).EQ.0) GO TO 102
      K=LOCS(M)
      L=1
      IF((M/2)*2.NE.M) L=-1
      YNK=Y (K)-Y (K+L)
      BQ (K)=2.*(T (K)-T (K+L))/YNK-BQ  (K+L)
      TAU (K)=2.*(Q (K)-Q (K+L))/YNK-TAU (K+L)
      DCPX (K)=2.*(CPX (K)-CPX (K+L))/YNK-DCPX (K+L)
      DTAU (K)=2.*(TAU (K)-TAU (K+L))/YNK-DTAU (K+L)
      DBQ (K)=2.*(BQ (K)-BQ (K+L))/YNK-DBQ (K+L)
      DO 103 J=1,NSP
      DALP (J,K)=2.*(ALP (J,K)-ALP (J,K+L))/YNK-DALP (J,K+L)
  103 DDALP (J,K)=2.*(DALP (J,K)-DALP (J,K+L))/YNK-DDALP (J,K+L)
  101 CONTINUE
  102 CONTINUE
      DO 7000 I=1,LAST
      TAUN(I)=TAU(I)
      BQN(I)=BQ(I)
      DCPXN(I)=DCPX(I)
      DTAUN(I)=DTAU(I)
      DBQN(I)=DBQ(I)
      DO 7001 J=1,NSP
      DALPN(J,I)=DALP(J,I)
 7001 DDALPN(J,I)=DDALP(J,I)
```

```
7000 CONTINUE
     NPTS=LAST
     RETURN
     END
     SUBROUTINE SHEAR2(CFF,VISD)
     COMMON/AC/IBOD,PIN
     COMMON/DF/YN(55)
     COMMON/HP/ALPN(7,55),CPN(7,55),CPXN(55),EMN(55),GAMN(55),HN(7,55),
    1LS,PN(55),QN(55),RHON(55),RN(55),THN(55),TN(55),WN(55),XMUN(55)
     COMMON/PG/JCHEM,NSP,T(55)
     COMMON/SQ/BQN(55),DALPN(7,55),DBQN(55),DCPXN(55),DDALPN(7,55),
    1DTAUN(55),TAUN(55)
     COMMON/WV/NPTS,RE,XBP,XJ
     DIMENSION LOCS(8)
     KKI=0
     DO 100 K=1,8
 100 LOCS(K)=0
     LAST=NPTS
     LAST1=NPTS+1
     LAST2=NPTS-1
     YN(LAST1)=2.*YN(LAST)-YN(LAST2)
     QN(LAST1)=QN(LAST2)
     TN(LAST1)=TN(LAST2)
     CPXN(LAST1)=CPXN(LAST2)
     PN(LAST1)=PN(LAST2)
     THN(LAST1)=THN(LAST2)
     TAUN(LAST)=0.
     BQN(LAST)=0.
     DCPXN(LAST)=0.
     DO 3001 J=1,NSP
     DALPN(J,LAST)=0.
3001 ALPN(J,LAST1)=ALPN(J,LAST2)
     DO 6002 K=2,LAST
     DELY2=YN(K+1)-YN(K)
     DELY1=YN(K)-YN(K-1)
     IF(DELY2.LT.1.E-06.OR.DELY1.LT.1.E-06) GO TO 1301
     SUM=DELY1+DELY2
     RATIO1=DELY1/DELY2
     RATIO2=DELY2/DELY1
     SU=1./SUM
     OD=1./DELY2
     RMR=RATIO1-RATIO2
     TAUN(K)=(QN(K+1)*RATIO1-QN(K)*RMR-QN(K-1)*RATIO2)*SU
     DTAUN(K)=2.*(QN(K+1)*DELY1*SU-QN(K)+QN(K-1)*DELY2*SU)/DELY1*OD
     BQN(K)=(TN(K+1)*RATIO1-TN(K)*RMR-TN(K-1)*RATIO2)*SU
     DBQN(K)=2.*(TN(K+1)*DELY1*SU-TN(K)+TN(K-1)*DELY2*SU)/DELY1*OD
     DCPXN(K)=(CPXN(K+1)*RATIO1-CPXN(K)*RMR-CPXN(K-1)*RATIO2)*SU
     DO 4001 J=1,NSP
     DALPN(J,K)=(ALPN(J,K+1)*RATIO1-ALPN(J,K)*RMR-ALPN(J,K-1)*RATIO2)
```

```
     1*SU
     DDALPN(J,K)=2.*(ALPN(J,K+1)*DELY1*SU-ALPN(J,K)+ALPN(J,K-1)*DELY2
     1*SU)/DELY1*DD
4081 CONTINUE
     GO TO 6002
1301 KKI=KKI+1
     LOCS(KKI)=K
6002 CONTINUE
     TAUN(1)=0.0
     DY=YN(2)-YN(1)
     IF(IBCD.EQ.1)TAUN(1)=CFF*PE*RHON(1)*QN(1)**2*.5/VISD
     BQN(1)=0.0
     DCPXN(1)=0.
     DTAUN(1)=(QN(2)-QN(1))*2./(YN(2)-YN(1))**2
     IF(IBCD.EQ.1) DTAUN(1)=4.*(QN(2)-QN(1))/DY**2-2.*(TAUN(1)+TAUN(2)
     1)/DY+DTAUN(2)
     DBQN(1)=(TN(2)-TN(1))*2./(YN(2)-YN(1))**2
     IF(IBOD.EQ.1) DBQN(1)=4.*(TN(2)-TN(1))/DY**2-2.*BQN(2)/DY+DBQN(2)
     DO4082J=1, NSP
     DALPN(J, 1)=0.0
     DDALPN(J, 1)=2.*(ALPN(J, 2)-ALPN(J, 1))/(YN(2)-
     1YN(1))**2
     IF(IBCD.EC.1) DDALPN(J,1)=4.*(ALPN(J,2)-ALPN(J,1))/DY**2-2.*DALPN
     1(J,2)/DY+DDALPN(J,2)
4082 CONTINUE
     DO 101 M=1,8
     IF(LOCS(M).EQ.0) GO TO 102
     K=LOCS(M)
     L=1
     IF((M/2)*2.NE.M) L=-1
     YNK=YN(K)-YN(K+L)
     BQN(K)=2.*(TN(K)-TN(K+L))/YNK-BQ N(K+L)
     TAUN(K)=2.*(QN(K)-QN(K+L))/YNK-TAUN(K+L)
     DCPXN(K)=2.*(CPXN(K)-CPXN(K+L))/YNK-DCPXN(K+L)
     DTAUN(K)=2.*(TAUN(K)-TAUN(K+L))/YNK-DTAUN(K+L)
     DBQN(K)=2.*(BQN(K)-BQN(K+L))/YNK-DBQN(K+L)
     DO 103 J=1,NSP
     DALPN(J,K)=2.*(ALPN(J,K)-ALPN(J,K+L))/YNK-DALPN(J,K+L)
 103 DDALPN(J,K)=2.*(DALPN(J,K)-DALPN(J,K+L))/YNK-DDALPN(J,K+L)
 101 CONTINUE
 102 CONTINUE
     NPTS=LAST
     RETURN
     END
     SUBROUTINE LPOINT(I,OPTP)
     COMMON/AB/EPP,EPQ,EPT
     COMMON/AC/IBOD,PIN
     COMMON/AL/GAR,GEW
     COMMON/BA/ALP(7,55),EMINF,WINF
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      COMMON/BB/S1B,S2B,S3BT
      COMMON/BC/GAMB,PB,QB,RHCB,THB,WB,XMUB,YB
      COMMON/CA/WDOTN(7,55),XN(55)
      COMMON/CJ/CP(7,55),CP1(7),CPX(55)
      COMMON/CK/WTMOLE(7)
      COMMON/DP/YN(55)
      COMMON/EC/CPIN,RO
      COMMON/EF/EM(55),GAM(55),P(55),TH(55),Y(55)
      COMMON/EG/EIN,PR,XLE
      COMMON/EF/GAMINF,H1(7),PINF
      COMMON/FE/DFL
      COMMON/GK/DELX
      COMMON/HL/ALPHA,BETA
      COMMON/HM/ALPN(7,55),CPN(7,55),CPXN(55),EMN(55),GAMN(55),HN(7,55),
     1LS,PN(55),QN(55),RHON(55),RN(55),THN(55),TN(55),WN(55),XMUN(55)
      COMMON/HN/CHC(2),CPB(7),CPXP(2),DALDIF(7),DALPB(7),DDALPB(7),DELS,
     AEMP(2),HB(7),HC(7),RP(2),S3A(7),S3B(7),S3D(7),WDOTB(7),XP(2)
      COMMON/CF/ALPB(7),PHI(55)
      COMMON/PC/W(55),X(55)
      COMMON/PC/JCHEM,NSP,T(55)
      COMMON/QA/H(7,55),Q(55),RHO(55),XMU(55)
      COMMON/CS/RHOP(2),WDOT(7,55),WDOTC(7),WP(2),XMUP(2)
      COMMON/SG/BQN(55),DALPN(7,55),DBQN(55),DCPXN(55),DDALPN(7,55),
     1DTAUN(55),TAUN(55)
      COMMON/SS/AL1,AL2,BQ1,BQ2,C1,C2,CH1,CH2,DB1,DB2,DD1,DD2,DT1,DT2,DV
     A1,DV2,PX1,PX2,TA1,TA2,TH1,TH2,V1,V2,Y1,Y2
      COMMON/TS/DVISB,DVISC,IFS,MMM,VISB,VISC
      COMMON/TU/BQ(55),DALP(7,55),DBQ(55),DCPX(55),DDALP(7,55),DTAU(55),
     1TAU(55)
      COMMON/TV/ALPP(7,2),BET,BQP(2),CACHP(7,2),DALPP(7,2),DBQP(2),
     1DCPXP(2),DDALPP(7,2),DTAUP(2),DTCHP(2),GAMP(2),PP(2),QP(2),
     2TAUP(2),THP(2),TP(2),YP(2)
      COMMON/UV/III1,IERR,IPRESS,IPRESU,ISUB
      COMMON/VT/DACH(7,55),DTCH(55),DVISO,VISC
      COMMON/WV/NPTS,RE,XBP,XJ
      DIMENSION DACHB(7)
      KPRESS=0
      L=I
      K=I+1
      IF(OPTP.EQ.C.) GO TO 2000
      K=I-1
      IF(IFS.NE.2) GO TO 8500
      IF((MMM/2)*2.NE.MMM) GO TO 8500
      EM1R=XM2(ALPHA,BETA,TH(I   ),XMU(I   ),THN(I  ),XMUN(I  ))
      EM1L=XM2(ALPHA,BETA,TH(K   ),XMU(K   ),THN(I  ),XMUN(I  ))
      GO TO 8501
 8500 CONTINUE
      EM1R=XM1(ALPHA,BETA,TH(I),XMU(I),THN(I),XMUN(I))
      EM1L=XM1(ALPHA,BETA,TH(K),XMU(K),THN(I),XMUN(I))
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8501 CONTINUE
2000 CONTINUE
     YB=(Y(K)+Y(I))/2.
     KIP4=0
8372 CONTINUE
     RATG=(YB-Y(I))/(Y(K)-Y(I))
     THB=TH(I)+RATG*(TH(K)-TH(I))
     XMUB=XMU(I)+RATG*(XMU(K)-XMU(I))
     EM2=XM2(ALPHA,BETA,THB,XMUB,THN(I),XMUN(I))
     IF(OPTP.NE.".) EM2=EM1L+RATG*(EM1R-EM1L)
     YBT=YB
     XB=XBF
     YB=YN(I)-EM2*DELX
     TESTY=(YB-YBT)/(Y(K)-Y(I))
     IF(ABS(TESTY).LT.0.J1) GO ~  4371
     KIP4=KIP4+1
     IF(KIP4.LE.20) GO TO 8372
     WRITE(6,9191)
9191 FORMAT(1H1)
     WRITE(6,2020)
2020 FORMAT(56H UNABLE TO LOCATE Y LOCATION OF CHARACTERISTIC IN LPOINT
    1)
     STOP
8371 RATG=(YB-Y(I))/(Y(K)-Y(I))
  51 THB=TH(I)+RATG*(TH(K)-TH(I))
     QB=Q(I)+RATG*(Q(K)-Q(I))
     PB=P(I)+RATG*(P(K)-P(I))
     TT=T(I)+RATG*(T(K)-T(I))
     TAUB=TAU(I)+RATG*(TAU(K)-TAU(I))
     BQB=BQ(I)+RATG*(BQ(K)-BQ(I))
     DCPXB=DCPX(I)+RATG*(DCPX(K)-DCPX(I))
     DTAUB=DTAU(I)+RATG*(DTAU(K)-DTAU(I))
     DBQB=DBQ(I)+RATG*(DBQ(K)-DBQ(I))
     DTCHP(1)=DTCH(I)+RATG*(DTCH(K)-DTCH(I))
     DTCHB=(DTCHP(1)+DTCH(I))*.5
     CPXB=C.0
     WB=0.C
     CH20=C.
     CH2B=C.C
     CALL THERMO(TT,HB,CPB)
     DO4060J=1, NSP
     ALPB(J)=ALP(J, I)+RATG*(ALP(J,K)-ALP(J, I))
     DALPB(J)=DALP(J,I)+RATG*(DALP(J,K)-DALP(J,I))
     DDALPB(J)=DDALP(J,I)+RATG*(DDALP(J,K)-DDALP(J,I))
     CH20=CH2C+DALP(J, I)*CP(J, I)
     CH2B=CH2B+DALPB(J)*CPB(J)
     CPXB=CPXB+ALPB(J)*CPB(J)
     WB=WB+ALPB(J)/WTMOLE(J)
     WDOTB(J)=WDOT(J,I)+RATG*(WDOT (J,K)-WDOT(J,I))
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      DACHH=D.CH(J,I)+RATG*(DACH(J,K)-DACH(J,I))
      DACHB(J)=(DACHN+DACH(J,I))*.5
      DACHP(J,1)=DACHH
 4060 CONTINUE
      WB=1./WB
      RB=RO/WB
      GAMB=CPXB/(CPXB-RB/CPIN)
      OR=1./RB
      RHOB=PB*WB*GEW/TT
      EMB=QB*EPINF*SQRT(GAR/GAMB*OR/TT)
      XMUB=ZMU(EMB)
      IF(DEL.EQ.0.) GO TO 8392
      Y    P(1)=Y    B
      X    P(1)=X    B
      Q    P(1)=Q    B
      P    P(1)=P    B
      T    P(1)=TT
      W    P(1)=W    B
      R    P(1)=R    B
      TH   P(1)=TH   B
      EM   P(1)=EM   B
      BQ   P(1)=BQ   B
      RHO  P(1)=RHO  B
      XMU  P(1)=XMU  B
      CPX  P(1)=CPX  B
      GAM  P(1)=GAM  B
      TAU  P(1)=TAU  B
      DBQ  P(1)=DBQ  B
      DTAUP(1)=DTAUB
      DCPXP(1)=CCPXB
      DO 3939 J=1,NSP
      ALP  P(J,1)=ALP  B(J)
      DALP P(J,1)=DALP B(J)
 3939 DDALPP(J,1)=DDALPB(J)
 8392 CONTINUE
      IF(BETA.NE.0.0)GOTO4070
      TAUN(I)=TAU(I)
      BQN(I)=BQ(I)
      DCPXN(I)=DCPX(I)
      DTAUN(I)=DTAU(I)
      TN(I)=T(I)+DTCH(I)
      WN(I)=W(I)
      DBQN(I)=CBQ(I)
      CPXN(I)=CPX(I)
      CH2C=CH2D
      DO4071J=1, NSP
      DALPN(J, L)=DALP(J,I)
      DDALPN(J, L)=DDALP(J,I)
      HC(J)=H(J,I)
```

```
      WDOTC(J)=WDOTN(J,I)
 4071 CONTINUE
 4070 CONTINUE
      IF(BETA.EQ.0.0) GO TO 4072
      CH2C=0.0
      DO 4073 J=1,NSP
      HC(J)=HN(J,I)
      WDOTC(J)=WDOTN(J,I)
 4073 CH2C=CH2C+DALPN(J,I)*CPN(J,I)
 4072 CONTINUE
      V1=VISB
      V2=VISC
      DV1=DVISB
      DV2=DVISC
      TA1=TAUB
      TA2=TAUN(I)
      DT1=DTAUB
      DT2=DTAUN(I)
      BQ1=BQB
      BQ2=BQN(I)
      Y1=YB
      Y2=YN(I)
      TH1=THB
      TH2=THN(I)
      S1B=S1(XJ,RE)
      C1=CPXB
      C2=CPXN(I)
      DB1=DBQB
      DB2=DBQN(I)
      PX1=DCPXB
      PX2=DCPXN(I)
      CH1=CH2B
      CH2=CH2C
      IF(DEL.EQ.0.)1,2
    1 S2B=S2(XJ,RE)
      V1=VISD
      DV1=DVISD
      TA1=TAU(I)
      DT1=DTAU(I)
      BQ1=BQ(I)
      Y1=Y(I)
      TH1=TH(I)
      S1D=S1(XJ,RE)
      GO TO 56
    2 S2B=S2(XJ,RE)
   56 IF(DEL.EQ.0.)3,4
    3 V1=VISD
      DV1=DVISD
      C1=CPX(I)
```

```
      BQ1=BC(I)
      DB1=DEQ(I)
      TA1=TAU(I)
      TH1=TH(I)
      Y1=Y(I)
      PX1=DCPX(I)
      CH1=CH2D
      S20=S2(XJ,RE)
    4 S3BT=0.
      S3DT=C.0
      DO4075J=1, NSP
      AL1=DALPB(J)
      AL2=DALPN(J,L)
      DD1=DDALPB(J)
      DD2=DDALPN(J,L)
      V1=VISB
      DV1=DVISB
      BQ1=BQB
      TH1=THB
      Y1=YB
      S3B(J)=S3(XJ,RE)
      IF(DEL.EQ.0.)5,8
    5 V1=VISD
      DV1=DVISD
      AL1=DALP(J,I)
      DD1=DDALP(J,I)
      BQ1=BC(I)
      TH1=TH(I)
      Y1=Y(I)
      S3D(J)=S3(XJ,RE)
      S3DT=S3DT+S3D(J)/WTMOLE(J)
    8 S3BT=S3BT+S3B(J)/WTMOLE(J)
 4075 CONTINUE
      IF(DEL.NE.0.) RETURN
      B1=F1(I)
      DUM=XJ
      I15=0
      YAX=YB*YN(I)
      IF(YAX.LT.1.E-06.AND.XJ.NE.0.) I15=1
      XX=XJ
      IF(I15.EQ.1)60,61
   60 XJ=0.
   61 B2=F2(I,S1B,S2B,S3BT)
      XJ=XX
      IF(JCHEM.EQ.1) GO TO 7254
      B3=0.
      GO TO 7257
 7254 TP1=(T(I)+DTCH(I)+TT)/2.
      B3=F3(TP1,DTCHB,TT,TN(I),THB,THN(I),DACHB,WB,WN(I))
```

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7257 OPTT=1.
     IF(OPTP.NE.0.) OPTT=-1.
     B4=F4(BETA,-OPTT,XMUB,THB,XMUN(I),THN(I))
     B2=(B2+B3)*B4
     IF(OPTP.NE.0..AND.IPRES U.EQ.0) GO TO 7444
     IF(OPTP.NE.0..AND.IPRES U.EQ.1) GO TO 7482
     IF(IBCD.EC.1) GO TO 7444
     IF(IPRESS.EQ.1) GO TO 7482
     AX=1.
     IF(I15.EC.0) GO TO 100
     AX=XJ*SIN(XMUB)/SIN(THB-XMUB)
     IF(BETA.GT.0.0)AX=(AX+XJ*SIN(XMUN(I))
    1/SIN(THN(I)-XMUN(I)))*.5
     AX=1.-AX
 100 CONTINUE
     PN(I)=PB-(THB*AX+B2*(XN(I)-XB))/B1
     GO TO 7445
7482 CONTINUE
     KPRESS=KPRESS+1
     IF(KPRESS.LT.6) GO TO 3232
     IERR=7482
     WRITE(6,3131) IERR,I,THN(I),PN(I),YN(I),THB,PB,YB
3131 FORMAT(2I5,6F13.5)
     STOP
3232 THDUM=THN(I)
     KIP4=0
     THN(I)=THB+OPTT*B1*(PN(I)-PB)+OPTT*B2*(XN(I)-XB)
     IF(ABS(THN(I)-THDUM).GT.1.E-04) GO TO 8372
     YN(I)=Y(I)+.5*(TAN(TH(I))+TAN(THN(I)))*DELX
     GO TO 7445
7444 PN(I)=PB+OPTT*(THN(I)-THB)/B1-B2/B1*(XN(I)-XB)
7445 CONTINUE
     IF(ABS(PN(L)-P(L)).LE.EPP) PN(L)=P(L)
     DELS=2.*(XN(I)-X(I))/(COS(TH(I))+COS(THN(I)))
     TERM2=RHO(I)*Q(I)
     IF(BETA.GT.0.0)TERM2=(TERM2+RHON(I)
    1*QN(I))*.5
     OT=1./TERM2
     QN(I)=(S1C*DELS-PN(I)+P(I))*OT+Q(I)
     IF(ABS(QN(L)-Q(L)).LE.EPQ) QN(L)=Q(L)
     IF(BETA.EC.0.0)CPXN(I)=CPX(I)
     DTCHEM=DTCH(I)+(PN(I)-P(I))*(QN(I)+Q(I))/(CPX(I)+CPXN(I))*EIN*OT
     DTDIFF=S2C*DELS*EIN*2./(CPX(I)+CPXN(I))*OT
     TN(I)=T(I)+DTCHEM+DTDIFF
     IF(ABS(TN(L)-T(L)).LE.EPT) TN(L)=T(L)
     CPXN(I)=0.0
     WN(I)=0.0
     CALL THERMO(TN(I),H1,CP1)
     DO4080J=1,NSP
```

```
      DALDIF(J)=S3D(J)*DELS/TERM2
      ALPN(J,I)=ALP(J,I)          +DALDIF(J)+DACH(J,I)
      HN(J,I)=H1(J)
      CPN(J,I)=CP1(J)
      WN(I)=WN(I)+ALPN(J, I)/WTMOLE(J)
      CPXN(I)=CPXN(I)+ALPN(J, I)*CPN(J, I)
 4080 CONTINUE
      WN(I)=1./WN(I)
      RN(I)=RC/WN(I)
      GAMN(I)=CPXN(I)/(CPXN(I)-RN(I)/CPIN)
      OR=1./RN(I)
      RHON(I)=PN(I)*WN(I)*GEW/TN(I)
      EMN(I)=QN(I)*EMINF*SQRT(GAR/GAMN(I)*OR/TN(I))
      XMUN(I)=ZMU(EMN(I))
      RETURN
      END
      FUNCTION DERY(X1,X2,X3)
      COMMON/QR/DEL1,DEL2,RAT1,RAT2,SUM
      DERY=(X1*RAT1-X2*(RAT1-RAT2)-X3*RAT2)/SUM
      RETURN
      END
      SUBROUTINE THSSS(THSS)
      COMMON/AX/JSUBL,JSUBU
      COMMON/EF/EM(55),GAM(55),P(55),TH(55),Y(55)
      COMMON/CR/DEL1,DEL2,RAT1,RAT2,SUM
      COMMON/RS/GPMS,PS,THS,THSL,THSU
      JSUBP=JSUBU+1
      JSUBM=JSUBU-1
      CALL  SHEAR(JSUBP,ASH1)
      CALL  SHEAR(JSUBU,ASH2)
      CALL  SHEAR(JSUBM,ASH3)
      EMS=0.
      DEL2=Y(JSUBP)-Y(JSUBU)
      DEL1=Y(JSUBU)-Y(JSUBM)
      SUM=DEL2+DEL1
      RAT1=DEL1/DEL2
      RAT2=DEL2/DEL1
      AY=DERY(ASH1,ASH2,ASH3)
      COSTH=COS(TH(JSUBU))
      TERM1=-AY*COSTH
      EMY=DERY(EM(JSUBP),EM(JSUBU),EM(JSUBM))
      TANTH=TAN(TH(JSUBU))
      EMNN=EMY/COSTH-EMS*TANTH
      GPM=GAM(JSUBU)*P(JSUBU)*EM(JSUBU)**2
      TERM2=2.*COSTH*EM(JSUBU)*EMNN*PS
      GPMY=DERY(GAM(JSUBP)*P(JSUBP)*EM(JSUBP)**2,GPM,GAM(JSUBM)*P(JSUBM)
     1*EM(JSUBM)**2)
      GPMN=GPMY/COSTH-GPMS*TANTH
      THY=DERY(TH(JSUBP),TH(JSUBU),TH(JSUBM))
```

```
      THNN=THY/COSTH-THS*TANTH
      TERM3=GPMN*COSTH*THNN
      TERM4=-GPMS*COSTH*COSTH*(EM(JSUBU)**2-1.)*THS
      THSY=DERY(THSU,THS,THSL)
      TERM5=GPM*SIN(TH(JSUBU))*THSY
      THYP=DERY(TH(JSUBP+1),TH(JSUBP),TH(JSUBU))
      THYL=DERY(TH(JSUBU),TH(JSUBM),TH(JSUBM-1))
      THNNP=THYP/COSTH-THSU*TANTH
      THNNL=THYL/COSTH-THSL*TANTH
      THNY=DERY(THNNP,THNN,THNNL)
      TERM6=-GPM*COSTH*THNY
      D=GPM*(EM(JSUBU)**2*COSTH*COSTH-1.)
      XNUM=TERM1+TERM2+TERM3+TERM4+TERM5+TERM6
      THSS=XNUM/D
      RETURN
      END
      FUNCTION ZMU(EM)
      ZMU=ATAN(1.0/SQRT(EM*EM-1.0))
      RETURN
      END
      SUBROUTINE THERMC(TI,H,CB)
      COMMON/EC/CPIN,RO
      COMMON/HK/RCO2,RH2O,WFUEL
      COMMON/TW/TIN
      DIMENSION WTMOLE(9)
      DIMENSION H(7),CB(7)
      DIMENSION Q(9),AP(9)
      WTMOLE(1)=1.008
      WTMOLE(2)=16.0
      WTMOLE(3)=18.016
      WTMOLE(4)=2.016
      WTMOLE(5)=32.0
      WTMOLE(6)=17.008
      WTMOLE(7)=28.014
      WTMOLE(8)=44.011
      WTMOLE(9)=WFUEL
      T=TI*TIN
      C1=RO/CPIN
      C2=C1/TIN
      DO 10 J=1,9
      H1=C2/WTMOLE(J)
      H2=C1/WTMOLE(J)
      CALL COEFF(J,T,A,B,C,D,E,F,G)
      Q(J)=T*(A+T*(B*.5+T*(C/3.+T*(D*.25+E*.2*T))))+F
      Q(J)=Q(J)*H1
      AP(J)=A+T*(B+T*(C+T*(D+E*T)))
      AP(J)=AP(J)*H2
   10 CONTINUE
      H(1)=Q(1)
```

```
      H(2)=C(2)
      H(3)=RH2O  (3)+RCO2*Q(8)
      H(4)=Q(4)
      H(5)=Q(5)
      H(6)=Q(6)
      H(7)=Q(7)
      CB(1)=AP(1)
      CB(2)=AP(2)
      CB(3)=RH2O*AP(3)+RCO2*AP(8)
      CB(4)=AP(4)
      CB(5)=AP(5)
      CB(6)=AP(6)
      CB(7)=AP(7)
      RETURN
      END
      SUBROUTINE TBL(TX,TEMPY,X,Y,N)
      DIMENSION X(1),Y(1)
      DO 10 J5=1,N
      IF(TX-X(J5)) 8,9,10
    8 J6=J5-1
      TEMPY=Y(J6)+(Y(J5)-Y(J6))*(TX-X(J6))/(X(J5)-X(J6))
      GO TO 11
    9 TEMPY=Y(J5)
      GO TO 11
   10 CONTINUE
   11 RETURN
      END
      FUNCTION XM1(ALPHA,BETA,TA,XA,TC,XC)
      XM1=ALPHA*TAN(TA+XA)
      IF(BETA.GT.0.)XM1=XM1+BETA*TAN(TC+XC)
      RETURN
      END
      FUNCTION XM2(AL,B,TA,XA,TC,XC)
      XM2=AL*TAN(TA-XA)
      IF(B.GT.0.)XM2=XM2+B*TAN(TC-XC)
      RETURN
      END
      FUNCTION XM3(A,B,TD,TC)
      XM3=A*TAN(TD)
      IF(B.GT.0.0)XM3=XM3+B*TAN(TC)
      RETURN
      END
      SUBROUTINE HOCUS(TI,P1,U1,RHO1,ALPHA,DX,L)
      COMMON/AC/IBOD,PIN
      COMMON/BC/IOCHEM
      COMMON/CA/WDOTN(7,55),XN(55)
      COMMON/GE/RAD,ROO,UIN,VISINF
       COMMON/HI/DALCH(7),DTCHEM
      COMMON/PC/ALPHN(7),IFULL,PRES
```

```
      COMMON/QS/RHOP(2),WDOT(7,55),WDOTC(7),WP(2),XMUP(2)
      COMMON/TK/TIN
      DIMENSION ASAVE(7),WTMOLE(7),ALPHA(7)
      WTMOLE(1)=1.008
      WTMOLE(2)=16.
      WTMOLE(3)=18.016
      WTMOLE(4)=2.016
      WTMOLE(5)=32.0
      WTMOLE(6)=17.008
      WTMOLE(7)=28.014
      TXX=TI
      PXX=P1
      UXX=U1
      TERM=RHO1*U1
      TI=TI*TIN*.001
      P1=P1/FIN*PRES/2116.
      U1=U1*UIN
      DELTAT=4.E-7
      DELTAX=U1*DELTAT
      JER=INT(DX/DELTAX)
      IF (JER.EQ.0) JER=1
      DELX=DX/FLOAT(JER)
      TSAVE=TI
      DO 201 J=1,7
  201 ASAVE(J)=ALPHA(J)
      DT=DELX/U1
      P=P1
      OP=2116./89517.
      RH=P*CP/TI*.001
      DO 10 JERRY=1,JER
      P=P1
      DUM=0.0
      DO 96 J=1,7
96    DUM=DUM+ASAVE(J)/WTMOLE(J)
      RHOI=RH/DUM
        IF(ICCHEM.EQ.0)
     1WRITE(6,250) TI,P,RHOI,ASAVE,DT,TN,ALPHN
  250 FORMAT(* FOCUS FROM HOCUS*,10E11.3/17X,10E11.3/)
      CALL FOCUS(TI,P,RHOI,ASAVE,DT,TN)
        IF(ICCHEM.EQ.0)
     1WRITE(6,250) TI,P,RHOI,ASAVE,DT,TN,ALPHN
        IF(ICCHEM.EQ.0)
     1WRITE(6,232)
  232 FORMAT(//)
      IF(JERRY.NE.1) GO TO 100
      DO 110 J=1,7
  110 WDOT(J,L)=TERM*(ALPHN(J)-ASAVE(J))/DELX
  100 CONTINUE
      IF(JERRY.EQ.JER)GO TO 10
```

```
      TI=TN
      DO 20 J=1,7
20    ASAVE(J)=ALPHN(J)
10    CONTINUE
      DTCHEM=(TN-TSAVE)*1000./TIN
      DO 40 J=1,7
      DALCH(J)=ALPHN(J)-ALPHA(J)
   40 WDOTN(J,L)=TERM*(ALPHN(J)-ASAVE(J))/DELX
      TI=TXX
      P1=PXX
      U1=UXX
      RETURN
      END
      SUBROUTINE COEFF(I,T,A   ,B   ,C   ,D   ,E   ,F   ,G   )
      IF(T-1000)10,10,20
   10 GO TO (15,16,13,11,12,17,14,18,19),I
   11 A   = 2.8460849E 00
      B   = 4.1932116E-03
      C   =-9.6119332E-06
      D   = 9.5122662E-09
      E   =-3.3093421E-12
      F   =-9.6725372E 02
      G   =-1.4117850E 00
      GO TO 40
   12 A   = 3.7189946E 00
      B   =-2.5167288E-03
      C   = 8.5837353E-06
      D   =-8.2998716E-09
      E   = 2.7082180E-12
      F   =-1.0576766E 03
      G   = 3.9080704E 00
      GO TO 40
   13 A   = 4.1565016E 00
      B   =-1.7244334E-03
      C   = 5.6982316E-06
      D   =-4.5930044E-09
      E   = 1.4233654E-12
      F   =-3.0288770E 04
      G   =-6.8616246E-01
      GO TO 40
   14 A   = 3.6916148E 00
      B   =-1.3332552E-03
      C   = 2.6503100E-06
      D   =-9.7688341E-10
      E   =-9.9772234E-14
      F   =-1.0628336E 03
      G   = 2.2874980E 00
      GO TO 40
   15 A   = 2.5000000E 00
```

```
      B    = 0.0
      C    = 0.0
      D    = 0.0
      E    = 0.0
      F    = 2.5470497E 04
      G    =-4.6001096E-01
      GO TO 40
   16 A    = 3.0218894E 00
      B    =-2.1737249E-03
      C    = 3.7542203E-06
      D    =-2.9947200E-09
      E    = 9.0777547E-13
      F    = 2.9137190E 04
      G    = 2.6460076E 00
      GO TO 40
   17 A    = 3.8234708E 00
      B    =-1.1187229E-03
      C    = 1.2466819E-06
      D    =-2.1035896E-10
      E    =-5.2546551E-14
      F    = 3.5852787E 03
      G    = 5.8253029E-01
      GO TO 40
   18 A=2.1701
      B=1.0378E-02
      C=-1.07339E-05
      D=6.34592E-09
      E=-1.62807E-12
      F=-4.83526E+04
      G=10.6644
      GO TO 40
   19 A=2.49125
      B=7.64362E-03
      C=7.97754E-06
      D=-1.29578E-08
      E=5.03078E-12
      F=-5421.86
      G=0.
      GO TO 40
   20 GO TO (25,26,23,21,22,27,24,28,29),I
   21 A    = 3.0436897E 00
      B    = 6.1187110E-04
      C    =-7.3993551E-09
      D    =-2.0331907E-11
      E    = 2.4593791E-15
      F    =-8.5491002E 02
      G    =-1.6481339E 00
      GO TO 40
   22 A    = 3.5976129E 00
```

```
      B    = 7.8145603E-04
      C    =- 2.2386670E-07
      D    = 4.2490159E-11
      E    =-3.3460204E-15
      F    =-1.1927918E 03
      G    = 3.7492659E 00
      GO TO 40
   23 A    = 2.6707532E 00
      B    = 3.9317115E-03
      C    =-8.5351570E-07
      D    = 1.1790853E-10
      E    =-6.1973568E-15
      F    =-2.9888994E 04
      G    = 6.8838391E 00
      GO TO 40
   24 A    = 2.8545761E 00
      B    = 1.5976316E-03
      C    =-6.2566254E-07
      D    = 1.1315849E-10
      E    =-7.6897070E-15
      F    =-8.9017445E+02
      G    = 6.3902879E 00
      GO TO 40
   25 A    = 2.5000000E 00
      B    = 0.0
      C    = 0.0
      D    = 0.0
      E    = 0.0
      F    = 2.5470497E 04
      G    =-4.6001096E-01
      GO TO 40
   26 A    = 2.5372567E 00
      B    =-1.8422190E-05
      C    =-8.8017921E-09
      D    = 5.9643621E-12
      E    =-5.5743608E-16
      F    = 2.9230007E 04
      G    = 4.9467942E 00
      GO TO 40
   27 A    = 2.8895544E 00
      B    = 9.9835061E-04
      C    =-2.1879904E-07
      D    = 1.9802785E-11
      E    =-3.8452940E-16
      F    = 3.8811792E 03
      G    = 5.5597016E 00
      GO TO 40
   28 A=4.41293
      B=3.19229E-03
```

```
      C=-1.29786E-06
      D=2.4147E-13
      E=-1.6743E-14
      F=-4.8944E+04
      G=-.72876
      GO TO 40
   29 A=3.16941
      B=1.02274E-02
      C=-3.85032E-06
      D=6.77198E-10
      E=-4.50135E-14
      F=-5845.93
      G=0.
   40 RETURN
      END
      FUNCTION S2(XJ,RE)
      COMMON/EG/EIN,PR,XLE
      COMMON/SS/AL1,AL2,BQ1,BQ2,C1,C2,CH1,CH2,DB1,DB2,DD1,DD2,DT1,DT2,DV
     A1,DV2,PX1,PX2,TA1,TA2,TH1,TH2,V1,V2,Y1,Y2
      RPR=1./PR
      TERM1=V1*C1*DB1*RPR+V2*C2*DB2*RPR
      TERM2=C1*DV1*BQ1*RPR+C2*DV2*BQ2*RPR
      TERM3=(V1*BQ1*CH1+V2*BQ2*CH2)*XLE*RPR
      TERM4=(V1*BQ1*PX1+V2*BQ2*PX2)*RPR
      TERM5=(V1*TA1**2+V2*TA2**2)*EIN
      IF(XJ.NE.0.) GO TO 10
      TERM6=0.
      GO TO 2
   10 YT=Y1*Y2
      IF(YT.LE.1.E-10) GO TO 20
      TERM6=V1*C1*BQ1*COS(TH1)/Y1*RPR+V2*C2*BQ2*COS(TH2)/Y2*RPR
      GO TO 2
   20 CONTINUE
      TERM6=V1*C1*DR1*RPR+V2*C2*DB2*RPR
    2 S2=(TERM1+TERM2+TERM3+TERM4+TERM5+TERM6)/RE*.5/EIN
      RETURN
      END
      FUNCTION S3(XJ,RE)
      COMMON/EG/EIN,PR,XLE
      COMMON/SS/AL1,AL2,BQ1,BQ2,C1,C2,CH1,CH2,DB1,DB2,DD1,DD2,DT1,DT2,DV
     A1,DV2,PX1,PX2,TA1,TA2,TH1,TH2,V1,V2,Y1,Y2
      RPP=1./PR
      TERM1=V1*CD1+V2*CD2
      TERM2=DV1*AL1+DV2*AL2
      IF(XJ.NE.0.) GO TO 10
      TERM3=0.
      GO TO 2
   10 YT=Y1*Y2
      IF(YT.LE.1.E-10) GO TO 20
```

```
      TERM3=COS(TH1)*V1*AL1/Y1+COS(TH2)*V2*AL2/Y2
      GO TO 2
   20 CONTINUE
      TERM3=TERM1
    2 S3=(TERM1+TERM2+TERM3)*XLE*RPR/RE*.5
      RETURN
      END
      FUNCTION F1(M)
      COMMON/BO/GAMB,PB,QB,RHOB,THB,WB,XMUB,YB
      COMMON/HL/ALPHA,BETA
      COMMON/HM/ALPN(7,55),CPN(7,55),CPXN(55),EMN(55),GAMN(55),HN(7,55),
     1L,PN(55),QN(55),RHON(55),RN(55),THN(55),TN(55),WN(55),XMUN(55)
      RP=1./PB
      F1=SIN(XMUB)*COS(XMUB)/GAMB*RP
      RPN=1./PN(M)
      IF(BETA.GT.0.)F1=(F1+SIN(XMUN(M))*COS(XMUN(M))/GAMN(M)*RPN)*.5
      RETURN
      END
      FUNCTION F2(M,S11,S21,S31)
      COMMON/BO/GAMB,PB,QB,RHOB,THB,WB,XMUB,YB
      COMMON/OP/YN(55)
      COMMON/HL/ALPHA,BETA
      COMMON/HM/ALPN(7,55),CPN(7,55),CPXN(55),EMN(55),GAMN(55),HN(7,55),
     1L,PN(55),QN(55),RHON(55),RN(55),THN(55),TN(55),WN(55),XMUN(55)
      COMMON/CA/H(7,55),Q(55),RHO(55),XMU(55)
      COMMON/WV/NPTS,RE,XBP,XJ
      IF(XJ.EQ.0.0)TERM1=0.0
      IF(XJ.NE.0.)TERM1=SIN(THB)/YB
      IF(XJ.NE.0..AND.BETA.GT.0.)TERM1=.5*(TERM1+SIN(THN(M))/YN(M))
      QS=1./QB**2
      TERM2=S11/RHOB*QS
      SQ=1./QN(M)**2
      IF(BETA.GT.0.)TERM2=.5*(TERM2+S11/RHON(M)*SQ)
      P1=1./PB
      TERM3=S21*(GAMB-1.)/GAMB*P1/QB
      P2=1./PN(M)
      IF(BETA.GT.0.)TERM3=.5*(TERM3+S21*(GAMN(M)-1.)/GAMN(M)*P2/QN(M))
      RQ=1./QB
      TERM4=S31*WB/RHOB*RQ
      QD=1./QN(M)
      IF(BETA.GT.0.)TERM4=.5*(TERM4+S31*WN(M)/RHON(M)*QD)
      F2=(TERM1+TERM2-TERM3-TERM4)
      RETURN
      END
      FUNCTION F4(B,OPT,XMU1,TH1,XMU2,TH2)
      F4=SIN(XMU1)/COS(TH1+OPT*XMU1)
      IF(B.GT.0.)F4=(F4+SIN(XMU2)/COS(TH2+OPT*XMU2))*.5
      RETURN
      END
```

```
      SUBROUTINE HERMAN(YN,DT,A,Y,CI,BB,CC,SCALE)
      DIMENSION P(10,10),SMALB(10),Q(10),A(10,10),Y(7),YN(7),CI(4),FINK(
     14)
      TIM1=DT/2.0
      TIM2=DT
      T0=TIM1**2
      T1=(DT**2-T0)*.5
      T2=(DT**3-TIM1*T0)/3.0
      T3=T0*.5
      T4=TIM1*T0/3.0
      K=1
      DO 19 I=1,4
      DO 10 J=1,4
      P(K,J)=-A(I,J)*T3
   10 P(K+1,J)=-A(I,J)*T1
   19 K=K+2
      K=1
      DO 20 I=1,4
      DO 11 J=1,4
      P(K,J+4)=-A(I,J)*(T4)
   11 P(K+1,J+4)=-A(I,J)*(T2)
   20 K=K+2
      J=1
      DO 12 I=1,8,2
      S=1./SCALE
      P(I,J)=P(I,J)+TIM1*S
      P(I,J+4)=P(I,J+4)+T0*S
      K=I+1
      P(K,J)=P(K,J)+(TIM2-TIM1)*S
      P(K,J+4)=P(K,J+4)+2.*T1*S
      J=J+1
   12 CONTINUE
      DO 13 I=1,8
   13 Q(I)=0.0
      FINK(1)=Y(1)
      FINK(2)=Y(2)
      FINK(3)=Y(6)
      FINK(4)=Y(3)
      K=1
      DO 15 I=1,4
      DO 14J=1,4
   14 Q(K)=Q(K)+A(I,J)*FINK(J)*(TIM2-TIM1)
      Q(K+1)=Q(K)
   15 K=K+2
      DO 16 I=1,4
      J=2*I
      Q(J-1)=Q(J-1)+CI(I)*(TIM2-TIM1)
   16 Q(J)=Q(J)+CI(I)*(TIM2-TIM1)
      DO 202 I=1,8
```

```
      Q(I)=Q(I)/1.0E-5
      DO 202 J=1,8
  202 P(I,J)=P(I,J)/1.0E-5
      CALL CLEM(8,SMALB,P,Q)
      CALL SCLT(SMALB,DT,CC,BB,Y,YN)
      RETURN
      END
      SUBROUTINE CLEM(M,X,B,D)
      DIMENSION AT(10,11),X(10)
      DIMENSION B(10,10),D(10)
      M1=M+1
      DO 12 I=1,M
   12 X(I)=0.0
      DO 200 I=1,M
  200 AT(I,M1)=D(I)
      DO 201 I=1,M
      DO 201 J=1,M
  201 AT(I,J)=B(I,J)
      DO 32 N=1,M
      O=AT(N,N)
      IT=0
      DO 9 I=N,M
      IF(ABS(AT(I,N))-ABS(O)) 9,9,8
    8 O=AT(I,N)
      IT=I
    9 CONTINUE
      IF(IT-N)7,7,70
   70 DO 71 J=N,M1
      TEMP=AT(N,J)
      AT(N,J)=AT(IT,J)
   71 AT(IT,J)=TEMP
    7 DO 10 I=1,M1
   10 AT(N,I)=AT(N,I)/O
      IF(M-N)50,50,18
   18 N1=N+1
      DO 30 I=N1,M
      O=AT(I,N)
      DO 30 J=N,M1
   30 AT(I,J)=AT(I,J)-AT(N,J)*O
   32 CONTINUE
   50 X(M)=AT(M,M+1)
      DO 65 N=2,M
      NR=M+1-N
      O=AT(NR,M+1)
      DO 60 I=NR,M
   60 O=O-AT(NR,I)*X(I)
   65 X(NR)=O/AT(NR,NR)
      RETURN
      END
```

```
      SUBROUTINE SOLT(SMALB,DT,CC,BB,Y,YN)
      DIMENSION SMALB(10),Y(7),YN(7)
      TIME=DT
      TNX=TIME**2
      YN(1)=Y(1)+SMALB(1)*TIME+SMALB(5)*TNX
      YN(2)=Y(2)+SMALB(2)*TIME+SMALB(6)*TNX
      YN(6)=Y(6)+SMALB(3)*TIME+SMALB(7)*TNX
      YN(3)=Y(3)+SMALB(4)*TIME+SMALB(6)*TNX
      YN(4)=CC-(YN(1)+YN(6))*.5-YN(3)
      YN(5)=BB-(YN(2)+YN(6)+YN(3))*.5
      RETURN
      END
      FUNCTION S1(XJ,RE)
      COMMON/SS/AL1,AL2,BQ1,BQ2,C1,C2,CH1,CH2,DB1,DB2,DD1,DD2,DT1,DT2,DV
     A1,DV2,PX1,PX2,TA1,TA2,TH1,TH2,V1,V2,Y1,Y2
      TERM1=V1*DT1+V2*DT2
      TERM2=DV1*TA1+DV2*TA2
      IF(XJ.NE.0.) GO TO 10
      TERM3=0.
      GO TO 2
   10 YT=Y1*Y2
      IF(YT.LE.1.E-10) GO TO 20
      TERM3=COS(TH1)*V1*TA1/Y1+COS(TH2)*V2*TA2/Y2
      GO TO 2
   20 CONTINUE
      TERM3=TERM1
    2 S1=(TERM1+TERM2+TERM3)/RE*.5
      RETURN
      END
      SUBROUTINE PUNCH
      COMMON/AC/IBOD,FIN
      COMMON/BA/ALP(7,55),EMINF,WINF
      COMMON/DB/BETB(4),IS(4)
      COMMON/EF/EM(55),GAM(55),P(55),TH(55),Y(55)
      COMMON/EG/EIN,PR,XLE
      COMMON/FH/XK1,XK3,XPOT
      COMMON/HJ/KOUNT,LL,NPT
      COMMON/PC/ALPHN(7),IFUEL,PRES
      COMMON/PQ/JCHEM,NSP,T(55)
      COMMON/TW/TIN
      COMMON/WV/NPTS,RE,XBP,XJ
      COMMON/XY/APRS,APUS,DELTAY,EBODS,IBODS,INTACT,IPRS,IPUS,ITYP,
     1JBODS,MMAX,RHEAT,XK2,XK4,YBOT,YTP
      COMMON/YX/ABODS,BPRESS,CPRESS
      COMMON/YZ/BPRESU,CHEMFC,CPRESU,EMSUB,RTH,XSTEP
      COMMON/ZY/ABOD,BBOD,CBOD,EBOD,FBOD,GBOD,IAVE,IPUNCH,JBOD,KKKKK
      REWIND 7
  100 FORMAT(16I5)
  101 FORMAT(8E10.3)
```

```
  200 FORMAT(I5,5X,7E10.3)
  102 FORMAT(7E10.3,F10.5)
  103 FORMAT(5F10.5)
  104 FORMAT(7E11.4)
      WRITE(7,100) KKKKK ,LL
      WRITE(7,200) IPUNCH,XSTEP
      INTACT=0
      ISHOCK=0
      DO 1111 I=1,4
 1111 IF(IS(I).NE.0) ISHOCK=1
      WRITE(7,100)NPTS,NPT,ITYP,ISHOCK,MMAX,KOUNT
      WRITE(7,100)JCHEM,IAVE,                      INTACT
      WRITE(7,102)XJ,        EMSUB,RTH,DELTAY,YBOT,YTP,CHEMFC,XBP
      RO=RE/RTH
      WRITE(7,101)RO,PR,XLE,EMINF,TIN,WINF,PRES
      WRITE(7,101)XPOT,XK1,XK2,XK3,XK4
      WRITE(7,200)IBODS,ABODS,BBOD,CBOD
      WRITE(7,200)JBODS,EBODS,FBOD,GBOD
      WRITE(7,200)IPRS,APRS     ,BPRESS,CPRESS
      WRITE(7,200)IPUS,APUS     ,BPRESU,CPRESU
      IF(ISHOCK.EQ.0) GO TO 5
      WRITE(7,100)(IS(I),I=1,4)
      WRITE(7,101)(BETB(I),I=1,4)
    5 CONTINUE
      DO 10 I=1,NPTS
      A    =P(I)/PIN
      ALP7=ALP(7,I)-ALP(4,I)*(1.-RHEAT)
      ALP4=ALP(4,I)/RHEAT
      WRITE(7,103)Y(I),A    ,TH(I),EM(I),T(I)
      WRITE(7,104) ALP(1,I),ALP(2,I),ALP(3,I),ALP4,ALP(5,I),ALP(6,I),ALP
     17
   10 CONTINUE
      REWIND 7
      END
      SUBROUTINE INDATA
      COMMON/AC/IBOD,PIN
      COMMON/AL/GAR,GEW
      COMMON/BA/ALP(7,55),EMINF,WINF
      COMMON/BC/XMASS(55)
      COMMON/CJ/CP(7,55),CP1(7),CPX(55)
      COMMON/CK/WTMOLE(7)
      COMMON/DB/BETB(4),IS(4)
      COMMON/ED/CPIN,RO
      COMMON/EF/EM(55),GAM(55),P(55),TH(55),Y(55)
      COMMON/EG/EIN,PR,XLE
      COMMON/EP/GAMINF,M1(7),RINF
      COMMON/FH/XK1,XK3,XPOT
      COMMON/GE/RAD,ROO,UIN,VISINF
      COMMON/GF/DELY,CVISA,KOUNTO,VISA
```

```
      COMMON/HJ/KOUNT,LL,NPT
      COMMON/HK/RCO2,RH2O,WFUEL
      COMMON/OR/THBP,YBP,YBPN
      COMMON/FC/W(55),X(55)
      COMMON/PC/ALPHN(7),IFUEL,PRES
      COMMON/PC/JCHEM,NSP,T(55)
      COMMON/GA/H(7,55),Q(55),RHO(55),XM[illegible](55)
      COMMON/RC/R(55)
      COMMON/TW/TIN
      COMMON/UV/II11,IERR,IPRESS,IPRESU,ISUB
      COMMON/WV/NPTS,RE,XBP,XJ
      COMMON/WX/APRESS,APRESU
      COMMON/XY/APRS,APUS,DELTAY,EBODS,IBODS,INTACT,IPRS,IPUS,ITYP,
     1JBODS,MMAX,RHEAT,XK2,XK4,YBOT,YTP
      COMMON/YX/ABODS,BPRESS,CPRESS
      COMMON/YZ/BPRESU,CHEMFC,CPRESU,EMSUB,RTH,XSTEP
      COMMON/ZY/ABOD,BBOD,CBOD,EBOD,FBOD,GBOD,IAVE,IPUNCH,JBOD,KKKKK
      IIN=5
      ISUB=0
      XBP=0.
      YBP=10000.
      THBP=0.
      RAD=0.
      IFUEL=1
      WFUEL=2.016
  100 FORMAT(16I5)
  101 FORMAT(8E10.0)
  404 FORMAT(7E11.4)
  200 FORMAT(I5,5X,7E10.0)
      READ(IIN,100)        KKKKK,LL
      READ(IIN,200) IPUNCH,XSTEP
      READ(IIN,100) NPTS,NPT,ITYP,ISHOCK,MMAX,KOUNT
      READ(IIN,100) JCHEM,IAVE,                    INTACT
      IF(KOUNT.LT.1) KOUNT=0
      KOUNTC=KOUNT
      WRITE(6,111) KKKKK,LL
  111 FORMAT(8H1KKKKK =I5,5X,4HLL =I3/)
      WRITE(6,112) IPUNCH,XSTEP
  112 FORMAT(9H IPUNCH =I2,5X,7HXSTEP =E10.3/)
      WRITE(6,113) NPTS,NPT,ITYP,ISHOCK,MMAX
  113 FORMAT(7H NPTS =I3,5X,5HNPT =I2,5X,6HITYP =I2,5X,8HISHOCK =I2,5X,6
     1HMMAX =I3/)
      WRITE(6,114) JCHEM,IAVE,           INTACT
  114 FORMAT(8H JCHEM =I2,5X,6HIAVE =I2,5X,
     18HINTACT =I2/)
      IF(ITYP.NE.2.AND.ITYP.NE.4) GO TO 12
      IF(INTACT.EQ.0.AND.ISHOCK.EQ.0) GO TO 12
      WRITE(6,9191)
 9191 FORMAT(1H1)
```

```
      WRITE(6,102)
  102 FORMAT(91H TYPE 2 OR TYPE 4 FLOWS MAY NOT START WITH SHOCKS OR HAV
     6E SHOCKS COMING OFF SPLITTER PLATES/43H RECHECK INPUTS AND SUBMIT
     1WITH PROPER TYPE)
      STOP
   12 CONTINUE
  104 READ(IIN,101) XJ,      EMSUB,RTH,DELTAY,YBOT,YTP,CHEMFC,XBP
      READ(IIN,101) RE,PR,XLE,EMINF,TIN,WINF,PRES
      READ(IIN,101) XPOT,XK1,XK2,XK3,XK4
      READ(IIN,200) IBOC,ABOD,BBOD,CBOD
      READ(IIN,200) JBOD,EBOD,FBOD,GBOD
      READ(IIN,200) IPRESS,APRESS,BPRESS,CPRESS
      READ(IIN,200) IPRESU,APRESU,BPRESU,CPRESU
      IF(XBP.LT.0.) XBP=0.
      J=XJ+.5
      XJ=J
      WRITE(6,115) XJ,EMSUB,RTH,DELTAY,YBOT,YTP,CHEMFC
  115 FORMAT(5H XJ =E10.3,2X,7HEMSUB =E10.3,2X,5HRTH =E10.3,2X,8HDELTAY
     1=E10.3,2X,6HYBOT =E10.3,2X,5HYTP =E10.3,2X,8HCHEMFC =E10.3/)
      WRITE(6,116) RE,PR,XLE,EMINF,TIN,WINF,PRES
  116 FORMAT(5H RE =E10.3,2X,4HPR =E10.3,2X,5HXLE =E10.3,2X,7HEMINF =E10
     1.3,2X,5HTIN =E10.3,2X,6HWINF =E10.3,2X,6HPRES =E10.3/)
      WRITE(6,117) XPOT,XK1,XK2,XK3,XK4
  117 FORMAT(7H XPOT =E10.3,2X,5HXK1 =E10.3,2X,5HXK2 =E10.3,2X,5HXK3 =E1
     10.3,2X,5HXK4 =E10.3/)
      WRITE(6,118) IBOD,ABOD,BBOD,CBOD
  118 FORMAT(7H IBOD =I2,2X,6HABOD =E10.3,2X,6HBBOD =E10.3,2X,6HCBOD =E1
     10.3/)
      WRITE(6,119) JBOD,EBOD,FBOD,GBOD
  119 FORMAT(7H JBOD =I2,2X,6HEBOD =E10.3,2X,6HFBOD =E10.3,2X,6HGBOD =E1
     10.3/)
      WRITE(6,120) IPRESS,APRESS,BPRESS,CPRESS
  120 FORMAT(9H IPRESS =I2,2X,8HAPRESS =E10.3,2X,8HBPRESS =E10.3,2X,8HCP
     1RESS =E10.3/)
      WRITE(6,121) IPRESU,APRESU,BPRESU,CPRESU
  121 FORMAT(9H IPRESU =I2,2X,8HAPRESU =E10.3,2X,8HBPRESU =E10.3,2X,8HCP
     1RESU =E10.3/)
  411 IBODS=IBOD
      ABODS=ABOD
      IPRS=IPRESS
      APRS=APRESS
      JBODS=JBOD
      EBODS=EBOD
      IPUS=IPRESU
      APUS=APRESU
      IF(ISHOCK.EQ.0) GO TO 5
      READ(IIN,100) (IS(I),I=1,4)
      READ(IIN,101) (BETB(I),I=1,4)
      WRITE(6,128) (IS(I),I=1,4)
```

```
 128 FORMAT(8H IS(1) =I3,2X,7HIS(2) =I3,2X,7HIS(3) =I3,2X,7HIS(4) =I3/)
     WRITE(6,129) (BETB(I),I=1,4)
 129 FORMAT(10H BETB(1) =E10.3,2X,9HBETB(2) =E10.3,2X,9HBETB(3) =E10.3,
    12X,9HBETB(4) =E10.3/)
   5 CONTINUE
     DO 10 I=1,NPTS
     READ(IIN,101) Y(I),P(I),TH(I),EM(I),T(I)
     READ(IIN,404) (ALP(J,I),J=1,NSP)
  10 CONTINUE
     IF(ITYP.EQ.1)GO TO 4201
     IBOD=0
     JBOD=0
     IF(ITYP.EQ.3) JBOD=JBODS
     IF(ITYP.EQ.4) IBOD=IBODS
4201 RHEAT=1.
     RH2O=1.
     RCO2=0.
4204 WTMOLE(4)=WFUEL
     RE=RE*RTM
     IERR=0
     CALL COEFF(5,TIN,AZ,BZ,CZ,DZ,HZ,FZ,GZ)
     CPIN=(AZ+BZ*TIN+CZ*TIN**2+DZ*TIN**3+HZ*TIN**4)*RO/WTMOLE(5)
     CALL COEFF(7,TIN,AZ,BZ,CZ,DZ,HZ,FZ,GZ)
     CPII=(AZ+BZ*TIN+CZ*TIN**2+DZ*TIN**3+HZ*TIN**4)*RO/WTMOLE(7)
     CPIN=.232*CPIN+.768*CPII
     RINF=RO/WINF
     GAMINF=1./(1.-RINF/CPIN)
     RINFF=RCO/WINF
     UIN=EMINF*SQRT(GAMINF*RINFF*TIN)
     RF=1./RINFF
     RHOINF=PRES*RF/TIN
     VISINF=RHOINF*UIN*RTM/RE
     GAR=GAMINF*RINF
     GEW=GAMINF*EMINF**2/WINF
     EIN= (GAMINF-1.) * EMINF**2
     EMS=1./EMINF**2
     FIN=1./GAMINF*EMS
     WRITE(6,6898)
6898 FORMAT(////48X,31HP R O G R A M   V I S - C H A R //60X,7HW I T H
    1//42X,43HE M B E D D E D   S U B S O N I C   F L O W//53X,21HS H O
    1 C K   W A V E S//33X,63HA N D   F I N I T E   R A T E   H 2 - A I
    1 R   C H E M I S T R Y)
     IF(XJ.EQ.0.) WRITE(6,5610)
     IF(XJ.NE.0.) WRITE(6,5611)
     IF(JCHEM.EQ.0) WRITE(6,5612)
     IF(JCHEM.EQ.1) WRITE(6,5613)
5610 FORMAT(///10X,31HTYPE OF FLOW IS TWO DIMENSIONAL)
5611 FORMAT(///10X,28HTYPE OF FLOW IS AXISYMMETRIC)
5612 FORMAT(10X,19HCHEMISTRY IS FROZEN)
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5613 FORMAT(10X,24HCHEMISTRY IS FINITE RATE)
     WRITE(6,5600) RTH
5600 FORMAT(
    110X,28HJET OR NOZZLE RADIUS (RTH) = E13.5,4H FT.)
     WRITE(6,5601) EMINF,UIN,TIN,PRES,RHOINF,GAMINF,WINF,RE,PP,XLE
5601 FORMAT(///20X,20HREFERENCE CONDITIONS/20X,20H--------------------/
    110X,18HMACH NO. (EMINF) = E13.5/10X,16HVELOCITY (UIN) = E13.5,
    1 7H FT/SEC/10X,19HTEMPERATURE (TIN) =E13.5,10H DEGREES K/10X,17HPR
    1ESSURE (PRES) =E13.5,9 H LB/FT**2/10X,18HDENSITY (RHOINF) =E13.5,
    112H SLUGS/FT**3/10X,37
    1HFROZEN SPECIFIC HEAT RATIO (GAMINF) =E13.5/10X,25HMOLECULAR WEIGH
    1T (WINF) =E13.5/10X,22HREYNOLDS NUMBER (RE) =E13.5/10X,21HPRANDTL
    1NUMBER (PR) =E13.5/10X,20HLEWIS NUMBER (XLE) =E13.5)
     WRITE(6,5602)
5602 FORMAT(///20X,15HOUTPUT HEADINGS/20X,15H---------------/
    110X, 9HX - X/RTH/10X, 9HY - Y/RTH/10X,16HQ - VELOCITY/UIN/10X,
    119HT - TEMPERATURE/TIN/10X,17HP - PRESSURE/PRES/10X,30HTH - FLOW D
    1EFLECTION (RADIANS) /10X,16HEM - MACH NUMBER/10X,20HRHO - DENSITY/
    1RHOINF/10X,19HGAM - SPECIFIC HEAT
    1     /10X,33HXMASS - NON-DIMENSIONAL MASS FLOW
    1                      /10X,23HPHI - EQUIVALENCE RATIO/10X,
    120HW - MOLECULAR WEIGHT//10X14HMASS FRACTIONS/15X10HALP(1) - H/15X
    110HALP(2) - O/15X,12HALP(3) - H2O/15X,11HALP(4) - H2/15X,11HALP(5)
    1 - O2/15X,11HALP(6) - OH/15X,11HALP(7) - N2)
 413 DO 1774 I=1,NPTS
     X(I)=XBP
     P(I)=P(I)*PIN
     ALP(4,I)=RHEAT*ALP(4,I)
     ALP(7,I)=(1.-RHEAT)*ALP(4,I)+ALP(7,I)
     DO 788 J=1,NSP
 788 IF(ALP(J,I).LT.1.1E-10) ALP(J,I)=1.1E-10
     ALP(7,I)=1.-(ALP(1,I)+ALP(2,I)+ALP(3,I)+ALP(4,I)+ALP(5,I)+ALP(6,I)
    1)
1774 CONTINUE
     DO 8883 I=1,NPTS
     CALL THERMO(T(I),H1,CP1)
     CPX(I)=0.0
     W(I)=0.0
     DO1776 J=1, NSP
     CP(J,I)=CP1(J)
     H(J,I)=H1(J)
     CPX(I)=CPX(I)+ALP(J,I)*CP(J,I)
1776 W(I)=W(I)+ALP(J,I)/WTMOLE(J)
     W(I)=1./W(I)
     RHO(I)=GEW*W(I)*P(I)/T(I)
     R(I)=RC/W(I)
     GAM(I)=CPX(I)/(CPX(I)-R(I)/CPIN)
     OM=1./EMINF
     OR=1./R(I)
```

```
      Q(I)=EM(I)*OM/SQRT(GAR/GAM(I)*OR/T(I))
      IF(EM(I).GT.1.)
     1XMU(I)=ATAN(1./SQRT(EM(I)**2-1.))
 8883 CONTINUE
      IF(INTACT.EQ.1) CALL COML
      XJ1=1.+XJ
      XMASS(1)=0.
      DO 1785 I=1,NPTS
      IF(I.EQ.1) GO TO 1785
      XJ1=1.+XJ
      YFUN=(Y(I)*(1.-XJ+Y(I)*XJ)- Y(I-1)*(1.-XJ+Y(I-1)*XJ))/XJ1
      RQAV=(RHO(I)*Q(I)*COS(TH(I))+ RHO(I-1)*Q(I-1)*COS(TH(I-1)))/2.
      XMASS(I)=XMASS(I-1)+RQAV*YFUN
 1785 CONTINUE
      DELY=(YBP-Y(1))/FLOAT(NPTS-1)
      RETURN
      END
      FUNCTION F3(TP1,DTC,T1,TC,TH1,THC,DA,W1,WC)
      COMMON/CK/WTMOLE(7)
      COMMON/GK/DELX
      COMMON/HL/ALPHA,BETA
      DIMENSICN DA(7)
      NSP=7
      A=ALPHA
      B=BETA
      TERM1=DTC/((A-B)*TP1+B*(T1+TC))
      TERM2=0.
      DO 10 J=1,NSP
      TERM2=TERM2+DA(J)/WTMOLE(J)
   10 CONTINUE
      TERM5=A*W1+B*WC
      TERM2=TERM2*TERM5
      TERM3=A*CCS(TH1)+B*COS(THC)
      F3=-(TERM1+TERM2)*TERM3/DELX
      RETURN
      END
      SUBROUTINE POCUS(TI,PRESSI,RHOI,ALPHI,DT,TN)
      COMMON/PO/ALPHA(7),IFUEL,PRES
      DIMENSION ALPHI(7),AD(10,10),CI(10),Y(7),YN(7),ALPHA(7)
      DIMENSION T0(7),T1(7),B(7),C(7),D(7),E(7),G(7),Z(7)
      T0(1)=6.0
      T0(2)=6.0
      T0(3)=0.5
      T0(4)=0.5
      T0(5)=0.5
      T0(6)=0.5
      T0(7)=0.5
      T1(1)=6.0
      T1(2)=6.0
```

```
T1(3)=3.0259
T1(4)=4.0960
T1(5)=2.9282
T1(6)=3.6392
T1(7)=2.4808
B(1)=39.7055
B(2)=2.5674
B(3)=3.5961
B(4)=27.4123
B(5)=1.7771
B(6)=3.3496
B(7)=2.3043
C(1)=0.0
C(2)=0.0
C(3)=.5486
C(4)=1.5999
C(5)=.1595
C(6)=.1619
C(7)=.1531
D(1)=0.0
D(2)=0.0
D(3)=-31.7850
D(4)=-34.5288
D(5)=-1.8504
D(6)=1.3139
D(7)=-1.4976
E(1)=0.0
E(2)=0.0
E(3)=6.3657
E(4)=38.9184
E(5)=2.5521
E(6)=4.3679
E(7)=2.6093
G(1)=404.5564
G(2)=29.1774
G(3)=-26.9024
G(4)=-8.088
G(5)=-.522
G(6)=3.4213
G(7)=-.5961
Z(1)=.063
Z(2)=1.0
Z(3)=1.13
Z(4)=.126
Z( )=2.0
Z(6)=1.063
Z(7)=1.75
PSSSS=PRESSI
KASE=IFUEL
```

```
      IF(KASE.EQ.2) PRESS1=PRESSI*.35
      IF(KASE.EG.3) PRESSI=.2*PRESSI
      RHOI=RHOI*PRESSI/PSSSS
      KTEST=0
      EL0=1.0
      DLTI=0.0
      EPS=.001
      TIME0=1.38725E-5*EL0
      DT=DT/TIME0
      P0=PRESSI*1.01325E6
      RHO0=P0*1.924465E-10
      RHOI=RHOI*.5154/RHO0
      PRESSI=1.0
      T=TI
      HI=0.0
      DO 65 I=1,7
      IF(T-T1(I)) 62,61,61
   61 HI=(D(I)+E(I)*T)*ALPHI(I)+HI
      GO TO 65
   62 IF(T-T0(I)) 63,63,64
   63 HI=(G(I)+B(I)*T)*ALPHI(I)+HI
      GO TO 65
   64 HI=(G(I)+B(I)*T+C(I)*(T-T0(I))**2)*ALPHI(I)+HI
   65 CONTINUE
   92 CONTINUE
      JJJ = 25
      JJ=0
      T = TI
      TSAVE=T
      KOUNT=0
      RHO=RHOI
      DELTA=DLTI
      GAMMA=DT*DELTA+1.
      PRESS=PRESSI
      H=HI
      SUMY=0.
      DO 11 I=1,7
      ALPHA(I)=ALPHI(I)
      Y(I)=RHO*ALPHA(I)/Z(I)
      YN(I)=0.0
   11 SUMY=SUMY+Y(I)
      DUM1=8.67031E-7*RHO0*EL0
      DUM2=DUM1*RHO0/16.
      IF(ALPHA(3).GT.1.E-10)GO TO 6
      IF(ALPHA(6).GT.1.E-10) GO TO 6
      IF(ALPHA(5).GT.1.E-10) GO TO 30
      IF(ALPHA(2).GT.1.E-10) GO TO 30
      F5=(1.85E17*EXP (-25./T))*(DUM1*EXP (-29./T)/T)
      R5=1.E16*DUM1*RHO0/16.
```

```
      B11=-(F5*.5+2.*B5*Y(1))*SUMY
      CC1=B5*Y(1)**2*SUMY
      CC=GAMMA*(Y(2)+Y(1)*.5)
      C1=F5*CC*SUMY+CC1
      A11=DELTA+B11
      DUM=C1/A11
      YN(1)=-DUM+(Y(1)+DUM)*EXP (A11*DT)
      IF(YN(1).LT.0.0) YN(1)=0.0
      YN(4)=CC-YN(1)*.5
      GO TO 99
   30 IF(ALPHA(4).GT.1.E-10) GO TO 6
      IF(ALPHA(1).GT.1.E-10) GO TO 6
      F8=(5.8E16*EXP (-30.3/T))*(DUM1*EXP (-30.3/T)/T)
      B8=6.E14*DUM1*RHO0/16.
      B11=-(F8*.5+2.*B8*Y(1))*SUMY
      CC1=B8*Y(1)*Y(1)*SUMY
      BB=GAMMA*(Y(2)+Y(1)*.5)
      C1=F8*BB*SUMY+CC1
      A11=DELTA+B11
      DUM=C1/A11
      YN(1)=-DUM+(Y(1)+DUM)*EXP (A11*DT)
      YN(2)=BB-YN(1)*.5
      IF(YN(2).LT.0.0) YN(2)=0.0
      YN(5)=BB-YN(2)*.5
      GO TO 99
    6 CONTINUE
      KOUNT=1
      IF(KASE.EQ.2) T=1./(1.1087/T-.09497)
      IF(KASE.EQ.3) T=1./(.786/T+.2381)
      F1=3.E14*EXP (-8.81/T)*DUM1
      F2=3.E14*EXP (-4.03/T)*DUM1
      F3=3.E14*EXP (-3.02/T)*DUM1
      F4=F3
      B1=2.48E13*EXP (-.66/T)*DUM1
      B2=1.3E14*EXP (-2.49/T)*DUM1
      B3=1.33E15*EXP (-10.95/T)*DUM1
      B4=3.12E15*EXP (-12.51/T)*DUM1
       T=TSAVE
      TSAVE=T
      IF(KASE.EQ.2) T=1.241+.05524*T
      F6=9.66E18*EXP (-62.2/T)/T*DUM1
      F7=8.00E16*EXP (-52.5/T)/T*DUM1
      B6=1.E17*DUM2
      B7=1.E16*DUM2
      T=TSAVE
      F5=1.85E17*EXP (-54./T)/T*DUM1
      F8=5.80E16*EXP (-60.6/T)/T*DUM1
      B5=1.E16*DUM2
      B8=6.E14*DUM2
```

```
      DUM1=(Y(2)+Y(6)+Y(3))*.5
      DUM2=(Y(1)+Y(6))*.5+Y(3)
      DUM3=Y(1)*.5+Y(6)+Y(3)
      DUM4=F1*Y(1)*DUM1+B1*Y(2)*Y(6)
      DUM5=F2*Y(2)*DUM2+B2*Y(1)*Y(6)
      DUM6=F3*Y(6)*DUM2+B3*Y(1)*Y(3)
      DUM7=F4*Y(5)*Y(6)-B4*Y(2)*Y(3)
      DUM8=(F2*.5-B7*SUMY)*Y(2)+B2*Y(6)
      DUM9=(F1*.5-B7*SUMY)*Y(1)+B1*Y(6)
      DUM10=(F2*.5-B1)*Y(2)+(B2-F1*.5)*Y(1)
      DUM11=(F1*.5-B3)*Y(1)-F3*Y(6)
      DUM12=F1*DUM1-B3*Y(3)-F3*.5*Y(6)
      DUM13=(F8*SUMY+F1*Y(1))*.5
      DUM14=B6*Y(1)*SUMY-F3*DUM3
      DUM15=2.*F4*Y(6)
      DUM16=SUMY*Y(1)
      DUM17=B6*SUMY*Y(6)
      B12=DUM9-F2*DUM2
      B21=DUM8-F1*DUM1
      B19=(F6-F5)*SUMY-F2*Y(2)+DUM11
      B29=(F2-B4)*Y(2)-DUM13
      B91=DUM12+B21-CUM8+DUM17
      B27=SUMY*(F7-F8/2.)+DUM10+DUM15
      B79=F6*SUMY-DUM11+(2.*B4-F2)*Y(2)
      B77=-(DUM14+SUMY*F7+(F1*.5+B2)*Y(1)+(B1+F2*.5)*Y(2)+2.*DUM15)
      B92=-B4*Y(3)
      B22=-SUMY*(2.*B8*Y(2)+B7*Y(1))-B1*Y(6)+F2*DUM2-DUM13+B92
      B11=DUM12-F5*SUMY*.5-(F2*.5+B7*SUMY)*Y(2)-B2*Y(6)-DUM17-2.*B5*DUM1
     16
      B97=DUM14+DUM15
      B99=DUM11-(F1*.5*Y(1)+F6*SUMY+B4*Y(2))
      B71=-(DUM12+DUM8+DUM17)
      B72=2.*B4*Y(3)-DUM9-F2*DUM2
      B17=SUMY*(F7-F5/2.)-DUM10-DUM14-2.*F3*DUM3
      CC1=DUM5-DUM4+DUM6+(B6*Y(6)+B5*Y(1)+B7*Y(2))*DUM16
      CC2=DUM4-DUM5-DUM7+(B7*Y(1)+B6*Y(2))*SUMY*Y(2)
      CC7=DUM4+DUM5-DUM6+2.*DUM7+(B6*Y(6)-B7*Y(2))*DUM16
      CC9=DUM6-DUM7-B6*Y(6)*DUM16
   14 BB=GAMMA*(Y(5)+(Y(2)+Y(6)+Y(3))*.5)
      CC=GAMMA*(Y(4)+Y(3)+(Y(1)+Y(6))*.5)
      AD(1,1)=B11+DELTA-F1*BB
      AD(1,2)=B12+F2*CC
      AD(1,3)=B17+F3*CC
      AD(1,4)=B19
      AD(2,1)=B21+F1*BB
      AD(2,2)=B22+DELTA-F2*CC
      AD(2,3)=B27
      AD(2,4)=B29
      AD(3,1)=B71+F1*BB
```

```
      AD(3,2)=B72+F2*CC
      AD(3,3)=B77+DELTA-F3*CC
      AD(3,4)=B79
      AD(4,1)=B91
      AD(4,2)=B92
      AD(4,3)=B97+F3*CC
      AD(4,4)=B99+DELTA
      CI(1)=CC1+F5*SUMY*CC
      CI(2)=CC2+F8*SUMY*BB
      CI(3)=CC7
      CI(4)=CC9
      SCALE=0.0
      DO 50 I=1,4
      DO 50 J=1,4
   50 SCALE=AMAX1(SCALE,ABS(AD(I,J)))
      DO 51 I=1,4
      DO 52 J=1,4
   52 AD(I,J)=AD(I,J)/SCALE
   51 CI(I)=CI(I)/SCALE
      CALL HERMAN(YN,DT,AD,Y,CI,BB,CC,SCALE)
   99 DO 90 J=1,6
      IF(YN(J).GE.0.0) GO TO 90
      DT=DT/10.
      KTEST=KTEST+1
      IF(KTEST-3) 92,27,27
   90 CONTINUE
      DUM=0.0
      DO 1 J=1,6
    1 DUM=DUM+YN(J)*Z(J)
      RHON=DUM/(1.-ALPHA(7))
      YN(7)=RHON*ALPHA(7)/Z(7)
      SUMYN=0.0
      DO 2 J=1,7
    2 SUMYN=SUMYN+YN(J)
      TT=PRESS/SUMYN
      DO 4 J=1,6
    4 ALPHA(J)=YN(J)*Z(J)/RHON
      AH=0.0
      BH=0.0
      CH=0.0
      DO 505 I=1,7
      IF(TT-T1(I)) 502,501,501
  501 BH=BH-E(I)*ALPHA(I)*.5
      CH=CH+D(I)*ALPHA(I)
      GO TO 505
  502 IF(TT-T0(I)) 503,503,504
  503 BH=BH-B(I)*ALPHA(I)*.5
      CH=CH+G(I)*ALPHA(I)
      GO TO 505
```

```
504 AH=AH+C(I)*ALPHA(I)
    BH=BH+ALPHA(I)*(C(I)*T0(I)-B(I)*.5)
    CH=CH+ALPHA(I)*(G(I)+C(I)*T0(I)**2)
505 CONTINUE
    CH=CH-H
    IF(AH) 507,506,507
506 T=CH/BH/2.
    GO TO 508
507 T=(BH+SQRT (BH*BH-AH*CH))/AH
508 CONTINUE
    IF(JJ)31,31,22
 31 ERR1=TT-T
    IF(ABS(TT/T-1.0).LE.EPS) GO TO 27
    GAM1=GAMMA
    GAMMA=.98*GAMMA
130 GAM2=GAMMA
    DELTA=(GAMMA-1.)/DT
    JJ=JJ+1
    IF (JJ-JJJ) 84,84,12
 84 IF (KOUNT.EQ.1) GO TO 14
    T=TSAVE
    GO TO 6
 22 ERR2=TT-T
    IF(ABS(TT/T-1.0).LE.EPS) GO TO 27
 25 GAMMA=GAM1-ERR1*(GAM2-GAM1)/(ERR2-ERR1)
    GAM1=GAM2
    ERR1=ERR2
    GO TO 130
 12 WRITE(6,13)
 13 FORMAT(1H0,23H JJ IS GREATER THAN JJJ)
 27 TN=T
    DO 28 J=1,7
 28 ALPHN(J)=ALPHA(J)
    DT=DT*TIMEB
    PRESSI=PSSSS
    RETURN
    END
```