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A MATHEMATICAL MODEL FOR THE STARTING PROCESS OF A TRANSONIC LUDWIEG TUBE WIND TUNNEL

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A simplified mathematical model is presented for the unsteady flow process of starting a transonic Ludwieg tube wind tunnel. The hardware modeled consists of a porous-walled test section surrounded by a plenum chamber with an exhaust system independent of the tunnel's main starting valves, which are located downstream of the diffuser-test section. In the present method, the hardware is modeled as three control volumes: the plenum, the test section,

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20. ABSTRACT (Continued)

and the diffuser. The plenum is treated with the unsteady integral continuity equation with one-dimensional influx or outflux through the porous wall, through the plenum exhaust system, and through the flaps, which exhaust into the diffuser. The other two control volumes are treated with the steady integral continuity equation and a steady, adiabatic, one-dimensional energy equation whose stagnation conditions vary in time according to the classical solution for an unsteady expansion wave. Numerical solutions are compared with experimental pressure-time histories of a small, transonic, high Reynolds number tunnel referred to as HIRT. Agreement between the model and experiment is good.

PREFACE

The work reported herein was conducted by the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), under Program Element 65807F. The results were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of AEDC, AFSC, Arnold Air Force Station, Tennessee. The research was done under ARO Project No. V37A-32A in support of the High Reynolds Number Wind Tunnel (HIRT) project. The author of this report was Frederick L. Shope, ARO, Inc. The manuscript (ARO Control No. ARO-VKF-TR-75-147) was submitted for publication on September 26, 1975.

The author wishes to acknowledge R. F. Starr and M. O. Varner for their many helpful discussions and the fruitful suggestions they made during the course of this effort.

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1.0 INTRODUCTION

This report documents an effort to mathematically model the aerodynamics involved in the unsteady process of starting a Ludwieg Tube wind tunnel. In essence, the model represents the end product of many people assimilating a large amount of experimental data obtained from a transonic Ludwieg tube facility and, thus, depends on several experimentally derived parameters and assumptions. The wind tunnel configuration studied here consists of a very long, circular supply tube which contracts to a rectangular, porous-walled test section. The test section expands through a diffuser into a valve manifold. Surrounding the test section is a plenum chamber with exhaust valves which can be controlled independently of the main valves. In addition, the plenum contains a set of ejector flaps which allow the plenum to exhaust itself into the diffuser.

When one considers that larger scale transonic Ludwieg tube facilities would have a price of order $10,000,000 and would produce a usable run time of only a few seconds per run, it is clear that considerable effort must be concentrated to ensure that the tunnel can be started rapidly under a wide range of operating conditions. A laboratory scale pilot facility (Ref. 1) (known as "Pilot HIRT") at Arnold Engineering Development Center provides an experimental vehicle to measure the effects of many of the important parameters in the tunnel starting process and to provide basic experimental data for verification of math models.

To clarify the need for a mathematical model of starting such a device, a brief explanation of the tunnel operation is required. Prior to a run, the tunnel is pumped to the desired charge pressure and temperature. A tunnel run is initiated by first opening the main valves downstream of the diffuser. This opening process sends unsteady expansion waves up the tunnel to the supply tube. Were it not for the plenum, the flow in the test section would become steady soon after the trailing edge of the unsteady wave from the valve, initiated by the valve area becoming steady, passed the test section into the supply tube. The test section flow cannot become steady until the plenum volume has been exhausted to the point where the summation of mass flow across the porous wall, through the flaps, and out the plenum exhaust (dumped to atmosphere) becomes zero and allows the plenum pressure to become steady. Since current state-of-the-art, fast-opening valves easily reach the required flow area in advance of the plenum becoming steady, the plenum is the primary limitation upon how quickly the tunnel can be started and steady flow established in the test section.

The present model assumes that the unsteady expansion wave emanating from the main valves propagates instantaneously to all parts of the wind tunnel and that property variation within the wave at any location in the diffuser, test section, nozzle, or supply tube is totally controlled by the area-time curve of the main valve. While partially retaining the effect of the unsteady wave, this assumption allows use of the steady continuity equation in the test section coupled with the well-known exact solution for one-dimensional, variable area, isentropic flow (Ref. 2). Use of these equations at any instant requires a knowledge of stagnation conditions driving the flow, which vary through the nonisentropic expansion wave. Variation of the stagnation properties is computed via the exact solution for a one-dimensional unsteady wave in a variable area duct (Ref. 3). The unsteadiness of the plenum is handled via the unsteady continuity equation by equating the rate of mass accumulation in the plenum to the summation of all the flow rates entering and leaving the plenum. The air in the plenum is assumed to be a calorically perfect gas and its temperature is assumed either isentropic or equal to the stagnation temperature of the flow in the test section (whichever is greater), an experimentally based assumption. The main valves are treated as one-dimensional sonic orifices driven by the stagnation pressure and temperature of the unsteady wave. The plenum exhaust valves are handled similarly by assuming that the flow in the plenum is stagnant. Flow through the ejector flaps and across the porous wall is computed via an adaptation of the work of Ref. 4, which empirically corrected the flow rates with the pressure drops across these devices.

In the discussion which follows, the mathematical model will first be presented, including a more detailed description of the physical situation, the assumptions underlying the model, the mathematical formulation, and the solution procedure. Next, the model will be compared with a sample of experimental data from the Pilot HIRT facility. The appendixes contain some of the mathematical details and a brief user's manual for the computer program.

2.0 THE MATHEMATICAL MODEL

2.1 DESCRIPTION OF THE PHYSICAL SITUATION TO BE MODELED

All of the essential features of the proposed HIRT facility which are to be modeled are given in Fig. 1. The overall length of the facility is 1,880 ft, and the supply tube has an inside diameter of 15 ft. The main valve system consists of a number of fast-acting valves, and the plenum exhaust also requires a multiple valve system. The pilot facility provides a precisely scaled (1/13) flow envelope but has a single sliding sleeve valve in place of the valve manifold of the full-scale tunnel and a single plenum exhaust valve fed by multiple tubes from the plenum.

A tunnel run is initiated by opening the main valves and possibly the plenum valves, not necessarily together or in the same length of time. Both sets of valves send nonisentropic expansion waves throughout the tunnel and primarily up the charge tube. The main valve system produces the steepest (or strongest) wave because it handles a much greater portion

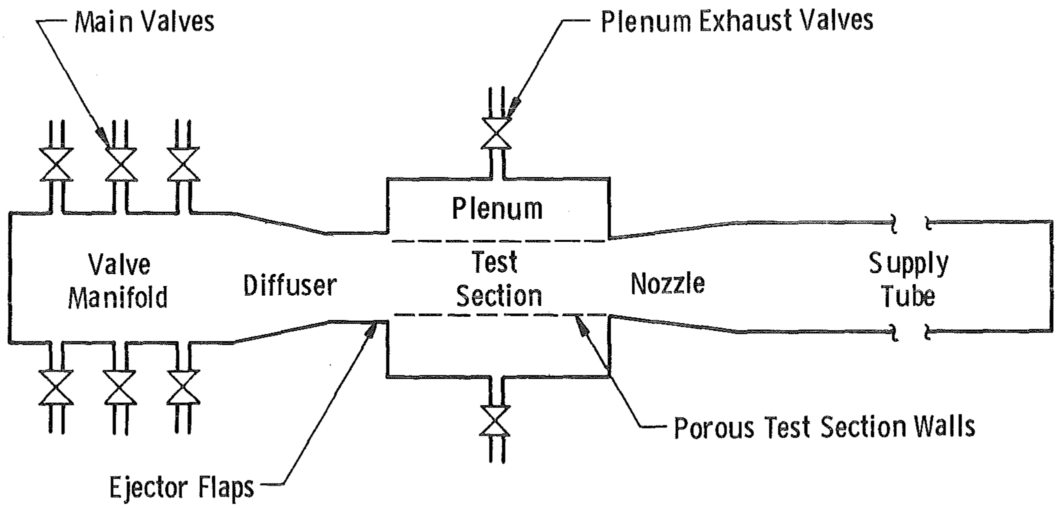


Figure 1. Major components of the High Reynolds Number Wind Tunnel.

of the flow rate than the plenum exhaust. At any point in the supply tube, the gas remains totally stagnant until the first expansion wave reaches that point; and the flow at that point does not become steady until the last expansion wave passes the point. The main valve system sends out its last expansion wave when the flow area becomes constant. The plenum also continues to send out expansion (and sometimes compression) waves until the plenum pressure becomes steady. But the plenum does not become steady until the sum of all the flows into and out of it are zero (Fig. 2), and it invariably controls the start time of the tunnel. Since the main valves are much faster than the plenum response, the pressure in the test section drops rapidly below the plenum pressure, causing mass flow to enter the test section from the plenum. As the plenum gradually catches up to the test section, the wall crossflow (across the porous test section wall) gradually decreases and, in some cases, reverses. This process, coupled with the increasing main valve area, gradually increases the flow rate drawn from the supply tube. However, the flow rate from the tube may continue to increase only until the nozzle exit becomes choked, after which the supply tube flow becomes steady since the choke point will no longer pass additional expansion or compression waves (unless the compression wave is strong enough to unchoke the nozzle). Whether the nozzle eventually chokes and whether the test section eventually steadies out to supersonic or subsonic flow depends on the relative flow areas of the main valves, the plenum exhaust valves, and the test section, the direction of the flap and wall crossflows, and how the various steady conditions are approached in time relative to each other. Subsonic and very slightly supersonic test section Mach numbers can be obtained without steady-state plenum exhaust, though the plenum exhaust may be opened temporarily and then closed in order to reduce the starting time. For subsonic flows, the steady main valve area - in terms of the ideal, one-dimensional area at the choke point - must be as much less than the nozzle area (where the nozzle meets the entrance to the test section) as is dictated by the steady test section Mach number to be attained (neglecting diffuser losses). A slightly supersonic test section can be obtained with a steady main valve area greater than or equal to the nozzle area if the flaps and porosity are set properly, giving a flow situation as follows: with the nozzle choked and the plenum steadied at a pressure very near the static test section pressure such that the static pressure and dynamic heads of the main flow force a small crossflow into the plenum, the net test section flow decreases from the choked flow rate at the nozzle. The slightly subcritical flow rate leaving the test section thus produces a slightly supersonic condition, resulting in a favorable pressure gradient for the plenum to exhaust its incoming crossflow out the flaps and hence become steady. Normally, however, supersonic conditions (up to Mach 1.3 in the pilot) are obtained by having the plenum exhaust area become steady at a flow area sufficient to pass all of the mass flow rate entering the plenum via wall crossflow and sometimes via reverse flap flow.

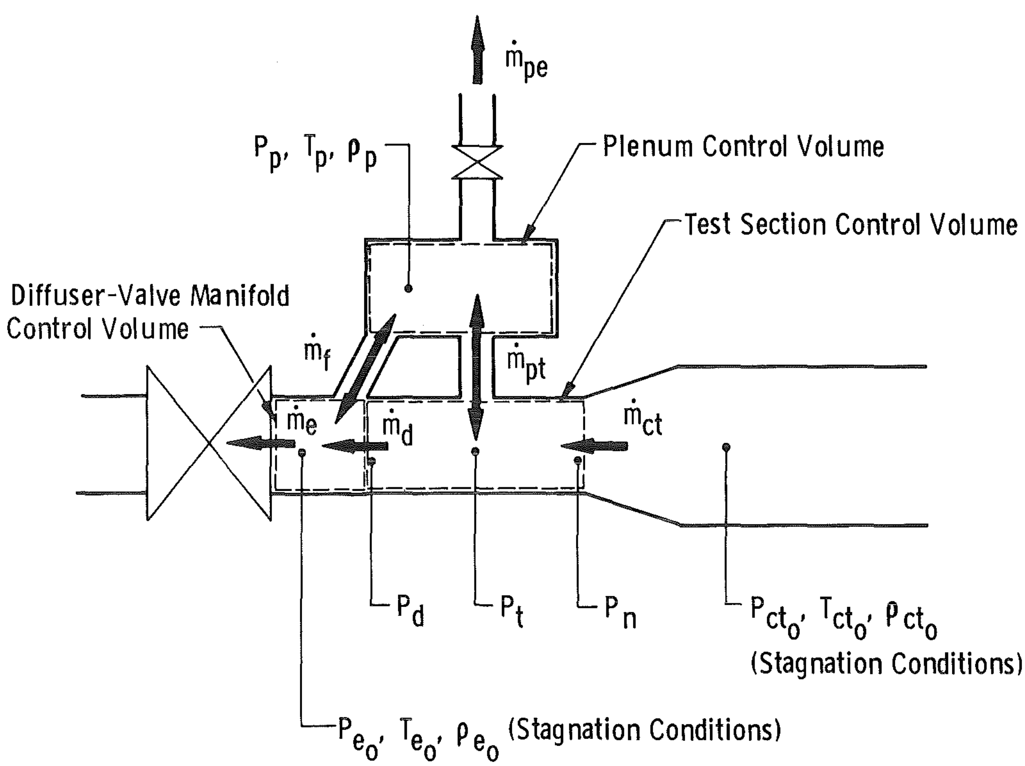


Figure 2. Schematic illustration of the flow process during start.

To understand the flow in terms of the mathematical model, the various flow configurations might be best thought of in terms of the steady energy equation relating the local pressure to the mass flux (Fig. 3). Subsonic flows fall on the branch to the right of the choke point, supersonic flows to the left. In general, all points in the tunnel are initially at point A, which corresponds to no flow. Higher flow rates with correspondingly lower static pressures are illustrated by movement from point A to B

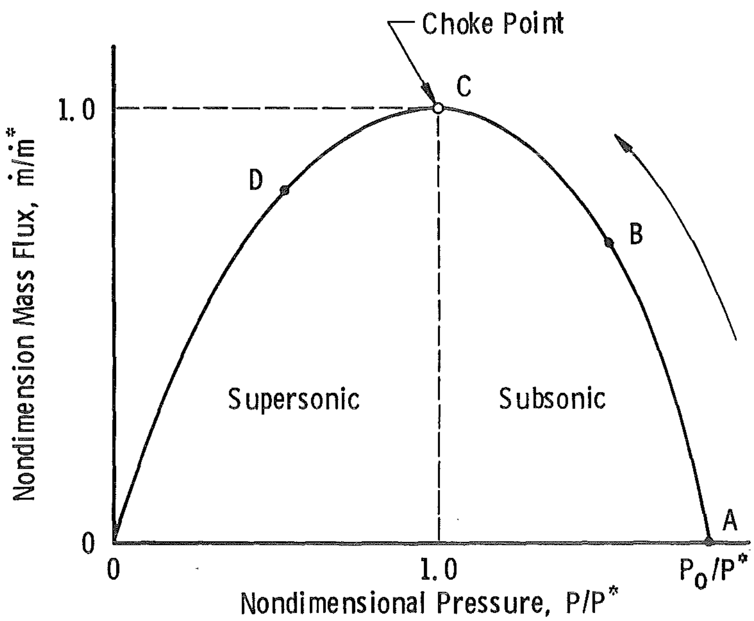


Figure 3. Qualitative plot of the energy equation.

on the energy equation. Flows which become subsonically steady would halt to the right of C; while for supersonic flows, some portions of the tunnel would proceed beyond C to D. If the energy dome is then plotted versus axial position in the test section as shown in Figs. 4, 5, and 6, the importance of the wall crossflow and the relative timewise approach of various components to their steady conditions may be made clearer. For a normal subsonic run, Fig. 4 shows the energy dome at the entrance and exit of the test section. The constant time contours are shown as straight lines for purposes of illustration, though in reality they would have to be nonlinear to some degree in order for all points on the contour to fall on the surface of the dome cylinder and because the wall crossflow does not necessarily vary linearly along the test section. As the flow begins, the constant time contours do not remain parallel because the flow rate leaving the test section will not balance that at the entrance, the difference being the wall crossflow. For the most probable case of the plenum lagging the test section pressure, the crossflow will be into the test section, giving a greater flow rate at the exit than at the entrance. As time proceeds, however, the plenum pressure eventually catches up to the test section so that the contours do become nearly straight and parallel as the crossflow becomes insignificant. This process assumes that the plenum exhaust, if opened, is eventually closed.

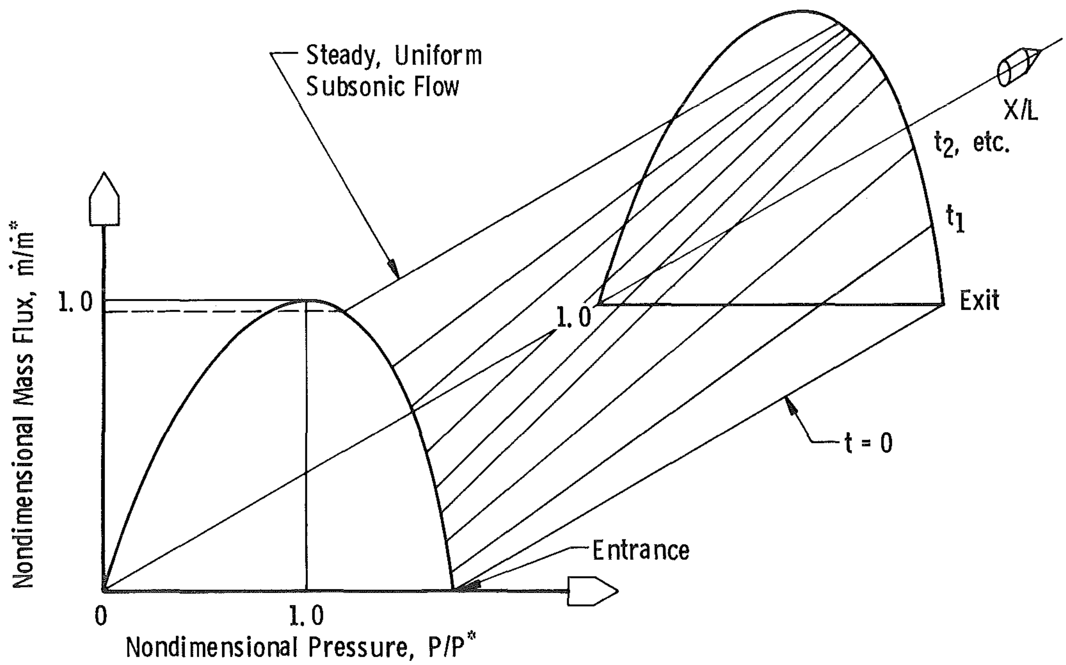


Figure 4. Energy dome versus position in test section for normal subsonic flow.

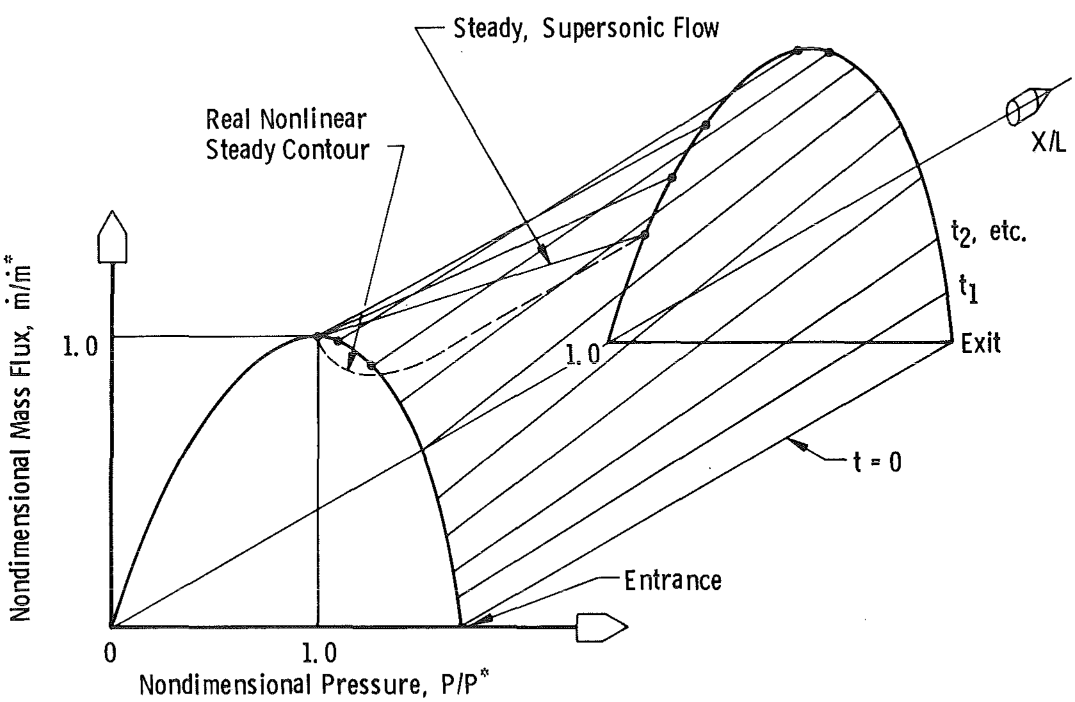


Figure 5. Energy dome versus position in test section for normal supersonic flow.

If the plenum exhaust is not closed and the steady main valve area is sufficiently large, the supersonic case of Fig. 5 may result. The initial constant time contours are similar to the subsonic case. However, the origins of the contours at the entrance eventually stop at the peak of the dome while at the exit they proceed over the choke point downward on the supersonic branch as the crossflow reverses from entering to leaving the test section. The contours, however well approximated by straight lines in the subsonic case, become significantly nonlinear for the higher supersonic Mach numbers, as illustrated by the dotted "real nonlinear steady contour" in Fig. 5. This results from a combination of the nonlinear variation of the wall crossflow and boundary layer growth. These nonlinear effects, though certainly present in the subsonic case, are more pronounced in the supersonic case because the pressure at the nozzle must remain unchanged at the choke value while the pressure at the exit varies significantly with the exit Mach number.

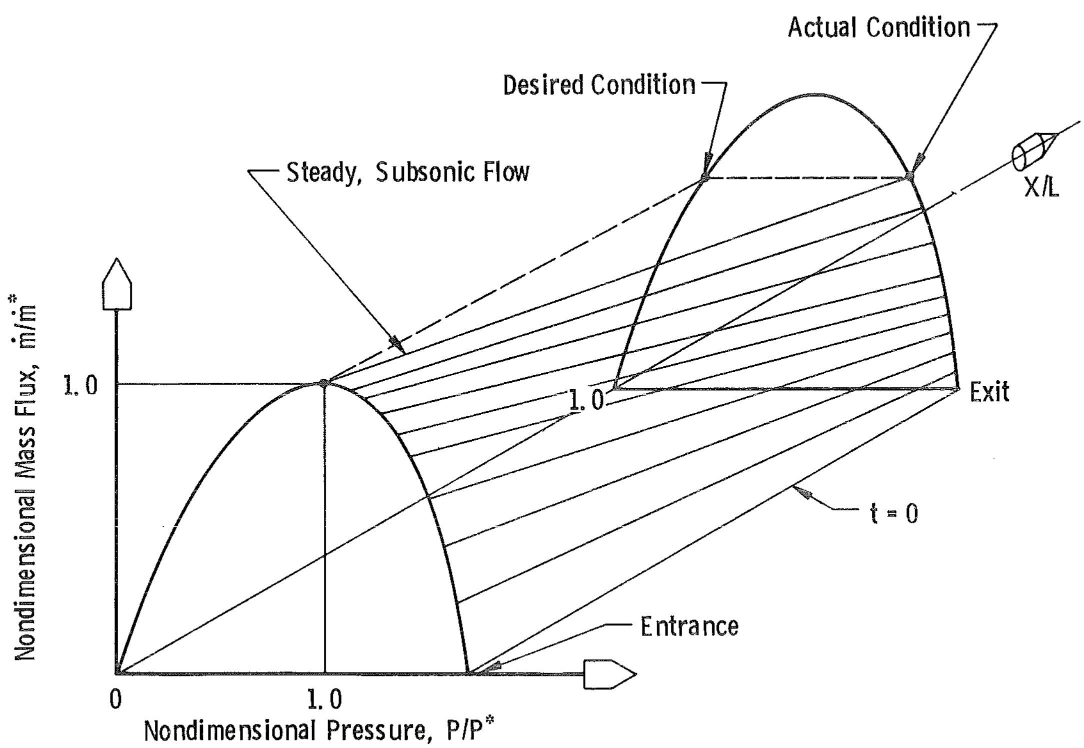


Figure 6. Energy dome versus position in test section for subsonic flow with choked nozzle.

The slopes of the constant time contours in Figs. 4 and 5 depend on the magnitude of the wall crossflow, which in turn depends partially on the pressure difference between the plenum and the test section. Since the timewise variation of the plenum pressure can be controlled by controlling the flow area-time curve of the plenum exhaust valves, it appears that the shortest starting time for the tunnel would be obtained by controlling the plenum pressure to precisely follow the test section pressure so that the plenum would reach its steady conditions simultaneously with the main valve system. This would result in the constant time contours remaining parallel right up to their final position, or up to the choke point for a supersonic run. In Fig. 6, the plenum is exhausted fast enough so that the wall crossflow is always out of the test section, resulting in less flow rate leaving the exit of the test section than entering. Thus, the constant time contour at the entrance dome reaches its peak while the point on the exit dome is forced by the plenum exhaust to become steady before reaching the peak though the desired steady condition lies on the other side of the dome and cannot be reached. Hence, it appears that the manner in which the various portions of the tunnel approach their steady conditions in time relative to each other can affect the final outcome of a run.

The foregoing discussion of the test section flow in terms of the energy domes serves as an introduction to one of the key elements of the mathematical model, namely, the steady energy equation in an unsteady environment. The domes also provide graphic visualization for the flow process.

2.2 GOAL OF THE MODELING

The purpose of this mathematical model is to study the starting process, controlled by the plenum, in order to size the plenum exhaust system; determine the effect upon start time of the interaction of the area-time curves of the main valves, flaps, and plenum exhaust; and, in general, to provide the essential information necessary for trading off facility cost and start time. To provide this information, the model must accept the following input data. The gross level mass flow rate depends upon the cross-sectional area of the supply tube and nozzle exit. The geometric factor, on which the wall crossflow primarily depends, is the porosity, the fraction of the total surface area of the test section walls drilled out to allow flow between the test section and plenum. Thus, the dimensions of the test sections and porosity must be provided along with the experimentally derived coefficients for the flow model. A key design parameter having first-order impact on the start time is the plenum volume ratioed to the test section volume. The area-time curves of the main valves, plenum exhaust valves, and the flaps are required along with the experimental coefficients for the flap flow model. Finally, the characteristics of the gas must be provided in terms of the ideal gas constant and the specific heat ratio.

This input to the model is then used to compute the following data concerning the flow. As functions of time the static and stagnation properities - pressure, density, and temperature - along with mass flow rate and Mach number are computed for three stations along the tunnel circuit: the supply tube at the nozzle entrance, the test section entrance, and the test section exit. The plenum properties along with the mass flux through the porous wall, flaps, plenum exhaust, and main valves are computed as functions of time.

There are many other considerations, neglected herein, which might be of interest for other applications. One of the most important is the boundary layer, whose growth on the walls of the supply tube and test section varies with time. This unsteadiness occurs because at any given station along the tunnel, the particles of air passing that station at succeeding times into the run have travelled over successively longer lengths of tube from their starting points. If the effect of the boundary-layer growth on the local mass flow rate is thought of in terms changing the effective flow area, one might suspect that the test section would never become steady. In reality, however, the boundary-layer growth, sufficiently late in the starting process, varies with approximately the same proportion in the nozzle and test section so that, though the effective flow areas may be varying, the area ratios (A/A*) are not. As experimentally documented in Refs. 1 and 5, this results in essentially constant Mach number once the plenum has become steady, thus justifying the neglect of the boundary layer herein.

Neglect of the boundary layer means that no prediction is made of property variation over the cross section of the flow area. Similarly, detailed variation of properties along the length of the test section is not predicted. Such information would be useful for studying wall loading or flow uniformity but is of secondary importance for present purposes. Very severe nonuniformity occurs in the diffuser section (connecting the test section and main valve manifold), which has been subjected to a detailed experimental study in Ref. 4. The complexity of the diffuser flow results from a combination of effects: shock waves, flow separation, flap exhaust, and the presence of the model or probe support sector. The performance of the diffuser is important because of its effect on the noise environment in subsonic flow in the test section and because its stagnation losses significantly impact the sizing of the real flow area of the main valve system. However, for purposes of the starting model, diffuser losses may be neglected if the main valve area is assumed to be the ideal, one-dimensional flow area needed to pass a given mass flow rate for a given set of driving stagnation conditions as determined from wave mechanics.

Three additional effects neglected herein deserve mention. First, wave spreading is neglected. This phenomenon is due to the difference in propagation speed between the leading and trailing edges of the unsteady wave. Since the wave propagation speed (equal to the local speed of sound minus the local velocity) is less for the trailing edge than the leading edge, the time delay between a change in main valve area and the sensing of this change in the supply tube is greater for the last area change than the first. In fact, this delay is different for each position along the tunnel. However, over the greatest distance of importance in the pilot facility, this difference in delay is less than 0.5 msec and is neglected in the model. Besides wave spreading, the model also neglects the finite time required for a disturbance to travel from one point to another. Such a consideration is important for determining the relative times for first motion of main valves and plenum exhaust valves; but for purposes of the starting model, the tunnel components determining start time - plenum, test section, and supply tube exit - are sufficiently close together that the propagation times (on the order of one millisecond in the pilot) are small compared with the starting time under study. However, neglect of the propagation time and wave spreading should not be construed to mean that the finite wave width is neglected. This width, or time difference between passage of a given point of the leading and trailing edges of the wave, depends primarily on the opening time of the valve but is also increased by the nonideal flow processes in the diffuser. Such effects are accounted for herein by correction of the area-time curve of the main valve. A final additional effect, accounted for empirically but not modeled in detail, is the nonisentropicity of the thermodynamics of the plenum. It has been experimentally observed that the temperature in the plenum approximates an isentropic process only during the initial portion of the starting process, but over the entire start time for the tunnel, the asymptotic plenum temperature is much closer to the stagnation temperature in the test section than that for a completely isentropic expansion. A good model of this process would have to include the mixing of the virgin plenum air with that entering from the test section as well as account for the heat transfer from the walls of the plenum. This possible refinement to the present model is not yet included.

2.3 FORMAL ASSUMPTIONS

Before proceeding to the equations comprising the mathematical model, the following list of assumptions should be reviewed:

a. Flow across all control volume surfaces is one dimensional.

b. The fluid is assumed to be a calorically perfect gas (constant specific heats).

c. Flow within the envelope comprised of the supply tube, test section, and main valves is inviscid, adiabatic, and irrotational except as accounted for by the unsteady wave equations.

d. Within this envelope and at a constant time, property variation from point to point is isentropic. Entropy variation with time is governed by the wave equations. Thus, at any given instant, the one-dimensional, variable area, isentropic equations of gas dynamics (Ref. 2) are applicable.

e. Wave propagation time and wave spreading are zero. This justifies the steady assumption needed to invoke the equations of Ref. 2.

2.4 MATHEMATICAL FORMULATION

The set of equations comprising the model naturally divides into two groups, one for subsonic flow and one for supersonic flow. Since the set of equations for supersonic flow is nearly an exact subset of the subsonic case, the latter will be presented first, followed by a discussion of the changes needed for supersonic flow. The subsonic model is in the form of 19 algebraic equations, not necessarily linear, involving 19 unknowns. This system of equations must be solved numerically at successive points in time until all properties have approached their asymptotic values. The solution at any time t depends entirely on the property values obtained for the solution at t - Δt, a short time earlier, as well as the given valve area-time curves, which may be thought of as forcing functions. Quantities which vary between t - Δt and t are usually evaluated at an intermediate time t* such that $(t - \Delta t) < t^* < t$. The time t* is usually taken as the midpoint of the time interval.

The model is based on mass conservation for three control volumes as illustrated in Fig. 2. Conservation of mass for the plenum is derived from the unsteady integral continuity equation for a control volume to give

$$\rho_p(t) = \rho_p(t - \Delta t) + [\dot{m}_{pt}(t^*) + \dot{m}_{pe}(t^*) + \dot{m}_f(t^*)] \frac{\Delta t}{V_p} \qquad (1)$$

Here ρ_p is the mass density in the plenum, assumed uniform throughout, and V_p is the volume of the plenum. The quantities $\dot{m}_{pt}(t^*)$, $\dot{m}_{pe}(t^*)$, and $\dot{m}_f(t^*)$ represent, respectively, the mass flow rates between the plenum and test section (pt), out the plenum exhaust (pe), and through the flaps (f). The formal continuity equation can not be precisely integrated because the dependence of the mass flow rates on t or ρ_p can not be written in simple closed form. However, the law of the mean provides that $\rho_p(t)$ may still be precisely computed if the flow rates are treated as constant but evaluated at a suitable intermediate point t*. If Δt is now chosen sufficiently small so that the flow rates may be suitably approximated by linear functions of time, t* can obviously be chosen as $t - 1/2\Delta t$, the midpoint. For the other two control volumes in Fig. 2, the steady continuity equation is used, having been justified by assumption (e) of the last section. By noting that Eq. (1) assumes the flap and wall crossflows are positive when flow is into the plenum, continuity for the test section becomes

$$\dot{m}_{ct}(t^*) = \dot{m}_{pt}(t^*) + \dot{m}_d(t^*) \qquad (2)$$

and for the diffuser-valve manifold control volume

$$\dot{m}_d(t^*) = \dot{m}_e(t^*) + \dot{m}_f(t^*) \tag{3}$$

The three new mass flow rates introduced here are, in terms of the subscripts, that leaving the supply tube (ct, for charge tube, as it is often called), the primary tunnel exit (e) provided by the main valves, and the diffuser-end (d) of the test section. It should be noted from Fig. 2 that $\dot{m}_d$ corresponds to a point upstream of where the flap flow enters the main stream.

Proceeding next to model each of these six mass flow rates, consider first the flow through the plenum exhaust and the main valves, which are both treated as single one-dimensional sonic orifices driven by the stagnation conditions.

$$\dot{m}_e(t^*) = a \frac{P_{e_o}(t^*) A_e(t^*)}{\sqrt{T_{e_o}(t^*)}} \tag{4}$$

$$\dot{m}_{pe}(t^*) = a \frac{P_p(t^*) A_{pe}(t^*)}{\sqrt{T_p(t^*)}} \tag{5}$$

In Eq. (4), P_{e_o} and T_{e_o} are the stagnation pressure and temperature in the valve manifold; and in Eq. (5), P_p and T_p are the pressure and temperature in the plenum, approximated as stagnant. The quantities A_e and A_{pe} are the total flow areas of the main valves and plenum exhaust valves. These areas are assumed to be the ideal, one-dimensional flow areas of a sonic orifice. If the real valve areas are used, discharge coefficients must be included in Eqs. (4) and (5). The constant a is given by

$$a = \sqrt{\left(\frac{2}{\gamma + 1}\right)^{\frac{\gamma+1}{\gamma-1}} \frac{\gamma}{R}} \tag{6}$$

where R is the ideal gas constant and γ is the ratio of the specific heats.

Consider next the flap and wall crossflows, which have been neatly modeled by Varner (Ref. 2) as simply proportional to the pressure drop across the devices. With a second order adaptation added here, Varner's model takes the following form

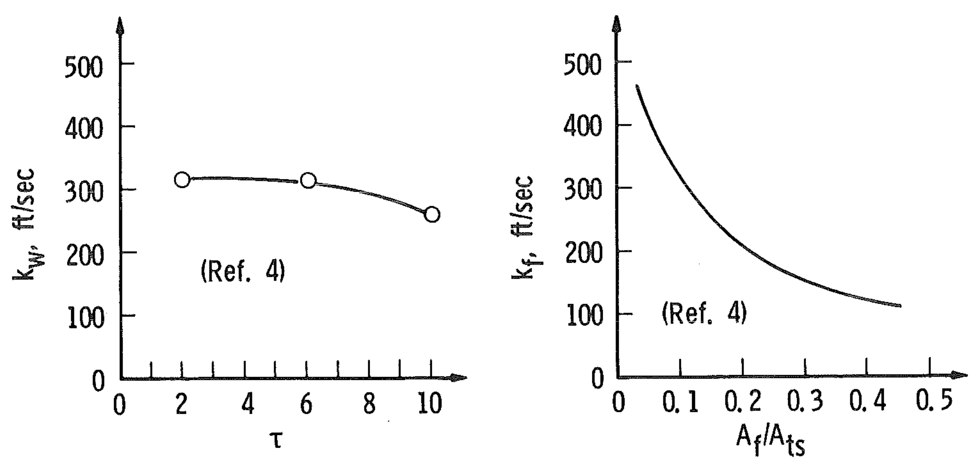
$$\dot{m}_{pt}(t^*) = -\frac{\bar{A}_w}{k_w}\left[P_p(t^*) - A_{15} P_t(t^*)\right] \tag{7}$$

$$\dot{m}_f(t^*) = -\frac{A_f(t^*)}{k_f}\left[P_p(t^*) - A_{16} P_d(t^*)\right] \tag{8}$$

Here A_w and A_f are the effective flow areas through the porous wall and through the flaps. While A_f is the actual geometric area, A_w depends on the total surface area of the test section walls (A_{tsw}), the porosity (τ), and a flow coefficient. Varner gives this relationship as

$$A_w = 0.17 \tau \, A_{tsw} \tag{9}$$

The flow coefficients k_w and k_f were determined by Varner from experimental data from Pilot HIRT and are given in Fig. 7. The values of k_w in Fig. 7 are for the porosity shown in Fig. 8. The coefficients[1] A_{15} and A_{16} multiplying, respectively, the mean test section pressure P_t and the diffuser end test section pressure P_d were added in an effort to improve the accuracy of the asymptotic values of the numerical solution. The rationale for each of these constants is different. Rigorous modeling of the crossflow must include not only the effect of pressure forces but also the momentum of the fluid as it moves along the test section wall. The coefficient A_{15} thus represents an attempt to include momentum effects as a small correction to the existing crossflow model. Experimental evidence from the pilot facility indicates that this small momentum effect can make the difference between choking and not choking when the desired steady conditions are very near sonic flow. In particular, it has been observed that during supersonic flow, where the net crossflow must be from the test section to the plenum, the test section pressure is actually slightly less than the plenum pressure.



a. Porous wall flow coefficient versus porosity (τ)

b. Ejector flap flow coefficient versus area ratio (A_f/A_{ts})

Figure 7. Porous wall and flap flow coefficients.

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[1]The subscripts 15, 16, and 17 have no significance beyond consistency with variable names in the computer program.

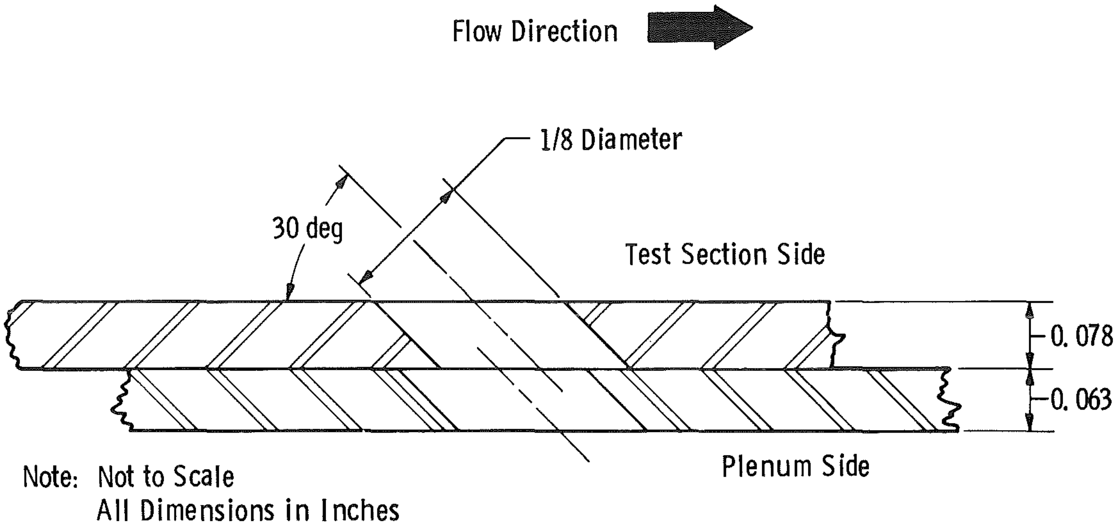


Figure 8. Wall porosity in Pilot HIRT.

This has been attributed to the fluid momentum in the test section overcoming the slightly adverse pressure gradient. The other constant, A_{16} in the flap model, was added to account for some of the losses in the upstream portion of the diffuser. Unfortunately, both of these constants were found to be functions of the test section Mach number, thus indicating the need for more accurate modeling.

The mean test section pressure P_t in Eq. (7) is computed from a weighted average of the pressure at the nozzle-end of the test section P_n and at the diffuser end P_d. That is,

$$P_t(t^*) = (1 - A_{17})P_n(t^*) + A_{17}P_d(t^*) \tag{10}$$

where $0 \leqslant A_{17} \leqslant 1$. Since a detailed model of axial property variation in the test section has not yet been included in the start model, properties are computed only at the nozzle and diffuser ends of the test section. For subsonic flows, the value of A_{17} was not found critical to the accuracy of the solution and was thus taken as 0.5, assuming a linear variation. For supersonic flow, a value of 0.9 was used to account for the more pronounced axial gradients.

The remaining two mass flow rates ($\dot{m}_{ct}$ and $\dot{m}_d$) may be related to pressures already introduced above using the steady energy equation discussed earlier and shown in Fig. 3. At the diffuser end of the test section, the energy equation is

$$\left[\frac{\dot{m}_d(t^*)}{\dot{m}_o(t^*)}\right]^2 = \frac{2}{\gamma - 1}\left\{\left[\frac{P_d(*)}{P_{ct_o}(t^*)}\right]^{\frac{2}{\gamma}} - \left[\frac{P_d(t^*)}{P_{ct_o}(t^*)}\right]^{\frac{\gamma+1}{\gamma}}\right\} \tag{11}$$

where as before the subscript "ct" refers to the charge tube and the subscript "o" indicates stagnation properties. The quantiy $\dot{m}_o$ is defined as

$$\dot{m}_o(t^*) \equiv \sqrt{\frac{\gamma}{R}} \frac{P_{ct_o}(t^*)}{\sqrt{T_{ct_o}(t^*)}} A_{ts} \tag{12}$$

where A_{ts} is the cross-sectional area of the test section. The stagnation properties (P_{ct_o} and T_{ct_o}) are thought of as originating from the unsteady wave when it reaches the charge tube and are assumed the same, for any given time, throughout all of the flow envelope except the plenum. At the nozzle end of the test section, the flow rate is equal to that in the charge tube, since its value has not yet been modified by any wall crossflow. At this station, the energy equation is, therefore,

$$\left[\frac{\dot{m}_{ct}(t^*)}{\dot{m}_{o(t^*)}}\right]^2 = \frac{2}{\gamma - 1}\left\{\left[\frac{P_n(t^*)}{P_{ct_o}(t^*)}\right]^{\frac{2}{\gamma}} - \left[\frac{P_n(t^*)}{P_{ct_o}(t^*)}\right]^{\frac{\gamma+1}{\gamma}}\right\} \tag{13}$$

To complete the portion of the model not arising from the unsteady wave, the thermodynamic equations of state for the plenum are needed. To compute the properties at t* for use in Eqs. (5), (7), and (8) while Eq. (1) gives the density at t, the density at t* is computed from

$$\rho_p(t^*) = 1/2[\rho_p(t) + \rho_p(t - \Delta t)] \tag{14}$$

The plenum temperature is assumed equal to the greater of the isentropic temperature and the stagnation temperature in the test section.

That is,

$$T_p(t^*) = \max\left\{T_p(t^* - \Delta t)\left[\frac{\rho_p(t^*)}{\rho_p(t^* - \Delta t)}\right]^{\gamma-1}, T_{ct_o}(t^*)\right\} \tag{15}$$

In either event, the pressure may then be obtained from the perfect gas law:

$$P_p(t^*) = \rho_p(t^*) R T_p(t^*) \tag{16}$$

Closing the system of equations presented so far requires relationships for how the stagnation properties vary in time. A careful accounting of the number of equations and the number of unknowns to this point would reveal that, given values of P_{ct_o} and T_{ct_o} and assuming $P_{e_o} = P_{ct_o}$ and $T_{e_o} = T_{ct_o}$ (which is what is done for the subsonic case), it is possible to compute the value of $\dot{m}_{ct}$. This value of the flow rate from the charge tube represents that required by the sum total of all the expansion waves which at a given time have reached the charge tube from all parts of the tunnel. That is, $\dot{m}_{ct}$ identifies an intermediate point within the entire unsteady wave, which begins with the first motion of a valve somewhere in the tunnel and ends when the plenum reaches its asymptotic pressure. Thus, $\dot{m}_{ct}$ may be used to compute all other stagnation properties for that point in the unsteady wave. By using the equations of Ref. 3 and after some algebra, the charge tube Mach number at the desired point in the wave may be related to $\dot{m}_{ct}$ by the equation:

$$\dot{m}_{ct}(t^*) = M_{ct}(t^*)\left[1 + \frac{\gamma - 1}{2} M_{ct}(t^*)\right]^{-\frac{\gamma+1}{\gamma-1}} \dot{m}_c \tag{17}$$

where $\dot{m}_c$ is defined from

$$\dot{m}_c = \sqrt{\frac{\gamma}{R}} \frac{P_c}{\sqrt{T_c}} A_{ct} \tag{18}$$

Here A_{ct} is the cross-sectional area of the charge tube, and P_c and T_c are the charge conditions, that is, the air pressure and temperature after the tunnel has been pumped up but before any valves are opened. These charge conditions are assumed to apply uniformly throughout the envelope, including the plenum. After obtaining the charge tube Mach number, the stagnation pressure and temperature are readily computed from the following equations from Ref. 3:

$$P_{ct_o}(t^*) = \left\{\frac{1 + \frac{\gamma - 1}{2} M_{ct}^2(t^*)}{\left[1 + \frac{\gamma - 1}{2} M_{ct}(t^*)\right]^2}\right\}^{\frac{\gamma}{\gamma-1}} P_c \tag{19}$$

$$T_{ct_o}(t^*) = \left\{\frac{1 + \frac{\gamma - 1}{2} M_{ct}^2(t^*)}{\left[1 + \frac{\gamma - 1}{2} M_{ct}(t^*)\right]^2}\right\} T_c \tag{20}$$

Equations (1) through (20) thus comprise the subsonic portion of the starting model and are summarized in Table 1. The supersonic case is physically different from the subsonic case and requires solution of a different set of equations as noted in Table 1. The distinguishing factor of the supersonic case is that the nozzle exit is choked, making the flow rate and stagnation conditions steady there. Once the nozzle chokes, the charge tube Mach number is a constant depending only on the area ratio between the charge tube and nozzle exit. From Ref. 2, the steady Mach number can be obtained by reverting the equation:

Table 1. List of Exact Simultaneous Equations

Equation	Independent Variable to be Computed	Included in Supersonic Case?	Text Equation Number	Program Equation Number
$\rho_p(t) = \rho_p(t - \Delta t) + [\dot{m}_{pt}(t^*) + \dot{m}_{pe}(t^*) + \dot{m}_f(t^*)] \frac{\Delta t}{V_p}$	$\rho_p(t)$	Yes	1	5
$\dot{m}_{ct}(t^*) = \dot{m}_{pt}(t^*) + \dot{m}_d(t^*)$	$\dot{m}_{ct}$, M < 1 $\dot{m}_d$, M > 1	Yes	2	6
$\dot{m}_d(t^*) = \dot{m}_e(t^*) + \dot{m}_f(t^*)$	$\dot{m}_d$	No	3	7
$\dot{m}_e(t^*) = \alpha \frac{P_{e_o}(t^*) A_e(t^*)}{\sqrt{T_{e_o}(t^*)}}$	$\dot{m}_e$	No	4	1
$\dot{m}_{pe}(t^*) = \alpha \frac{P_p(t^*) A_{pe}(t^*)}{\sqrt{T_p(t^*)}}$	$\dot{m}_{pe}$	Yes	5	2
$\dot{m}_{pt}(t^*) = -\frac{A_w}{k_w}[P_p(t^*) - A_{15} P_t(t^*)]$	$\dot{m}_{pt}$	Yes	7	4
$\dot{m}_f(t^*) = -\frac{A_f(t^*)}{k_f}[P_p(t^*) - A_{16} P_d(t^*)]$	$\dot{m}_f$	Yes	8	3
$P_t(t^*) = (1 - A_{17})P_n(t^*) + A_{17}P_d(t^*)$	P_t	Yes	10	11
$\left[\frac{\dot{m}_d(t^*)}{\dot{m}_o(t^*)}\right]^2 = \frac{2}{\gamma - 1}\left\{\left[\frac{P_d(t^*)}{P_{ct_o}(t^*)}\right]^{\frac{2}{\gamma}} - \left[\frac{P_d(t^*)}{P_{ct_o}(t^*)}\right]^{\frac{\gamma+1}{\gamma}}\right\}$	P_d [a]	Yes	11	12
$\left[\frac{\dot{m}_{ct}(t^*)}{\dot{m}_o(t^*)}\right]^2 = \frac{2}{\gamma - 1}\left\{\left[\frac{P_n(t^*)}{P_{ct_o}(t^*)}\right]^{\frac{2}{\gamma}} - \left[\frac{P_n(t^*)}{P_{ct_o}(t^*)}\right]^{\frac{\gamma+1}{\gamma}}\right\}$	P_n [a]	No	13	13
$\dot{m}_o(t^*) = \sqrt{\frac{\gamma}{R}} \frac{P_{ct_o}(t^*)}{\sqrt{T_{ct_o}(t^*)}} A_{ts}$	$\dot{m}_o$	No	12	14
$\rho_p(t^*) = 1/2[\rho_p(t) + \rho_p(t - \Delta t)]$	$\rho_p(t^*)$	Yes	14	18
$T_p(t^*) = \max\left\{T_p(t^* - \Delta t)\left[\frac{\rho_p(t^*)}{\rho_p(t^* - \Delta t)}\right]^{\gamma-1}, T_{ct_o}(t^*)\right\}$	T_p	Yes	15	17
$P_p(t^*) = \rho_p(t^*) R T_p(t^*)$	P_p	Yes	16	19
$\dot{m}_{ct}(t^*) = M_{ct}(t^*)\left[1 + \frac{\gamma - 1}{2} M_{ct}(t^*)\right]^{-\frac{\gamma+1}{\gamma-1}} \dot{m}_c$	M_{ct} [a]	No	17	8
$P_{ct_o}(t^*) = \left\{\frac{1 + \frac{\gamma - 1}{2} M_{ct}^2(t^*)}{\left[1 + \frac{\gamma - 1}{2} M_{ct}(t^*)\right]^2}\right\}^{\frac{\gamma}{\gamma-1}} P_c$	P_{ct_o}	No	19	9
$T_{ct_o}(t^*) = \left\{\frac{1 + \frac{\gamma - 1}{2} M_{ct}^2(t^*)}{\left[1 + \frac{\gamma - 1}{2} M_{ct}(t^*)\right]^2}\right\} T_c$	T_{ct_o}	No	20	10
$P_{e_o}(t^*) = P_{ct_o}(t^*), T_{e_o}(t^*) = T_{ct_o}(t^*)$		No	—	—

[a]Require Numerical Reversion

$$\frac{A_{ct}}{A_{ts}} = \frac{1}{M_{ct}(t^*)}\left\{\frac{2}{\gamma + 1}\left[1 + \frac{\gamma - 1}{2} M_{ct}^2(t^*)\right]\right\}^{\frac{\gamma+1}{2(\gamma-1)}} \tag{21}$$

With this final Mach number, the steady stagnation conditions (P_{ct_o}, T_{ct_o}, and $\dot{m}_o$) along with the steady charge tube flow rate ($\dot{m}_{ct}$) can be computed one final time from Eqs. (19), (20), (13), and (17), after which these equations and variables may be dropped from the simultaneous solution. Since $\dot{m}_{ct}$ is now constant, the flow rate leaving the test section ($\dot{m}_d$) is solely dependent on the wall crossflow ($\dot{m}_{pt}$) according to Eq. (2) and is independent of the flow rate out the main valves ($\dot{m}_e$), assuming the valve area A_e is sufficient to pass all the charge tube flow not removed by the plenum exhaust. Thus, Eqs. (3) and (4) may also be dropped from the system of equations. This is fortunate since it is no longer true that $P_{e_o} = P_{ct_o}$, which results from the nonisentropic recompression of the supersonic flow entering the diffuser. Thus, the original system of 19 equations and 19 unknowns reduces to 10 equations and 10 unknowns for the supersonic case.

These two sets of equations were solved using an iterational technique which unfortunately failed to converge in the vicinity of the choke point in time. To provide an alternate solution procedure when the iterational technique failed to converge, a small perturbation solution was developed for the original exact equations. The small perturbation solution was then used as an initial guess for the iterational procedure when it converged and as the complete solution when it did not. The results of this lengthy derivation are recorded in Appendix A, but the essential ideas are discussed below.

The exact solution already assumes that Δt is a small quantity. For the small perturbation solution, therefore, any of the 19 variables at time t^* may be assumed to be related to their values at $t^* - \Delta t$ by the general form

$$v_i(t^*) = v_i(t^* - \Delta t) + \epsilon_i(t^*) \tag{22}$$

where ϵ_i is the small increment in the variable and $i = 1, 2, ..., 19$. If these small perturbation equations are used to expand the original exact equations, a new system of equations involving the increments rather than the variables themselves is obtained. For all exact equations, except the energy equations relating the pressure and mass flux at the entrance and exit of the test section (Eqs. (11) and (13)), only terms of order ϵ_i need be retained in the small perturbation equations. Such is not the case for the energy equations because in the region of the peak (or choke point) in Fig. 3, there is no linear approximation to the function. In the expanded equation, the coefficient of ϵ_i approaches zero as the Mach number approaches one. Thus, the term of order ϵ_i^2, whose coefficient is nonzero at Mach number one, governs the form of the expansion. The resulting subsonic system of equations is thus comprised of 17 linear equations and 2 second-degree equations, which can be solved analytically. The supersonic case is composed of 9 linear equations and 1 of second degree.

2.5 SOLUTION PROCEDURE

The procedure used to solve these two systems of equations is discussed in the following section. Included is a discussion of the overall logical procedure, the order in which the equations of the exact solutions are used, convergence considerations, and a general description of the computer program used to accomplish the calculation. The general solution procedure is illustrated by the flow chart in Fig. 9. The decision whether to use the supersonic or subsonic branch is decided by whether $P_d(t^* - \Delta t) < P^*$ or $P_d(t^* - \Delta t) > P^*$, that is whether the diffuser end of the test section was supersonic or subsonic at the midpoint of the previous time interval. If the previous interval was supersonic, the current one is also assumed to be supersonic. If the previous interval was subsonic but $1 - M(t^* - \Delta t) \leqslant M(t^* - \Delta t) - M(t^* - 2\Delta t)$, then the supersonic branch is used for the current time interval; otherwise the solution is assumed to remain subsonic. This criterion is checked for both ends of the test section, and the switch to the supersonic branch is contingent upon either or both positions satisfying the inequality. In either event, the small perturbation solution is computed to provide a good starting point for the exact iterational procedure. If convergence does not occur before a given number of iterations, the small perturbation solution is used as the final solution, and the next time interval is begun.

The "exact iterational procedure" referred to above is accomplished by taking an initial guess for one of the 19 variables and then proceeding from equation to equation, determining new values for each of the 19 variables until a complete circuit is made and a second value of the variable initially guessed at is obtained. This process is repeated until the difference between two successive values of certain of the variables is within a preset limit. For the subsonic case, the equation order is as follows:

4, 3, 11, 10, 7, 2, 17, 19, 20, 12, 13, 10, 7, 8, 1, 14, 15, 16,
5, ...

The supersonic equation order is

10, 7, 2, 11, 10, 7, 8, 1, 14, 15, 16, 5, ...

Some of these equations (Eqs. (11), (13), and (17)) require reversion from the form given but cannot be reverted analytically in closed form and must be solved numerically. The variable to be solved for in each equation is indicated in Table 1, and the three requiring numerical reversion are marked with an asterisk.

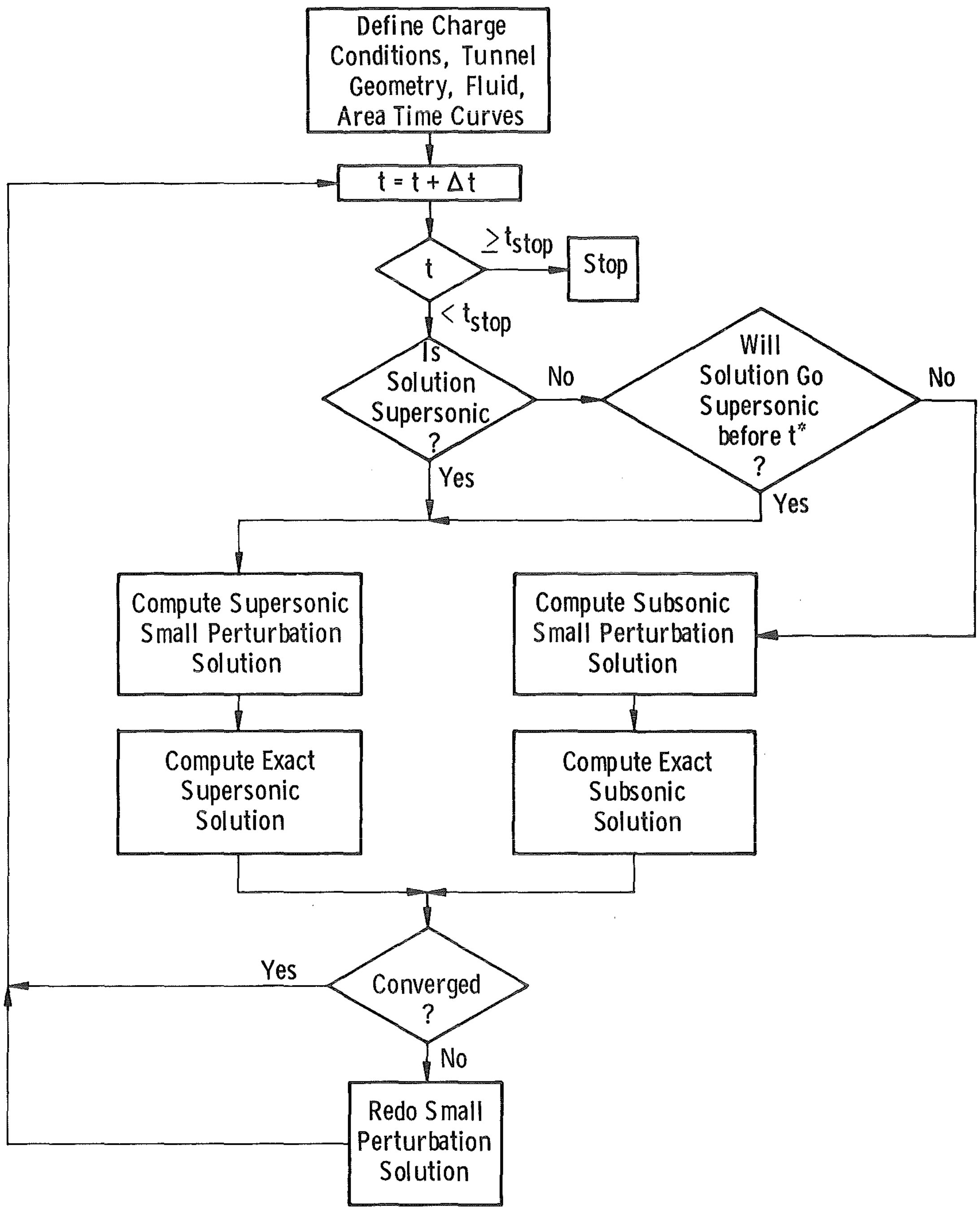


Figure 9. Flow chart of solution procedure.

The complete solution thus requires numerical iteration at three distinct levels, which necessitates careful consideration of convergence criteria as well as what to do when the criteria can not be met because of stability problems. The most basic level of numerical iteration involves reversion of the two energy equations and the mass flux - Mach number wave equation. Considering the general case where the function Y = F(X) must be solved for X given a value of Y and a guess X_1, the procedure is simply to adjust X_1 in the direction which reduces the error criterion

$$E_1 = \frac{Y - F(X)}{Y} \tag{23}$$

until $|E_1| \leqslant |E_{max}|$, E_{max} being the present, maximum allowable error. The precise logic of the procedure is illustrated in the flow chart in Fig. 10. Since this procedure must

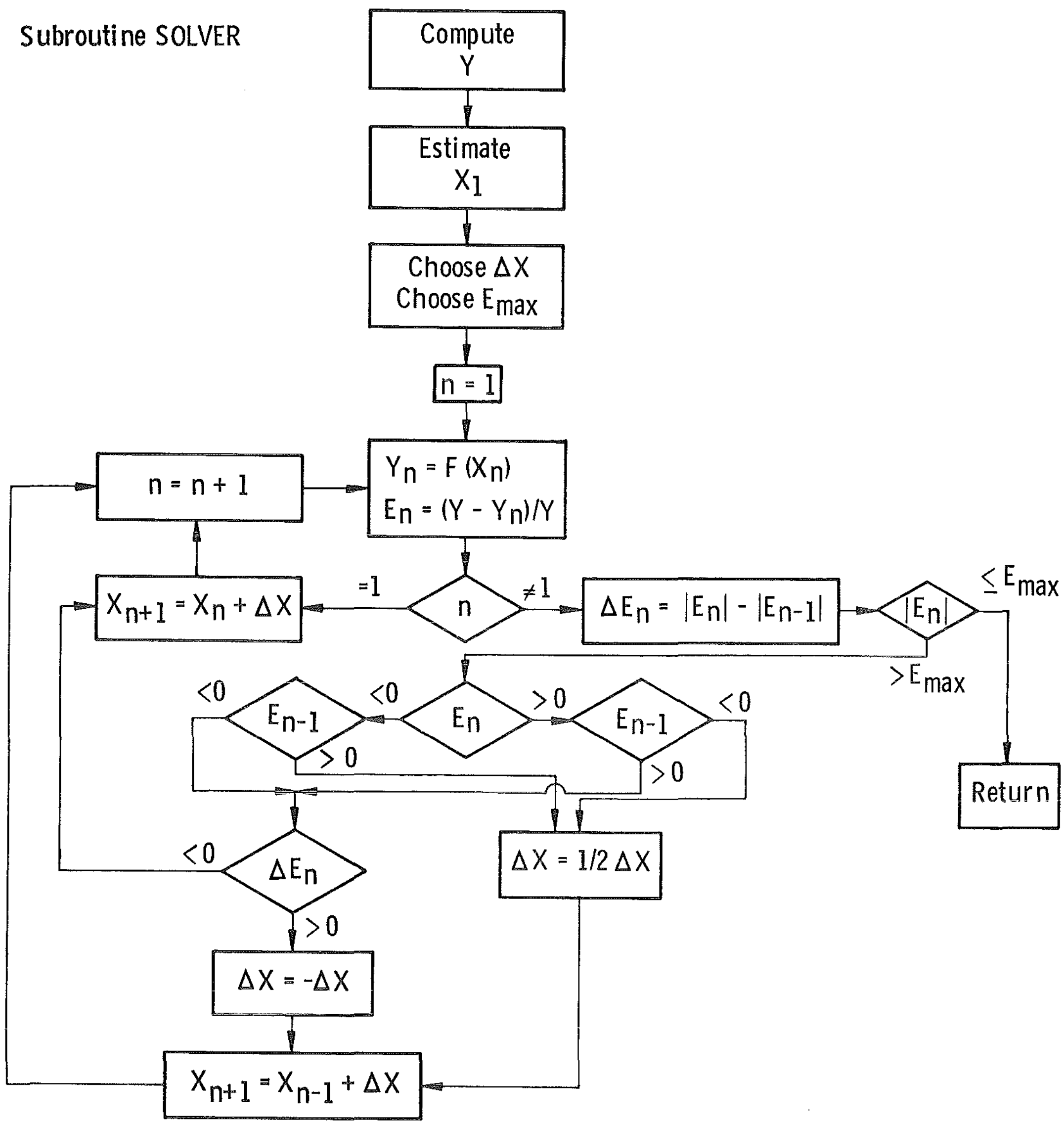


Figure 10. Logic for numerical solution of an algebraic equation Y = F(X) for X, given Y when $X = F^{-1}(Y)$ is not a closed form function.

be repeated many times at each time interval, it is of considerable importance (because of impact on computer time) to achieve a solution with as few iterations as possible. Since the number of iterations depends to a large extent on the accuracy of the guess X_1, considerable effort was expended in obtaining approximate reversions of the three equations. It was inadvertently discovered that the energy equation may be approximated with surprising accuracy over the entire range of present interest with a single ellipse, the reversion of which is trivial. The wave equation presented more of a problem. Since an easily revertable second-degree expansion around $M_{ct} = 0$ failed to match the accuracy of the elliptic energy equation, the expansion was carried to the seventh degree and then formally reverted according to the procedure of Ref. 6. These expansions are summarized in Appendix B.

The next higher level of iteration is, of course, the simultaneous solution of the exact model equations, during which stability problems were encountered in the vicinity of the choke point. The error criterion for halting the iteration may be generally expressed as

$$\left| \frac{v_i^{(n)} - v_i^{(n+1)}}{\frac{1}{2}\left[v_i^{(n)} + v_i^{(n+1)}\right]} \right| \leq P_{err} \tag{24}$$

where test variables (v_i) are the pressures P_n, $P_p(t)$, $P_p(t^*)$, P_d, P_t, and P_{ct_o}; P_{err} is the maximum allowable error; and n is the iteration number. Figure 11 illustrates the stability problem encountered in striving to meet this error limit. Shown is how the plenum pressure P_p (t^*) varied with iteration number at two succeeding time points, one converging and one not. Such stability problems are known to occur in applying the iterational technique to locating the intersection of two curves on a plane when the curves have the same slope (same or opposite sign) at the point of intersection. Whether this simple explanation in 2-space is applicable to 19-space where no two of the 19 functions lie in the same plane is unclear. In any event, improvement in convergence rate was sought via the following procedures, most of which improved the situation:

a. Relative Errors. It was found that if E_{max} was much greater than 1/10 P_{err}, the numerical reversions could oscillate enough themselves from one iteration to the next to slow convergence.

b. Computational Precision. Single precision arithmetic (~8 digits on an IBM 370) was found inadequate to achieve errors of $E_{max} = 10^{-5}$ ($P_{err} = 10^{-4}$), and double precision (~16 digits) was, therefore, adopted.

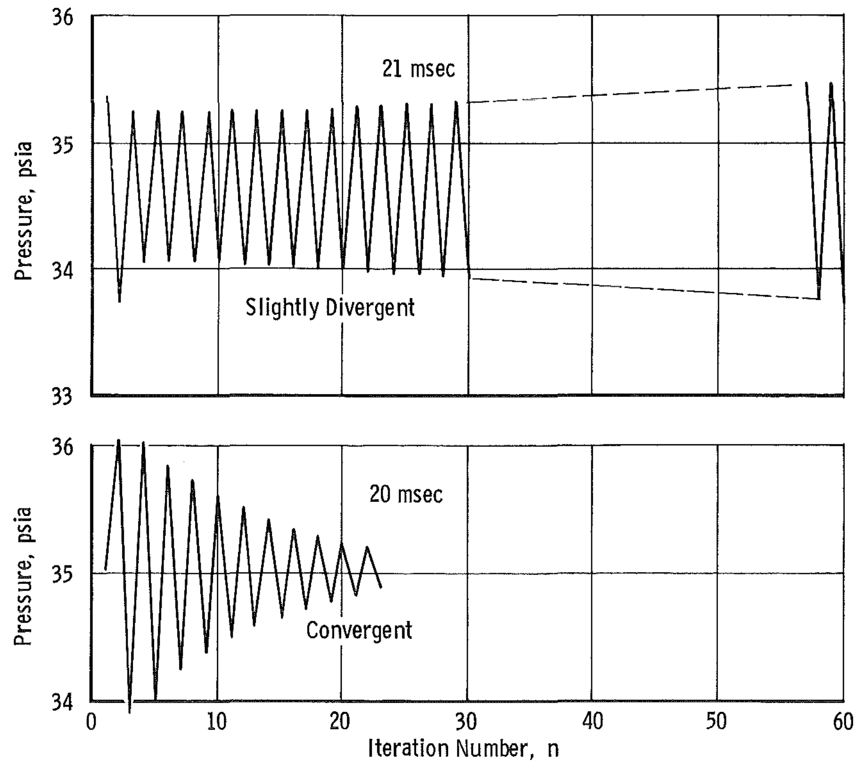


Figure 11. Plenum pressure versus iteration number for convergent and divergent cases.

c. Solution Weighting. The clearly periodic oscillation of Fig. 11 suggests that the average of any two successive values should be closer to the final asymptote than either value. Accordingly, solution weighting,

$$v_i^{(n)} = A_{11} v_i^{(n)} + (1 - A_{11}) v_i^{(n+1)} \tag{25}$$

was employed on a regular basis.

d. Weight Cutting. It was further discovered that convergence rate could be greatly improved after the number of iterations reached a certain point if a lesser weight was applied to the current value $v_i^{(n)}$.

e. Error Cutting. It was found that, later in a computation when some of the pressures were very near their asymptotes, the amount of variation from one time point to the next eventually approached the error limit. This in effect allowed these values to vary at random within the error limits and deteriorate the convergence rate. It was thus found prudent to reduce the error limits as necessary so as to maintain

$$P_{err} \leq \left| \frac{v_i(t^*) - v_i(t^* - \Delta t)}{\frac{1}{2}[v_i(t^*) + v_i(t^* - \Delta t)]} \right| \tag{26}$$

and $E_{max} \leqslant 1/10\ P_{err}$.

f. Extrapolation. A second-order extrapolation function

$$v_i(t^*) = 2v_i(t^* - \Delta t) - v_i(t^* - 2\Delta t) \tag{27}$$

was tested in an effort to improve the starting values for iteration through the 19 equations, but this generally produced no improvement in convergence rate. A third-order function

$$v_i(t^*) = 3v_i(t^* - \Delta t) - 3v_i(t^* - 2\Delta t) + v_i(t^* - 3\Delta t) \tag{28}$$

was found not much better. Ultimately, of course, it is illogical to expect any finite order extrapolation scheme to predict the effect of changes in the forcing functions (area-time curves) if those coming changes had not been anticipated by the derivatives of less than that order.

g. Small Perturbation Solution. In place of an extrapolation function, there was used the more logical small perturbation solution. This considerably improved the convergence rate and provided sufficiently accurate results in lieu of the exact solution when it failed to converge in a reasonable length of time.

The complete mathematical model along with the above described convergence enhancement logic have been programmed in Fortran IV for solution on an IBM 370/165. The computer program HIRTSM1 (for HIRT Starting Model) is composed of the normally expected components: the main program (MAIN) containing the exact equations, the convergence control logic, and the overall solution control logic; subroutines to control input (INPUT), output (PRINT and DUMP), and variable definition and initialization (CONST and INIT): and a subroutine which performs the calculation for the analytical solution to the simultaneous small perturbation equations (SMPERT). In addition, the program contains a package of utility subroutines: one routine contains the logic of Fig. 10 to numerically revert any given function (SOLVER); a second expands out the binominal coefficients (BINOM) to give a series which is reverted by a third subroutine (REVERT) to the seventh-degree term; a fourth subroutine (QSIMUL) determines the points of intersection of two conics (the two final energy equations resulting from SMPERT) by converting them to a single fourth-degree polynominal, which has an exact analytical solution for the four roots (QANDC). Use of this program is described in Appendix C.

The program can be run in a partition of 110K bytes and easily completes about 200 time increments in less than a minute of central processor time, though occasionally a run may require up to three minutes. Peripheral storage is not essential, though provisions are made to dump the entire solution on to a direct (random) access data set (such as a disk file) so that the solution may be picked up at any point and continued. The results of calculations with HIRTSM1 are compared in the next section with experimental results from the Pilot HIRT facility.

3.0 RESULTS

Presented below is a comparison between the mathematical model and experimental pressure-time histories from Pilot HIRT. Included is a brief description of those characteristics of the tunnel important to the model. After a comparison of the model and data, some other results of the calculations are shown. The section concludes with a discussion of how the model can be applied in the design of certain portions of the tunnel.

3.1 DESCRIPTION OF PILOT HARDWARE

Figure 12 shows an elevation line drawing of the Pilot HIRT facility, to which the present mathematical model was applied. Figure 13 shows most of the geometric data required by the model and also accurately illustrates the real life hardware, which is simplified in the model. The geometric parameters in the precise form used in the model are summarized in Table 2. The tunnel uses two alternate types of starting devices, the sliding sleeve valve shown in Fig. 13 and, for quicker starts, a Mylar® diaphragm and cutter located at the interface of the diffuser and the valve assembly. The plenum exhaust system, shown schematically in Fig. 14, also uses a diaphragm in addition to two valves to control the exhaust flow. The diaphragm initiates the flow, and the ball valve, whose setting cannot be changed during a run, determines the amount of plenum exhaust during the steady portion of the run. The quick-acting valve, however, may be rapidly closed during the run to provide a temporarily elevated plenum exhaust in excess of what the ball valve will pass. The complete system in Fig. 14 is modeled as the area-time curve of a one-dimensional sonic orifice, as is the multiple port system on the main valve.

The portion of the tunnel shown in Fig. 13 was heavily instrumented with pressure taps to measure pressure-time histories at various locations in the nozzle, test section, diffuser, and plenum. Output from the pressure transducers was sampled every 2 msec by a data acquisition system based on a PDP 11/10 digital computer with certain of the signals also displayed on a recording oscillograph. Of primary interest here are the plenum pressure-time histories, which comprise the primary basis for comparison of the theory and experiment.

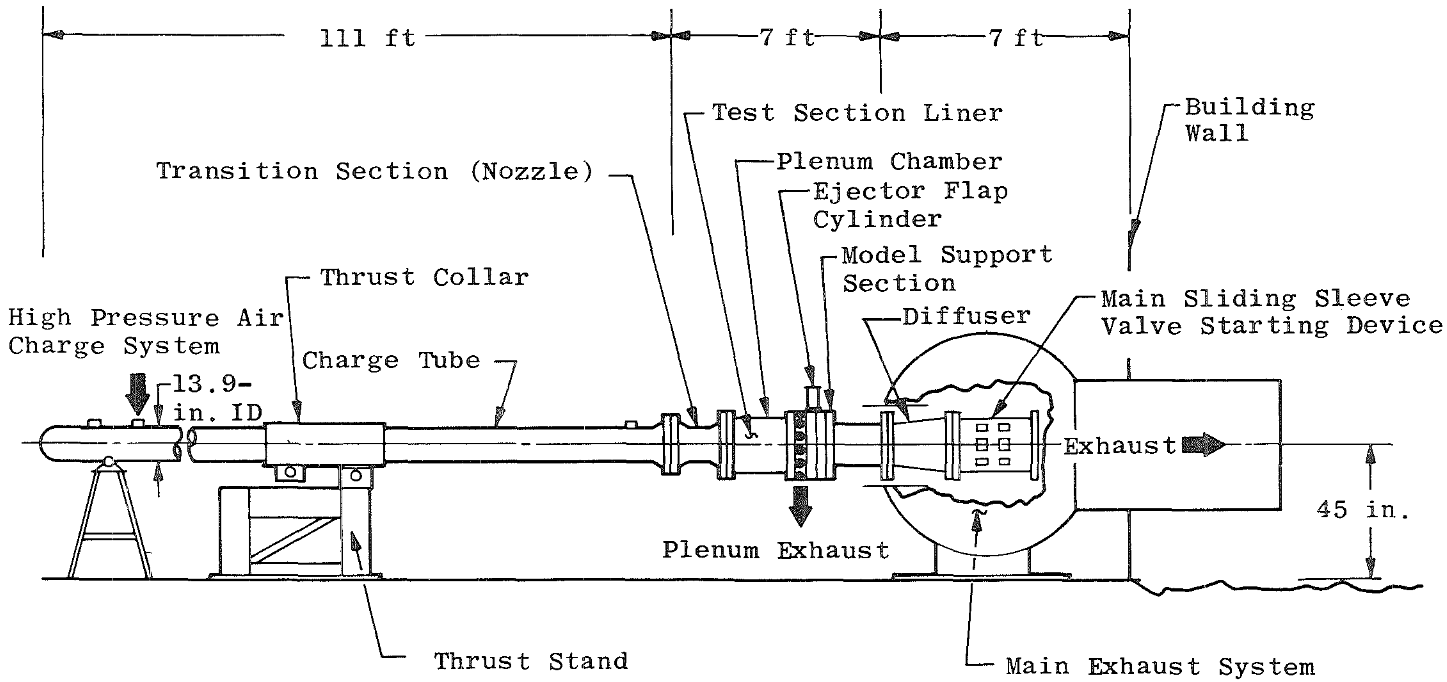


Figure 12. Pilot HIRT elevation line drawing.

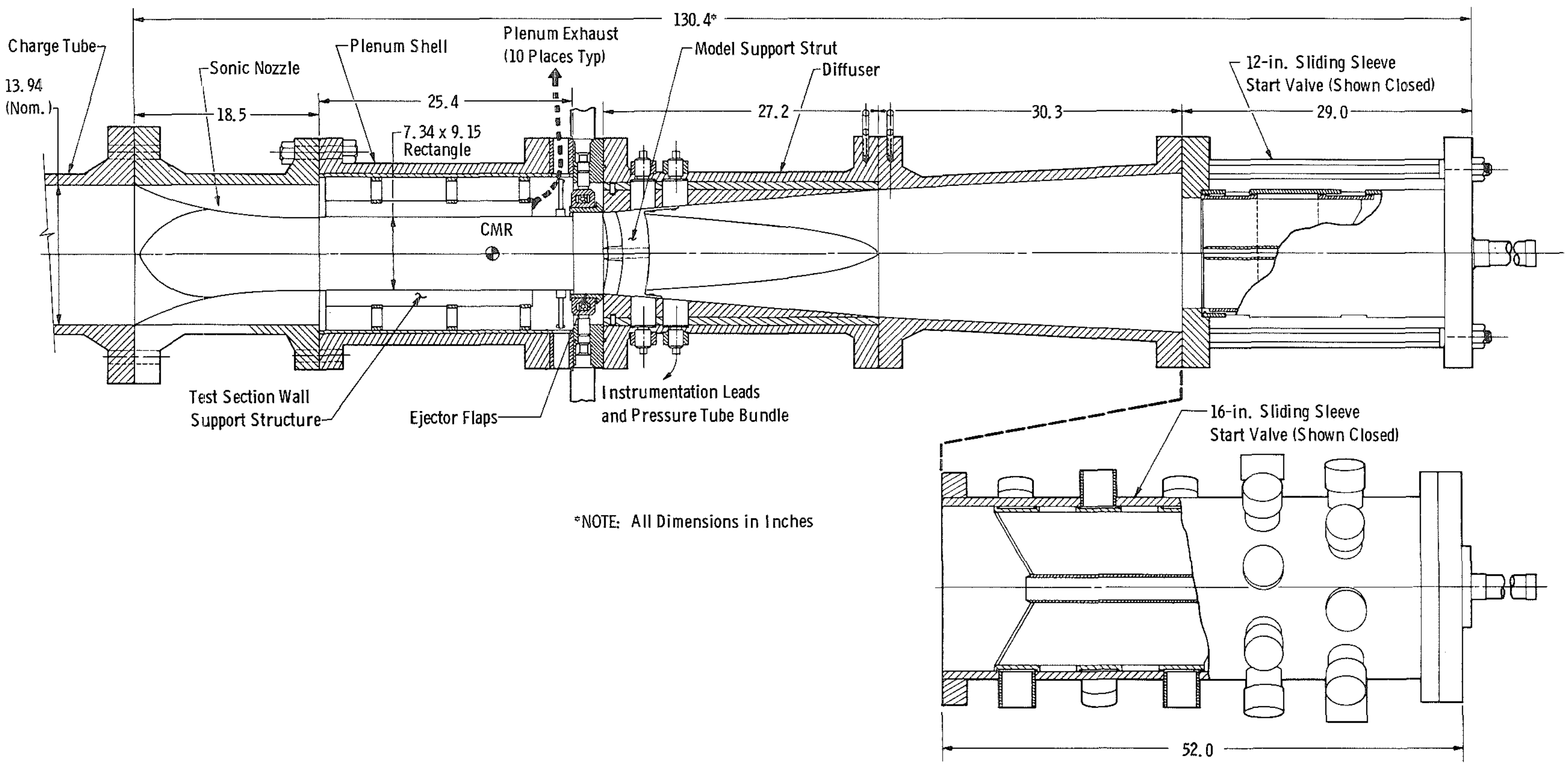


Figure 13. Cross-sectional view of nozzle, test section, diffuser, and main valve system.

Table 2. Geometric Data for Pilot HIRT Required by Mathematical Model

Charge Tube Diameter	1.162 ft
Charge Tube Flow Area	1.060 ft^2
Ratio of Charge Tube Area to Test Section Area	2.271
Test Section Length	2.114 ft
Test Section Width	0.7633 ft
Test Section Height	0.6117 ft
Test Section Flow Area	0.4669 ft^2
Test Section Wall Surface Area	5.813 ft^2
Test Section Porosity	3.5 to 10%
Test Section Volume	0.9870 ft^3
Flap Flow Area	0 to 0.2062 ft^2
Ratio of Plenum Volume to Test Section Volume	1.75 to 4.0
Nominally	2.8

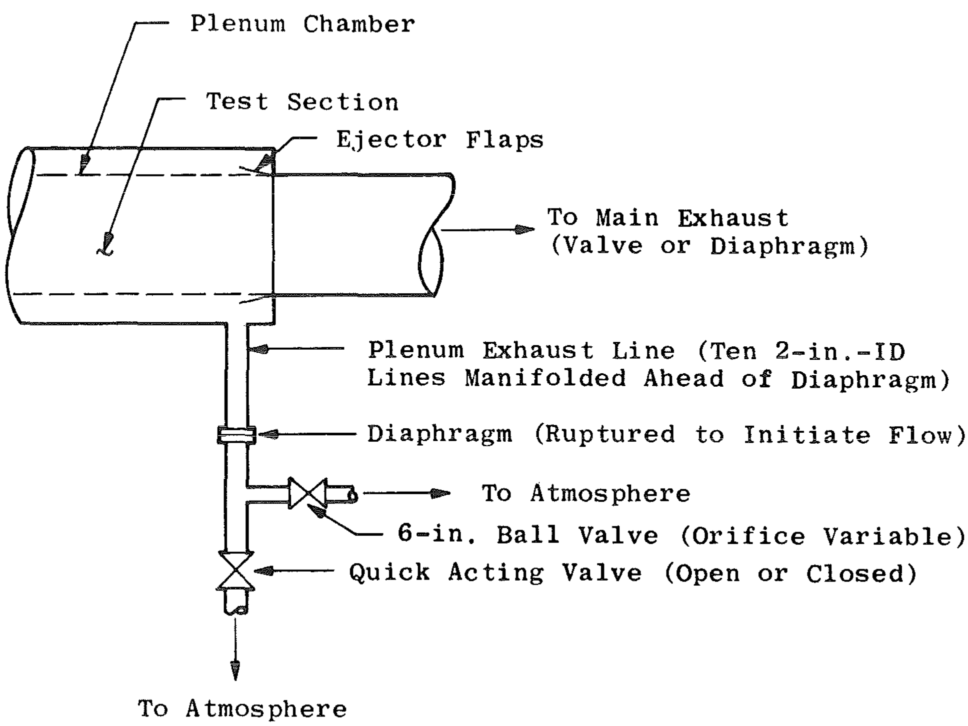


Figure 14. Plenum exhaust system.

3.2 COMPARISON OF MATH MODEL AND EXPERIMENT

Data for nine different tunnel settings were studied with the mathematical model. Some basic data for runs typical of these nine conditions are summarized in Table 3. The data of primary interest in this table include the plenum-to-test section volume ratio, porosity, the opening times of the main valve and plenum exhaust valve, the maximum plenum exhaust area, and the experimental test section Mach number. The conditions listed for Run 2258 may be considered nominal values from which variations in plenum volume, porosity, flap setting, and test section Mach number were examined.

Figure 15 compares the experimental plenum pressure as a function of time with the present mathematical model for the nominal conditions (Run 2258). The data illustrated is for a plenum volume 2.8 times the test section volume, a porosity of 4-1/2 percent, and a flap setting of 0.4 in. (the gap between the flap and the test section wall where the flap flow empties into the diffuser). The main starting device was a Mylar diaphragm; and the exit flow area, the primary factor determining the asymptotic test section Mach number (0.921), was obtained by capping off the proper number of exit ports on the main exhaust manifold (Fig. 13, 16-in. valve). Since the desired Mach number was subsonic, the plenum exhaust system was not used. The resulting data for these tunnel settings are plotted in Fig. 15 as circles, and the solid line represents the output of the computer program. The program was run for the indicated tunnel settings (Table 3), but several not readily apparent inputs were assumed. The starting device (diaphragm) was treated as a linear area-time curve reaching its maximum area in 2 msec. The maximum area shown in Table 3 is approximately 99.46 percent of the test section flow area, which is based on the ideal, one-dimensional flow area ratio needed to produce a test section Mach number of 0.921. The resulting theoretical plenum pressure-time history shown in Fig. 15 agrees well with the experimental data. The greatest discrepancy occurs at 25 msec and reaches a peak there of 6.5 percent. This difference, due to a temporary leveling of the experimental data between 10 and 25 msec, results from the finite time required for the initial expansion wave to traverse the plenum volume, which includes the plenum exhaust lines shown in Fig. 14. These lines extend to a distance of about 4 ft from the major portion of the plenum. Since the model assumes a uniform plenum, it cannot account for this factor. Figure 15 also illustrates another deficiency of the model, which in this case produces the 3.1-percent error at a time of about 100 msec. Part of this error is due to error accumulation in the small perturbation solution, to which the program reverted entirely beyond 45 msec because of nonconvergence of the exact iterational solution. Another part of the error, in this case the smaller part, is due to neglect of the axial momentum of the test section flow by the crossflow model, which results in the smaller slope of the theoretical curve in the region of 60 to 90 msec. Since this discrepancy has been found to be generally small for subsonic runs, the coefficient in the crossflow model (A_{15}) has been left equal to one.

Table 3. Summary of Run Conditions for Experimental Data to be Compared with Theory

Run Number	Charge Pressure, P_c, psia	Plenum Volume (-), V_p/V_{ts}	Porosity, τ, %	Maximum Flow Area: Main Valve, A_e, ft^2	Maximum Flow Area: Plenum Ex, A_{pe}, ft^2	Maximum Flow Area: Flaps, A_f, ft^2	Total Opening Times: Main Valve, sec	Total Opening Times: Plenum Ex, sec	Total Opening Times: Flaps, sec	Plenum Delay, sec	Asymptotic Plenum Pressure, psia	Test Section Mach Number (-), M_∞
2226	60.11	2.8	4.5	0.466886	0	0.045835[a]	0.002	---	---	---	25.00	0.992
2236	62.37	2.8	4.5	0.466331	0	0.2062[b]	0.002	---	---	---	25.55	0.962
2241	61.84	2.8	1.5	0.465911	0	0.09167[c]	0.002	---	---	---	23.83	1.013
2251	81.47	2.5	4.5	0.465911	0.1090	0.09167	0.002	0.040	---	0.005	30.56	1.039
2255	81.27	2.5	4.5	0.465911	0.1090	0.09167	0.002	0.040	---	0.004	24.04	1.228
2258	70.51	2.8	4.5	0.464351	0	0.09167	0.002	---	---	---	30.47	0.921[d]
2260	70.90	4.0	4.5	0.466290	0	0.09167	0.002	---	---	---	29.36	0.960
2263	74.10	1.75	4.5	0.466662	0	0.09167	0.002	---	---	---	29.64	0.975
2742	152.15	2.5	4.0	0.465911	0.1090	0.09167	0.030	0.040	---	0.005	53.25	1.100

(a) [illegible]$_f$ = 0.2 in.^{2}

(b) [illegible]$_f$ = 0.9 in.^{2}

(c) δ_f = 0.4 in.

(d) Nominal Conditions

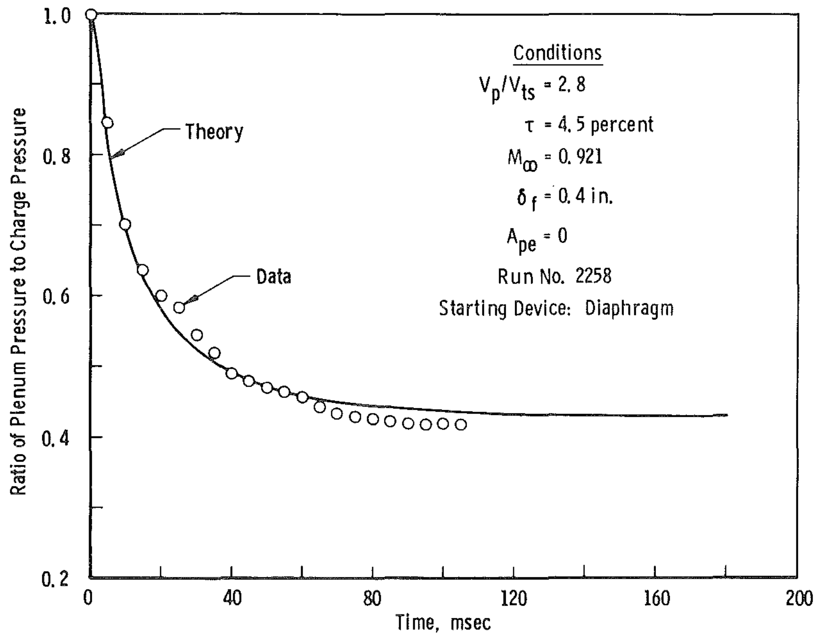


Figure 15. Plenum pressure versus time for subsonic run with medium plenum volume.

Since the amount of plenum volume which must be drawn down to the asymptotic pressure may logically be expected to have a first-order impact on the starting time, the plenum volume was the first parameter varied from the nominal conditions for Run 2258 (Fig. 15). Figures 16 and 17 show the plenum pressure for a smaller plenum volume ratio (1.75) and a larger ratio (4.0), respectively. As expected, the smaller volume case flattens more quickly than the medium volume case, and the larger volume more slowly. As in Fig. 15, the accuracy of the model is generally good for both the smaller and larger plenum volumes, though the effect of the wave propagation time in the plenum is much more pronounced for the larger volume.

Now return to a medium plenum volume case but vary another parameter - plenum exhaust - for a slightly supersonic run. The theoretical analysis depends on an experimentally derived plenum exhaust area-time curve, shown in Fig. 18, in the nondimensional form used by the computer program. Unfortunately, the uncertainty in the shape of this curve is quite large, and only the steady area is known accurately. Illustrated in Figs. 19 and 20 are the data for two supersonic cases, Mach 1.039 and 1.228. Both the theory and experiment of Fig. 18 show a slight over-shoot bottoming out at 30 msec and then approaching the asymptote from below. In addition, the experimental data show a slight rebound peaking at 60 msec, a result not predicted by the model. The rebound probably results from the overshoot, which would tend to draw the test section below its asymptotic pressure while the plenum exhaust area was decreasing

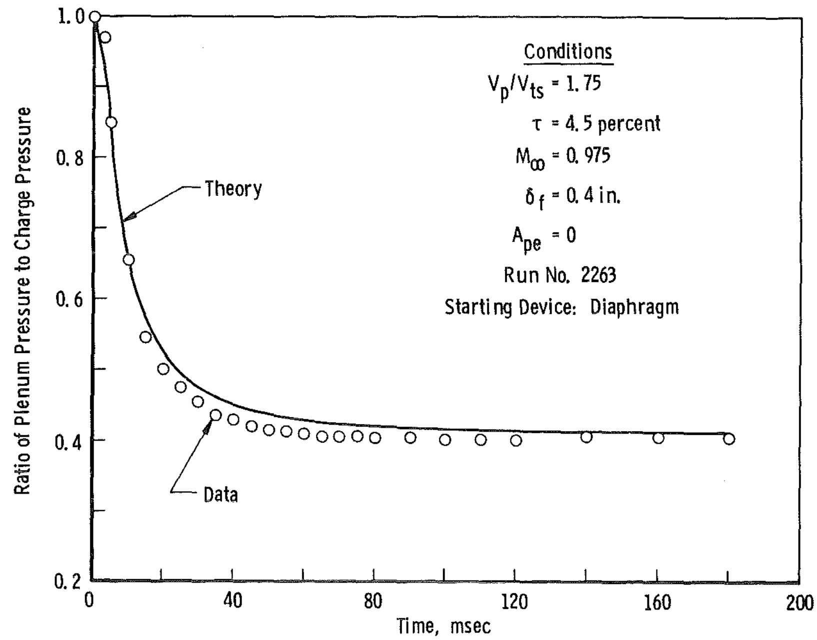


Figure 16. Plenum pressure versus time for subsonic run with small plenum volume.

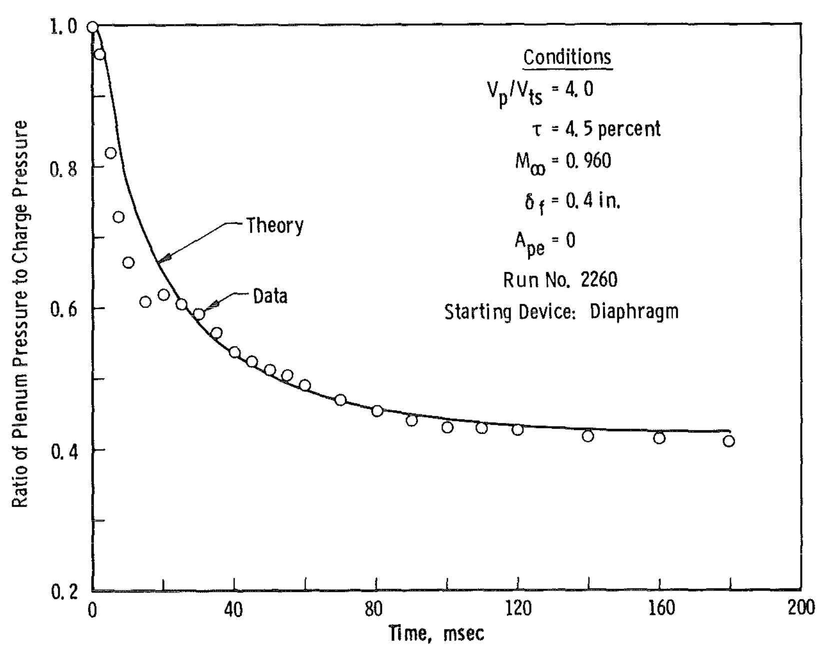


Figure 17. Plenum pressure versus time for subsonic run with large plenum volume.

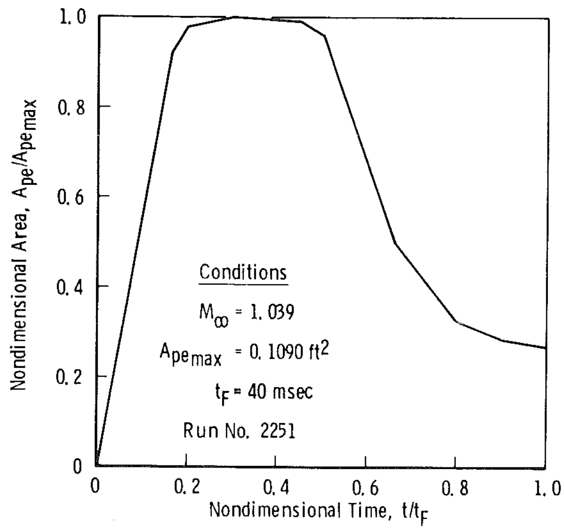


Figure 18. Plenum exhaust area-time curve for Mach 1.039 run.

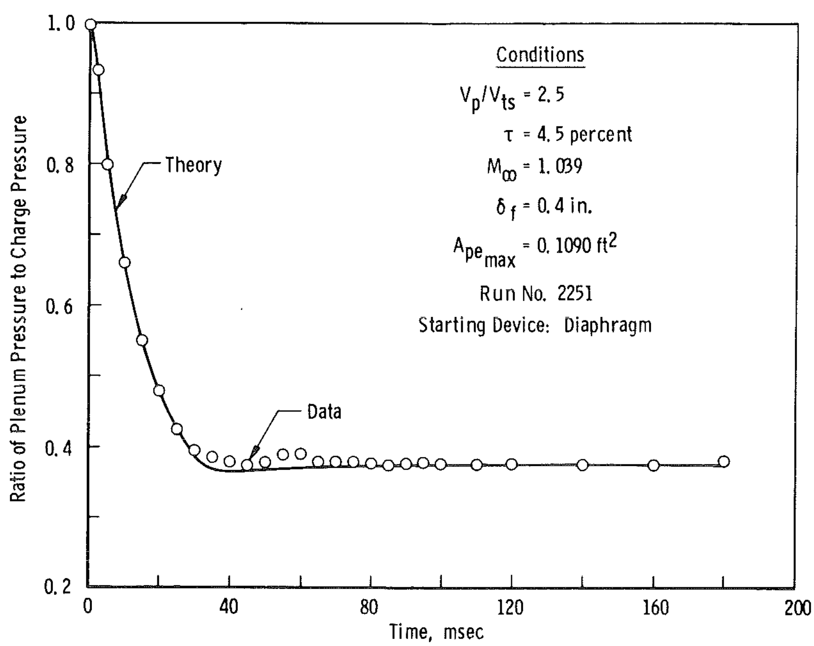


Figure 19. Plenum pressure versus time for supersonic run (Mach 1.039) with plenum exhaust.

to its steady value at 40 to 50 msec. This combination of occurrences would then produce a slight refilling of the plenum, manifesting itself in the observed rebound. For the higher Mach number (1.288) of Fig. 20, the plenum exhaust curve of the previous case was retained intact up to its peak but was linearly stretched beyond the peak to make it approach the steady area needed for the tunnel to reach the desired asymptotic Mach number. The peak area and closing time were unchanged. The disagreement between theory and data at the knee of the curve may be charged to the uncertainty in the plenum exhaust area-time curve, which is known to vary somewhat from run to run since the plenum diaphragm rupture is not precisely repeatable.

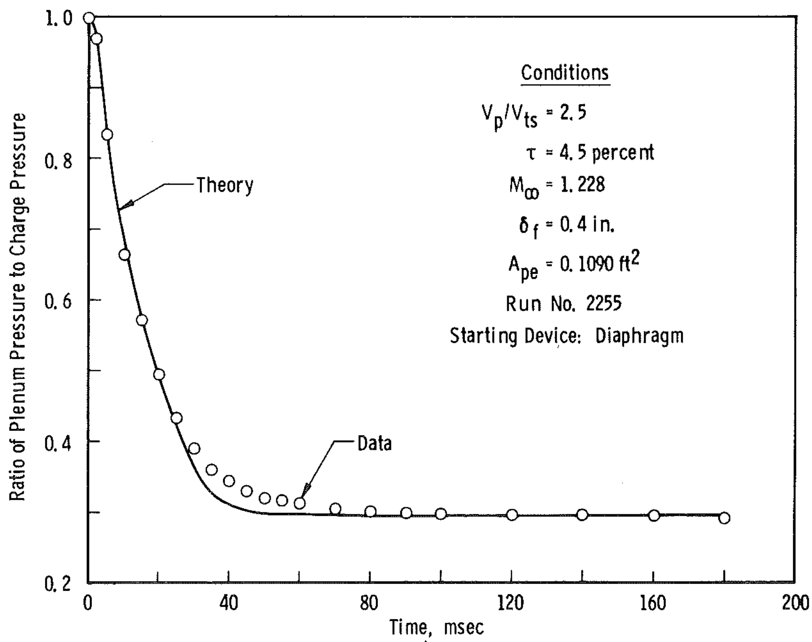


Figure 20. Plenum pressure versus time for supersonic run (Mach 1.228) with plenum exhaust.

The next parameter variation for which the model was tested was the opening time of the main starting device. Figure 21 shows the data and theory for a supersonic run made with a relatively slow opening 12-in. sliding sleeve valve instead of the diaphragm. Though not apparent from the excellent agreement for this case, there is also some uncertainty in the effective opening time of the main valve, assumed to be 30 msec for the theoretical calculation. This uncertainty results because the choke point of the tunnel changes position as the valve area increases, moving from the valve to the nozzle exit. Since the time at which this change occurs is not easily determined experimentally, the exact effective opening time is not known. In addition, the area-time curves are not precisely repeated from run to run.

To continue with the testing of the model for variations in other parameters, the program was run for a case of reduced porosity (1.5 percent), maintaining the nominal conditions of medium plenum volume and flap setting. Figure 22 shows that the model agrees well with the data. Cases were also run for which the flap flow area was halved

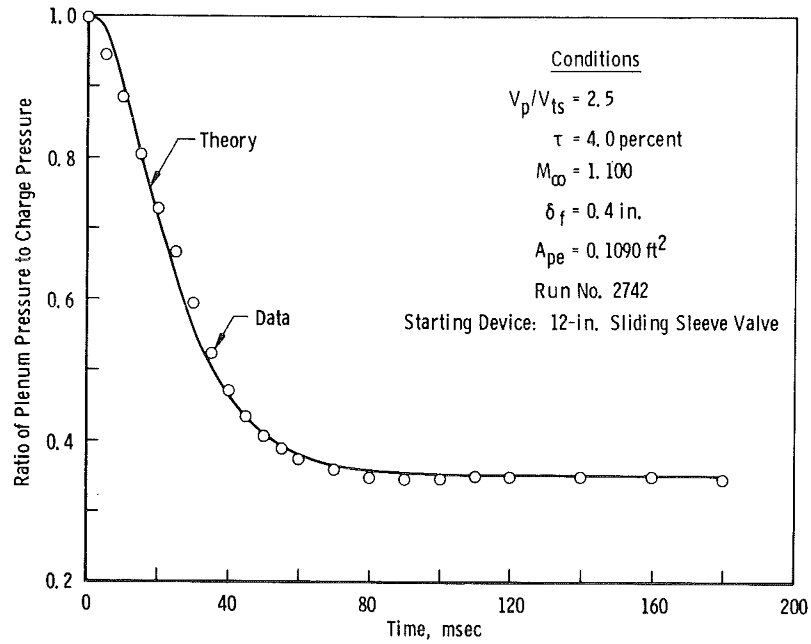


Figure 21. Plenum pressure versus time for supersonic run with sliding sleeve valve and plenum exhaust.

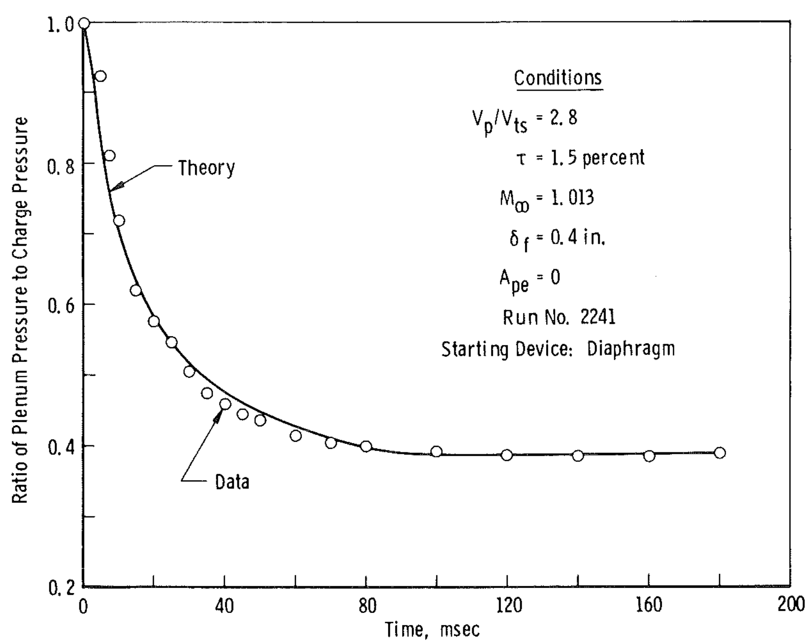


Figure 22. Plenum pressure versus time for supersonic run with 1-1/2-percent porosity and no plenum exhaust.

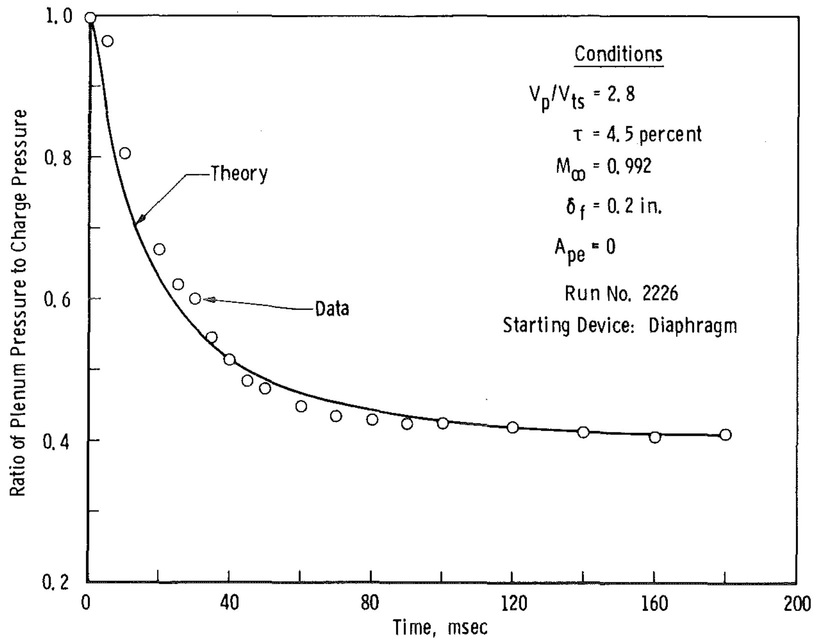


Figure 23. Plenum pressure versus time for subsonic run with small flap setting.

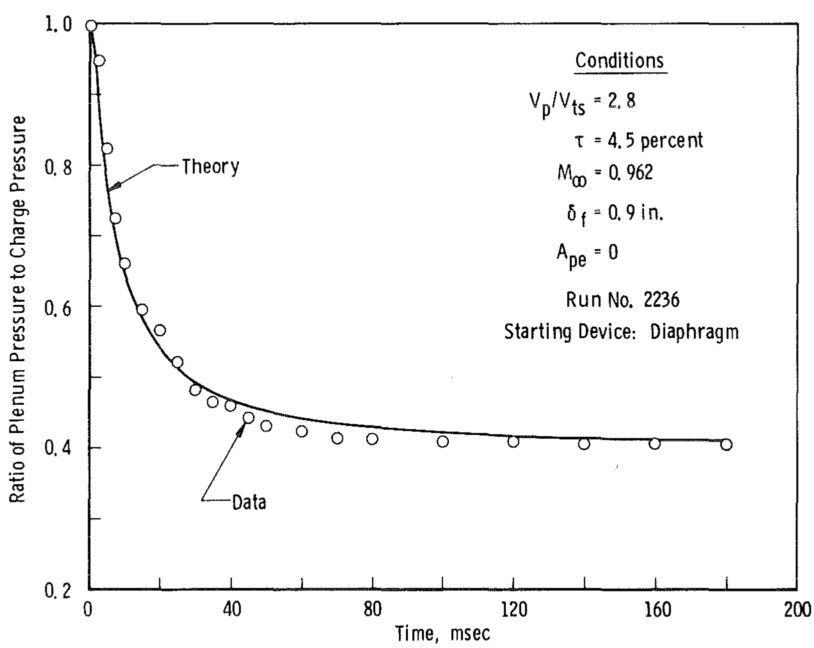


Figure 24. Plenum pressure versus time for subsonic run with large flap setting.

and doubled from the nominal settings. Illustrated in Figs. 23 and 24, both theoretical calculations are in acceptable agreement with experiment. As in previous cases, the disagreement just above the knees is due to the neglect of the finite wave propagation time across the plenum. The disagreement very early in the run (10 msec) is due to uncertainty in the rupture time of the diaphragm, and the slowness of the model in approaching the asymptote may be charged to inadequate handling of the momentum terms in the crossflow model.

3.3 OTHER RESULTS FROM THE MATH MODEL

To predict the data of primary interest, plenum pressure, the model must also calculate many other quantities including pressures and mass flow rates at various locations in the tunnel. Figure 25 shows the pressure-time histories for the case of nominal plenum volume (2.8) for a subsonic run with a diaphragm starting device. Besides plenum pressure, the stagnation pressure and static pressures at opposite ends of the test section are shown. This graph illustrates that the test section pressure initially drops much faster than the plenum, as expected since the rate of plenum depletion is limited by the porosity and flap area. Early in the run, the pressure at the exit of the test section leads the pressure at the entrance because the wall crossflow leaving the plenum increases the flow rate from the entrance to the exit. Eventually, of course, the test section and plenum pressures approach each other as the flap and wall crossflows become negligible and the steady conditions are reached. The stagnation pressure becomes nearly flat long before the static pressures in the test section and changes very slowly beyond 20 msec.

The subsonic case in Fig. 25 may be contrasted to the supersonic case in Fig. 26, which shows the same set of pressure curves. Besides the more rapid drop of all curves prior to 40 msec, due to the plenum exhaust, the most striking difference from the subsonic case is the approach of opposite ends of the test section to distinctly different asymptotes. The entrance to the test section levels rather suddenly at the choking pressure ratio, while the exit continues to drop to the lower pressure ratio corresponding to the supersonic Mach number. Another interesting feature is that the asymptotic pressure at the test section exit is lower than for the plenum even though the net wall crossflow must be into the plenum (to reduce the flow rate along the test section as needed for supercritical flow). Crossflow against the pressure gradient occurs because of the increasing momentum retained by the crossflow while separating off from the high-speed test section flow. Another feature of Fig. 26 due to this momentum is the crossing of the test section pressure curves at 12 msec, which signifies the reversing of the wall crossflow. To improve the crossflow model's representation of the effect of this momentum (which is neglected in modeling the crossflow rate as a function of pressure difference only), the momentum correction coefficient A_{15} in Eq. (7) was introduced. This quantity expediently models the small

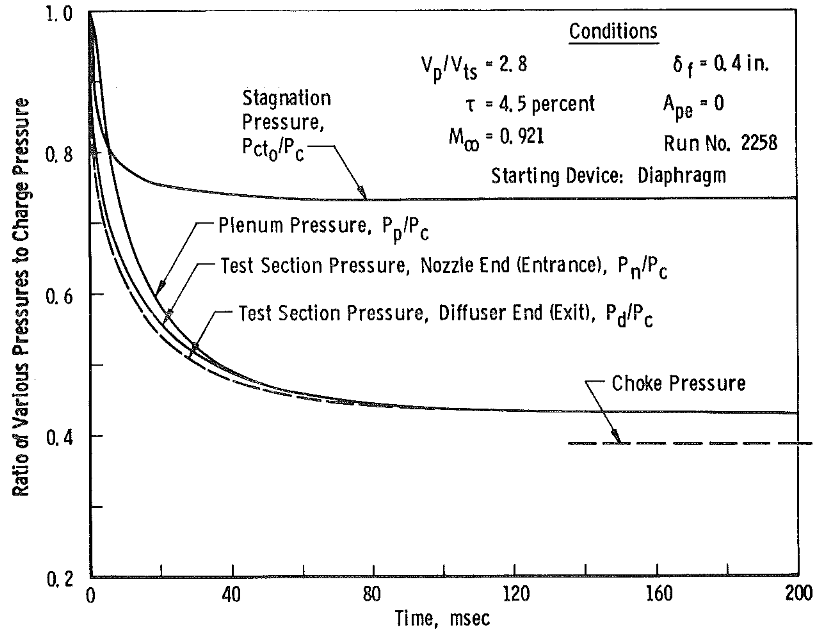


Figure 25. Various pressures versus time for nominal conditions.

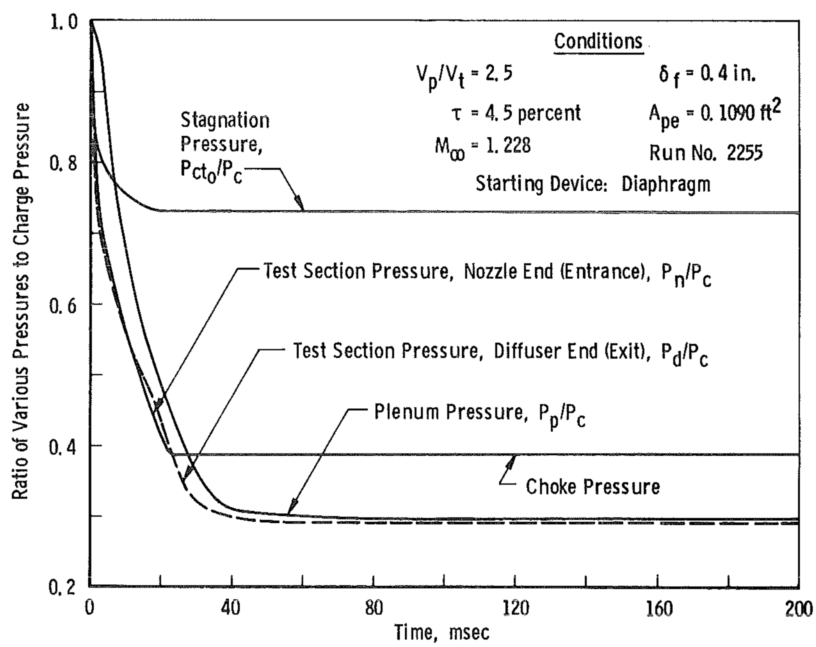
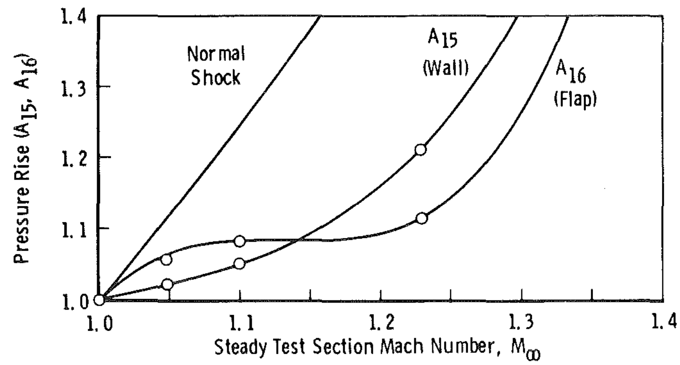
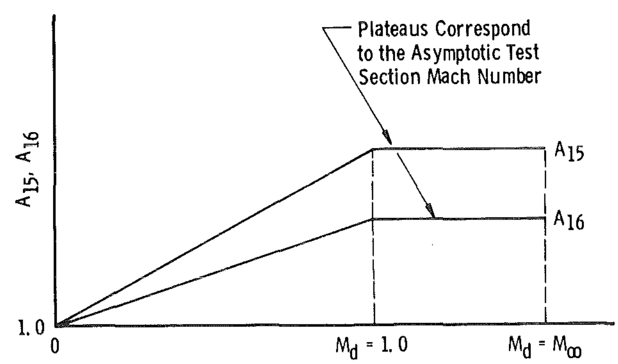


Figure 26. Various pressures versus time for supersonic run with plenum exhaust.

additional crossflow due to momentum in terms of a slightly elevated driving pressure. The steady-state value of A_{15} at a given steady test section Mach number was derived empirically for a given steady plenum pressure. These steady-state values of A_{15} are shown in Fig. 27a. During a run, however, A_{15} was assumed to vary according to the ramp function of Fig. 27b to simulate the increasing momentum.



a. Momentum correction coefficient (A_{15}) and flap correction coefficient (A_{16}) versus steady test section Mach number



b. Assumed variation with test section Mach number (M_d) of momentum (A_{15}) and flap (A_{16}) correction coefficients during starting process

Figure 27. Steady-state values of correction coefficients, A_{15} and A_{16}.

Looking at the mass flow rate-time curves corresponding to Figs. 25 and 26 provides further insight into the behavior of the mathematical model. Figure 28 shows the flow rate entering (from the charge tube) and leaving the test section, the flow rate through the flaps, and across the porous wall for the nominal conditions and subsonic flow. The flap and wall crossflows, though leaving the plenum in this run, are shown on the positive axis for convenience. All data are expressed as ratios of the steady, asymptotic flow rate through the main valves. The flow in the test section is seen to rise very rapidly, in concert with the breaking diaphragm, and to approach the final flow rate only as the flap and crossflows approach zero. Both flows from the plenum reach peaks at about 3 msec, which results from the pressure differences between the plenum and test section reaching a maximum. The crossflow further manifests itself in the disparity between the flow entering and leaving the test section. Various experimentally derived flow rates are given in Ref. 4 for the pilot tunnel. These relatively well behaved results for the subsonic case may be contrasted to the tangle of curves resulting from a supersonic case with plenum exhaust (Fig. 29), which is based on the same conditions as Fig. 26. Initially similar to the subsonic case with peak flap and crossflows at 3 msec, the curves are considerably modified by the opening of the plenum exhaust at 4 msec (a programmed delay). The leveling of the flap and crossflow curves at 22 msec is associated with choking in the test section. Eventually, the plenum exhaust forces both the crossflow and flap flow to reverse and eventually to exactly balance the plenum exhaust flow rate when steady flow is reached. Reversal of the flap flow requires, in terms of the flow model (Eq. (8)), a driving pressure at the flap exit greater than the plenum pressure and in general greater than the computed pressure at the exit of the test section. Though the flap correction coefficient (A_{16}) is applied much like the wall crossflow coefficient, the physical explanation cannot be the same since the free-stream momentum is in the opposite direction of the reversed

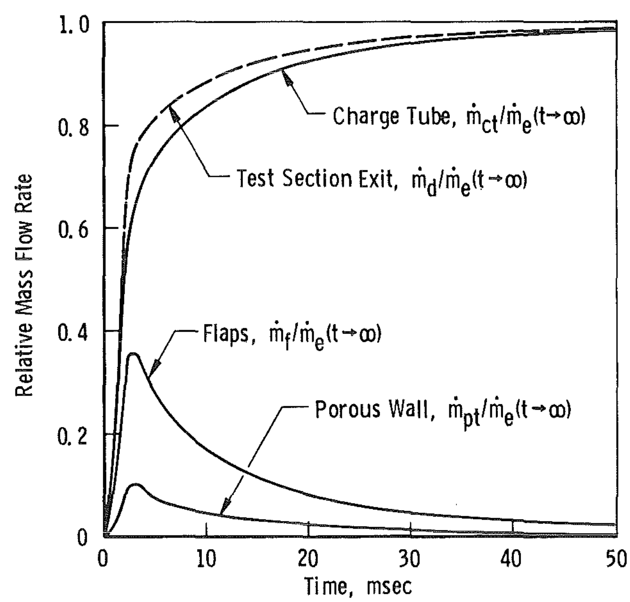


Figure 28. Relative theoretical mass flow rates for nominal conditions (Run 2258) of subsonic flow with no plenum exhaust.

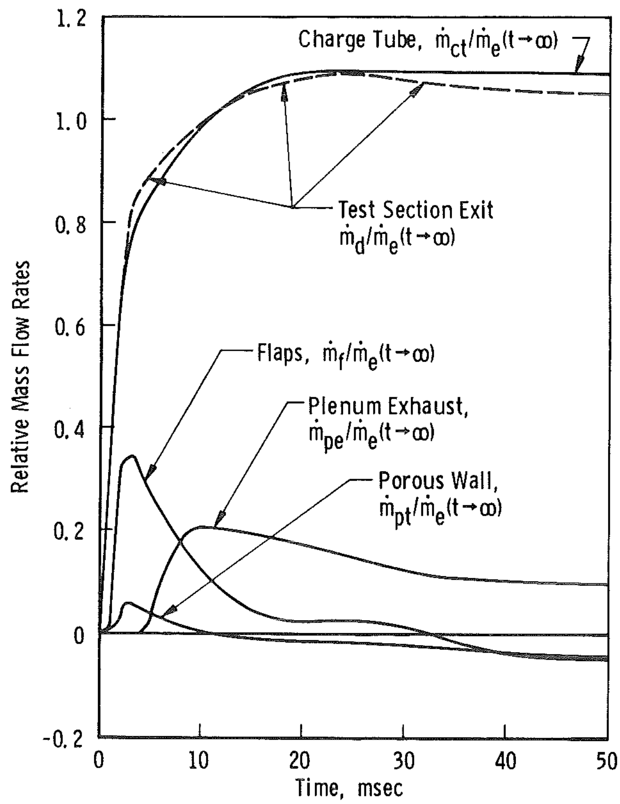


Figure 29. Relative mass flow rates for a supersonic run (Mach 1.228) with plenum exhaust (Run 2255).

flap flow. A more likely explanation is the shock structure and flow separation at the diffuser entrance. Since precise modeling of this complex flow is beyond the scope of the present work, the flap flow correction coefficient (A_{16}) was added to Eq. (8). Experimentally derived values of A_{16} as a function of steady test section Mach number are plotted in Fig. 27a along with the static pressure jump across a normal shock. The pressure rise during the reversed flap flow must be due to a flow more complex than a normal shock, since the pressure jump across the shock rises much more rapidly than experiment indicates. The lines through the circled points are cubic fits and are probably not accurate beyond Mach 1.25. As with the momentum correction, the flap correction was assumed to vary in time according to the ramp function in Fig. 27b.

3.4 APPLICATION OF THE MATH MODEL

Besides prediction of tunnel start time, there are several other ways the model can be applied in the design of a wind tunnel. Since the plenum exhaust area-time curves can be varied arbitrarily in the model, the number of plenum valves (or total valve area) to achieve various start times can be determined. In addition, the sensitivity of the start time to the shape of the area-time curves can be predicted. This is important because it indicates how finely controllable and repeatable (and expensive) the valves must be. Another potential application is estimation of the structural loading of the test section wall due to transient pressure differences between the plenum and test section.

To illustrate some of these possibilities, the program was run for the three different plenum exhaust area time curves shown in Fig. 30. The solid line is a typical area-time curve from Pilot HIRT, and the two broken lines are variations having the same average open area. Processing the model with the triangular curve should indicate whether a curve with the same peak as the basic curve but having a different shape would significantly affect starting time. The trapezoidal curve should indicate whether a smaller number of valves kept at full open for a longer time could achieve the same start time as the more peaked curves. The plenum pressure-time histories for these three curves are shown in Fig. 31. It is clear that the triangular curve has little effect on the shape of the pressure curve and does not affect starting time. On the other hand, the trapezoidal curve has a larger effect but still does not lengthen the starting time. The logical conclusions for the tunnel configuration studied here is that very accurate controllability is not required of the plenum valves and that the tunnel could be started just as quickly with about

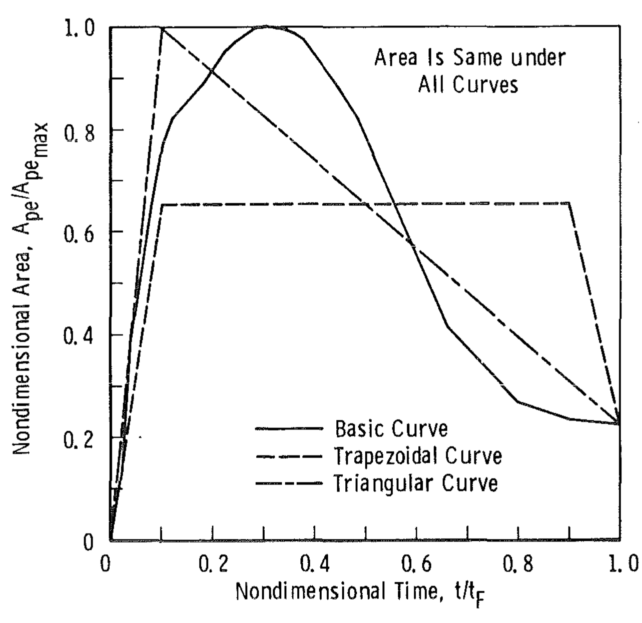


Figure 30. Nondimensional equal area plenum exhaust area-time curves.

2/3 of the available valve area if the valves were kept fully open for a longer duration. If these results were found to apply to a large scale facility, a considerable cost reduction could be realized.

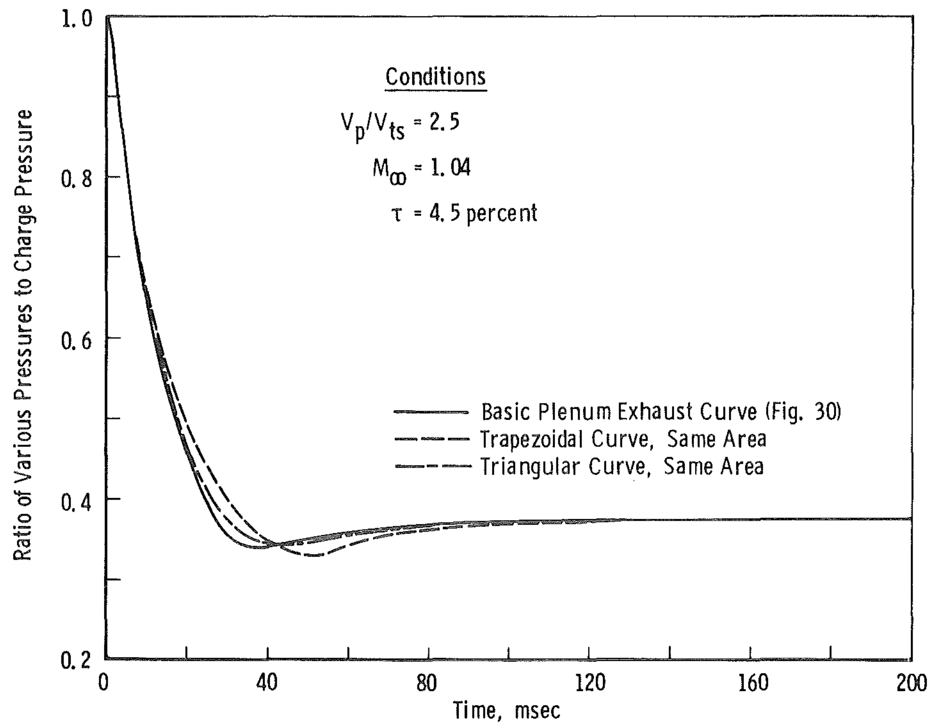


Figure 31. Plenum pressures versus time for three plenum exhaust area-time curves with same integrated area.

A second example of application of the model is illustrated by Fig. 32, which shows the pressure differential across the wall at the test section exit as a function of time for several conditions. From these results, it can be seen that reducing the porosity has little impact on wall loading, but raising the Mach number from 0.921 to 1.228 or reducing the flap gap by 1/2 significantly increases the loading by 25 and 50 percent, respectively. In contrast, lengthening the effective valve opening time from 2 to 30 msec reduces the peak load to about 1/3 of the nominal case. The peaks of the curves for the diaphragm runs occur just as the diaphragm reaches its full open area. The curve for the valve run, however, peaks first when the plenum exhaust area peaks and later when the valve reaches its steady area around 30 msec. Two data points for the peak pressure differential from Ref. 4 are shown in Fig. 32 and agree with the model.

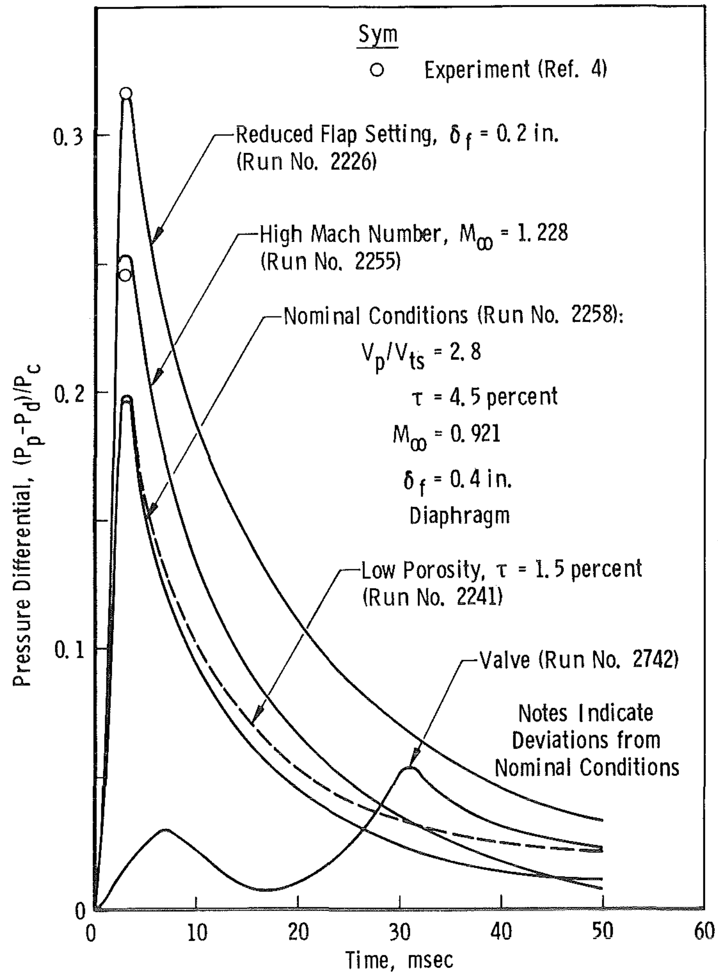


Figure 32. Transient loading of test section wall at exit for nominal conditions and selected deviations.

4.0 SUMMARY AND CONCLUSIONS

A mathematical flow model for the process of starting a transonic Ludwieg tube wind tunnel has been developed. The present model uses the integral continuity equation for three specific control volumes, the steady form for the diffuser and test section control volumes, and the unsteady form for the plenum. The solution in the two former control volumes also uses the steady, isentropic energy equation, assumed applicable throughout the diffuser and test section control volumes for a given set of stagnation conditions. However, the stagnation conditions are allowed to vary in time according to the well-known exact solution for an unsteady, one-dimensional expansion wave. Application of this model takes the form of a numerical solution of 19 simultaneous algebraic equations to be solved at successive time points until the flow becomes steady. The iterational solution procedure for these exact equations becomes nonconvergent in the vicinity of choking and is replaced with an analytical solution to a set of small perturbation equations until the choke point is passed. The numerical procedure is programmed for computer solution.

The mathematical model was evaluated by comparison with experimental plenum pressure-time histories from a small Ludwieg tube wind tunnel. Agreement between the model and experiment was found to be good. Other numerical results from the computer model were also presented to illustrate application of the model to design of a large facility. Specific conclusions drawn from the present study include (1) verification of the model's ability to predict accurately plenum pressure-time histories and, therefore, tunnel starting time; (2) prediction that starting time is insensitive to the precise shape of area-time curve of the plenum exhaust and, therefore, that very precise controllability is not required of the plenum valves; (3) prediction that starting time is not significantly lengthened by even large changes in the shape of the plenum exhaust area-time curve if the area under the curve and open time are maintained, thus permitting considerable reduction in the number of start valves suggested by data from the pilot facility; and (4) verficiation that aerodynamic loading of the test section walls (and, therefore, the support structure) can be reduced by lengthening the opening time of the main starting valves, within limitations of the required starting time.

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APPENDIX A
SMALL PERTURBATION SOLUTION

This section presents the essential details of the small perturbation solution, the knowledge of which may be important to a user of the computer program HIRTSM1. Table A-1 shows the small perturbation variables and the exact variables they represent. Use of the expansions (Eq. (22)) in the exact equations listed in Table 1 produces the approximate small perturbation equations listed in Table A-2. Definitions of the coefficients A_1, B_1, C_1 ..., if needed, should be extracted directly from the computer program (subroutine SMPERT) where they are coded as CA1, CB1, CC1, ..., respectively. The equations of Table A-2 can be solved analytically without recourse to numerical iterative procedures. To accomplish this task, the linear equations were solved algebraically to eliminate all variables except those contained in the quadratic equations, Eqs. (12) and (13). After eliminating all variables but ϵ_{12} and ϵ_{13} from the two quadratics, Eqs. (12) and (13) were converted to a single quartic (subroutine QSIMUL), which was solved analytically for its four roots. If necessary, the reader can extract the algebraic details of this procedure from the computer program. The correctness of the algebra has been inferred from computation of residuals from the equations of Table A-2 (replacing the zeros on the right-hand side with residuals). For all cases tested, the residuals were found to be on the order of the computer's accuracy ($\sim 10^{-16}$). Similarly, the accuracy of the expansions in representing the exact equations was tested by computing residuals from the exact equations using perturbed values for the variables. The largest residuals (percentage basis) were generally less than 10^{-4}.

Table A-1. Perturbation Variables

Original Variable	Perturbation Variable
$\dot{m}_e$ (t*)	ϵ_1
$\dot{m}_{pe}$ (t*)	ϵ_2
$\dot{m}_f$ (t*)	ϵ_3
$\dot{m}_{pt}$ (t*)	ϵ_4
ρ_p (t)	ϵ_5
$\dot{m}_d$ (t*)	ϵ_6
$\dot{m}_{ct}$ (t*)	ϵ_7
M_{ct} (t*)	ϵ_8
P_{e_o} (t*)	ϵ_9
T_{e_o} (t*)	ϵ_{10}
P_t (t*)	ϵ_{11}
P_d (t*)	ϵ_{12}
P_n (t*)	ϵ_{13}
$\dot{m}_o$ (t*)	ϵ_{14}
P_p (t*)	ϵ_{17}[a]
ρ_p (t*)	ϵ_{18}
T_p (t*)	ϵ_{19}
A_e (t*)	ϵA_e
A_{pe} (t*)	ϵA_{pe}
A_f (t*)	ϵA_f

(a)Variables 15 and 16 were eliminated.

Table A-2. Perturbation Equations

Program Equation Number[a]	Perturbation Equation[b]
1	$A_1\epsilon_1 + B_1\epsilon_9 + C_1\epsilon_{Ae} + D_1\epsilon_{10} = 0$
2	$A_2\epsilon_2 + B_2\epsilon_{17} + C_2\epsilon_{Ape} + D_2\epsilon_{19} = 0$
3	$A_3\epsilon_3 + B_3\epsilon_{Af} + C_3\epsilon_{17} + D_3\epsilon_{12} = 0$
4	$A_4\epsilon_4 + B_4\epsilon_{17} + C_4\epsilon_{11} = 0$
5	$A_5\epsilon_5 + B_5\epsilon_2 + C_5\epsilon_3 + D_5\epsilon_4 + E_5 = 0$
6	$A_6\epsilon_6 + B_6\epsilon_4 + C_6\epsilon_7 = 0$
7	$A_7\epsilon_6 + B_7\epsilon_3 + C_7\epsilon_1 = 0$
8	$A_8\epsilon_7 + B_8\epsilon_8 = 0$
9	$A_9\epsilon_9 + B_9\epsilon_8 = 0$
10	$A_{10}\epsilon_{10} + B_{10}\epsilon_8 = 0$
11	$A_{11}\epsilon_{11} + B_{11}\epsilon_{13} + C_{11}\epsilon_{12} = 0$
12	$A_{12}\epsilon_6 + B_{12}\epsilon_{14} + C_{12}(Pct_o\epsilon_{12} - P_d\epsilon_9) + D_{12}(Pct_o\epsilon_{12} - P_d\epsilon_9)^2 = 0$
13	$A_{13}\epsilon_7 + B_{13}\epsilon_{14} + C_{13}(Pct_o\epsilon_{13} - P_n\epsilon_9) + D_{13}(Pct_o\epsilon_{13} - P_n\epsilon_9)^2 = 0$[c]
14	$A_{14}\epsilon_{14} + B_{14}\epsilon_9 + C_{14}\epsilon_{10} = 0$
17[d]	$A_{17}\epsilon_{17} + B_{17}\epsilon_{18} = 0$
18	$A_{18}\epsilon_{18} + B_{18}\epsilon_5 + C_{18} = 0$
19	$A_{19}\epsilon_{19} + B_{19}\epsilon_{18} + C_{19}\epsilon_{17} = 0$

(a) See Table 1 for Corresponding Exact Equations

(b) Refer to Listing of Computer Program, Subroutine SMPERT, for Definitions of A_i, B_i, ...

(c) Variables P_{ct_o}, P_d, and P_n Are Evaluated at $t^* - \Delta t$ As Are All the Coefficients A_i, B_i, ...

(d) Equations 15 and 16 Were Eliminated

APPENDIX B
APPROXIMATED EQUATIONS

Reversion of Eqs. (11), (13), and (17) requires a time-consuming numerical procedure which has a major impact on the run time of HIRTSM1. To reduce the number of iterations needed for the reversions, approximations to the original equations were used to provide accurate initial guesses to the numerical procedure. Since these approximations may be of general interest, they are listed below. A good approximation to the mass flux-Mach number wave equation was obtained by expanding

$$\hat{m} = M\left(1 + \frac{\gamma - 1}{2} M\right)^{-\frac{\gamma+1}{\gamma-1}} \tag{B-1}$$

in a series of powers of M using the binominal expansion. Reversion of this series for $\gamma = 1.4$ then produced

$$\begin{aligned} M = {} & \hat{m} - 1.200\,\hat{m}^2 + 2.0400\,\hat{m}^3 + 4.0480\,\hat{m}^4 + 8.7965\,\hat{m}^5 \\ & + 20.106\,\hat{m}^6 + 47.960\,\hat{m}^7 + \cdots \end{aligned} \tag{B-2}$$

where $\hat{m} \equiv \dot{m}/\dot{m}_c$. The approximation used for the energy equation is much simpler and was discovered quite by accident. It was found that the equation

$$\tilde{m}^2 = \tilde{P}^{2/\gamma} - \tilde{P}^{\frac{\gamma+1}{\gamma}} \tag{B-3}$$

could be very reasonably approximated over the interval $0 \leqslant M \leqslant 1.4$ by the ellipse

$$\left(\frac{\tilde{m}}{\tilde{m}^*}\right)^2 + \left(\frac{\tilde{P} - \tilde{P}^*}{1 - \tilde{P}^*}\right)^2 = 1 \tag{B-4}$$

where

$$\tilde{m} \equiv \sqrt{\frac{\gamma - 1}{2}}\,\frac{\dot{m}}{\dot{m}_o}$$

$$\tilde{P} \equiv \frac{P}{P_o}$$

and

$$\tilde{P} = \tilde{P}^*,\ \tilde{m} = \tilde{m}^* \text{ for } M = 1$$

APPENDIX C
DESCRIPTION OF THE COMPUTER PROGRAM HIRTSM1

Because of the complexity of the numerical calculations, potential users of the model must have access to the computer program (a manual calculation on a scientific calculator took about six hours to step through five time increments). For this reason, a listing of the source deck is given in this section along with a brief description of its content and use. Table C-1 lists the 15 subroutines comprising HIRTSM1. Of primary interest are the routines MAIN and SMPERT, which house the exact model equations and the small perturbation equations, respectively. Table C-2 defines some of the more important variables used in the program, information which is potentially useful if a program modification is necessary.

Of primary interest to the potential user, however, is the input, instructions for which are listed in Table C-3. The first card (NCTL) allows the user to retain manual control over some of the superficial program logic. While intended primarily for debugging purposes, the NCTL variable may be used to restart a run previously written onto a data file. To make a normal run and relinquish all control to the program, a blank card may be used. The second card (INSTR) provides the means to invoke certain program options via integer instructions. Table C-4 gives a set of values which have been used successfully to date, though occasional adjustments are necessary for some cases. Of particular importance for supersonic cases is INSTR(26). As the program approaches the choke point in the calculation (timewise, speaking), the number of iterations (ITER) for convergence always becomes inordinately large (~100); and the program must switch to the small pertubation solution entirely by automatically setting INSTR(23) = 2 when ITER ⩾ INSTR(22). However, for supersonic cases, the solution is often not close to its asymptote, and significant error can accumulate from the small perturbation solution. To reduce this error, INSTR(26) may be used to direct the program to attempt to revert back to the exact solution a certain number of time increments (the input value of INSTR(26)) beyond the choke point. Sometimes the attempted reversion will be unsuccessful because the solution is either still too close to the choke point or is already too close to its asymptote; in which case ITER ⩾ INSTR(22) will occur, and the program will continue with the small perturbation solution. When this situation occurs, the exact solution is not given a chance to correct the accumulated error, which may affect the asymptote by as much as 10 percent. If this result is encountered, different values of INSTR(26) should be tried, since even a temporary successful reversion to the exact solution can improve the accuracy of the solution considerably.

The remaining data cards constitute primarily a description of the tunnel and its geometry. While most of the table entries are self explanatory, some of them deserve more emphasis. On card number 4, the values of A15 and A16, if used, should be entered as negative to invoke the use of ramps. On card number 5, the weight used in computation of the test section pressure for subsonic flow is programmed as 0.5. The input value is used only in supersonic flow. On card number 6, the variable A14 is used to sort the roots from the quartic. A value of -0.2 has been found more effective than -0.1. If the root sorting logic finds more than one value of ϵ_{13} acceptable, the program will halt in bewilderment, requiring some trial and error adjustment of A_{14} by the user. On card number 7, it has been found best to keep $EMAX $\leqslant$ PERR/10. The quantity A10 is used to obtain debugging information when T > A10. Following card number 10, three separate decks for the nondimensional area-time curves for the main valves, plenum exhaust valves, and flaps must be provided. Each deck must contain the number of cards entered on card number one. The times and areas must be nondimensionalized by the values entered on card numbers 9 and 8, respectively, and, therefore, will vary only between zero and one. The times must proceed in ascending order. Table C-5 gives recommended values for some of these entries. The remaining input instructions (I1, I2, ...) may be ignored unless NCTL has been entered as other than zero, in which case the user is invited to decipher the program logic in order to determine the endless uses to which this option may be put.

Table C-6 presents a sample job stream and data deck. The first four cards are peculiar to the computer facility. The first "GO" card designates data set 03 a dummy in order to suppress debugging printouts sent to DSRN* IDEBUG. The remaining data cards may be understood via Table A-3.

A portion of the output from this run is shown in Table A-7. The first four pages show the input data along with the initial values of most program variables. In addition, an interpretation of the INSTR(I) options selected is printed. The flow area-time curves are the redimensionalized form in units of seconds and square feet (or whatever units are used in the input data). The form of the remaining output is that due to the selection of INSTR(5) = 2 and generally displays all computed properties at the midpoint or end of each time interval. Each five lines of data separated by a space corresponds to a single time interval, and each block of five numbers corresponds to the similarly positioned block of five variable names in the page heading. Interpretation of these names may be accomplished via Table C-2. The illustrated run went to 180 msec, generated about 1,700 records (lines of print), and required 42.6 sec of central processor (CPU) time on an IBM 370/165. This run may be used as a check case by potential users.

Table C-8 presents a machine listing of the final source deck. All necessary subprograms are included except those available from the IBM subroutine library, from which HIRTSM1 uses DABS, DSQRT, DSIN, DCOS, DATAN2, CDSQRT, and CDABS.

*Data Set Reference Number

Table C-1. Description of Subroutines

PRIMARY MODEL SUBROUTINES

Subroutine Name	Function
MAIN	1. Overall program control 2. Exact model equations 3. Convergence control
SMPERT	Small perturbation equations

SPECIALIZED UTILITY SUBROUTINES

Subroutine Name	Function
INPUT	Obtains initial data from DSRN IIN
CONST	Defines certain program constants
INIT	Initializes certain program variables
DUMP	Prints out all program variables at beginning and end of run and as needed for debugging
PRINT	Prints numerical solution and controls paging

GENERAL UTILITY SUBROUTINES

Subroutine Name	Function
SOLVER	Provides logic for numerical reversion of a function (see Fig. 10)
BINOM	Expands a binomial to seven terms
REVERT	Reverts a series to seven terms
QSIMUL	Converts two conics to a quartic
QANDC	Computes the exact roots of a quartic
CUBRT	Computes the exact roots of a cubic
DREAL	Returns the real part of a double precision complex number
DIMAG	Returns the imaginary part of a double precision complex number

Table C-2. Definition of Major Program Variables

REAL ARRAYS

Variable Name	Definition
AREA	Input nondimensional area-time curves for main valves, flaps, and plenum exhaust valves
AREATS	Interpolated areas for time t*
AREAM	Peak of area-time curves (dimensional)
TV	Nondimensional times for area-time curves
E	Convergence criteria errors
TVF	Total time for main valves, flaps, and plenum exhaust valves (dimensional)
TDELAY	Delays times for first motion of valves and flaps
RW	Coefficients for the reverted expansion of the mass Flux-Mach number wave equation
V	Array equivalenced to major property values
RSTR	Array equivalenced to certain real commoned variables to simplify writing of solution onto a storage device for restarting a run
ISTR	Array equivalenced to certain integer variables for storage and restarting

REAL SCALARS

Pxi	Pressure
MDxi	Mass flow rate
Txi	Temperature
Rxi	Density
Mxi	Mach number
Axi	Flow areas

Table C-2. Continued.

x-codes:

x = N	Nozzle exit (test section entrance)
= P	Plenum
= PT	Plenum at time t (PPT) or wall crossflow (MDPT)
= D	Diffuser entrance (test section exit)
= T	Test section midpoint (PT)
= CTO	Stagnation condition, charge tube
= CT	Charge tube
= E	Main valve exit
= F	Flaps
= PE	Plenum exhaust
= C	Charge conditions

i - codes:

i = blank	Values at current time interval and current iteration
i = 1	Converged values from last time interval
i = 2	Values from last iteration, current interval
i = 3	Scratch area
G	Specific heat ratio (γ)
R	Ideal gas constant
PERR	Error limit on pressures
KF	Flap flow coefficient
KW	Wall crossflow coefficient
TSL	Test section length
TSH	Height

Table C-2. Continued.

TSW	Width
TSP	Perimeter
TSA	Flow area
TSWA	Wall surface area
TSV	Volume
CTD	Charge tube diameter
CTA	Charge tube flow area
PV	Plenum volume
PVOTSV	Plenum: test section volume ratio
TAUW	Porosity
T	Time at end of current interval (t)
T1	Time at end of last interval (t - Δt)
DT	Time increment
TSTR	Midpoint of current interval (t*)
TSTOP	Time for termination of run
Ai	Miscellaneous program constants

INTEGER ARRAYS

INSTR	Program control instructions (see input)
NVT	Number of time points in each of three input area-time curves

INTEGER SCALARS

IDEBUG	Data set reference number (DSRN) for debugging output, normally dummied
IIN	DSRN of input data (usually 05 for card reader)
IOUT	DSRN of primary output data (usually 06 for line printer)
ITER	Number of iterations

Table C-2. Concluded.

NP	Printing time interval
IFLGi	Miscellaneous program control flags

Table C-3. Description of Program Input
a. Main Program

Variable	Index	Value	Action	Default Value	Format
NCTL		0	Proceed through normal programmed solution procedure	0	I3
		1	Read INSTR(*)		
		2	Write heading		
		3	Read data file and print results		
		4	Proceed to normal calculation		
		5	Call INPUT		
		6	Call INIT		
		7	Call CONST		
		8	Call DUMP		
		9	Call SOLVER		
		10	Call PRINT		
		11	Call BINOM		
		12	Call REVERT		
		13	Stop		
INSTR	1	06	Print debugging data		26I3
		03	Skip debugging prints (DSRN 03 Is Dummy)	03	(One Card)
	2	05	Input DSRN	05	
	3	06	Output DSRN	06	
	4		Printing time interval	1	
	5	1	Pressures in psf		
		2	Pressures in psi	2	
	6	≠0	Call PRINT on every iteration } set to zero when IDEBUG = IOUT		
		0	Call PRINT on ON convergence } set to zero when IDEBUG = IOUT	0	
	7	1	Extrapolate to next time interval as an initial guess		
		2	Do not extrapolate	2	
	8	1	Use reverted series from mass flux - Mach number wave equation		
		2	Use second-degree approximation	1	
	9	1	Use iterative solution to energy and wave equations		
		2	Use approximate expansions for energy and wave equations	1	
	10	1	Average current value with previous average value		
		2	Average current value with previous unaveraged value		
		0	Do not invoke option	0	

Table 3. Continued
a. Concluded

Variable	Index	Value	Action	Default Value	Format
INSTR	11	>0	Iteration limit beyond which current weight is halved	0	
	12	1	Do not invoke option		
		>1	Divide error limits PERR and $EMAX by INSTR(12) if the fractional difference between successive time intervals is less than (errors) x (INSTR(12))	1	
	13	≠0	Print only time and pressure data		
		0	Print everything		
	14	>1	Set DT = DT*INSTR(14) based on INSTR(12) ceiteria, do not cut error limits		
		1	Do not invoke option	1	
	15	≠03	Read solution from DSRN = INSTR(15), skip other input		
		03	Do not read solution	03	
	16	[1,1000][a]	First record number to be read	0	
	17	[1,1000]	Last record number to be read	0	
	18	≠03	Write solution on DSRN = INSTR(18)		
		03	Do not write solution	03	
	19	[1,1000]	First record number to be written	0	
	20	0	Do not invoke option		
		>0	When weight is halved, increment INSTR(11) by INSTR(20)	0	
	21	0	Do not invoke option		
		≠0	Set INSTR(7) = 2 to extrapolate next time interval when weight is halved	0	
	22	0	Do not invoke option, set INSTR(22) = $2^{31}-1$		
		>0	Set INSTR(23) = 2 when number of iterations > INSTR(22)	9999999	
	23	0	Do not use small perturbation expansion		
		1	Use small perturbation initial guess for next time interval		
		2	Use small perturbation expansions as solution	0	
	24	≠0	SMPERT prints small perturbation results		
		0	Does not print without error	0	
	25	1	Use isentropic solution in plenum		
		2	Use anisentropic solution in plenum	2	
	26	0	Do not invoke option		
		>0	Revert to exact equation after the input number of time increments beyond choking	9999999	

[a]Square brackets [ ] indicate the range of the variable.

Table 3. Concluded
b. Subroutine INPUT

Variable, units	Card Number[a]	Value	Meaning	Default Value	Format
NVT(1)	1	[2,50]	Number of area-time points for main valve		26I3
NVT(2)		[2,50]	Number of area-time points for plenum exhaust valve		
NVT(3)		[2,50]	Number of area-time points for flaps		
PC, psia	2		Charge pressure		5E16.8
TC, °R			Charge temperature		
TSL, ft	3		Test section length		5E16.8
TSH, ft			Test section height		
TSW, ft			Test section width		
CTD, ft			Charge tube diameter		
PVOTSV			Ratio of plenum volume to test section volume		
TAUW	4		Porosity (fraction, not percent)		5E16.8
KW, ft/sec			Wall crossflow coefficient } from Dr. Varner's flow model		
KF, ft/sec			Flap flow coefficient } from Dr. Varner's flow model		
A15[b]			Crossflow constant MDPT = -AWOKW x (PP - A15 x PT)	1.0	
A16[b]			Flap flow constant MDF = -AF/KF x (PP - A16 x PD)	1.0	
A17	5	>0	Test section pressure weight, PT = A17 x PD + (1.DO - A17) x PN	1.0	5E16.8
R, ft²/sec²-°R	6		Perfect gas constant		5E16.8
G			Ratio of specific heats (γ)		
A11		(0,1)[c]	Fraction of new values to be accepted	0.5	
A13, sec			Set INSTR(23) = 2 When T > A13	1.D70	
A14			$\epsilon 12$ and $\epsilon 13$ limits	-0.1	
DT, sec	7		Time increment for numerical calculation		5E16.8
TSTOP, sec			Time to halt calculation		
$EMAX		(0,1)	Maximum allowable error - used in SOLVER } fractions, not percent		
PERR		(0,1)	Maximum allowable error - used in MAIN } fractions, not percent		
A10, sec			Time at which INSTR(6) is set different from zero	1.D70	
AREAM(1), ft²	8		Maximum main valve flow area		5E16.8
AREAM(2), ft²			Maximum plenum exhaust flow area		
AREAM(3), ft²			Maximum flap flow area		
TVF(1), sec	9		Final time in main valve area-time curve		5E16.8
TVF(2), sec			Final time in plenum exhaust area-time curve		
TVF(3), sec			Final time in flap area-time curve		
TDELAY(1), sec	10		Time delay for main valve		5E16.8
TDELAY(2), sec			Time delay for plenum exhaust		
TDELAY(3), sec			Time delay for flaps		
TV(1,I) AREA(1,I)		[0.,1.]	Nondimensional time (final = 1.0) and nondimensional area (maximum = 1.0) for {main valve}		2E16.8
TV(2,I) AREA(2,I)		[0.,1.]	Nondimensional time (final = 1.0) and nondimensional area (maximum = 1.0) for {plenum exhaust}		
TV(3,I) AREA(3,I)		[0.,1.]	Nondimensional time (final = 1.0) and nondimensional area (maximum = 1.0) for {flaps}		
I1[d]	1	0	Return 1 } one card		
		1	Read ISTR(I2) } one card		
		2	Read RSTR(I2) } one card		
		3	Read V(I2,I3) } one card		
I2			Indices of array elements to be read } one card		
I3					26I3
ISTR	>1		Enter one per card each preceded by a no. 1 card above - see common and equivalence statements to determine indices		I3
RSTR	>1				E16.8
V	>1				E16.8

[a]Card Order in Input Deck

[b]If Less than Zero, Ramps of Fig. 27b Will Be Used

[c]Round Brackets Exclude End Points

[d]These Cards Omitted Unless NCTL ≠ 0

Note: If INSTR(5) = 1, any set of units for which g_c = 1 in F = 1/g_c ma will work properly.

Table C-4. Suggested Values for INSTR(I)

I	Suggested Value of INSTR (I)
1	03
2	05
3	06
4	01
5	02
6	00
7	02
8	01
9	01
10	01
11	40[a]
12	10
13	0 or 1
14	01
15	03
16	00
17	00
18	03
19	00
20	10[a]
21	00
22	01
23	01
24	00
25	02
26	09[a]

(a) Adjustment May Be Necessary for Specific Cases

Table C-5. Recommended Values for Certain Variables

Variable Names	Recommended Value
KW, KF	See Fig. 7
A15, A16	See Fig. 27a, Enter Negative
A11	0.5 or Leave Blank
A13	Leave Blank
A14	-0.2
A17	0.9
PERR	0.49999999E-04
$EMAX	0.49999999E-05

Table C-6. Sample Jobstream and Input Data Deck

```
/*PRIORITY      2
//VKFD5145      JOB            (ARO,
//   VRV00090,01,V37A-31A)$09452SHOPE,MSGLEVEL=(2,0),CLASS=A,TIME=3
// EXEC FORTEPDS,PGMNO=VRV00090
//GO.FT03F001 DD DUMMY
//GO.FT05F001 DD *
000
                      02        01 20 10                          10 00 20 01 00     09
 02 10 02
  0.15215000E+03  0.53000000E+03
  2.11400000E 00  0.61170000E 00  0.76330000E 00  1.16200000E 00  2.50000000E 00
  0.04000000E 00  0.31000000E+03  0.20000000E+03 -1.04988410E 00 -1.08312800E 00
  0.90000000E 00
  0.17176000E+04  1.40000000E 00                                 -0.20000000E 00
  0.00100000E 00  0.18000000E 00  0.49999999E-05  0.49999999E-04
  0.46591116E 00  0.90371714E -1  0.09167000E 00
  0.03000000E 00  0.04000000E 00  0.00000000E 00
  0.00000000E 00  0.00500000E 00  0.00000000E 00
  0.00000000E 00  0.00000000E 00
  1.00000000E 00  1.00000000E 00
  0.00000000E 00  0.00000000E 00
  0.16400000E 00  0.92300000E 00
  0.20000000E 00  0.98000000E 00
  0.30000000E 00  1.00000000E 00
  0.45000000E 00  0.99298055E 00
  0.50000000E 00  0.97332608E 00
  0.66000000E 00  0.64902737E 00
  0.80000000E 00  0.52478305E 00
  0.90000000E 00  0.49810913E 00
  1.00000000E 00  0.48687801E 00
  0.00000000E 00  1.00000000E 00
  1.00000000E 00  1.00000000E 00
/*
```

TABLE C-7
SAMPLE OUTPUT FROM HIRTSM1 FOR RUN 2742

```
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$                                                                              $
$  HIRTSM1 - MATHEMATICAL STARTING MODEL FOR A LUDWIEG TUBE WIND TUNNEL        $
$                                                                              $
$  ARNOLD RESEARCH ORGANIZATION, ARNOLD AIR FORCE STATION, TN                  $
$                                                                              $
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$

INSTR 1 INSTR 2 INSTR 3 INSTR 4 INSTR 5 INSTR 6 INSTR 7 INSTR 8 INSTR 9 INSTR10 INSTR11 INSTR12 INSTR13 INSTR14 INSTR15 INSTR16
INSTR17 INSTR18 INSTR19 INSTR20 INSTR21 INSTR22 INSTR23 INSTR24 INSTR25 INSTR26
      3       5       6       1       2       0       2       1       1       1      20      10       0       1       3       0
      0       3       0      10       0      20       1       0       2       9

IDEBUG    IIN   IOUT     I1  IPAGE  NPAGE     NP     IP   ITER     I2      I   IFLG  IFLG1  IFLG2  IFLG3  IFLG4  IFLG5  IFLG6
   3       5      6       0      0     50      1      0      0      0     26      0      1      1      0      0      0      0

 IFLG7  IFLG8  IFLG9     ND     NN    NCT  ITIME NVT(1) NVT(2) NVT(3)     I3     I4     I5  IT(1)  IT(2)  IT(3)   NCTL
    0      0      0      0      0      0      0      2     11      2      0      0      0      2      2      2      0

      TSL                TSH                TSW                CTD               PVOTSV              TAUW                KW                 KF
 0.21140000D 01     0.61170000D 00     0.76330000D 00     0.11620000D 01     0.25000000D 01     0.40000000D-01     0.31000000D 03     0.20000000D 03

      AEM                APM                AFM                TSA                TSP                TSWA               CTA                TSV
 0.46591116D 00     0.90371714D-01     0.91670000D-01     0.46691061D 00     0.27500000D 01     0.58135000D 01     0.10604789D 01     0.98704903D 00

      PV                 AWOKW
 0.24676226D 01     0.12752190D-03

      PC                 RC                 TC                 PP                 RP                 TP                 PP1                RP1
 0.15215000D 03     0.24067696D-01     0.53000000D 03     0.15215000D 03     0.24067696D-01     0.53000000D 03     0.15215000D 03     0.24067696D-01

      TP1                PPT                RPT                TPT                PCT0               RCT0               TCT0               PE0
 0.53000000D 03     0.15215000D 03     0.24067696D-01     0.53000000D 03     0.15215000D 03     0.24067696D-01     0.53000000D 03     0.15215000D 03

      RE0                TE0                AC                 ACT0               MDPE               MDCT               MDE                MDF
 0.24067696D-01     0.53000000D 03     0.11289221D 04     0.11289221D 04     0.0                0.0                0.0                0.0

       T                 T1                 MN                 TSTR               MDPT               MDD                PD                 PN
 0.0                0.0                0.0                0.0                0.0                0.0                0.15215000D 03     0.15215000D 03

      PT                 MD                 MCT                PP2                MDE2               MDPE2              MDF2               MDCT2
 0.15215000D 03     0.0                0.0                0.15215000D 03     0.0                0.0                0.0                0.0

     SEMAX              TSTOP               DT                 PSOP0              TSOT0              RSOR0              MSOM0              MDTSTR
 0.49999999D-05     0.18000000D 00     0.10000000D-02     0.52828179D 00     0.83333333D 00     0.63393815D 00     0.57870370D 00     0.73415627D 01

     MDTS0              MDCTC              MDCT0              PERM               PN3                PP3                MDF3               PE03
 0.12686220D 02     0.28813801D 02     0.28813801D 02     0.49999999D-04     0.15215000D 03     0.15215000D 03     0.0                0.15215000D 03

     TE03               MDTS03             PCT03              TDELAY             TDELAY             TDELAY
 0.53000000D 03     0.12686220D 02     0.15215000D 03     0.0                0.50000000D-02     0.0

      A1                 A2                 A3                 A4                 A5                 A6                 A7                 A8
 0.16521834D-01     0.14400000D 03     0.69444444D-02     0.57870370D 00     0.17280000D 01     0.47171821D 00     0.16658684D 00    -0.28571429D 00

      A9                 A10                A11                A12                A13                A14                A15                A16
 0.48000000D 01     0.99999945D 70     0.50000000D 00     0.50000000D 00     0.99999945D 70    -0.20000000D 00    -0.10498841D 01    -0.10831280D 01

      A17                A18                A19                A20                A21                A22                A23                A24
 0.90000000D 00     0.40264195D-80     0.41756987D-80     0.42560006D-80     0.43280664D-80     0.45730902D-80     0.46678052D-80     0.47717859D-80
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       G              GM1            GP1            GM102          GP102          OOG            GM1OG          GP1OG
0.14000000D 01  0.40000000D 00  0.24000000D 01  0.20000000D 00  0.12000000D 01  0.71428571D 00  0.28571429D 00  0.17142857D 01

     GOGM1          GOGP1          SGM102         TOG            TOGP1          OOGM1          GPOGM1         GPGM12
0.35000000D 01  0.58333333D 00  0.44721360D 00  0.14285714D 01  0.83333333D 00  0.25000000D 01  0.60000000D 01  0.30000000D 01

     TOGM1          MGPGM2         MGPOGM         OOGP1          R              OOR            GR             DTO2
0.50000000D 01 -0.30000000D 01 -0.60000000D 01  0.41666667D 00  0.17176080D 04  0.58220502D-03  0.24046512D 04  0.50000000D-03

     DTOPV          OOKF           INFIN          OOA1           OODT           MGOGM1         TMGOGS         GPO2GS
0.40524836D-03  0.50000000D-02  0.99999945D 70  0.60525968D 02  0.10000000D 04 -0.35000000D 01  0.30612245D 00  0.61224490D 00

     SGOR
0.28549729D-01

V EQUIVALENCE ARRAY
. 0.15215000D 03  0.15215000D 03  0.15215000D 03  0.15215000D 03  0.15215000D 03  0.15215000D 03  0.15215000D 03  0.0
  0.0             0.0             0.0             0.0             0.0             0.12686220D 02  0.28813801D 02  0.53000000D 03
  0.53000000D 03  0.53000000D 03  0.53000000D 03  0.24067696D-01  0.24067696D-01  0.24067696D-01  0.24067696D-01  0.11289221D 04
  0.0             0.0             0.0             0.0             0.0             0.0             0.15215000D 03  0.15215000D 03
  0.15215000D 03  0.15215000D 03  0.15215000D 03  0.15215000D 03  0.15215000D 03  0.0             0.0             0.0
  0.0             0.0             0.0             0.12686220D 02  0.28813801D 02  0.53000000D 03  0.53000000D 03  0.53000000D 03
  0.53000000D 03  0.24067696D-01  0.24067696D-01  0.24067696D-01  0.24067696D-01  0.11289221D 04  0.0             0.0
  0.0             0.91670000D-01  0.0             0.0             0.15215000D 03  0.15215000D 03  0.15215000D 03  0.15215000D 03
  0.15215000D 03  0.15215000D 03  0.15215000D 03  0.0             0.0             0.0             0.0             0.0
  0.0             0.12686220D 02  0.28813801D 02  0.53000000D 03  0.53000000D 03  0.53000000D 03  0.53000000D 03  0.24067696D-01
  0.24067696D-01  0.24067696D-01  0.24067696D-01  0.11289221D 04  0.0             0.0             0.0             0.0
  0.0             0.0             0.15215000D 03  0.15215000D 03  0.15215000D 03  0.15215000D 03  0.15215000D 03  0.15215000D 03
  0.15215000D 03  0.0             0.0             0.0             0.0             0.0             0.0             0.12686220D 02
  0.28813801D 02  0.53000000D 03  0.53000000D 03  0.53000000D 03  0.53000000D 03  0.24067696D-01  0.24067696D-01  0.24067696D-01
  0.24067696D-01  0.11289221D 04  0.0             0.0             0.0             0.0             0.0             0.0

     RW(1)          RW(2)          RW(3)          RW(4)          RW(5)          RW(6)          RW(7)
0.10000000D 01  0.12000000D 01  0.20400000D 01  0.40480000D 01  0.87696000D 01  0.20106240D 02  0.47961472D 02

INSTR( 1)=    3  SEND DEBUGGING OUTPUT TO DSRN  3

INSTR( 2)=    5  OBTAIN INPUT FROM DSRN  5

INSTR( 3)=    6  SEND REGULAR OUTPUT TO DSRN  6

INSTR( 4)=    1  PRINTING TIME INTERVAL:  1

INSTR( 5)=    2  INPUT AND OUTPUT PRESSURES IN PSIA

INSTR( 6)=    0  PRINT DATA ONLY WHEN CONVERGED

INSTR( 7)=    2  DO NOT EXTRAPOLATE TO NEXT TIME INTERVAL

INSTR( 8)=    1  USE SEVENTH DEGREE REVERTED SERIES AS INITIAL GUESS TO MASS FLUX-MACH NUMBER WAVE EQUATION

INSTR( 9)=    1  USE ITERATIVE SOLUTION TO ENERGY AND WAVE EQUATIONS

INSTR(10)=    1  AVERAGE VALUES OF CURRENT ITERATION WITH AVERAGE VALUES OF PREVIOUS ITERATION

INSTR(11)=   20  CURRENT WEIGHT IS HALVED BEYOND      20 ITERATIONS
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INSTR(12)=	10	DIVIDE ERRORS BY 10 WHEN TIME-DIFFERENCES ARE LESS THAN 10 TIMES THE ERRORS
INSTR(13)=	0	PRINT ALL DATA
INSTR(14)=	1	DO NOT INVOKE DT-RAISING OPTION
INSTR(15)=	3	DO NOT READ SOLUTION FROM PERMANENT DATA SET
INSTR(16)=	0	FIRST RECORD TO BE READ: 0
INSTR(17)=	0	LAST RECORD TO BE READ: 0
INSTR(18)=	3	DO NOT WRITE SOLUTION ON PERMANENT DATA SET
INSTR(19)=	0	FIRST RECORD TO BE WRITTEN: 0
INSTR(20)=	10	INCREMENT INSTR(11) BY 10 WHENEVER WEIGHT IS HALVED
INSTR(21)=	0	DO NOT CHANGE EXTRAPOLATION OPTION (INSTR(7))
INSTR(22)=	20	SET INSTR(23)=2 WHEN ITER >= 20
INSTR(23)=	1	USE SMALL PERTURBATION EXPANSIONS AS INITIAL GUESS FOR NEXT TIME INTERVAL
INSTR(24)=	0	RESULTS FROM SMPERT NOT PRINTED
INSTR(25)=	2	SET TP AND TPT = MAX(ISEN TP,TC(0))
INSTR(26)=	9	REVERT TO EXACT SUPERSONIC SOLUTION 9 TIME INCREMENTS AFTER CHOKE

J 1	J 2	J 3	J 4	J 5	J 6	J 7	J 8	J 9	J10	J11	J12	J13	J14	J15	J16	J17	J18	J19	J20	J21	J22	J23	J24	J25	J26
3	5	6	1	2	0	2	1	1	1	20	10	0	1	3	0	0	3	0	10	0	20	1	0	2	9

FLOW AREAS VERSUS TIME

I	TV(1,I)	AREA(1,I)	TV(2,I)	AREA(2,I)	TV(3,I)	AREA(3,I)
1	0.0	0.0	0.0	0.0	0.0	0.91670000D-01
2	0.30000000D-01	0.46591116D 00	0.50000000D-02	0.0	0.0	0.91670000D-01
3	0.0	0.0	0.11560000D-01	0.83413092D-01	0.0	0.0
4	0.0	0.0	0.13000000D-01	0.88564280D-01	0.0	0.0
5	0.0	0.0	0.17000000D-01	0.90371714D-01	0.0	0.0
6	0.0	0.0	0.23000000D-01	0.89737354D-01	0.0	0.0
7	0.0	0.0	0.25000000D-01	0.87961146D-01	0.0	0.0
8	0.0	0.0	0.31400000D-01	0.58653716D-01	0.0	0.0
9	0.0	0.0	0.37000000D-01	0.47425544D-01	0.0	0.0
10	0.0	0.0	0.41000000D-01	0.45014976D-01	0.0	0.0
11	0.0	0.0	0.45000000D-01	0.44000000D-01	0.0	0.0

T	TSTR	T1	PT	PP	PD	PN	PPT	ND
PCTO	PEO	MCT	MD	MN	MDCT	MDPT	MDD	NM
MDF	MDE	MDPE	MDTSO	MDCTO	TP	TPT	TEO	NCT
TCTO	RP	RPT	REO	RCTO	AE	APE	AF	ITER
E(1)	E(2)	E(3)	E(4)	E(5)	E(6)	E(7)	DT	J16
0.0	0.0	0.0	0.152150D 03	0.152150D 03	0.152150D 03	0.152150D 03	0.152150D 03	0
0.152150D 03	0.152150D 03	0.0	0.0	0.0	0.0	0.0	0.0	0
0.0	0.0	0.0	0.126862D 02	0.288138D 02	0.530000D 03	0.530000D 03	0.530000D 03	0
0.530000D 03	0.240677D-01	0.240677D-01	0.240677D-01	0.240677D-01	0.0	0.0	0.0	0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.100000D-02	-1
0.100000D-02	0.500000D-03	0.0	0.151568D 03	0.152074D 03	0.151570D 03	0.151565D 03	0.151998D 03	21
0.151569D 03	0.151569D 03	0.273812D-02	0.694732D-02	0.621917D-02	0.786372D-01	-0.927192D-02	0.878475D-01	19
-0.331411D-01	0.121702D 00	0.0	0.126447D 02	0.287194D 02	0.529924D 03	0.529849D 03	0.529421D 03	19
0.529421D 03	0.240591D-01	0.240505D-01	0.240020D-01	0.240020D-01	0.776519D-02	0.0	0.916700D-01	3
0.442799D-04	0.989949D-05	0.198061D-04	0.782624D-05	0.182267D-04	0.436644D-04	0.436644D-04	0.100000D-02	-1
PERR CUT TO 0.49999999D-05 AND SEMAX CUT TO 0.49999999D-06								
0.200000D-02	0.150000D-02	0.100000D-02	0.150304D 03	0.151785D 03	0.150299D 03	0.150308D 03	0.151573D 03	18
0.150348D 03	0.150348D 03	0.855315D-02	0.215218D-01	0.194300D-01	0.243934D 00	-0.262455D-01	0.270181D 00	25
-0.923444D-01	0.362571D 00	0.0	0.125573D 02	0.285211D 02	0.529637D 03	0.529425D 03	0.528199D 03	19
0.528199D 03	0.240265D-01	0.240025D-01	0.238638D-01	0.238638D-01	0.232956D-01	0.0	0.916700D-01	10
0.891248D-06	0.663618D-06	0.132856D-05	0.226175D-05	0.157648D-05	0.852219D-06	0.852219D-06	0.100000D-02	-1
0.300000D-02	0.250000D-02	0.200000D-02	0.148907D 03	0.151254D 03	0.148895D 03	0.148919D 03	0.150935D 03	21
0.149039D 03	0.149039D 03	0.148910D-01	0.370687D-01	0.338401D-01	0.421478D 00	-0.401483D-01	0.461626D 00	21
-0.138061D 00	0.599771D 00	0.0	0.124635D 02	0.283080D 02	0.529106D 03	0.528787D 03	0.526881D 03	19
0.526881D 03	0.239663D-01	0.239302D-01	0.237151D-01	0.237151D-01	0.388259D-01	0.0	0.916700D-01	10
0.198541D-08	0.119035D-05	0.238428D-05	0.458196D-05	0.229179D-05	0.258359D-08	0.258359D-08	0.100000D-02	-1
0.400000D-02	0.350000D-02	0.300000D-02	0.147420D 03	0.150526D 03	0.147398D 03	0.147442D 03	0.150118D 03	24
0.147690D 03	0.147690D 03	0.215295D-01	0.531828D-01	0.489560D-01	0.604559D 00	-0.520260D-01	0.656585D 00	21
-0.176481D 00	0.833162D 00	0.0	0.123668D 02	0.280883D 02	0.528378D 03	0.527968D 03	0.525514D 03	18
0.525514D 03	0.238839D-01	0.238376D-01	0.235616D-01	0.235616D-01	0.543563D-01	0.0	0.916700D-01	10
0.355785D-06	0.138066D-05	0.276666D-05	0.430807D-05	0.233162D-05	0.313059D-06	0.313059D-06	0.100000D-02	-1
0.500000D-02	0.450000D-02	0.400000D-02	0.145855D 03	0.149633D 03	0.145819D 03	0.145890D 03	0.149149D 03	18
0.146317D 03	0.146317D 03	0.284065D-01	0.697672D-01	0.646495D-01	0.791146D 00	-0.622755D-01	0.853422D 00	21
-0.209144D 00	0.106267D 01	0.0	0.122682D 02	0.278643D 02	0.527480D 03	0.526992D 03	0.524113D 03	18
0.524113D 03	0.237826D-01	0.237276D-01	0.234050D-01	0.234050D-01	0.698867D-01	0.0	0.916700D-01	10
0.451639D-06	0.148317D-05	0.297319D-05	0.371255D-05	0.208170D-05	0.385848D-06	0.385848D-06	0.100000D-02	-1
0.600000D-02	0.550000D-02	0.500000D-02	0.144154D 03	0.148439D 03	0.144105D 03	0.144203D 03	0.147731D 03	9
0.144875D 03	0.144875D 03	0.357640D-01	0.872758D-01	0.814911D-01	0.987357D 00	-0.694685D-01	0.105683D 01	17
-0.230891D 00	0.128783D 01	-0.978732D-01	0.121645D 02	0.276288D 02	0.526274D 03	0.525555D 03	0.522632D 03	17
0.522632D 03	0.236469D-01	0.235663D-01	0.232400D-01	0.232400D-01	0.854170D-01	0.635771D-02	0.916700D-01	10
0.924620D-06	0.178422D-05	0.358060D-05	0.339026D-05	0.215702D-05	0.765156D-06	0.765156D-06	0.100000D-02	-1
0.700000D-02	0.650000D-02	0.600000D-02	0.142203D 03	0.146678D 03	0.142141D 03	0.142264D 03	0.145627D 03	19
0.143275D 03	0.143275D 03	0.440922D-01	0.106629D 00	0.100638D 00	0.120527D 01	-0.707997D-01	0.127607D 01	18
-0.231349D 00	0.150757D 01	-0.290630D 00	0.120493D 02	0.273671D 02	0.524482D 03	0.523406D 03	0.520977D 03	17
0.520977D 03	0.234461D-01	0.233260D-01	0.230564D-01	0.230564D-01	0.100947D 00	0.190731D-01	0.916700D-01	10
0.173806D-05	0.241179D-05	0.484827D-05	0.324127D-05	0.248934D-05	0.138259D-05	0.138259D-05	0.100000D-02	-1

T PCTO MDF TCTO E(1)	ISTR PEO MDE RP E(2)	T1 MCT MDPE RPT E(3)	PT MD MDTSO REO E(4)	PP MN MDCTO RCTO E(5)	PD MDCT TP AE E(6)	PN MDPT TPT APE E(7)	PPT MDD TEO AF DT	ND NM NCT ITER J16
0.8000000D-02	0.7500000D-02	0.7000000D-02	0.139964D 03	0.144296D 03	0.139894D 03	0.140033D 03	0.142969D 03	20
0.141508D 03	0.141508D 03	0.535115D-01	0.128109D 00	0.122425D 00	0.144646D 01	-0.658874D-01	0.151234D 01	22
-0.208685D 00	0.172110D 01	-0.477635D 00	0.119217D 02	0.270774D 02	0.522035D 03	0.520659D 03	0.519132D 03	16
0.519132D 03	0.231736D-01	0.230212D-01	0.228528D-01	0.228528D-01	0.116478D 00	0.317885D-01	0.916700D-01	11
0.496893D-05	0.105743D-05	0.212872D-05	0.351006D-06	0.231028D-05	0.382935D-05	0.382935D-05	0.100000D-02	-1
0.9000000D-02	0.8500000D-02	0.8000000D-02	0.137249D 03	0.140887D 03	0.137184D 03	0.137313D 03	0.139819D 03	20
0.139450D 03	0.139450D 03	0.647682D-01	0.153179D 00	0.148691D 00	0.172753D 01	-0.507014D-01	0.177823D 01	22
-0.147972D 00	0.192624D 01	-0.656084D 00	0.117730D 02	0.267397D 02	0.516965D 03	0.516965D 03	0.516965D 03	16
0.516965D 03	0.228480D-01	0.226748D-01	0.226150D-01	0.226150D-01	0.132008D 00	0.445039D-01	0.916700D-01	12
0.136451D-05	0.273400D-06	0.843812D-06	0.277742D-05	0.207063D-05	0.101492D-05	0.101492D-05	0.100000D-02	-1
0.1000000D-01	0.9500000D-02	0.9000000D-02	0.134740D 03	0.138076D 03	0.134677D 03	0.134803D 03	0.136854D 03	17
0.137639D 03	0.137639D 03	0.749578D-01	0.176577D 00	0.172732D 00	0.197535D 01	-0.423509D-01	0.201770D 01	16
-0.111144D 00	0.212887D 01	-0.828250D 00	0.116418D 02	0.264417D 02	0.515037D 03	0.515037D 03	0.515037D 03	15
0.515037D 03	0.224759D-01	0.222770D-01	0.224048D-01	0.224048D-01	0.147539D 00	0.572193D-01	0.916700D-01	11
0.313698D-06	0.488217D-06	0.923293D-06	0.265050D-05	0.116771D-05	0.211124D-06	0.211124D-06	0.100000D-02	-1
0.1100000D-01	0.1050000D-01	0.1000000D-01	0.132080D 03	0.134977D 03	0.132025D 03	0.132134D 03	0.133625D 03	23
0.135801D 03	0.135801D 03	0.855832D-01	0.201099D 00	0.198125D 00	0.222723D 01	-0.318372D-01	0.225906D 01	19
-0.669061D-01	0.232599D 01	-0.991490D 00	0.115084D 02	0.261387D 02	0.513062D 03	0.513062D 03	0.513062D 03	16
0.513062D 03	0.220561D-01	0.218351D-01	0.221907D-01	0.221907D-01	0.163069D 00	0.699348D-01	0.916700D-01	11
0.158536D-06	0.423144D-06	0.825413D-06	0.334842D-05	0.159422D-05	0.995457D-07	0.995457D-07	0.100000D-02	-1
0.1200000D-01	0.1150000D-01	0.1100000D-01	0.129272D 03	0.131642D 03	0.129234D 03	0.129311D 03	0.130183D 03	20
0.133946D 03	0.133946D 03	0.966034D-01	0.226777D 00	0.224875D 00	0.248158D 01	-0.197063D-01	0.250128D 01	22
-0.163700D-01	0.251767D 01	-0.114506D 01	0.113736D 02	0.258324D 02	0.511051D 03	0.511051D 03	0.511051D 03	12
0.511051D 03	0.215958D-01	0.213565D-01	0.219738D-01	0.219738D-01	0.178599D 00	0.826502D-01	0.916700D-01	11
0.110093D-06	0.327626D-06	0.683904D-06	0.402426D-05	0.206660D-05	0.742843D-07	0.742843D-07	0.100000D-02	-1
0.1300000D-01	0.1250000D-01	0.1200000D-01	0.126401D 03	0.128266D 03	0.126383D 03	0.126418D 03	0.126852D 03	17
0.132138D 03	0.132138D 03	0.107661D 00	0.253021D 00	0.252222D 00	0.272991D 01	-0.798923D-02	0.273789D 01	14
0.329967D-01	0.270490D 01	-0.117365D 01	0.112418D 02	0.255332D 02	0.509070D 03	0.509070D 03	0.509070D 03	11
0.509070D 03	0.211237D-01	0.208910D-01	0.217615D-01	0.217615D-01	0.194130D 00	0.867757D-01	0.916700D-01	12
0.671984D-06	0.307757D-07	0.524027D-07	0.284086D-05	0.175627D-05	0.393086D-06	0.393086D-06	0.100000D-02	-1
0.1400000D-01	0.1350000D-01	0.1300000D-01	0.123555D 03	0.125037D 03	0.123559D 03	0.123552D 03	0.123692D 03	20
0.130432D 03	0.130432D 03	0.118388D 00	0.279171D 00	0.279320D 00	0.296634D 01	0.143011D-02	0.296291D 01	19
0.739744D-01	0.288894D 01	-0.117285D 01	0.111173D 02	0.252504D 02	0.507184D 03	0.507184D 03	0.507184D 03	10
0.507184D 03	0.206686D-01	0.204463D-01	0.215604D-01	0.215604D-01	0.209660D 00	0.887902D-01	0.916700D-01	12
0.539832D-06	0.245356D-07	0.370432D-07	0.298028D-05	0.176009D-05	0.297300D-06	0.297300D-06	0.100000D-02	-1
0.1500000D-01	0.1450000D-01	0.1400000D-01	0.120758D 03	0.121989D 03	0.120781D 03	0.120735D 03	0.120720D 03	16
0.128836D 03	0.128836D 03	0.128702D 00	0.305103D 00	0.305997D 00	0.318391D 01	0.828235D-02	0.317563D 01	20
0.105272D 00	0.307036D 01	-0.115210D 01	0.110006D 02	0.249853D 02	0.505402D 03	0.505402D 03	0.505402D 03	16
0.505402D 03	0.202358D-01	0.200254D-01	0.213717D-01	0.213717D-01	0.225190D 00	0.892421D-01	0.916700D-01	12
0.400052D-06	0.131868D-07	0.342077D-07	0.299565D-05	0.169809D-05	0.209011D-06	0.209011D-06	0.100000D-02	-1

T PCTO MDF TCTO E(1)	TSTR PEU MDE RP E(2)	T1 MCT MDPE RPT E(3)	PT MU MDTSU REU E(4)	PP MN MDCTO RCTO E(5)	PD MDCT TP AE E(6)	PN MDPT TPT APE E(7)	PPT MDD TEO AF DT	ND NM NCT ITER J16
0.1600000D-01	0.1550000D-01	0.1500000D-01	0.1180080D 03	0.1191100D 03	0.1180460D 03	0.1179690D 03	0.1179020D 03	13
0.1273420D 03	0.1273420D 03	0.1386100D 00	0.3308640D 00	0.3322970D 00	0.3389540D 01	0.1272950D-01	0.3376810D 01	21
0.1273520D 00	0.3249460D 01	-0.1132500D 01	0.1089120D 02	0.2473680D 02	0.5037210D 03	0.5037210D 03	0.5037210D 03	15
0.5037210D 03	0.1982430D-01	0.1962320D-01	0.2119440D-01	0.2119440D-01	0.2407210D 00	0.8969390D-01	0.9167000D-01	12
0.2704570D-06	0.2218090D-08	0.4328000D-07	0.2906550D-05	0.1588930D-05	0.1333770D-06	0.1333770D-06	0.1000000D-02	-1
0.1700000D-01	0.1650000D-01	0.1600000D-01	0.1152890D 03	0.1163680D 03	0.1153390D 03	0.1152390D 03	0.1152060D 03	17
0.1259370D 03	0.1259370D 03	0.1481650D 00	0.3566050D 00	0.3583860D 00	0.3583030D 01	0.1514240D-01	0.3567890D 01	19
0.1415200D 00	0.3426370D 01	-0.1113760D 01	0.1078810D 02	0.2450270D 02	0.5021270D 03	0.5021270D 03	0.5021270D 03	11
0.5021270D 03	0.1942930D-01	0.1923540D-01	0.2102710D-01	0.2102710D-01	0.2562510D 00	0.9014580D-01	0.9167000D-01	12
0.1591400D-06	0.1577050D-07	0.5353800D-07	0.2797010D-05	0.1478650D-05	0.7462190D-07	0.7462190D-07	0.1000000D-02	-1
0.1800000D-01	0.1750000D-01	0.1700000D-01	0.1125920D 03	0.1137360D 03	0.1126490D 03	0.1125350D 03	0.1126130D 03	19
0.1246120D 03	0.1246120D 03	0.1574020D 00	0.3824570D 00	0.3844010D 00	0.3765690D 01	0.1578110D-01	0.3749910D 01	12
0.1486980D 00	0.3601210D 01	-0.1092310D 01	0.1069070D 02	0.2428150D 02	0.5006110D 03	0.5006110D 03	0.5006110D 03	17
0.5006110D 03	0.1904740D-01	0.1885940D-01	0.2086870D-01	0.2086870D-01	0.2717820D 00	0.9031890D-01	0.9167000D-01	12
0.7625330D-07	0.2569530D-07	0.6136910D-07	0.2678340D-05	0.1377960D-05	0.3267720D-07	0.3267720D-07	0.1000000D-02	-1
0.1900000D-01	0.1850000D-01	0.1800000D-01	0.1099080D 03	0.1111980D 03	0.1099660D 03	0.1098490D 03	0.1101070D 03	18
0.1233580D 03	0.1233580D 03	0.1663420D 00	0.4085290D 00	0.4104450D 00	0.3938440D 01	0.1481710D-01	0.3923620D 01	17
0.1494680D 00	0.3774150D 01	-0.1068230D 01	0.1059850D 02	0.2407200D 02	0.4991670D 03	0.4991670D 03	0.4991670D 03	15
0.4991670D 03	0.1867620D-01	0.1849300D-01	0.2071860D-01	0.2071860D-01	0.2873120D 00	0.9021310D-01	0.9167000D-01	12
0.7839900D-08	0.3270740D-07	0.6729660D-07	0.2555380D-05	0.1282290D-05	0.4386120D-08	0.4386120D-08	0.1000000D-02	-1
0.2000000D-01	0.1950000D-01	0.1900000D-01	0.1072260D 03	0.1087350D 03	0.1072800D 03	0.1071730D 03	0.1076670D 03	17
0.1221710D 03	0.1221710D 03	0.1750070D 00	0.4349470D 00	0.4366400D 00	0.4102140D 01	0.1242100D-01	0.4089720D 01	14
0.1444010D 00	0.3945320D 01	-0.1044790D 01	0.1051100D 02	0.2387320D 02	0.4977900D 03	0.4977900D 03	0.4977900D 03	19
0.4977900D 03	0.1831310D-01	0.1813320D-01	0.2057600D-01	0.2057600D-01	0.3028420D 00	0.9010740D-01	0.9167000D-01	11
0.3630140D-07	0.6787350D-07	0.1407800D-06	0.4865940D-05	0.2452330D-05	0.1288490D-07	0.1288490D-07	0.1000000D-02	-1
0.2100000D-01	0.2050000D-01	0.2000000D-01	0.1045360D 03	0.1063270D 03	0.1045770D 03	0.1044950D 03	0.1052730D 03	18
0.1210430D 03	0.1210430D 03	0.1834190D 00	0.4618630D 00	0.4631260D 00	0.4257620D 01	0.8758400D-02	0.4248860D 01	17
0.1340480D 00	0.4114810D 01	-0.1021810D 01	0.1042780D 02	0.2368430D 02	0.4964730D 03	0.4964730D 03	0.4964730D 03	18
0.4964730D 03	0.1795510D-01	0.1777700D-01	0.2044010D-01	0.2044010D-01	0.3183730D 00	0.9000170D-01	0.9167000D-01	11
0.4196540D-07	0.7243070D-07	0.1416520D-06	0.4664600D-05	0.2312240D-05	0.1581320D-07	0.1581320D-07	0.1000000D-02	-1
0.2200000D-01	0.2150000D-01	0.2100000D-01	0.1018260D 03	0.1039560D 03	0.1018460D 03	0.1018050D 03	0.1029070D 03	14
0.1199710D 03	0.1199710D 03	0.1915920D 00	0.4894360D 00	0.4900430D 00	0.4405490D 01	0.3954590D-02	0.4401530D 01	18
0.1187890D 00	0.4282740D 01	-0.9991160D 00	0.1034850D 02	0.2350430D 02	0.4952120D 03	0.4952120D 03	0.4952120D 03	15
0.4952120D 03	0.1759940D-01	0.1742180D-01	0.2031060D-01	0.2031060D-01	0.3339030D 00	0.8989590D-01	0.9167000D-01	11
0.1225300D-06	0.7564210D-07	0.1428710D-06	0.4465030D-05	0.2171710D-05	0.3401640D-07	0.3401640D-07	0.1000000D-02	-1
0.2300000D-01	0.2250000D-01	0.2200000D-01	0.9908380D 02	0.1016060D 03	0.9907320D 02	0.9909440D 02	0.1005560D 03	19
0.1189510D 03	0.1189510D 03	0.1995320D 00	0.5178420D 00	0.5175300D 00	0.4546200D 01	-0.1899830D-02	0.4548100D 01	20
0.9884940D-01	0.4449250D 01	-0.9765740D 00	0.1027310D 02	0.2333290D 02	0.4940050D 03	0.4940050D 03	0.4940050D 03	17
0.4940050D 03	0.1724360D-01	0.1706540D-01	0.2018710D-01	0.2018710D-01	0.3494330D 00	0.8979020D-01	0.9167000D-01	11
0.1355140D-06	0.7557440D-07	0.1405400D-06	0.4249880D-05	0.2056950D-05	0.4168790D-07	0.4168790D-07	0.1000000D-02	-1

T PCT0 MDF TCT0 E(1)	TSTR PE0 MDE RP E(2)	TI MCT MDPE RPT E(3)	PT MD MDTS0 RE0 E(4)	PP MN MDCT0 RCT0 E(5)	PD MDCT TP AE E(6)	PN MDPT TPT APE E(7)	PPT MDD TE0 AF DT	ND NM NCT ITER J16
0.240000D-01	0.235000D-01	0.230000D-01	0.963018D 02	0.992677D 02	0.962479D 02	0.963556D 02	0.982141D 02	21
0.117981D 03	0.117981D 03	0.207231D 00	0.547250D 00	0.545702D 00	0.467988D 01	-0.878253D-02	0.468866D 01	16
0.741495D-01	0.461451D 01	-0.949925D 00	0.102013D 02	0.231698D 02	0.492852D 03	0.492852D 03	0.492852D 03	16
0.492852D 03	0.168861D-01	0.167069D-01	0.200695D-01	0.200695D-01	0.364964D 00	0.892933D-01	0.916700D-01	11
0.150447D-06	0.712918D-07	0.132201D-06	0.406464D-05	0.195592D-05	0.407527D-07	0.407527D-07	0.100000D-02	-1
0.250000D-01	0.245000D-01	0.240000D-01	0.934731D 02	0.969353D 02	0.933601D 02	0.935860D 02	0.958754D 02	17
0.117064D 03	0.117064D 03	0.214664D 00	0.577838D 00	0.574643D 00	0.480641D 01	-0.167197D-01	0.482313D 01	17
0.443486D-01	0.477878D 01	-0.919405D 00	0.101332D 02	0.230152D 02	0.491754D 03	0.491754D 03	0.491754D 03	16
0.491754D 03	0.165262D-01	0.163455D-01	0.199578D-01	0.199578D-01	0.380494D 00	0.884052D-01	0.916700D-01	11
0.144818D-06	0.651898D-07	0.121291D-06	0.387749D-05	0.186391D-05	0.360170D-07	0.360170D-07	0.100000D-02	-1
0.260000D-01	0.255000D-01	0.250000D-01	0.906007D 02	0.946203D 02	0.904069D 02	0.907944D 02	0.935672D 02	17
0.116203D 03	0.116203D 03	0.221771D 00	0.609726D 00	0.604321D 00	0.492513D 01	-0.258572D-01	0.495099D 01	17
0.852927D-02	0.496246D 01	-0.870614D 00	0.100693D 02	0.228700D 02	0.490717D 03	0.490717D 03	0.490717D 03	17
0.490717D 03	0.161656D-01	0.159857D-01	0.198529D-01	0.198529D-01	0.396024D 00	0.856715D-01	0.916700D-01	11
0.113959D-06	0.499298D-07	0.935715D-07	0.374677D-05	0.181228D-05	0.253475D-07	0.253475D-07	0.100000D-02	-1
0.270000D-01	0.265000D-01	0.260000D-01	0.876965D 02	0.923463D 02	0.873916D 02	0.880014D 02	0.913093D 02	17
0.115406D 03	0.115406D 03	0.228468D 00	0.642980D 00	0.634571D 00	0.503500D 01	-0.364051D-01	0.507140D 01	11
-0.346677D-01	0.510607D 01	-0.805065D 00	0.100101D 02	0.227355D 02	0.489753D 03	0.489753D 03	0.489753D 03	16
0.489753D 03	0.158081D-01	0.156306D-01	0.197555D-01	0.197555D-01	0.411555D 00	0.810922D-01	0.916700D-01	11
0.104241D-06	0.333232D-07	0.636159D-07	0.359996D-05	0.174142D-05	0.129507D-07	0.129507D-07	0.100000D-02	-1
0.280000D-01	0.275000D-01	0.270000D-01	0.847570D 02	0.901085D 02	0.843002D 02	0.852138D 02	0.890733D 02	18
0.114675D 03	0.114675D 03	0.234711D 00	0.677865D 00	0.665367D 00	0.513567D 01	-0.483494D-01	0.518402D 01	13
-0.859660D-01	0.526999D 01	-0.741868D 00	0.995572D 01	0.226121D 02	0.488865D 03	0.488865D 03	0.488865D 03	14
0.488865D 03	0.154531D-01	0.152755D-01	0.196661D-01	0.196661D-01	0.427085D 00	0.765129D-01	0.916700D-01	11
0.633284D-07	0.272164D-07	0.518359D-07	0.333886D-05	0.162860D-05	0.110432D-07	0.110432D-07	0.100000D-02	-1
0.290000D-01	0.285000D-01	0.280000D-01	0.817640D 02	0.878780D 02	0.810994D 02	0.824286D 02	0.868305D 02	14
0.114011D 03	0.114011D 03	0.240478D 00	0.714884D 00	0.696793D 00	0.522721D 01	-0.615016D-01	0.528871D 01	11
-0.145778D 00	0.543449D 01	-0.680768D 00	0.990626D 01	0.224998D 02	0.488055D 03	0.488055D 03	0.488055D 03	14
0.488055D 03	0.150956D-01	0.149157D-01	0.195846D-01	0.195846D-01	0.442616D 00	0.719336D-01	0.916700D-01	11
0.423989D-07	0.206246D-07	0.395483D-07	0.309215D-05	0.151214D-05	0.751280D-08	0.751280D-08	0.100000D-02	-1
0.300000D-01	0.295000D-01	0.290000D-01	0.787005D 02	0.856262D 02	0.777476D 02	0.796535D 02	0.845517D 02	14
0.113415D 03	0.113415D 03	0.245724D 00	0.754704D 00	0.728816D 00	0.530928D 01	-0.756393D-01	0.538492D 01	15
-0.215054D 00	0.559997D 01	-0.621561D 00	0.986187D 01	0.223989D 02	0.487324D 03	0.487324D 03	0.487324D 03	14
0.487324D 03	0.147308D-01	0.145460D-01	0.195115D-01	0.195115D-01	0.458146D 00	0.673544D-01	0.916700D-01	11
0.186695D-06	0.908252D-08	0.110318D-07	0.296926D-05	0.156113D-05	0.251391D-07	0.251391D-07	0.100000D-02	-1
0.310000D-01	0.305000D-01	0.300000D-01	0.763310D 02	0.834333D 02	0.752141D 02	0.774480D 02	0.824056D 02	14
0.112989D 03	0.112989D 03	0.249516D 00	0.785182D 00	0.754811D 00	0.536788D 01	-0.776504D-01	0.544553D 01	14
-0.231043D 00	0.567656D 01	-0.564770D 00	0.983014D 01	0.223269D 02	0.486801D 03	0.486801D 03	0.486801D 03	18
0.486801D 03	0.143690D-01	0.141920D-01	0.194592D-01	0.194592D-01	0.465911D 00	0.627751D-01	0.916700D-01	14
0.321694D-05	0.373704D-06	0.638569D-06	0.270881D-05	0.296659D-05	0.403502D-06	0.403502D-06	0.100000D-02	-1

	T PCTO MUF TCTO E(1)	TSTR PEO MDE RP E(2)	T1 MCT MDPE RPT E(3)	PI MD MDTSO REO E(4)	PP MN MDCTO RCTO E(5)	PD MDCT TP AE E(6)	PN MDPT TPT APE E(7)	PPT MDD TEO AF DT	ND NM NCT ITER J16
	0.320000D-01	0.315000D-01	0.310000D-01	0.748092D 02	0.814401D 02	0.737365D 02	0.758818D 02	0.805322D 02	11
	0.112713D 03	0.112713D 03	0.251996D 00	0.802802D 00	0.773584D 00	0.540589D 01	-0.679581D-01	0.547385D 01	16
	-0.190793D 00	0.566467D 01	-0.513504D 00	0.980955D 01	0.222801D 02	0.486461D 03	0.486461D 03	0.486461D 03	15
	0.486461D 03	0.140355D-01	0.138790D-01	0.194252D-01	0.194252D-01	0.465911D 00	0.584532D-01	0.916700D-01	19
	0.474809D-05	0.568020D-06	0.991515D-06	0.399072D-05	0.437484D-05	0.538521D-06	0.538521D-06	0.100000D-02	-1
SWITCHING TO SMALL PERTURBATION SOLUTION ENTIRELY									
	0.330000D-01	0.325000D-01	0.320000D-01	0.735874D 02	0.797058D 02	0.725698D 02	0.746050D 02	0.788342D 02	0
	0.112504D 03	0.112504D 03	0.253882D 00	0.816861D 00	0.789084D 00	0.543471D 01	-0.594439D-01	0.549416D 01	0
	-0.158468D 00	0.565265D 01	-0.484954D 00	0.979393D 01	0.222446D 02	0.486461D 03	0.486182D 03	0.486203D 03	0
	0.486203D 03	0.137366D-01	0.135942D-01	0.193994D-01	0.193994D-01	0.465911D 00	0.564482D-01	0.916700D-01	1
0	0.442896D-04	0.533182D-05	0.947961D-05	0.396465D-04	0.420007D-04	0.444213D-05	0.444213D-05	0.100000D-02	0
	0.340000D-01	0.335000D-01	0.330000D-01	0.724545D 02	0.781269D 02	0.714872D 02	0.734218D 02	0.773317D 02	0
	0.112323D 03	0.112323D 03	0.255518D 00	0.830085D 00	0.803618D 00	0.545957D 01	-0.521024D-01	0.551168D 01	0
	-0.130567D 00	0.564227D 01	-0.458099D 00	0.978046D 01	0.222140D 02	0.486466D 03	0.486203D 03	0.485980D 03	0
	0.485980D 03	0.134644D-01	0.133345D-01	0.193771D-01	0.193771D-01	0.465911D 00	0.544432D-01	0.916700D-01	1
0	0.442896D-04	0.533182D-05	0.947961D-05	0.396465D-04	0.420007D-04	0.444213D-05	0.444213D-05	0.100000D-02	0
	0.350000D-01	0.345000D-01	0.340000D-01	0.714033D 02	0.766872D 02	0.704817D 02	0.723249D 02	0.759220D 02	0
	0.112167D 03	0.112167D 03	0.256936D 00	0.842524D 00	0.817243D 00	0.548103D 01	-0.457677D-01	0.552680D 01	0
	-0.106490D 00	0.563331D 01	-0.432742D 00	0.976882D 01	0.221876D 02	0.486475D 03	0.485980D 03	0.485787D 03	0
	0.485787D 03	0.132160D-01	0.130975D-01	0.193579D-01	0.193579D-01	0.465911D 00	0.524381D-01	0.916700D-01	1
0	0.442896D-04	0.533182D-05	0.947961D-05	0.396465D-04	0.420007D-04	0.444213D-05	0.444213D-05	0.100000D-02	0
	0.360000D-01	0.355000D-01	0.350000D-01	0.704275D 02	0.753725D 02	0.695471D 02	0.713078D 02	0.746352D 02	0
	0.112033D 03	0.112033D 03	0.258163D 00	0.854225D 00	0.830010D 00	0.549954D 01	-0.402984D-01	0.553984D 01	0
	-0.857226D-01	0.562558D 01	-0.408715D 00	0.975879D 01	0.221648D 02	0.486487D 03	0.485787D 03	0.485621D 03	0
	0.485621D 03	0.129891D-01	0.128808D-01	0.193414D-01	0.193414D-01	0.465911D 00	0.504331D-01	0.916700D-01	1
0	0.442896D-04	0.533182D-05	0.947961D-05	0.396465D-04	0.420007D-04	0.444213D-05	0.444213D-05	0.100000D-02	0
	0.370000D-01	0.365000D-01	0.360000D-01	0.695215D 02	0.741707D 02	0.686781D 02	0.703649D 02	0.734622D 02	0
	0.111917D 03	0.111917D 03	0.259225D 00	0.865229D 00	0.841965D 00	0.551549D 01	-0.355735D-01	0.555107D 01	0
	-0.678262D-01	0.561892D 01	-0.385870D 00	0.975013D 01	0.221451D 02	0.486501D 03	0.485621D 03	0.485477D 03	0
	0.485477D 03	0.127816D-01	0.126825D-01	0.193271D-01	0.193271D-01	0.465911D 00	0.484281D-01	0.916700D-01	1
0	0.442896D-04	0.533182D-05	0.947961D-05	0.396465D-04	0.420007D-04	0.444213D-05	0.444213D-05	0.100000D-02	0
	0.380000D-01	0.375000D-01	0.370000D-01	0.686755D 02	0.730645D 02	0.678651D 02	0.694860D 02	0.723763D 02	0
	0.111817D 03	0.111817D 03	0.260148D 00	0.875633D 00	0.853215D 00	0.552932D 01	-0.314664D-01	0.556079D 01	0
	-0.523347D-01	0.561314D 01	-0.369655D 00	0.974263D 01	0.221281D 02	0.486516D 03	0.485477D 03	0.485353D 03	0
	0.485353D 03	0.125996D-01	0.124987D-01	0.193147D-01	0.193147D-01	0.465911D 00	0.471242D-01	0.916700D-01	1
0	0.442896D-04	0.533182D-05	0.947961D-05	0.396465D-04	0.420007D-04	0.444213D-05	0.444213D-05	0.100000D-02	0
	0.390000D-01	0.385000D-01	0.380000D-01	0.678755D 02	0.720326D 02	0.670946D 02	0.686563D 02	0.713577D 02	0
	0.111729D 03	0.111729D 03	0.260958D 00	0.885594D 00	0.863929D 00	0.554142D 01	-0.278499D-01	0.556928D 01	0
	-0.387820D-01	0.560808D 01	-0.359654D 00	0.973606D 01	0.221132D 02	0.486533D 03	0.485353D 03	0.485244D 03	0
	0.485244D 03	0.124124D-01	0.123260D-01	0.193038D-01	0.193038D-01	0.465911D 00	0.465216D-01	0.916700D-01	1
0	0.442896D-04	0.533182D-05	0.947961D-05	0.396465D-04	0.420007D-04	0.444213D-05	0.444213D-05	0.100000D-02	0

	T PCTO MDF TCTO E(1)	TSTR PEO MDE RP E(2)	T1 MCT MDPE RPT E(3)	PT MD MDTSO REO E(4)	PP MN MDCTO RCTO E(5)	PD MDCT TP AE E(6)	PN MDPT TPT APE E(7)	PPT MDD TEO AF DT	ND NM NCT ITER J16
	0.400000D-01	0.395000D-01	0.390000D-01	0.671129D 02	0.710616D 02	0.663583D 02	0.678675D 02	0.703996D 02	0
	0.111651D 03	0.111651D 03	0.261673D 00	0.895205D 00	0.874205D 00	0.555209D 01	-0.246420D-01	0.557673D 01	0
	-0.268729D-01	0.660363D 01	-0.350093D 00	0.973027D 01	0.221000D 02	0.486550D 03	0.485244D 03	0.485148D 03	0
	0.485148D 03	0.122446D-01	0.121632D-01	0.192942D-01	0.192942D-01	0.465911D 00	0.459189D-01	0.916700D-01	1
0	0.442896D-04	0.533182D-05	0.947961D-05	0.396465D-04	0.420007D-04	0.444213D-05	0.444213D-05	0.100000D-02	0
	0.410000D-01	0.405000D-01	0.400000D-01	0.663851D 02	0.701462D 02	0.656534D 02	0.671168D 02	0.694965D 02	0
	0.111583D 03	0.111583D 03	0.262302D 00	0.904492D 00	0.884086D 00	0.556145D 01	-0.217931D-01	0.558325D 01	0
	-0.164363D-01	0.559971D 01	-0.340933D 00	0.972518D 01	0.220885D 02	0.486568D 03	0.485148D 03	0.485063D 03	0
	0.485063D 03	0.120864D-01	0.120096D-01	0.192858D-01	0.192858D-01	0.465911D 00	0.453163D-01	0.916700D-01	1
0	0.442896D-04	0.533182D-05	0.947961D-05	0.396465D-04	0.420007D-04	0.444213D-05	0.444213D-05	0.100000D-02	0
	0.420000D-01	0.415000D-01	0.410000D-01	0.656682D 02	0.692796D 02	0.649761D 02	0.664003D 02	0.686403D 02	0
	0.111523D 03	0.111523D 03	0.262856D 00	0.913497D 00	0.893557D 00	0.556968D 01	-0.192549D-01	0.558894D 01	0
	-0.730760D-02	0.559627D 01	-0.333452D 00	0.972071D 01	0.220783D 02	0.486587D 03	0.485063D 03	0.484989D 03	0
	0.484989D 03	0.119366D-01	0.118637D-01	0.192784D-01	0.192784D-01	0.465911D 00	0.448881D-01	0.916700D-01	1
0	0.442896D-04	0.533182D-05	0.947961D-05	0.396465D-04	0.420007D-04	0.444213D-05	0.444213D-05	0.100000D-02	0
	0.430000D-01	0.425000D-01	0.420000D-01	0.650175D 02	0.684545D 02	0.643215D 02	0.657135D 02	0.678237D 02	0
	0.111471D 03	0.111471D 03	0.263343D 00	0.922275D 00	0.902724D 00	0.557691D 01	-0.169808D-01	0.559389D 01	0
	0.667005D-03	0.559325D 01	-0.327554D 00	0.971679D 01	0.220694D 02	0.486606D 03	0.484989D 03	0.484923D 03	0
	0.484923D 03	0.117940D-01	0.117243D-01	0.192720D-01	0.192720D-01	0.465911D 00	0.446344D-01	0.916700D-01	1
0	0.442896D-04	0.533182D-05	0.947961D-05	0.396465D-04	0.420007D-04	0.444213D-05	0.444213D-05	0.100000D-02	0
	0.440000D-01	0.435000D-01	0.430000D-01	0.643699D 02	0.676657D 02	0.636864D 02	0.650534D 02	0.670429D 02	0
	0.111425D 03	0.111425D 03	0.263770D 00	0.930865D 00	0.911603D 00	0.558324D 01	-0.149340D-01	0.559818D 01	0
	0.760075D-02	0.559060D 01	-0.321877D 00	0.971335D 01	0.220616D 02	0.486625D 03	0.484923D 03	0.484856D 03	0
	0.484866D 03	0.116576D-01	0.115909D-01	0.192663D-01	0.192653D-01	0.465911D 00	0.443806D-01	0.916700D-01	1
0	0.442896D-04	0.533182D-05	0.947961D-05	0.396465D-04	0.420007D-04	0.444213D-05	0.444213D-05	0.100000D-02	0
	0.450000D-01	0.445000D-01	0.440000D-01	0.637438D 02	0.669097D 02	0.630688D 02	0.644187D 02	0.662946D 02	0
	0.111385D 03	0.111385D 03	0.264143D 00	0.939288D 00	0.920205D 00	0.558876D 01	-0.130844D-01	0.560185D 01	0
	0.135767D-01	0.558829D 01	-0.316400D 00	0.971035D 01	0.220548D 02	0.486645D 03	0.484866D 03	0.484816D 03	0
	0.484816D 03	0.115269D-01	0.114629D-01	0.192613D-01	0.192613D-01	0.465911D 00	0.441269D-01	0.916700D-01	1
0	0.442896D-04	0.533182D-05	0.947961D-05	0.396465D-04	0.420007D-04	0.444213D-05	0.444213D-05	0.100000D-02	0
	0.460000D-01	0.455000D-01	0.450000D-01	0.631366D 02	0.661825D 02	0.624658D 02	0.638074D 02	0.655736D 02	0
	0.111350D 03	0.111350D 03	0.264466D 00	0.947577D 00	0.928550D 00	0.559354D 01	-0.114013D-01	0.560494D 01	0
	0.186736D-01	0.558629D 01	-0.312017D 00	0.970776D 01	0.220489D 02	0.486665D 03	0.484816D 03	0.484773D 03	0
	0.484773D 03	0.114011D-01	0.113394D-01	0.192570D-01	0.192570D-01	0.465911D 00	0.440000D-01	0.916700D-01	1
0	0.442896D-04	0.533182D-05	0.947961D-05	0.396465D-04	0.420007D-04	0.444213D-05	0.444213D-05	0.100000D-02	0
	0.470000D-01	0.465000D-01	0.460000D-01	0.625456D 02	0.654791D 02	0.618741D 02	0.632170D 02	0.648751D 02	0
	0.111320D 03	0.111320D 03	0.264745D 00	0.955777D 00	0.936666D 00	0.559766D 01	-0.985253D-02	0.560751D 01	0
	0.229619D-01	0.558457D 01	-0.308673D 00	0.970552D 01	0.220438D 02	0.486685D 03	0.484773D 03	0.484736D 03	0
	0.484736D 03	0.112795D-01	0.112196D-01	0.192533D-01	0.192533D-01	0.465911D 00	0.440000D-01	0.916700D-01	1
0	0.442896D-04	0.533182D-05	0.947961D-05	0.396465D-04	0.420007D-04	0.444213D-05	0.444213D-05	0.100000D-02	0

	T PCTO MDF TCTO E(1)	TSTR PEO MDE RP E(2)	T1 MCT MDPE RPT E(3)	PT MD MDTSO REO E(4)	PP MN MDCTO RCTO E(5)	PD MDCT TP AE E(6)	PN MDPT TPT APE E(7)	PPT MDD TEO AF DT	ND NM NCT ITER J16
	0.480000D-01	0.475000D-01	0.470000D-01	0.619688D 02	0.647962D 02	0.612910D 02	0.626466D 02	0.641959D 02	0
	0.111294D 03	0.111294D 03	0.264982D 00	0.963920D 00	0.944563D 00	0.560116D 01	-0.840878D-02	0.560957D 01	0
	0.264900D-01	0.558311D 01	-0.305426D 00	0.970362D 01	0.220395D 02	0.486706D 03	0.484736D 03	0.484704D 03	0
	0.484704D 03	0.111614D-01	0.111032D-01	0.192502D-01	0.192502D-01	0.465911D 00	0.440000D-01	0.916700D-01	1
0	0.442896D-04	0.533182D-05	0.947961D-05	0.396465D-04	0.420007D-04	0.444213D-05	0.444213D-05	0.100000D-02	0
	0.490000D-01	0.485000D-01	0.480000D-01	0.614057D 02	0.641316D 02	0.607149D 02	0.620964D 02	0.635366D 02	0
	0.111273D 03	0.111273D 03	0.265181D 00	0.972026D 00	0.952230D 00	0.560410D 01	-0.704118D-02	0.561114D 01	0
	0.292905D-01	0.558188D 01	-0.302266D 00	0.970202D 01	0.220359D 02	0.486726D 03	0.484704D 03	0.484678D 03	0
	0.484678D 03	0.110464D-01	0.109897D-01	0.192475D-01	0.192475D-01	0.465911D 00	0.440000D-01	0.916700D-01	1
0	0.442896D-04	0.533182D-05	0.947961D-05	0.396465D-04	0.420007D-04	0.444213D-05	0.444213D-05	0.100000D-02	0
	0.500000D-01	0.495000D-01	0.490000D-01	0.608560D 02	0.634832D 02	0.601444D 02	0.615676D 02	0.628924D 02	0
	0.111255D 03	0.111255D 03	0.265345D 00	0.980114D 00	0.959649D 00	0.560651D 01	-0.571734D-02	0.561223D 01	0
	0.313888D-01	0.558087D 01	-0.299183D 00	0.970071D 01	0.220329D 02	0.486747D 03	0.484678D 03	0.484656D 03	0
	0.484656D 03	0.109343D-01	0.108789D-01	0.192454D-01	0.192454D-01	0.465911D 00	0.440000D-01	0.916700D-01	1
0	0.442896D-04	0.533182D-05	0.947961D-05	0.396465D-04	0.420007D-04	0.444213D-05	0.444213D-05	0.100000D-02	0
	0.510000D-01	0.505000D-01	0.500000D-01	0.603200D 02	0.628492D 02	0.595780D 02	0.610620D 02	0.622622D 02	0
	0.111241D 03	0.111241D 03	0.265476D 00	0.988203D 00	0.966789D 00	0.560844D 01	-0.439968D-02	0.561284D 01	0
	0.328040D-01	0.558006D 01	-0.296168D 00	0.969966D 01	0.220305D 02	0.486768D 03	0.484656D 03	0.484638D 03	0
	0.484638D 03	0.108246D-01	0.107703D-01	0.192436D-01	0.192436D-01	0.465911D 00	0.440000D-01	0.916700D-01	1
0	0.442896D-04	0.533182D-05	0.947961D-05	0.396465D-04	0.420007D-04	0.444213D-05	0.444213D-05	0.100000D-02	0
	0.520000D-01	0.515000D-01	0.510000D-01	0.597982D 02	0.622278D 02	0.590142D 02	0.605822D 02	0.616446D 02	0
	0.111231D 03	0.111231D 03	0.265576D 00	0.996312D 00	0.973605D 00	0.560992D 01	-0.304324D-02	0.561297D 01	0
	0.335493D-01	0.557944D 01	-0.293213D 00	0.969886D 01	0.220287D 02	0.486789D 03	0.484638D 03	0.484625D 03	0
	0.484625D 03	0.107171D-01	0.106639D-01	0.192423D-01	0.192423D-01	0.465911D 00	0.440000D-01	0.916700D-01	1
0	0.442896D-04	0.533182D-05	0.947961D-05	0.396465D-04	0.420007D-04	0.444213D-05	0.444213D-05	0.100000D-02	0

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	0.530000D-01	0.525000D-01	0.520000D-01	0.584032D 02	0.616094D 02	0.583644D 02	0.587528D 02	0.610188D 02	0
	0.111215D 03	0.110915D 03	0.265742D 00	0.100568D 01	0.100000D 01	0.561208D 01	-0.296090D-02	0.561289D 01	0
	0.279222D-01	0.558496D 01	-0.290272D 00	0.969767D 01	0.220260D 02	0.486811D 03	0.484605D 03	0.484605D 03	18
	0.484605D 03	0.106101D-01	0.105564D-01	0.191885D-01	0.192404D-01	0.465911D 00	0.440000D-01	0.916700D-01	1
Q	0.442896D-04	0.533182D-05	0.947961D-05	0.396465D-04	0.420007D-04	0.444213D-05	0.444213D-05	0.100000D-02	0
	0.540000D-01	0.535000D-01	0.530000D-01	0.578561D 02	0.609894D 02	0.577565D 02	0.587528D 02	0.604003D 02	0
	0.111215D 03	0.110949D 03	0.265742D 00	0.101459D 01	0.100000D 01	0.561208D 01	-0.212361D-02	0.561205D 01	0
	0.253852D-01	0.558666D 01	-0.287324D 00	0.969767D 01	0.220260D 02	0.486833D 03	0.484605D 03	0.484605D 03	0
	0.484605D 03	0.105029D-01	0.104494D-01	0.191943D-01	0.192404D-01	0.465911D 00	0.440000D-01	0.916700D-01	1
Q	0.442896D-04	0.533182D-05	0.947961D-05	0.396465D-04	0.420007D-04	0.444213D-05	0.444213D-05	0.100000D-02	0
	0.550000D-01	0.545000D-01	0.540000D-01	0.573465D 02	0.603759D 02	0.571902D 02	0.587528D 02	0.597919D 02	0
	0.111215D 03	0.110920D 03	0.265742D 00	0.102293D 01	0.100000D 01	0.561208D 01	-0.683532D-03	0.561061D 01	0
	0.253953D-01	0.558521D 01	-0.284407D 00	0.969767D 01	0.220260D 02	0.486856D 03	0.484605D 03	0.484605D 03	0
	0.484605D 03	0.103967D-01	0.103441D-01	0.191894D-01	0.192404D-01	0.465911D 00	0.440000D-01	0.916700D-01	1
Q	0.442896D-04	0.533182D-05	0.947961D-05	0.396465D-04	0.420007D-04	0.444213D-05	0.444213D-05	0.100000D-02	0

	T PCTO MDF TCTO E(1)	TSTR PEO MDE RP E(2)	T1 MCT MDPE RPI E(3)	PT MD MDTSO REO E(4)	PP MN MDCTO RCTO E(5)	PD MDCT IP AE E(6)	PN MDPT TPT APE E(7)	PPT MDD TEO AF DT	ND NM NCT ITER J16
	0.5600000D-01	0.5550000D-01	0.5500000D-01	0.5687350D 02	0.5977560D 02	0.5666470D 02	0.5875280D 02	0.5919960D 02	0
	0.1112150D 03	0.1108410D 03	0.2657420D 00	0.1030710D 01	0.1000000D 01	0.5612080D 01	0.1222320D-02	0.5608700D 01	0
	0.2745090D-01	0.5581250D 01	-0.2815520D 00	0.9697670D 01	0.2202600D 02	0.4868780D 03	0.4846050D 03	0.4846050D 03	0
	0.4846050D 03	0.1029290D-01	0.1024160D-01	0.1917580D-01	0.1924040D-01	0.4659110D 00	0.4400000D-01	0.9167000D-01	1
0	0.4428960D-04	0.5331820D-05	0.9479610D-05	0.3964650D-04	0.4200070D-04	0.4442130D-05	0.4442130D-05	0.1000000D-02	0
	0.5700000D-01	0.5650000D-01	0.5600000D-01	0.5643580D 02	0.5919340D 02	0.5617840D 02	0.5875280D 02	0.5862760D 02	0
	0.1112150D 03	0.1107240D 03	0.2657420D 00	0.1037930D 01	0.1000000D 01	0.5612080D 01	0.3474310D-02	0.5606450D 01	0
	0.3110780D-01	0.5575340D 01	-0.2787840D 00	0.9697670D 01	0.2202600D 02	0.4869010D 03	0.4846050D 03	0.4846050D 03	0
	0.4846050D 03	0.1019220D-01	0.1014270D-01	0.1915550D-01	0.1924040D-01	0.4659110D 00	0.4400000D-01	0.9167000D-01	1
0	0.4428960D-04	0.5331820D-05	0.9479610D-05	0.3964650D-04	0.4200070D-04	0.4442130D-05	0.4442130D-05	0.1000000D-02	0
	0.5800000D-01	0.5750000D-01	0.5700000D-01	0.5603160D 02	0.5863310D 02	0.5572930D 02	0.5875280D 02	0.5807900D 02	0
	0.1112150D 03	0.1105780D 03	0.2657420D 00	0.1044630D 01	0.1000000D 01	0.5612080D 01	0.5970390D-02	0.5603950D 01	0
	0.3598200D-01	0.5567970D 01	-0.2761190D 00	0.9697670D 01	0.2202600D 02	0.4869220D 03	0.4846050D 03	0.4846050D 03	0
	0.4846050D 03	0.1009520D-01	0.1004780D-01	0.1913010D-01	0.1924040D-01	0.4659110D 00	0.4400000D-01	0.9167000D-01	1
0	0.4428960D-04	0.5331820D-05	0.9479610D-05	0.3964650D-04	0.4200070D-04	0.4442130D-05	0.4442130D-05	0.1000000D-02	0
	0.5900000D-01	0.5850000D-01	0.5800000D-01	0.5565910D 02	0.5809740D 02	0.5531540D 02	0.5875280D 02	0.5755620D 02	0
	0.1112150D 03	0.1104100D 03	0.2657420D 00	0.1050830D 01	0.1000000D 01	0.5612080D 01	0.8625200D-02	0.5601300D 01	0
	0.4174770D-01	0.5559550D 01	-0.2735720D 00	0.9697670D 01	0.2202600D 02	0.4869440D 03	0.4846050D 03	0.4846050D 03	0
	0.4846050D 03	0.1000260D-01	0.9957330D-02	0.1910120D-01	0.1924040D-01	0.4659110D 00	0.4400000D-01	0.9167000D-01	1
0	0.4428960D-04	0.5331820D-05	0.9479610D-05	0.3964650D-04	0.4200070D-04	0.4442130D-05	0.4442130D-05	0.1000000D-02	0
	0.6000000D-01	0.5950000D-01	0.5900000D-01	0.5531630D 02	0.5758810D 02	0.5493450D 02	0.5875280D 02	0.5706040D 02	0
	0.1112150D 03	0.1102290D 03	0.2657420D 00	0.1056560D 01	0.1000000D 01	0.5612080D 01	0.1136860D-01	0.5598560D 01	0
	0.4813300D-01	0.5550420D 01	-0.2711500D 00	0.9697670D 01	0.2202600D 02	0.4869640D 03	0.4846050D 03	0.4846050D 03	0
	0.4846050D 03	0.9914450D-02	0.9871560D-02	0.1906980D-01	0.1924040D-01	0.4659110D 00	0.4400000D-01	0.9167000D-01	1
0	0.4428960D-04	0.5331820D-05	0.9479610D-05	0.3964650D-04	0.4200070D-04	0.4442130D-05	0.4442130D-05	0.1000000D-02	0

REVERTING TO EXACT SUPERSONIC SOLUTION

0.6100000D-01	0.6050000D-01	0.6000000D-01	0.5508830D 02	0.5693940D 02	0.5468110D 02	0.5875280D 02	0.5681840D 02	12
0.1112150D 03	0.1081280D 03	0.2657420D 00	0.1060370D 01	0.1000000D 01	0.5612080D 01	0.1647050D-01	0.5595610D 01	0
0.1509650D 00	0.5444650D 01	-0.2707650D 00	0.9697670D 01	0.2202600D 02	0.4846050D 03	0.4846050D 03	0.4846050D 03	0
0.4846050D 03	0.9850620D-02	0.9829690D-02	0.1870640D-01	0.1924040D-01	0.4659110D 00	0.4400000D-01	0.9167000D-01	15
0.0	0.8913860D-07	0.1786570D-06	0.7559450D-06	0.6753220D-06	0.0	0.3595440D-05	0.1000000D-02	-1
0.6200000D-01	0.6150000D-01	0.6100000D-01	0.5493650D 02	0.5670430D 02	0.5451250D 02	0.5875280D 02	0.5659030D 02	6
0.1112150D 03	0.1080320D 03	0.2657420D 00	0.1062920D 01	0.1000000D 01	0.5612080D 01	0.1786060D-01	0.5594220D 01	0
0.1544230D 00	0.5439780D 01	-0.2696470D 00	0.9697670D 01	0.2202600D 02	0.4846050D 03	0.4846050D 03	0.4846050D 03	0
0.4846050D 03	0.9809960D-02	0.9790230D-02	0.1868970D-01	0.1924040D-01	0.4659110D 00	0.4400000D-01	0.9167000D-01	2
0.0	0.2445370D-06	0.4900600D-06	0.2320720D-05	0.2072520D-05	0.0	0.1051340D-05	0.1000000D-02	-1
0.6300000D-01	0.6250000D-01	0.6200000D-01	0.5479560D 02	0.5648310D 02	0.5435590D 02	0.5875280D 02	0.5637590D 02	12
0.1112150D 03	0.1079380D 03	0.2657420D 00	0.1065290D 01	0.1000000D 01	0.5612080D 01	0.1920760D-01	0.5592870D 01	0
0.1578360D 00	0.5435050D 01	-0.2685950D 00	0.9697670D 01	0.2202600D 02	0.4846050D 03	0.4846050D 03	0.4846050D 03	0
0.4846050D 03	0.9771680D-02	0.9753130D-02	0.1867340D-01	0.1924040D-01	0.4659110D 00	0.4400000D-01	0.9167000D-01	3
0.0	0.2516140D-06	0.5041850D-06	0.2360730D-05	0.2107610D-05	0.0	0.1241620D-05	0.1000000D-02	-1

T PCTO MDF ICTO E(1)	TSTR PEO MDE RP E(2)	TI MCT MDPE RPT E(3)	PT MD MDTSO REO E(4)	PP MN MDCTO RCTO E(5)	PD MDCT TP AE E(6)	PN MDPT TPT APE E(7)	PPT MDD TEO AF DT	ND NM NCT ITER J16
0.640000D-01	0.635000D-01	0.630000D-01	0.546644D 02	0.562752D 02	0.542101D 02	0.587528D 02	0.561745D 02	11
0.111215D 03	0.107846D 03	0.265742D 00	0.106750D 01	0.100000D 01	0.561208D 01	0.204946D-01	0.559158D 01	0
0.161131D 00	0.543043D 01	-0.267606D 00	0.969767D 01	0.220260D 02	0.484605D 03	0.484605D 03	0.484605D 03	0
0.484605D 03	0.973571D-02	0.971829D-02	0.186576D-01	0.192404D-01	0.465911D 00	0.440000D-01	0.916700D-01	3
0.0	0.426506D-06	0.854542D-06	0.397811D-05	0.355055D-05	0.0	0.223881D-05	0.100000D-02	-1
0.650000D-01	0.645000D-01	0.640000D-01	0.545429D 02	0.560801D 02	0.540751D 02	0.587528D 02	0.559857D 02	12
0.111215D 03	0.107758D 03	0.265742D 00	0.106954D 01	0.100000D 01	0.561208D 01	0.217348D-01	0.559034D 01	0
0.164357D 00	0.542598D 01	-0.266679D 00	0.969767D 01	0.220260D 02	0.484605D 03	0.484605D 03	0.484605D 03	0
0.484605D 03	0.970196D-02	0.968563D-02	0.186423D-01	0.192404D-01	0.465911D 00	0.440000D-01	0.916700D-01	4
0.0	0.167213D-06	0.334989D-06	0.156500D-05	0.139642D-05	0.0	0.843832D-06	0.100000D-02	-1
0.660000D-01	0.655000D-01	0.650000D-01	0.544301D 02	0.558973D 02	0.539498D 02	0.587528D 02	0.558090D 02	8
0.111215D 03	0.107673D 03	0.265742D 00	0.107145D 01	0.100000D 01	0.561208D 01	0.229174D-01	0.558916D 01	0
0.167465D 00	0.542171D 01	-0.265810D 00	0.969767D 01	0.220260D 02	0.484605D 03	0.484605D 03	0.484605D 03	0
0.484605D 03	0.967034D-02	0.965506D-02	0.186276D-01	0.192404D-01	0.465911D 00	0.440000D-01	0.916700D-01	3
0.0	0.171264D-06	0.343070D-06	0.158854D-05	0.141707D-05	0.0	0.940377D-06	0.100000D-02	-1
0.670000D-01	0.665000D-01	0.660000D-01	0.543254D 02	0.557264D 02	0.538335D 02	0.587528D 02	0.556438D 02	9
0.111215D 03	0.107591D 03	0.265742D 00	0.107322D 01	0.100000D 01	0.561208D 01	0.240371D-01	0.558804D 01	0
0.170428D 00	0.541761D 01	-0.264997D 00	0.969767D 01	0.220260D 02	0.484605D 03	0.484605D 03	0.484605D 03	0
0.484605D 03	0.964077D-02	0.962648D-02	0.186135D-01	0.192404D-01	0.465911D 00	0.440000D-01	0.916700D-01	3
0.0	0.178703D-06	0.357937D-06	0.165150D-05	0.147289D-05	0.0	0.101235D-05	0.100000D-02	-1
0.680000D-01	0.675000D-01	0.670000D-01	0.542285D 02	0.555666D 02	0.537258D 02	0.587528D 02	0.554895D 02	9
0.111215D 03	0.107514D 03	0.265742D 00	0.107485D 01	0.100000D 01	0.561208D 01	0.251023D-01	0.558698D 01	0
0.173274D 00	0.541371D 01	-0.264237D 00	0.969767D 01	0.220260D 02	0.484605D 03	0.484605D 03	0.484605D 03	0
0.484605D 03	0.961313D-02	0.959979D-02	0.186001D-01	0.192404D-01	0.465911D 00	0.440000D-01	0.916700D-01	2
0.0	0.238298D-06	0.477259D-06	0.223576D-05	0.199353D-05	0.0	0.113211D-05	0.100000D-02	-1
0.690000D-01	0.685000D-01	0.680000D-01	0.541387D 02	0.554175D 02	0.536260D 02	0.587528D 02	0.553456D 02	11
0.111215D 03	0.107440D 03	0.265742D 00	0.107638D 01	0.100000D 01	0.561208D 01	0.261084D-01	0.558597D 01	0
0.175979D 00	0.540999D 01	-0.263528D 00	0.969767D 01	0.220260D 02	0.484605D 03	0.484605D 03	0.484605D 03	0
0.484605D 03	0.958734D-02	0.957489D-02	0.185873D-01	0.192404D-01	0.465911D 00	0.440000D-01	0.916700D-01	2
0.0	0.718790D-08	0.143945D-07	0.410105D-07	0.365599D-07	0.0	0.205824D-06	0.100000D-02	-1
0.700000D-01	0.695000D-01	0.690000D-01	0.540555D 02	0.552785D 02	0.535335D 02	0.587528D 02	0.552114D 02	5
0.111215D 03	0.107370D 03	0.265742D 00	0.107778D 01	0.100000D 01	0.561208D 01	0.270573D-01	0.558502D 01	0
0.178547D 00	0.540647D 01	-0.262867D 00	0.969767D 01	0.220260D 02	0.484605D 03	0.484605D 03	0.484605D 03	0
0.484605D 03	0.956329D-02	0.955168D-02	0.185752D-01	0.192404D-01	0.465911D 00	0.440000D-01	0.916700D-01	2
0.0	0.175002D-06	0.350430D-06	0.162185D-05	0.144557D-05	0.0	0.948412D-06	0.100000D-02	-1
0.710000D-01	0.705000D-01	0.700000D-01	0.539785D 02	0.551490D 02	0.534480D 02	0.587528D 02	0.550865D 02	11
0.111215D 03	0.107304D 03	0.265742D 00	0.107909D 01	0.100000D 01	0.561208D 01	0.279509D-01	0.558413D 01	0
0.180978D 00	0.540314D 01	-0.262251D 00	0.969767D 01	0.220260D 02	0.484605D 03	0.484605D 03	0.484605D 03	0
0.484605D 03	0.954088D-02	0.953007D-02	0.185638D-01	0.192404D-01	0.465911D 00	0.440000D-01	0.916700D-01	2
0.0	0.226083D-06	0.452678D-06	0.207158D-05	0.184610D-05	0.0	0.137053D-05	0.100000D-02	-1

TABLE 8
LISTING OF THE COMPUTER PROGRAM HIRTSM1

```
                    MAIN                DATE = 75157          11/58/40

C HIRTSM1 - HIRT STARTING MODEL
      IMPLICIT REAL*8 (A-H,M,O-Z,$)
      COMMON AREA(3,50),AREATS(3),AREAM(3),TV(3,50),A(10),E(7),B(30),
     1 TVF(3),TDELAY(3),RW(7)
      COMMON PC,RC,TC,AC,MDCTC,FA(3)        ,MDTSTR,INFIN,TMGOGS,GPO2GS,
     1 SGOR
      COMMON G,GM1,GP1,OOG,GP1O2,GM1O2,GP1OG,GM1OG,GOGP1,GOGM1,
     1 OOGM1,OOGP1,GPOGM1,SGM1O2,TOGM1,TOG,MGPGM2,TOGP1,GPGM12,
     2 MGPOGM,MGOGM1,R,GR,OOR,PI,PERR,AWOKW,OOA1,OOKF,KF,KW
      COMMON TSL,TSH,TSW,TSP,TSA,TSWA,TSV,CTD,CTA,PV,PVOTSV,TAUW
      COMMON T,T1,DT,TSTR,DTO2,TSTOP,OODT,DTOPV
      COMMON A1,A2,A3,A4,A5,A6,A7,A8,A9,A10,A11,A12,A13,A14,A15,A16,A17
      COMMON    PN ,    PP ,   PPT ,    PD ,    PT , PCTO ,  PEO ,  MDE ,
     -  MDD ,  MDF , MDPT , MDCT , MDPE ,MDTSO ,MDCTO ,  TEO ,   TP ,
     -  TPT , TCTO ,    RP ,   RPT ,   REO , RCTO , ACTO,  MCT ,   AE ,
     -  APE ,   AF ,    MN ,    MD
      COMMON    PN1,    PP1,   PPT1,    PD1,   PT1, PCTO1,  PEO1,  MDE1,
     -  MDD1,  MDF1, MDPT1, MDCT1, MDPE1,MDTSO1,MDCTO1,  TEO1,   TP1,
     -  TPT1, TCTO1,    RP1,   RPT1,  REO1, RCTO1, ACTO1,  MCT1,   AE1,
     -  APE1,   AF1,    MN1,    MD1
      COMMON    PN2,    PP2,   PPT2,    PD2,   PT2, PCTO2,  PEO2,  MDE2,
     -  MDD2,  MDF2, MDPT2, MDCT2, MDPE2,MDTSO2,MDCTO2,  TEO2,   TP2,
     -  TPT2, TCTO2,    RP2,   RPT2,  REO2, RCTO2, ACTO2,  MCT2,   AE2,
     -  APE2,   AF2,    MN2,    MD2
      COMMON    PN3,    PP3,   PPT3,    PD3,   PT3, PCTO3,  PEO3,  MDE3,
     -  MDD3,  MDF3, MDPT3, MDCT3, MDPE3,MDTSO3,MDCTO3,  TEO3,   TP3,
     -  TPT3, TCTO3,    RP3,   RPT3,  REO3, RCTO3, ACTO3,  MCT3,   AE3,
     -  APE3,   AF3,    MN3,    MD3
      COMMON PSOPO,TSOTO,RSORO,MSOMO
      COMMON $Y,$Y1,$Y2,$X1,$X2,$DX,$E1,$E2,$EMAX,$EP,$DF
      COMMON INSTR(26),IDEBUG,IIN,IOUT,NP,IP,ITER,NVT(3),I,NT,IPAGE,
     1NPAGE,$N,IT(3),J,IM1,ITIME,ND,NN,NCT,IFLG,IFLG1,IFLG2,IFLG3,IFLG4,
     2IFLG5,IFLG6,IFLG7,IFLG8,IFLG9,I1,I2,I3,I4,I5
      COMMON J1,J2,J3,J4,J5,J6,J7,J8,J9,J10,J11,J12,J13,J14,J15,J16,J17,
     1 J18,J19,J20,J21,J22,J23,J24,J25,J26
      COMMON NCTL
      DIMENSION V(30,4),RSTR(582),ISTR(35),IEXTP(7),JV(26)
      DIMENSION C(4,2)
      EQUIVALENCE (RSTR(1),AREA(1)),(ISTR(1),NP),(PN,V(1)),(JV(1),J1)
      INTEGER $N
      REAL*8 INFIN,KF,KW
      DATA IEXTP/1,2,6,7,10,14,16/
       DATA C/-.14885381D2,.45347501D2,-.43530673D2,.14068554D2,
     1 -.55230067D2,.14939843D3,-.13208170D3,.38913333D2/
      DEFINE FILE 01(300,1200,U,J16)
      POPO(D1)=(1.+GM1O2*D1**2)**MGOGM1
      MDOTPT(D1,D2)=-AWOKW*(D1-D2*A15)*A2
      ITIME=0
      IFLG1=1
      IFLG2=+1
      IFLG6=1
      IFLG9=1
      IFLG10=1
      IFLG11=0
      IFLG12=1
      IDEBUG=03
```

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                         MAIN                DATE = 75157          11/58/40
      IIN=05
      IOUT=06
      NP=1
      I5=0
   10 READ(IIN,120)NCTL
C--------------------
C MANUAL PROGRAM CONTROL
C--------------------
      IF(NCTL.EQ.0)GO TO 100
      WRITE(IOUT,15)NCTL
   15 FORMAT('0NCTL=',I3)
C               1   2   3    4  5  6  7  8  9 10 11 12  13 14
      GO TO(100,125,129,1116,20,30,40,50,60,70,80,90,151,95),NCTL
   20 CALL INPUT(&10)
   30 CALL INIT(&10)
   40 CALL CONST(&10)
   50 CALL DUMP(&10)
   60 CALL SOLVER(&10)
   70 CALL PRINT(&10)
   80 CALL BINOM(&10)
   90 CALL REVERT(&10)
   95 CALL SMPERT(&10)
C----------------------------------------------------
C READ AND DEFINE DEFAULTED RUN CONTROL INSTRUCTIONS
C----------------------------------------------------
  100 READ(IIN,120)INSTR
  120 FORMAT(26I3)
      IF(INSTR(1).NE.0)IDEBUG=INSTR(1)
      IF(INSTR(1).EQ.0)INSTR(1)=IDEBUG
      IF(INSTR(2).NE.0)IIN=INSTR(2)
      IF(INSTR(2).EQ.0)INSTR(2)=IIN
      IF(INSTR(3).NE.0)IOUT=INSTR(3)
      IF(INSTR(3).EQ.0)INSTR(3)=IOUT
      IF(INSTR(4).NE.0)NP=INSTR(4)
      IF(INSTR(4).EQ.0)INSTR(4)=1
      IF(INSTR(5).EQ.0)INSTR(5)=2
      IF(IDEBUG.EQ.IOUT)INSTR(6)=0
      IF(INSTR(7).EQ.0)INSTR(7)=2
      IF(INSTR(8).EQ.0)INSTR(8)=1
      IF(INSTR(9).EQ.0)INSTR(9)=1
      IF(INSTR(12).EQ.0)INSTR(12)=1
      IF(INSTR(14).EQ.0)INSTR(14)=1
      IF(INSTR(15).EQ.0)INSTR(15)=03
      IF(INSTR(18).EQ.0)INSTR(18)=03
      IF(INSTR(22).EQ.0)INSTR(22)=9999999
      IF(INSTR(25).EQ.0)INSTR(25)=2
      IF(INSTR(26).EQ.0)INSTR(26)=9999999
      DO 121 I=1,26
  121 JV(I)=INSTR(I)
      IF(NCTL.NE.0)GO TO 10
C-------------
C PRINT HEADING
C-------------
  125 WRITE(IOUT,130)
  130 FORMAT('1',29X,74('$')/30X,'$',72X,'$'/30X,'$  HIRTSM1 - MATHEMATI
     1CAL STARTING MODEL FOR A LUDWIEG TUBE WIND TUNNEL  $'/30X,'$',
```

```
     272X,'$'/30X,'$  ARNOLD RESEARCH ORGANIZATION, ARNOLD AIR FORCE STA
     3TION, TN',12X,'$'/30X,'$',72X,'$'/30X,74('$'))
      IF(NCTL.NE.0)GO TO 10
  129 IF(J15.EQ.03)GO TO 135
C-----------------------------------------
C READ SOLUTION FROM DATA FILE AND PRINT
C-----------------------------------------
      K1=0
  131 IF(J15.NE.07)GO TO 128
      READ(J15,END=132)RSTR,ISTR
      J16=J16+1
      GO TO 127
  128 READ(J15'J16)RSTR,ISTR
      FIND(J15'J16)
  127 IF(K1.EQ.0)CALL DUMP
      IPAGE=K1
      CALL PRINT
      K1=IPAGE
      IF(J16-1.EQ.J17)GO TO 132
      GO TO 131
  132 IF(INSTR(6).EQ.0)GO TO 134
      WRITE(IOUT,133)
  133 FORMAT('1')
      CALL DUMP
      IPAGE=0
      CALL PRINT
  134 J16=J19
      WRITE(IOUT,136)
  136 FORMAT('+*')
      DMD1=MD-MD1
      DMN1=MN-MN1
      IF(NCTL.NE.0)GO TO 10
      GO TO 1116
C-----------------------------------------------------
C READ INPUT,INITIALIZE VARIABLES,AND PRINT RESULTS
C-----------------------------------------------------
  135 J16=J19
      IFLG4=0
      CALL INPUT
      CALL CONST
      CALL INIT
      CALL DUMP
      IF(A16.GT.0.D0)GO TO 140
      IFLG11=1
      IF(A16.GE.(-1.D0))GO TO 139
      A15A=DABS(A15)
      A16A=DABS(A16)
      IFLG11=2
  139 A15=1.D0
      A16=1.D0
  140 CALL PRINT
      IF(J18.EQ.03)GO TO 150
      IF(J18.NE.07)GO TO 145
      WRITE(J18,141)
  141 FORMAT(32('*'),'SHOPE - VKF/ADP',33('*'))
      WRITE(J18)RSTR,ISTR
```

```
      J16=J16+1
      GO TO 150
  145 WRITE(J18'J16)RSTR,TSTR
C------------------------
C START NEW TIME INTERVAL
C------------------------
  150 T1=T
      T=T+DT
      IF(IFLG11.EQ.0)GO TO 280
      GO TO(269,282,276),IFLG11
  269 IF(MD1.GE.1.D0)GO TO 270
      A15=1.D0
      A16=1.D0
      GO TO 276
  270 A(1)=0.D0
      A(2)=0.D0
      DO 274 I=1,4
      A(3)=MD1**(I-1)
      DO 272 J=1,2
  272 A(J)=A(J)+C(I,J)*A(3)
  274 CONTINUE
      A15=A(1)
      A16=A(2)
      GO TO 276
  282 IF(MD1.GE.1.D0)GO TO 284
      A15=(A15A-1.D0)*MD1+1.D0
      A16=(A16A-1.D0)*MD1+1.D0
      GO TO 276
  284 A15=A15A
      A16=A16A
      IFLG11=3
  276 WRITE(IDEBUG,278)MD1,A15,A16
  278 FORMAT(' MD1=',E16.8,'  A15=',E16.8,'  A16=',E16.8)
  280 IF(IFLG2.LT.0)I5=I5+1
      IF(I5.NE.INSTR(26))GO TO 143
      INSTR(23)=1
      WRITE(IOUT,142)
  142 FORMAT('0REVERTING TO EXACT SUPERSONIC SOLUTION')
  143 IF((INSTR(10).EQ.0).OR.(ITER.LT.INSTR(11)))GO TO 152
C WEIGHT CUTTING
      A11=.5*A11
      A12=1.-A11
      INSTR(11)=INSTR(11)+INSTR(20)
      WRITE(IOUT,1205)ITER,A11,INSTR(11)
 1205 FORMAT('0',5X,'ITER=',I3,'  WT HALVED TO ',F5.3,'  INSTR(11) RAISED
     1D TO ',I7)
      IPAGE=IPAGE+2
  152 IF(T.GE.A10)IDEBUG=IOUT
      TSTR=T1+DT02
      ITIME=ITIME+1
      IF(IFLG1.EQ.2)IFLG4=1
C SET PRESSURES OF LAST ITERATION TO INFINITY FOR ERROR COMPUTATION
      DO 153 I=1,7
  153 V(I,3)=INFIN
      ITER=0
      IF(T.LE.TSTOP)GO TO(155,240),IFLG1
```

```
      IF(NCTL.NE.0)GO TO 10
  151 WRITE(IOUT,154)
  154 FORMAT('1')
      CALL DUMP
      IF(J18.EQ.07)WRITE(J18,156)
  156 FORMAT(2(/80('*')))
 9999 STOP
C------------------------------------
C COMPUTE AREAS OF VALVES AT TSTR
C------------------------------------
  155 DO 220 J=1,3
      I1=NVT(J)
      IF(TSTR.GT.TV(J,I1))GO TO 200
      I2=IT(J)
      DO 160 I=I2,I1
      IM1=I-1
      IF((TSTR.LE.TV(J,IM1)).OR.(TSTR.GT.TV(J,I)))GO TO 160
      IT(J)=I
      IFLG1=3
      A(1)=TSTR-TV(J,IM1)
      A(2)=1./(TV(J,I)-TV(J,IM1))
      AREATS(J)=(AREA(J,I)-AREA(J,IM1) )*A(1)*A(2)+AREA(J,IM1)
      GO TO 220
  160 CONTINUE
      WRITE(IOUT,190)
  190 FORMAT('0STOP AT 190')
      STOP
  200 AREATS(J)=AREA(J,NVT(J))
      GO TO(210,220,220),IFLG1
  210 IFLG1=2
  220 CONTINUE
      IF(IFLG1.EQ.3)IFLG1=1
C--------------------------------------------------
C BEGIN NEXT ITERATION AT SAME TIME INTERVAL
C--------------------------------------------------
  240 ITER=ITER+1
  244 IF(ITER.LT.INSTR(22))GO TO 242
      INSTR(23)=2
      IF(IFLG12.EQ.1)WRITE(IOUT,245)
  245 FORMAT('0SWITCHING TO SMALL PERTURBATION SOLUTION ENTIRELY')
      IFLG12=2
  241 ITER=1
  242 ND=0
      NN=0
      NCT=0
      IF(ITER.GE.INSTR(22))INSTR(23)=2
  243 IF(IFLG2.EQ.1)GO TO 250
C-----------------------------------------------------------------------
C   SET CHARGE TUBE AND NOZZLE VARIABLES TO STEADY CHOKED VALUES
C-----------------------------------------------------------------------
      IF(IFLG6.EQ.2)GO TO 250
      IFLG6=2
      SY=CTA/TSA
      IFLG=3
      IFLG2=+1
      CALL SOLVER
```

```
      MCT=$X1
      NCT=$N
      A(1)=(1.+GM102*MCT**2)/(1.+GM102*MCT)**2
      TCT0=TC*A(1)
      TE0=TCT0
      PCT0=PC*A(1)**GOGM1
      RCT0=PCT0*OOR/TCT0*A2
      ACT0=DSQRT(GR*TCT0)
      MDTS0=RCT0*ACT0*TSA
      MDCT0=RCT0*ACT0*CTA
      MN=1.
      PN=PSOP0*PCT0
      MDCT=RSOR0*RCT0*DSQRT(TSOT0)*ACT0*TSA
      IFLG2=-1
      WRITE(IOUT,249)
  249 FORMAT('0NOZZLE HAS CHOKED')
      MCT1=MCT
      TCT01=TCT0
      PCT01=PCT0
      RCT01=RCT0
      ACT01=ACT0
      MN1=MN
      PN1=PN
      MDCT1=MDCT
      MDTS01=MDTS0
      MDCT01=MDCT0
      PT=A17*PD+(1.D0-A17)*PN
      PT1=PT
  250 IF(INSTR(23).EQ.0)GO TO 255
      IF(T.GT.A13)INSTR(23)=2
      IF((INSTR(23).EQ.3).AND.(ITER.GE.INSTR(11)))GO TO 253
  252 IF(ITER.NE.1)GO TO 255
C-------------------------------
C CALL SMALL PERTURBATION PACKAGE
C-------------------------------
  253 DO 260 I=1,3
      I1=I+25
      V(I1,1)=AREATS(I)
      EA(I)= V(I1,1)-V(I1,2)
  260 CONTINUE
      IF((AREATS(3).EQ.0.D0).AND.(EA(3).EQ.0.D0))MDF1=0.D0
      IF((AREATS(2).EQ.0.D0).AND.(EA(2).EQ.0.D0))MDPE1=0.D0
      CALL SMPERT
      K1=DSIGN(1.5D0,PT-PCT0*PSOP0)
      IF(K1.EQ.IFLG2)GO TO 256
      IF(IFLG10.EQ.2)GO TO 258
      IFLG10=2
      IF(IFLG2.EQ.1)IFLG2=K1
      IF(IFLG2.EQ.(-1))GO TO 241
      GO TO 256
  258 IFLG10=1
  256 IF((INSTR(23).EQ.3).AND.(ITER.GE.INSTR(11)))GO TO 254
      IF(INSTR(23).EQ.2)GO TO 254
      GO TO 255
  254 IF(J18.EQ.03)GO TO 1190
      WRITE(J18'J16)RSTR,ISTR
```

```
      FIND(J18*J16)
      GO TO 1190
  255 IF(IFLG2)500,9999,251
C-----------------
C SUBSONIC BRANCH
C-----------------
  251 MDE=A1*PE0*AREATS(1)/DSQRT(TE0)*A2
      IFLG2=+1
      IFLG6=1
      IFLG12=1
      MDD=MDE+MDE
C DIFFUSER MACH NUMBER AND PRESSURE
      $Y=MDD/MDTSO
      IFLG=2
      CALL SOLVER
      MD=$X1
      ND=$N
      PD=PCTO*POPO(MD)
      PT=.5*(PD+PN)
      MDPT=MDOTPT(PP,PT)
      MDCT=MDD+MDPT
C CHARGE TUBE MACH NUMBER
      $Y=MDCT/MDCTC
      IFLG=4
      CALL SOLVER
      MCT=$X1
      NCT=$N
      A(1)=(1.+GM102*MCT**2)/(1.+GM102*MCT)**2
      TCTO=TC*A(1)
      PCTO=PC*A(1)**GOGM1
      RCTO=PCTO*OOR/TCTO*A2
      PE0=PCTO
      TE0=TCTO
      RE0=RCTO
      ACTO=DSQRT(GR*TCTO)
      A(1)=RCTO*ACTO
      MDCTO=A(1)*CTA
      MDTSO=A(1)*TSA
C NOZZLE MACH NUMBER AND PRESSURE
      $Y=MDCT/MDTSO
      IFLG=2
      CALL SOLVER
      MN=$X1
      NN=$N
      PN=PCTO*POPO(MN)
      IF(PT.LE.PCTO*PSOPO)GO TO 241
      GO TO 1000
C-----------------
C SUPERSONIC BRANCH
C-----------------
  500 PT=A17*PD+(1.D0-A17)*PN
      IFLG2=-1
      IFLG12=1
      MDPT=MDOTPT(PP,PT)
      MDD=MDCT-MDPT
      MDE=-MDE+MDD
```

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      TEO=TCTO
      PEO=MDE*DSQRT(TEO)*OOA1/AREATS(1)*A3
      REO=PEO*OOR/TEO *A2
C DIFFUSER PRESSURE AND MACH NUMBER
      $Y=MDD/MDTSO
      IFLG=2
      CALL SOLVER
      MD=$X1
      ND=$N
      PD=PCTO*POPO(MD)
C-----------------------
C UPDATE PLENUM CONDITIONS
C-----------------------
 1000 IF(IFLG2)1001,9999,1002
 1001 PT=(1.D0-A17)*PN+A17*PD
      GO TO 1003
 1002 PT=0.5D0*(PN+PD)
 1003 MDPT=MDOTPT(PP,PT)
      MDF=-AREATS(3)*OOKF*(PP-PD*A16)*A2
      RPT=RPT1+(MDPT+MDF+MDPE)*DTOPV
      RP=.5*(RPT1+RPT)
      IF(IFLG9.EQ.2)GO TO 1010
      PPT=PPT1*(RPT/RPT1)**G
      TPT=PPT*OOR/RPT*A2
      PP=PPT1*(RP/RPT1)**G
      TP=PP*OOR/RP *A2
      IF(INSTR(25).EQ.1)GO TO 1020
      IF(TPT.GE.TCTO)GO TO 1020
      IFLG9=2
 1010 TP=TCTO
      TPT=TCTO
      PP=RP*R*TP/A2
      PPT=RPT*R*TPT/A2
 1020 MDPE=-A1*PP*AREATS(2)/DSQRT(TP)*A2
C----------------
C CONVERGENCE CHECK
C----------------
      IFLG3=1
      DO 1050 I=1,7
 1050 E(I)=2.*DABS(V(I,1)-V(I,3))/(V(I,1)+V(I,3))
      DO 1100 I=1,7
      IF(E(I).GT.PERR)GO TO 1200
 1100 CONTINUE
C WRITE DATA ON FILE AND PRINT CONVERGED DATA
      IFLG3=2
      IF(J18.EQ.03)GO TO 1115
      WRITE(J18'J16)RSTR,ISTR
      FIND(J18'J16)
 1115 CALL PRINT
 1116 IF(INSTR(7).EQ.2)GO TO 1180
      IF(INSTR(6).NE.0)WRITE(IOUT,1120)V
 1120 FORMAT(15(/' ',8E16.8))
C----------------------------------------
C PERFORM EXTRAPOLATION TO NEXT TIME INTERVAL
C----------------------------------------
      DO 1170 I=1,7
```

```
      J=IEXTP(I)
C SAVE DATA FOR CURRENT INTERVAL
      A(I)=V(J,1)
      IF(ITIME.EQ.1)GO TO 1160
      IF(IFLG4.EQ.1)GO TO 1160
C EXTRAPOLATE
      V(J,1)=2.*V(J,1)-V(J,2)
      IF(INSTR(6).NE.0)CALL PRINT
C RESET DATA TO BEGINNING OF TIME INTERVAL
 1160 V(J,2)=A(I)
      IF(IFLG4.EQ.1)IFLG4=2
 1170 CONTINUE
C--------------------------------------------------------
C DETERMINE IF ERROR CUTTING OR DT DOUBLING IS REQUIRED
C--------------------------------------------------------
 1180 IF((INSTR(12).EQ.1).AND.(INSTR(14).EQ.1))GO TO 1190
      DO 1185 I=1,7
      IF((IFLG2.NE.1).AND.((I.EQ.1).OR.(I.EQ.6)))GO TO 1185
      E(I)=2.*DABS(V(I,1)-V(I,2))/(V(I,1)+V(I,2))/INSTR(12)
      IF(E(I).GT.PERR)GO TO 1185
      IF(INSTR(14).GT.1)GO TO 1184
C ERROR CUTTING
      PERR=PERR/INSTR(12)
      $EMAX=$EMAX/INSTR(12)
      WRITE(IOUT,1183)PERR,$EMAX
 1183 FORMAT('0      PERR CUT TO',E16.8,' AND $EMAX CUT TO',E16.8)
      IPAGE=IPAGE+2
      GO TO 1190
C DT DOUBLING
 1184 DT=DT*INSTR(14)
      DTOPV=DT/PV
      OODT=1./DT
      DTO2=DT*.5
      WRITE(IOUT,1187)DT
 1187 FORMAT('0      DT RAISED TO',E16.8)
      IPAGE=IPAGE+2
      GO TO 1190
 1185 CONTINUE
 1190 IF(ITIME.LE.2)GO TO 1191
C--------------------------------------------------------
C DETERMINE IF NEXT INTERVAL IS PREDICTED TO CHOKE
C--------------------------------------------------------
      DMD=MD-MD1
      DMN=MN-MN1
      IF(DMD.LT.DMD1)DMD=DMD1
      IF(DMN.LT.DMN1)DMN=DMN1
      IFLG2=DSIGN(1.5D0,PT-PCT0*PSOPO)
      IF((MD.GE.(1.D0-DMD)).OR.(MN.GE.(1.D0-DMN)))IFLG2=-1
 1191 DMD1=MD-MD1
      DMN1=MN-MN1
      IF(IFLG2.LT.0)IFLG10=2
      WRITE(IDEBUG,2000)IFLG2,DMD,DMN,MD,MN,MD1,MN1
 2000 FORMAT('0IFLG2=',I3,'  DMD,DMN=',2E13.5,'  MD,MN=',2E13.5,
     1 '  MD1,MN1=',2E13.5)
C RESET DATA TO BEGINNING OF TIME INTERVAL
      IF(INSTR(23).EQ.0)GO TO 1189
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      DO 1188 I=1,30
 1188 V(I,2)=V(I,1)
      GO TO 150
 1189 RPT1=RPT
      PPT1=PPT
      IF(INSTR(7).EQ.1)GO TO 150
      DO 1186 I=1,7
      J=IEXTP(I)
 1186 V(J,2)=V(J,1)
      GO TO 150
C-----------------------------
C RESET CONVERGENCE CONTROL DATA
C-----------------------------
 1200 IF(IDEBUG.EQ.IOUT)CALL PRINT
      IF(INSTR(6).NE.0)CALL PRINT
      I1=INSTR(10)
 1210 DO 1260 I=1,30
      GO TO(1220,1240),I1
      V(I,3)=V(I,1)
      GO TO 1260
 1220 IF(ITER.NE.1) V(I,1)=A11*V(I,1)+A12 *V(I,3)
      V(I,3)=V(I,1)
      GO TO 1260
 1240 V(I,4)=V(I,3)
      V(I,3)=V(I,1)
      IF(ITER.NE.1)V(I,1)=A11*V(I,1)+A12*V(I,4)
 1260 CONTINUE
      GO TO 240
      END
```

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      SUBROUTINE INPUT(*)
      IMPLICIT REAL*8 (A-H,M,O-Z,$)
      COMMON AREA(3,50),AREATS(3),AREAM(3),TV(3,50),A(10),E(7),B(30),
     1 TVF(3),TDELAY(3),RW(7)
      COMMON PC,RC,TC,AC,MDCTC,EAE,EAPE,EAF,MDTSTR,INFIN,TMGOGS,GPO2GS,
     1 SGOR
      COMMON G,GM1,GP1,OOG,GP1O2,GM1O2,GP1OG,GM1OG,GOGP1,GOGM1,
     1 OOGM1,OOGP1,GPOGM1,SGM1O2,TOGM1,TOG,MGPGM2,TOGP1,GPGM12,
     2 MGPOGM,MGOGM1,R,GR,OOR,PI,PERR,AWOKW,OOA1,OOKF,KF,KW
      COMMON TSL,TSH,TSW,TSP,TSA,TSWA,TSV,CTD,CTA,PV,PVOTSV,TAUW
      COMMON T,T1,DT,TSTR,DTO2,TSTOP,OODT,DTOPV
      COMMON A1,A2,A3,A4,A5,A6,A7,A8,A9,A10,A11,A12,A13,A14,A15,A16,A17
      COMMON    PN ,    PP ,   PPT ,    PD ,    PT , PCTO ,  PEO ,  MDE ,
     -  MDD ,   MDF , MDPT , MDCT , MDPE ,MDTSO ,MDCTO ,  TEO ,   TP ,
     -  TPT , TCTO ,    RP ,   RPT ,   REO , RCTO , ACTO,  MCT ,   AE ,
     -  APE ,   AF ,    MN ,    MD
      COMMON    PN1,    PP1,   PPT1,    PD1,    PT1, PCTO1,  PEO1,  MDE1,
     -  MDD1,   MDF1, MDPT1, MDCT1, MDPE1,MDTSO1,MDCTO1,  TEO1,   TP1,
     -  TPT1, TCTO1,    RP1,   RPT1,  REO1, RCTO1, ACTO1,  MCT1,   AE1,
     -  APE1,   AF1,    MN1,    MD1
      COMMON    PN2,    PP2,   PPT2,    PD2,    PT2, PCTO2,  PEO2,  MDE2,
     -  MDD2,   MDF2, MDPT2, MDCT2, MDPE2,MDTSO2,MDCTO2,  TEO2,   TP2,
     -  TPT2, TCTO2,    RP2,   RPT2,  REO2, RCTO2, ACTO2,  MCT2,   AE2,
     -  APE2,   AF2,    MN2,    MD2
      COMMON    PN3,    PP3,   PPT3,    PD3,    PT3, PCTO3,  PEO3,  MDE3,
     -  MDD3,   MDF3, MDPT3, MDCT3, MDPE3,MDTSO3,MDCTO3,  TEO3,   TP3,
     -  TPT3, TCTO3,    RP3,   RPT3,  REO3, RCTO3, ACTO3,  MCT3,   AE3,
     -  APE3,   AF3,    MN3,    MD3
      COMMON PSOPO,TSOTO,RSORO,MSOMO
      COMMON $Y,$Y1,$Y2,$X1,$X2,$DX,$E1,$E2,$EMAX,$EP,$DE
      COMMON INSTR(26),IDEBUG,IIN,IOUT,NP,IP,ITER,NVT(3),I,NT,IPAGE,
     1NPAGE,$N,IT(3),J,IM1,ITIME,ND,NN,NCT,IFLG,IFLG1,IFLG2,IFLG3,IFLG4,
     2IFLG5,IFLG6,IFLG7,IFLG8,IFLG9,I1,I2,I3,I4,I5
      COMMON J1,J2,J3,J4,J5,J6,J7,J8,J9,J10,J11,J12,J13,J14,J15,J16,J17,
     1 J18,J19,J20,J21,J22,J23,J24,J25,J26
      COMMON NCTL
      DIMENSION V(30,4),RSTR(579),ISTR(35)
      EQUIVALENCE (V(1),PN),(RSTR(1),AREA(1)),(ISTR(1),NP)
      INTEGER $N
      REAL*8 INFIN,KF,KW
      IF(NCTL.NE.0)GO TO 200
      READ(IIN,50)NVT,NT
   50 FORMAT(26I3)
      READ(IIN,100)PC,TC
  100 FORMAT(5E16.8)
      READ(IIN,100)TSL,TSH,TSW,CTD,PVOTSV,TAUW,KW,KF,A15,A16
     1,A17,A18,A19,A20,A21
      READ(IIN,100)R,G,A11,A13,A14
      READ(IIN,100)DT,TSTOP,$EMAX,PERR,A10
      READ(IIN,100)AREAM
      READ(IIN,100)TVF
      READ(IIN,100)TDELAY
      DO 110 J=1,3
      DO 105 I=1,50
      TV(J,I)=0.
  105 AREA(J,I)=0.
```

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      I1=NVT(J)
  110 READ(IIN,120)(TV(J,I),AREA(J,I),I=1,I1)
  120 FORMAT(2E16.8)
      RETURN
  200 READ(IIN,50)I1,I2,I3
      IF(I1.EQ.0)RETURN 1
      GO TO(220,240,260),I1
  220 READ(IIN,50)ISTR(I2)
      GO TO 200
  240 READ(IIN,100)RSTR(I2)
      GO TO 200
  260 READ(IIN,100)V(I2,I3)
      GO TO 200
      END
```

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 SUBROUTINE CONST(*)
 IMPLICIT REAL*8 (A-H,M,O-Z,$)
 COMMON AREA(3,50),AREATS(3),AREAM(3),TV(3,50),A(10),E(7),R(30),
1 TVF(3),TDELAY(3),RW(7)
 COMMON PC,RC,TC,AC,MDCIC,FAF,FAPF,FAF,MDTSTR,INFIN,TMGOGS,GPO2GS,
1 SGOR
 COMMON G,GM1,GP1,OOG,GP1O2,GM1O2,GP1OG,GM1OG,GOGP1,GOGM1,
1 OOGM1,OOGP1,GPOGM1,SGM1O2,TOGM1,TOG,MGPGM2,TOGP1,GPGM12,
2 MGPOGM,MGOGM1,R,GR,OOR,PI,PERR,AWOKW,OOA1,OOKF,KF,KW
 COMMON TSL,TSH,TSW,TSP,TSA,TSWA,TSV,CTD,CTA,PV,PVOTSV,TAUW
 COMMON T,T1,DT,TSTR,DTO2,TSTOP,OODT,DTOPV
 COMMON A1,A2,A3,A4,A5,A6,A7,A8,A9,A10,A11,A12,A13,A14,A15,A16,A17
 COMMON    PN ,   PP ,  PPT ,   PD ,   PT , PCTO ,  PFO ,  MDF ,
-  MDD ,  MDF , MDPT , MDCT , MDPE ,MDTSO ,MDCTO ,  TEO ,  TP ,
-  TPT , TCTO ,   RP ,  RPT ,  REO , RCTO , ACTO,  MCT ,   AE ,
-  APE ,   AF ,   MN ,   MD
 COMMON    PN1,   PP1,  PPT1,   PD1,   PT1, PCTO1,  PEO1,  MDF1,
-  MDD1,  MDF1, MDPT1, MDCT1, MDPE1,MDTSO1,MDCTO1,  TEO1,  TP1,
-  TPT1, TCTO1,   RP1,  RPT1,  REO1, RCTO1, ACTO1,  MCT1,   AE1,
-  APE1,   AE1,   MN1,   MD1
 COMMON    PN2,   PP2,  PPT2,   PD2,   PT2, PCTO2,  PFO2,  MDF2,
-  MDD2,  MDF2, MDPT2, MDCT2, MDPE2,MDTSO2,MDCTO2,  TEO2,  TP2,
-  TPT2, TCTO2,   RP2,  RPT2,  REO2, RCTO2, ACTO2,  MCT2,   AF2,
-  APE2,   AF2,   MN2,   MD2
 COMMON    PN3,   PP3,  PPT3,   PD3,   PT3, PCTO3,  PEO3,  MDF3,
-  MDD3,  MDF3, MDPT3, MDCT3, MDPE3,MDTSO3,MDCTO3,  TEO3,  TP3,
-  TPT3, TCTO3,   RP3,  RPT3,  REO3, RCTO3, ACTO3,  MCT3,   AE3,
-  APE3,   AF3,   MN3,   MD3
 COMMON PSOPO,TSOTO,PSORO,MSOMO
 COMMON $Y,$Y1,$Y2,$X1,$X2,$DX,$E1,$F2,$EMAX,$EP,$DF
 COMMON INSTR(26),IDEBUG,IIN,IOUT,NP,IP,ITER,NVT(3),I,VT,IPAGE,
1NPAGE,$N,IT(3),J,TM1,ITIME,ND,NN,NCT,IFLG,IFLG1,IFLG2,IFLG3,IFLG4,
2IFLG5,IFLG6,IFLG7,IFLG8,IFLG9,I1,I2,I3,I4,I5
 COMMON J1,J2,J3,J4,J5,J6,J7,J8,J9,J10,J11,J12,J13,J14,J15,J16,J17,
1 J18,J19,J20,J21,J22,J23,J24,J25,J26
 COMMON NCTL
 INTEGER $N
 REAL*8 INFIN,KF,KW
 PI=3.14159265358979
 GM1=G-1
 GP1=G+1
 GM1O2=.5*GM1
 GP1O2=GP1*.5
 OOG=1./G
 GM1OG=GM1*OOG
 GP1OG=GP1*OOG
 GPO2GS=0.5*GP1OG*OOG
 GOGM1=G/GM1
 GOGP1=G/GP1
 SGM1O2=DSQRT(GM1O2)
 TOG=2.*OOG
 TOGP1=2./GP1
 OOGM1=1./GM1
 GPOGM1=GP1*OOGM1
 GPGM12=.5*GPOGM1
 OOGP1=1./GP1
```

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      OOR=1./R
      GR=G*R
      MGPOGM=-GPOGM1
      MGPGM2=-GPGM12
      MGOGM1=-GOGM1
      TMGOGS=(2.-G)*OOG**2
      TOGM1=2./GM1
      IF(INSTR(5).EQ.1)GO TO 100
      A2=144.
      A3=1./A2
      GO TO 200
  100 A2=1.
      A3=A2
  200 CONTINUE
C SERIES FOR UNSTEADY MASS FLUX FROM MACH NUMBER
      A(8)=MGPOGM
      A(9)=GM102
      CALL BINOM
      CALL REVERT
      DO 220 I=1,7
  220 RW(I)=A(I)
      SGOR=DSQRT(G*OOR)
      IF(NCT(.EQ.7)RETURN 1
      RETURN
      END
```

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      SUBROUTINE INIT(*)
      IMPLICIT REAL*8 (A-H,M,O-Z,$)
      COMMON AREA(3,50),AREATS(3),AREAM(3),TV(3,50),A(10),E(7),B(30),
     1 TVE(3),TDELAY(3),RW(7)
      COMMON PC,RC,TC,AC,MDCTC,EAF,EAPE,FAF,MDTSTR,INFIN,TMGOGS,GPO2GS,
     1 SGQR
      COMMON G,GM1,GP1,OOG,GP1O2,GM1O2,GP1OG,GM1OG,GOGP1,GOGM1,
     1 OOGM1,OOGP1,GPOGM1,SGM1O2,TOGM1,TOG,MGPGM2,TOGP1,GPGM12,
     2 MGPOGM,MGOGM1,R,GR,OOR,PI,PERR,AWOKW,OOA1,OOKF,KF,KW
      COMMON TSL,TSH,TSW,TSP,TSA,TSWA,TSV,CTD,CTA,PV,PVOTSV,TAUW
      COMMON T,T1,DT,TSTR,DTO2,TSTOP,OODT,DTOPV
      COMMON A1,A2,A3,A4,A5,A6,A7,A8,A9,A10,A11,A12,A13,A14,A15,A16,A17
      COMMON    PN ,   PP ,  PPT ,   PD ,   PT , PCTO ,  PEO ,  MDE ,
     -  MOD ,  MDF , MDPT , MDCT , MDPF ,MDTSO ,MDCTO ,  TEO ,   TP ,
     -  TPT , TCTO ,   RP ,  RPT ,  REO , RCTO , ACTO,  MCT ,   AE ,
     -  APE ,   AF ,   MN ,   MD
      COMMON    PN1,   PP1,  PPT1,   PD1,   PT1, PCTO1,  PEO1,  MDE1,
     -  MOD1,  MDF1, MDPT1, MDCT1, MDPF1,MDTSO1,MDCTO1,  TEO1,   TP1,
     -  TPT1, TCTO1,   RP1,  RPT1,  REO1, RCTO1, ACTO1,  MCT1,   AE1,
     -  APE1,   AF1,   MN1,   MD1
      COMMON    PN2,   PP2,  PPT2,   PD2,   PT2, PCTO2,  PEO2,  MDE2,
     -  MOD2,  MDF2, MDPT2, MDCT2, MDPE2,MDTSO2,MDCTO2,  TEO2,   TP2,
     -  TPT2, TCTO2,   RP2,  RPT2,  REO2, RCTO2, ACTO2,  MCT2,   AE2,
     -  APE2,   AF2,   MN2,   MD2
      COMMON    PN3,   PP3,  PPT3,   PD3,   PT3, PCTO3,  PEO3,  MDE3,
     -  MOD3,  MDF3, MDPT3, MDCT3, MDPE3,MDTSO3,MDCTO3,  TEO3,   TP3,
     -  TPT3, TCTO3,   RP3,  RPT3,  REO3, RCTO3, ACTO3,  MCT3,   AE3,
     -  APE3,   AF3,   MN3,   MD3
      COMMON PSOPO,TSOTO,RSORO,MSOMO
      COMMON $Y,$Y1,$Y2,$X1,$X2,$DX,$E1,$E2,$EMAX,$EP,$DE
      COMMON INSTR(26),IDEBUG,IIN,IOUT,NP,IP,ITER,NVT(3),I,NT,IPAGE,
     1NPAGE,$V,IT(3),J,IM1,ITIME,ND,NN,NCT,IFLG,IFLG1,IFLG2,IFLG3,IFLG4,
     2IFLG5,IFLG6,IFLG7,IFLG8,IFLG9,I1,I2,I3,I4,I5
      COMMON J1,J2,J3,J4,J5,J6,J7,J8,J9,J10,J11,J12,J13,J14,J15,J16,J17,
     1 J18,J19,J20,J21,J22,J23,J24,J25,J26
      COMMON NCTL
      DIMENSION V(30,4)
      EQUIVALENCE (PN,V(1,1))
      INTEGER $V
      REAL*8 INFIN,KF,KW
      DO 5 I=1,3
      IT(I)=2
    5 AREATS(I)=0.
      TSA=TSW*TSH
      TSP=2.*(TSW+TSH)
      TSWA=TSL*TSP
      CTA=PI*CTD**2*.25
      TSV=TSA*TSL
      PV=TSV*PVOTSV
      DTOPV=DT/PV
      RC=PC*OOR/TC*A2
      AC=DSQRT(GR*TC)
      MDCTC=RC*AC*CTA
      MDTSO=RC*AC*TSA
      DO 50 J=1,4
      DO 10 I=1,7
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 10 V(I,J)=PC
    DO 20 I=8,13
 20 V(I,J)=0.
    V(14,J)=MDTSO
    V(15,J)=MDCTC
    DO 30 I=16,19
 30 V(I,J)=TC
    DO 40 I=20,23
 40 V(I,J)=RC
    V(24,J)=AC
    DO 45 I=25,30
 45 V(I,J)=0.
 50 CONTINUE
    T=0.
    T1=0.
    MD=0.
    TSTR=0
    DTO2=.5*DT
    OODT=1./DT
    MN=0.
    MCT=0.
    DO 160 J=1,3
    I1=NVT(J)
    DO 140 I=1,I1
    TV(J,I)=TV(J,I)*TVF(J)
140 AREA(J,I)=AREA(J,I)*AREAM(J)
    IF(TDELAY(J).EQ.0.)GO TO 160
    DO 150 I1=1,49
    I=51-I1
    AREA(J,I)=AREA(J,I-1)
150 TV(J,I)=TV(J,I-1)+TDELAY(J)
    NVT(J)=NVT(J)+1
160 CONTINUE
    DO 170 I=1,3
170 V(I+25,2)=AREA(I,1)
    PSOPO=TOGP1**GOGM1
    TSOTO=TOGP1
    RSORO=TOGP1**OOGM1
    MSOMO=PSORO*DSQRT(TSOTO)
    MDTSTR=MDTSO*MSOMO
    INFIN=1.E+70
    A1=DSQRT(TOGP1**GPOGM1*G*OOR)
    OOA1=1./A1
    A4=TOGP1**GPGM12
    A5=1./MSOMO
    A6=1.-PSOPO
    A7=2.*GP1/MDCTC
    A8=-GM1OG
    A9=2.*GP1
    IF(A10.EQ.0.)A10=INFIN
    IF(A11.EQ.0.)A11=.5
    IF(A13.EQ.0.)A13=INFIN
    IF(A14.EQ.0.)A14=-0.1
    IF(A14.GT.0.)A14=-A14
    A12=1.-A11
    IF(A15.EQ.0.D0)A15=1.D0
```

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      IF(A16.EQ.0.D0)A16=1.D0
      IF(A17.EQ.0.D0)A17=1.D0
      IPAGE=0
      NPAGE=50
      IP=0
      OOKF=1./KF
      AWOKW=.17*TAUW*TSWA/KW
      ITER=0
      IFLG=0
      IFLG2=1
      IFLG3=0
      IFLG4=0
      IFLG5=0
      IFLG6=0
      IFLG7=0
      IFLG8=0
      IFLG9=0
      ND=0
      NV=0
      NCT=0
      I1=0
      I2=0
      I3=0
      I4=0
      I5=0
      DO 200 I=1,7
  200 E(I)=0.
      IF(NCTL.EQ.6)RETURN 1
      RETURN
      END
```

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      SUBROUTINE DUMP (*)
      IMPLICIT REAL*8 (A-H,M,O-Z,$)
      COMMON AREA(3,50),AREATS(3),AREAM(3),TV(3,50),A(10),F(7),B(30),
     1 TVF(3),TDELAY(3),RW(7)
      COMMON PC,RC,TC,AC,MDCTC,EAF,EAPF,FAF,MDTSTP,INFIN,TMGOGS,GPO2GS,
     1 SGOR
      COMMON G,GM1,GP1,OOG,GP102,GM102,GP1OG,GM1OG,GOGP1,GOGM1,
     1 OOGM1,OOGP1,GPOGM1,SGM102,TOGM1,TOG,MGPGM2,TOGP1,GPGM12,
     2 MGPOGM,MGOGM1,P,GR,OOR,PT,PERR,AWOKW,OOA1,OOKF,KF,KW
      COMMON TSL,TSH,TSW,TSP,TSA,TSWA,TSV,CTD,CTA,PV,PVOTSV,TAUW
      COMMON T,T1,DT,TSTR,DTO2,TSTOP,OODT,DTOPV
      COMMON A1,A2,A3,A4,A5,A6,A7,A8,A9,A10,A11,A12,A13,A14,A15,A16,A17
      COMMON    PN ,    PP ,  PPT ,    PD ,    PT , PCTO ,  PEO ,  MDE ,
     -  MDD ,  MDF , MDPT , MDCT , MDPF ,MDTSO ,MDCTO ,  TEO ,   TP ,
     -  TPT , TCTO ,   RP ,  RPT ,  REO , RCTO , ACTO,  MCT ,   AE ,
     -  APF ,   AF ,   MN ,   MD
      COMMON    PN1,    PP1,  PPT1,    PD1,    PT1, PCTO1,  PEO1,  MDE1,
     -  MDD1,  MDF1, MDPT1, MDCT1, MDPF1,MDTSO1,MDCTO1,  TEO1,   TP1,
     -  TPT1, TCTO1,   RP1,  RPT1,  REO1, RCTO1, ACTO1,  MCT1,   AE1,
     -  APE1,   AF1,   MN1,   MD1
      COMMON    PN2,    PP2,  PPT2,    PD2,    PT2, PCTO2,  PEO2,  MDE2,
     -  MDD2,  MDF2, MDPT2, MDCT2, MDPF2,MDTSO2,MDCTO2,  TEO2,   TP2,
     -  TPT2, TCTO2,   RP2,  RPT2,  REO2, RCTO2, ACTO2,  MCT2,   AE2,
     -  APE2,   AF2,   MN2,   MD2
      COMMON    PN3,    PP3,  PPT3,    PD3,    PT3, PCTO3,  PEO3,  MDE3,
     -  MDD3,  MDF3, MDPT3, MDCT3, MDPF3,MDTSO3,MDCTO3,  TEO3,   TP3,
     -  TPT3, TCTO3,   RP3,  RPT3,  REO3, RCTO3, ACTO3,  MCT3,   AE3,
     -  APE3,   AF3,   MN3,   MD3
      COMMON PSOPO,TSOTO,RSORO,MSOMO
      COMMON $Y,$Y1,$Y2,$X1,$X2,$DX,$E1,$E2,$EMAX,$EP,$DE
      COMMON INSTR(26),IDEBUG,IIN,IOUT,NP,IP,ITER,NVT(3),I,NT,IPAGE,
     1NPAGE,$N,IT(3),J,IM1,ITIME,ND,NN,NCT,IFLG,IFLG1,IFLG2,IFLG3,IFLG4,
     2IFLG5,IFLG6,IFLG7,IFLG8,IFLG9,I1,I2,I3,I4,I5
      COMMON J1,J2,J3,J4,J5,J6,J7,J8,J9,J10,J11,J12,J13,J14,J15,J16,J17,
     1 J18,J19,J20,J21,J22,J23,J24,J25,J26
      COMMON NCTL
      DIMENSION JV(26),V(30,4)
      EQUIVALENCE (JV(1),J1),(V(1),PN)
      INTEGER $N
      REAL*8 INFIN,KF,KW
      LOGICAL*4 CHAR1(2),CHAR2(2,2)
      DATA CHAR1/'PSFA','PSIA'/,CHAR2/'SECO','ND  ','SEVE','NTH '/
      WRITE(IOUT,100)(I,I=1,26),INSTR
  100 FORMAT('0',16(' INSTR',I2)/' ',10(' INSTR',I2),2(/' ',16I8))
      WRITE(IOUT,120)IDEBUG,IIN,IOUT,I1,IPAGE,NPAGE,NP,IP,ITER,I2,I,
     1IFLG,IFLG1,IFLG2,IFLG3,IFLG4,IFLG5,IFLG6,IFLG7,IFLG8,IFLG9,ND,NN,
     2 NCT,ITIME,NVT,I3,I4,I5,IT,NCTL
  120 FORMAT('0 IDEBUG     IIN    IOUT      I1   IPAGE   NPAGE      NP      IP'
     1,'    ITER      I2       I    IFLG   IFLG1   IFLG2   IFLG3   IFLG4   IFLG5'
     2,'   IFLG6'/' ',18I7/'0   IFLG7   IFLG8   IFLG9      ND      NN     NCT'
     3,'   ITIME  NVT(1)  NVT(2)  NVT(3)      I3      I4      I5   IT(1)',
     4'   IT(2)   IT(3)    NCTL'
     -/' ',18I7)
      WRITE(IOUT,140)TSL,TSH,TSW,CTD,PVOTSV,TAUW,KW,KF,AREAM,TSA,
     1TSP,TSWA,CTA,TSV,PV,AWOKW
  140 FORMAT('0',7X,'TSL',13X,'TSH',13X,'TSW',13X,'CTD',12X,'PVOTSV',
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     1 11X,'TAUW',13X,'KW',14X,'KF'/' ',8E16.8/'0',7X,'AEM',13X,'APM',
     213X,'AFM',13X,'TSA',13X,'TSP',12X,'TSWA',13X,'CTA',13X,'TSV'/
     3' ',8E16.8/'0',7X,'PV',13X,'AWOKW',10X,'         ',10X,'        ',
     4 10X,'        ',10X,'        ',10X,'        ',10X,
     5        /' ',8E16.8)
      WRITE(IOUT,180)PC,RC,TC,PP,RP,TP,PP1,RP1,TP1,PPT,RPT,TPT,PCTO,
     1 RCTO,TCTO,PEO,REO,TEO,AC,ACTO,MDPE,MDCT,MDE,MDF,T,T1,MN,TSTR,
     2MDPT,MDD,PD,PN,PT,MD,MCT,PP2,MDE2,MDPE2,MDF2,MDCT2,$EMAX,
     3TSTOP, DT ,PSOPO,TSOTO,RSORO,MSOMO,MDTSTR,MDTSO,MDCTC,MDCTO,PERR
     4,PN3,PP3,MDF3,PE03,TE03,MDTS03,PCT03,TDELAY
 180 FORMAT('0',7X,'PC',14X,'RC',14X,'TC',14X,'PP',14X,'RP',14X,
     1'TP',14X,'PP1',13X,'RP1'/' ',8E16.8/'0',7X,'TP1',13X,'PPT',13X,
     2'RPT',13X,'TPT',12X,'PCTO',12X,'RCTO',12X,'TCTO',13X,'PEO'/' ',
     38E16.8/'0',7X,'REO',13X,'TEO',13X,'AC',12X,'ACTO',13X,'MDPE',11X,
     4'MDCT',13X,'MDE',13X,'MDF'/' ',8E16.8/'0',8X,'T',14X,'T1',14X,'MN'
     5,13X,'TSTR',12X,'MDPT',13X,'MDD',13X,'PD',14X,'PN'/' ',8E16.8/
     6'0',7X,'PT',14X,'MD',14X,'MCT',13X,'PP2',12X,'MDE2',12X,'MDPE2',
     7 11X,'MDF2',12X,'MDCT2'/' ',8E16.8/'0',6X,'$EMAX',11X,'TSTOP',
     811X,' DT ',12X,'PSOPO',11X,'TSOTO',11X,'RSORO',11X,'MSOMO',10X,
     9'MDTSTR'/' ',8E16.8/'0',6X,'MDTSO',11X,'MDCTC',11X,'MDCTO',
     A 10X,' PERR ',10X,'  PN3 ',10X,'  PP3 ',10X,' MDF3 ',10X,
     B ' PE03 '/' ',8E16.8/'0',6X,'TE03',11X,'MDTS03',11X,'PCT03',10X,
     C'TDELAY',10X,'TDELAY',10X,'TDELAY',10X,'        ',10X,'      '/' ',
     D8E16.8)
      WRITE(IOUT,200)A1,A2,A3,A4,A5,A6,A7,A8,A9,A10,A11,A12,A13,A14,A15,
     1 A16,A17,A18,A19,A20,A21,A22,A23,A24
 200 FORMAT('0',7X,'A1',14X,'A2',14X,'A3',14X,'A4',14X,'A5',14X,
     1'A6',14X,'A7',14X,'A8'/' ',8E16.8/'0',7X,'A9',14X,'A10',
     313X,'A11',13X,'A12',13X,'A13',13X,'A14',13X,'A15',13X,'A16'/' ',
     4 8E16.8/'0', 7X,'A17',13X,'A18',13X,'A19',13X,'A20',13X,'A21',
     5 13X,'A22',13X,'A23',13X,'A24'
     -/' ',8E16.8)
      WRITE(IOUT,220)G,GM1,GP1,GM102,GP102,OOG,GM1OG,GP1OG,GOGM1,
     1GOGP1,SGM102,TOG,TOGP1,OOGM1,GPOGM1,GPGM12,TOGM1,MGPGM2,MGPOGM,
     2OOGP1,R,OOR,GR,DTO2,DTOPV,OOKF,INFIN,OOA1,OODT,MGOGM1,TMGOGS,
     3 GPO2GS,SGOR
 220 FORMAT('1',8X,'G',14X,'GM1',13X,'GP1',12X,'GM102',11X,'GP102',
     1 12X,'OOG',12X,'GM1OG',11X,'GP1OG'/' ',8E16.8/'0',6X,'GOGM1',
     211X,'GOGP1',10X,'SGM102',12X,'TOG',12X,'TOGP1',11X,'OOGM1',
     310X,'GPOGM1',10X,'GPGM12'/' ',8E16.8/'0',6X,'TOGM1',10X,'MGPGM2',
     4 10X,'MGPOGM',11X,'OOGP1',13X, 'R',14X,'OOR',13X,'GR',13X,'DTO2'/
     5' ',8E16.8/'0',6X,'DTOPV',11X,'OOKF',12X,'INFIN',11X,'OOA1',
     6 12X,'OODT',11X,'MGOGM1',10X,'TMGOGS', 10X,'GPO2GS'/' ',8E16.8
     7 /'0',6X,'SGOR'
     - /' ',8E16.8)
      WRITE(IOUT,260)V
 260 FORMAT('0V EQUIVALENCE ARRAY',15(/' ',8E16.8))
      WRITE(IOUT,240)(I,I=1,7),RW
 240 FORMAT('0',7(5X,'RW(',I1,')',5X)/' ',7E16.8)
      NINSTR=26
      DO 1000 I=1,NINSTR
      IF(I.EQ.12)WRITE(IOUT,490)
 490 FORMAT('1')
      WRITE(IOUT,500)I,INSTR(I)
 500 FORMAT('0INSTR(',I2,')=',I7)
C              1   2   3   4   5   6   7   8   9  10  11  12  13  14  15
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C         16  17  18  19  20  21  22  23  24  25  26  27  28  29  30  31
      GO TO(510,520,530,540,550,560,570,580,590,600,610,620,630,640,650
     1,660,670,680,690,700,710,720,730,740,750,760
     = ),I
  510 WRITE(IOUT,511)INSTR(1)
  511 FORMAT('+',20X,'SEND DEBUGGING OUTPUT TO DSRN',I3)
      GO TO 1000
  520 WRITE(IOUT,521)INSTR(2)
  521 FORMAT('+',20X,'OBTAIN INPUT FROM DSRN',I3)
      GO TO 1000
  530 WRITE(IOUT,531)INSTR(3)
  531 FORMAT('+',20X,'SEND REGULAR OUTPUT TO DSRN',I3)
      GO TO 1000
  540 WRITE(IOUT,541)INSTR(4)
  541 FORMAT('+',20X,'PRINTING TIME INTERVAL:',I3)
      GO TO 1000
  550 WRITE(IOUT,551)CHAR1(INSTR(5))
  551 FORMAT('+',20X,'INPUT AND OUTPUT PRESSURES IN ',A4)
      GO TO 1000
  560 IF(INSTR(6).EQ.0)WRITE(IOUT,562)
      IF(INSTR(6).NE.0)WRITE(IOUT,561)
  561 FORMAT('+',20X,'PRINT DATA AFTER EVERY ITERATION')
  562 FORMAT('+',20X,'PRINT DATA ONLY WHEN CONVERGED')
      GO TO 1000
  570 IF(INSTR(7).EQ.1)WRITE(IOUT,571)
      IF(INSTR(7).EQ.2)WRITE(IOUT,572)
  571 FORMAT('+',20X,'LINEARLY EXTRAPOLATE TO NEXT TIME INTERVAL AS AN I
     1NITIAL GUESS')
  572 FORMAT('+',20X,'DO NOT EXTRAPOLATE TO NEXT TIME INTERVAL')
      GO TO 1000
  580                 WRITE(IOUT,581)(CHAR2(J,3-INSTR(8)),J=1,2)
  581 FORMAT('+',20X,'USE ',2A4,' DEGREE REVERTED SERIES AS INITIAL GUES
     1S TO MASS FLUX-MACH NUMBER WAVE EQUATION')
      GO TO 1000
  590 IF(INSTR(9).EQ.1)WRITE(IOUT,591)
      IF(INSTR(9).EQ.2)WRITE(IOUT,592)
  591 FORMAT('+',20X,'USE ITERATIVE SOLUTION TO ENERGY AND WAVE EQUATION
     1S')
  592 FORMAT('+',20X,'USE APPROXIMATE EXPANSIONS FOR ENERGY AND WAVE EQU
     1ATIONS')
      GO TO 1000
  600 IF(INSTR(10).EQ.0)WRITE(IOUT,601)
      IF(INSTR(10).EQ.1)WRITE(IOUT,602)
      IF(INSTR(10).EQ.2)WRITE(IOUT,603)
  601 FORMAT('+',20X,'DO NOT INVOKE AVERAGING OPTION')
  602 FORMAT('+',20X,'AVERAGE VALUES OF CURRENT ITERATION WITH AVERAGE V
     *ALUES OF PREVIOUS ITERATION')
  603 FORMAT('+',20X,'AVERAGE VALUES OF CURRENT ITERATION WITH UNAVERAGE
     1D VALUES OF PREVIOUS ITERATION')
      GO TO 1000
  610 WRITE(IOUT,611)INSTR(11)
  611 FORMAT('+',20X,'CURRENT WEIGHT IS HALVED BEYOND ',I7,' ITERATIONS'
     1)
      GO TO 1000
  620 IF(INSTR(12).EQ.1)WRITE(IOUT,621)
      IF(INSTR(12).NE.1)WRITE(IOUT,622)(INSTR(12),J=1,2)
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621 FORMAT('+',20X,'DO NOT INVOKE ERROR CUTTING OPTION')
622 FORMAT('+',20X,'DIVIDE ERRORS BY',I3,' WHEN TIME-DIFFERENCES ARE L
   1ESS THAN',I3,' TIMES THE ERRORS')
    GO TO 1000
630 IF(INSTR(13).EQ.0)WRITE(IOUT,631)
    IF(INSTR(13).NE.0)WRITE(IOUT,632)
631 FORMAT('+',20X,'PRINT ALL DATA')
632 FORMAT('+',20X,'PRINT ONLY TIMES AND PRESSURES')
    GO TO 1000
640 IF(INSTR(14).EQ.1)WRITE(IOUT,641)
    IF(INSTR(14).GT.1)WRITE(IOUT,642)INSTR(14),INSTR(12)
641 FORMAT('+',20X,'DO NOT INVOKE DT-RAISING OPTION')
642 FORMAT('+',20X,'SET DT =',I3,'*DT IF TIME-DIFFERENCES ARE LESS THA
   *N',I3,' TIMES THE ERRORS')
    GO TO 1000
650 IF(INSTR(15) .EQ. 03) WRITE(IOUT,651)
    IF(INSTR(15) .NE.03) WRITE(IOUT,652)INSTR(15)
651 FORMAT ('+',20X,'DO NOT READ SOLUTION FROM PERMANENT DATA SET')
652 FORMAT('+',20X,'READ SOLUTION FROM PERMANENT DATA SET',I3)
    GO TO 1000
660 WRITE(IOUT,661)INSTR(16)
661 FORMAT('+',20X,'FIRST RECORD TO BE READ:',I4)
    GO TO 1000
670 WRITE(IOUT,671)INSTR(17)
671 FORMAT('+',20X,'LAST RECORD TO BE READ:',I4)
    GO TO 1000
680 IF(INSTR(18) .EQ.  03) WRITE(IOUT,681)
    IF(INSTR(18) .NE.03) WRITE(IOUT,682) INSTR(18)
681 FORMAT('+',20X,'DO NOT WRITE SOLUTION ON PERMANENT DATA SET')
682 FORMAT('+',20X,'WRITE SOLUTION ON PERMANENT DATA SET',I3)
    GO TO 1000
690 WRITE(IOUT,691) INSTR(19)
691 FORMAT('+',20X,'FIRST RECORD TO BE WRITTEN:',I4)
    GO TO 1000
700 IF((INSTR(11) .NE.0).AND.(INSTR(20).NE.0)) WRITE(IOUT,701) INSTR(2
   *0)
    IF((INSTR(11).EQ.0).OR.(INSTR(20).EQ.0))WRITE(IOUT,702)
701 FORMAT('+',20X,'INCREMENT INSTR(11) BY ',I3,' WHENEVER WEIGHT IS H
   *ALVED')
702 FORMAT('+',20X,'DO NOT MODIFY INSTR(11)')
    GO TO 1000
710 IF(INSTR(21) .EQ.0) WRITE(IOUT,711)
    IF(INSTR(21) .NE.0)WRITE(IOUT,712)
711 FORMAT('+',20X,'DO NOT CHANGE EXTRAPOLATION OPTION (INSTR(7))')
712 FORMAT ('+',20X,'INVOKE EXTRAPOLATION OPTION (SET INSTR(7)=2) WHEN
   *WEIGHT IS HALVED')
    GO TO 1000
720 WRITE(IOUT,721)INSTR(22)
721 FORMAT('+',20X,'SET INSTR(23)=2 WHEN ITER >=',I7)
    GO TO 1000
730 IF(INSTR(23).EQ.0)WRITE(IOUT,731)
    IF(INSTR(23).EQ.1)WRITE(IOUT,732)
    IF(INSTR(23).EQ.2)WRITE(IOUT,733)
731 FORMAT('+',20X,'DO NOT USE SMALL PERTURBATION EXPANSIONS')
732 FORMAT('+',20X,'USE SMALL PERTURBATION EXPANSIONS AS INITIAL GUESS
   1 FOR NEXT TIME INTERVAL')
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  733 FORMAT('+',20X,'USE SMALL PERTURBATION EXPANSION AS SOLUTION')
      GO TO 1000
  740 IF(INSTR(24).EQ.0)WRITE(IOUT,741)
      IF(INSTR(24).NE.0)WRITE(IOUT,742)
  741 FORMAT('+',20X,'RESULTS FROM SMPERT NOT PRINTED')
  742 FORMAT('+',20X,'RESULTS FROM SMPERT ARE PRINTED')
      GO TO 1000
  750 IF(INSTR(25).EQ.1)WRITE(IOUT,751)
      IF(INSTR(25).EQ.2)WRITE(IOUT,752)
  751 FORMAT('+',20X,'ASSUME PLENUM IS ISENTROPIC')
  752 FORMAT('+',20X,'SET TP AND TPT = MAX(ISEN TP,TCTO)')
      GO TO 1000
  760 WRITE(IOUT,761)INSTR(26)
  761 FORMAT('+',20X,'REVERT TO EXACT SUPERSONIC SOLUTION ',I7,' TIME IN
     1CREMENTS AFTER CHOKE')
      GO TO 1000
 1000 CONTINUE
      WRITE(IOUT,1110)(J,J=1,26),JV
 1110 FORMAT('1',26('   J',I2)/' ',132('-')/' ',26I5)
      I1=0
      DO 1020 I=1,3
      IF(NVT(I).GT.I1)I1=NVT(I)
 1020 CONTINUE
      WRITE(IOUT,1040)((J,I=1,2),J=1,3),(I,(TV(J,I),AREA(J,I),J=1,3),
     1 I=1,I1)
 1040 FORMAT('0FLOW AREAS VERSUS TIME'/'0  I',3(5X,'TV(',I1,',',I1,')',
     1 8X,'AREA(',I1,',',I1,')',3X)/' ',99('=')/,50(/' ',I3,6E16.8))
      IF(NCTL.EQ.8)RETURN 1
      RETURN
      END
```

```
                    SOLVER                DATE = 75157            11/58/40

      SUBROUTINE SOLVER(*)
      IMPLICIT REAL*8 (A-H,M,O-Z,$)
      COMMON AREA(3,50),AREATS(3),AREAM(3),TV(3,50),A(10),E(7),B(30),
     1 TVE(3),TDELAY(3),RW(7)
      COMMON PC,RC,TC,AC,MDCTC,FAE,EAPE,EAF,MDTSTR,INFIN,TMSOGS,GPO2GS,
     1 SGOR
      COMMON G,GM1,GP1,OOG,GP1O2,GM1O2,GP1OG,GM1OG,GOGP1,GOGM1,
     1 OOGM1,OOGP1,GPOGM1,SGM1O2,TOGM1,TOG,MGPGM2,TOGP1,GPGM12,
     2 MGPOGM,MGOGM1,R,GR,OOR,PI,PERR,AWOKW,OOA1,OOKF,KF,KW
      COMMON TSL,TSH,TSW,TSP,TSA,TSWA,TSV,CTD,CTA,PV,PVOTSV,TAUW
      COMMON T,T1,DT,TSTR,DTO2,TSTOP,OODT,DTOPV
      COMMON A1,A2,A3,A4,A5,A6,A7,A8,A9,A10,A11,A12,A13,A14,A15,A16,A17
      COMMON     PN ,    PP ,   PPT ,    PD ,    PT , PCTO ,   PEO ,  MDE ,
     -  MDD ,   MDF , MDPT ,  MDCT ,  MDPE ,MDTSO ,MDCTO ,   TEO ,   TP ,
     -  TPT , TCTO ,    RP ,   RPT ,   REO , RCTO , ACTO,   MCT ,   AE ,
     -  APE ,    AF ,   MN ,    MD
      COMMON     PN1,    PP1,   PPT1,    PD1,    PT1, PCTO1,   PEO1,  MDE1,
     -  MDD1,   MDF1, MDPT1,  MDCT1,  MDPE1,MDTSO1,MDCTO1,   TEO1,   TP1,
     -  TPT1, TCTO1,    RP1,   RPT1,   REO1, RCTO1, ACTO1,   MCT1,   AE1,
     -  APE1,    AF1,   MN1,    MD1
      COMMON     PN2,    PP2,   PPT2,    PD2,    PT2, PCTO2,   PEO2,  MDE2,
     -  MDD2,   MDF2, MDPT2,  MDCT2,  MDPE2,MDTSO2,MDCTO2,   TEO2,   TP2,
     -  TPT2, TCTO2,    RP2,   RPT2,   REO2, RCTO2, ACTO2,   MCT2,   AE2,
     -  APE2,    AF2,   MN2,    MD2
      COMMON     PN3,    PP3,   PPT3,    PD3,    PT3, PCTO3,   PEO3,  MDE3,
     -  MDD3,   MDF3, MDPT3,  MDCT3,  MDPE3,MDTSO3,MDCTO3,   TEO3,   TP3,
     -  TPT3, TCTO3,    RP3,   RPT3,   REO3, RCTO3, ACTO3,   MCT3,   AE3,
     -  APE3,    AF3,   MN3,    MD3
      COMMON PSOP0,TSOT0,RSOR0,MSOM0
      COMMON $Y,$Y1,$Y2,$X1,$X2,$DX,$E1,$E2,$EMAX,$EP,$DE
      COMMON INSTR(26),IDEBUG,IIN,IOUT,NP,IP,ITER,NVT(3),I,NT,IPAGE,
     1NPAGE,$N,IT(3),J,IM1,ITIME,ND,NN,NCT,IFLG,IFLG1,IFLG2,IFLG3,IFLG4,
     2IFLG5,IFLG6,IFLG7,IFLG8,IFLG9,I1,I2,I3,I4,I5
      COMMON J1,J2,J3,J4,J5,J6,J7,J8,J9,J10,J11,J12,J13,J14,J15,J16,J17,
     1 J18,J19,J20,J21,J22,J23,J24,J25,J26
      COMMON NCTL
      INTEGER $V
      REAL*8 INFIN,KF,KW
C ELLIPTIC ENERGY EQUATION GIVING PRESSURE FROM MASS FLUX
      GUESS1(D1)=PSOP0+IFLG2*A6*DSQRT(1.-(A5*D1)**2)
C ELLIPTIC ENERGY EQUATION GIVING MACH NUMBER FROM MASS FLUX
      GUESS2(D1)=DSQRT((GUESS1(D1)**A8     -1.)*TOGM1)
C ELLIPTIC ENERGY/CONTINUITY EQUATION GIVING MACH NUMBER FROM AREA RATIO
      GUESS3(D1)=GUESS2(1./D1)
C APPROXIMATE UNSTEADY WAVE EQUATION GIVING MACH NUMBER FROM MASS FLUX
      GUESS4(D1)=OOGP1*(1.-DSQRT(1.-A9*D1))
      $DX=.001
      GO TO (10,20,30,40),IFLG
   10 $X1=GUESS1($Y)
      GO TO 50
   20 IF($Y.GE.MSOM0)GO TO 25
      $X1=GUESS2($Y)
      GO TO 50
   25 $X1=1.D0
      $V=0
      RETURN
```

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                         SOLVER              DATE = 75157          11/58/40
   30 $X1=GUESS3($Y*45)
      GO TO 50
   40 IF(INSTR(8).EQ.1)GO TO 45
      $X1=GUESS4($Y)
      GO TO 50
   45 $X1=0.
      DO 46 I=1,7
   46 $X1=$X1+RW(I)*$Y**I
   50 IF(INSTR(9).EQ.2)RETURN
      WRITE(IDEBUG,100)$Y,$DX,$EMAX
  100 FORMAT(' SOLVER'/'0$Y=',F16.8,'   $DX=',E16.8,'   $EMAX=',F16.8/
     1'0   N',5X,'X(N)',10X,'Y(N)',9X,'X(N-1)',8X,'Y(N-1)',9X,'E(N)',
     2 9X,'E(N-1)',10X,'DE',12X,'EP',12X,'DX'/' ',132('-'))
      $N=0
  120 GO TO(1100,1200,1300,1400),IFLG
  130 $E1=($Y-$Y1)/$Y
      IF($N.NE.0)GO TO 180
  140 $E2=$E1
      $Y2=$Y1
      $X2=$X1
      $X1=$X2+$DX
  160 $N=$N+1
      GO TO 120
  180 $EP=$E1*$E2
      $DE=DABS($E1)-DABS($E2)
      WRITE(IDEBUG,200)$N,$X1,$Y1,$X2,$Y2,$E1,$E2,$DE,$EP,$DX
  200 FORMAT(' ',I3,9E14.6)
      IF(DABS($E1).LE.$EMAX)RETURN
      IF($EP.GT.0.)GO TO 220
      $DX=.5*$DX
  210 $X1=$X2+$DX
      GO TO 160
  220 IF($DE.LT.0.)GO TO 140
      $DX=-$DX
      GO TO 210
C ENERGY EQUATION GIVING MASS FLUX FROM PRESSURE
 1100 $Y1=$X1**TOG-$X1**GP1OG
      $Y1=DSQRT($Y1)
      GO TO 130
C ENERGY EQUATION GIVING MASS FLUX FROM MACH NUMBER
 1200 $Y1=$X1*(1.+GM1O2*$X1**2)**MGPGM2
      GO TO 130
C AREA RATIO  VERSUS MACH NUMBER
 1300 $Y1=(TOGP1*(1.+GM1O2*$X1**2))**GPGM12/$X1
      GO TO 130
C UNSTEADY MASS FLUX FROM MACH NUMBER
 1400 $Y1=$X1*(1.+GM1O2*$X1)**MGPOGM
      GO TO 130
      END
```

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                    PRINT                DATE = 75157           11/58/40

      SUBROUTINE PRINT(*)
      IMPLICIT REAL*8 (A-H,M,O-Z,$)
      COMMON AREA(3,50),AREATS(3),AREAM(3),TV(3,50),A(10),E(7),B(30),
     1 TVE(3),TDELAY(3),RW(7)
      COMMON PC,RC,TC,AC,MDCTC,EAF,EAPF,EAF,MDTSTR,INFIN,TMGOGS,GP02GS,
     1 SGOR
      COMMON G,GM1,GP1,OOG,GP102,GM102,GP10G,GM10G,GOGP1,GOGM1,
     1 OOGM1,OOGP1,GPOGM1,SGM102,TOGM1,TOG,MGPGM2,TOGP1,GPGM12,
     2 MGPOGM,MSOGM1,R,GR,OOR,PI,PERR,AWOKW,OOA1,OOKF,KF,KW
      COMMON TSL,TSH,TSW,TSP,TSA,TSWA,TSV,CTD,CTA,PV,PVOTSV,TAUW
      COMMON T,T1,DT,TSTR,DT02,TSTOP,OODT,DTOPV
      COMMON A1,A2,A3,A4,A5,A6,A7,A8,A9,A10,A11,A12,A13,A14,A15,A16,A17
      COMMON     PN ,    PP ,   PPT ,    PD ,    PT , PCTO ,   PEO ,  MDE ,
     -  MDD ,   MDF , MDPT , MDCT , MDPE ,MDTSO ,MDCTO ,   TEO ,    TP ,
     -  TPT , TCTO ,    RP ,   RPT ,   REO , RCTO , ACTO,   MCT ,    AE ,
     -  APE ,    AF ,    MN ,    MD
      COMMON     PN1,    PP1,   PPT1,    PD1,    PT1, PCTO1,   PEO1,  MDE1,
     -  MDD1,   MDF1, MDPT1, MDCT1, MDPE1,MDTSO1,MDCTO1,   TEO1,    TP1,
     -  TPT1, TCTO1,    RP1,   RPT1,   REO1, RCTO1, ACTO1,   MCT1,    AE1,
     -  APE1,    AF1,    MN1,    MD1
      COMMON     PN2,    PP2,   PPT2,    PD2,    PT2, PCTO2,   PEO2,  MDE2,
     -  MDD2,   MDF2, MDPT2, MDCT2, MDPE2,MDTSO2,MDCTO2,   TEO2,    TP2,
     -  TPT2, TCTO2,    RP2,   RPT2,   REO2, RCTO2, ACTO2,   MCT2,    AE2,
     -  APE2,    AF2,    MN2,    MD2
      COMMON     PN3,    PP3,   PPT3,    PD3,    PT3, PCTO3,   PEO3,  MDE3,
     -  MDD3,   MDF3, MDPT3, MDCT3, MDPE3,MDTSO3,MDCTO3,   TEO3,    TP3,
     -  TPT3, TCTO3,    RP3,   RPT3,   REO3, RCTO3, ACTO3,   MCT3,    AE3,
     -  APE3,    AF3,    MN3,    MD3
      COMMON PSOPO,TSOTO,RSORO,MSOMO
      COMMON $Y,$Y1,$Y2,$X1,$X2,$DX,$E1,$E2,$EMAX,$EP,$DE
      COMMON INSTR(26),IDEBUG,IIN,IOUT,NP,IP,ITER,NVT(3),I,NT,IPAGE,
     1NPAGE,$N,IT(3),J,IM1,ITIME,ND,NN,NCT,IFLG,IFLG1,IFLG2,IFLG3,IFLG4,
     2IFLG5,IFLG6,IFLG7,IFLG8,IFLG9,I1,I2,I3,I4,I5
      COMMON J1,J2,J3,J4,J5,J6,J7,J8,J9,J10,J11,J12,J13,J14,J15,J16,J17,
     1 J18,J19,J20,J21,J22,J23,J24,J25,J26
      COMMON NCTL
      DIMENSION V(24,4)
      EQUIVALENCE (PN,V(1,1))
      INTEGER $N
      REAL*8 INFIN,KF,KW
      IP=IP+1
      IF(IP.NE.NP)RETURN
      IP=0
      I1=J16-1
      IF(INSTR(13).NE.0)GO TO 300
      IF(IPAGE.EQ.0)GO TO 100
      IF(IPAGE.LT.NPAGE)GO TO 140
  100 WRITE(IOUT,120)(I,I=1,7)
  120 FORMAT('1',8X,'T',13X,'TSTR',13X,'T1',14X,'PT',14X,'PP',14X,
     1'PD',14X,'PN',14X,'PPT',8X,'ND'/' ',6X,'PCTO',13X,'PEO',13X,'MCT'
     -,13X,'MD'
     2,14X,'MN',13X,'MDCT',12X,'MDPT',13X,'MDD',8X,'NM'/' ',7X,'MDF',13X,
     3,'MDE',12X,'MDPE',12X,'MDTSO',11X,'MDCTO',12X,
     4'TP',14X,'TPT',13X,'TEO',7X,'NCT'/' ',6X,'TCTO',
     5 13X,'RP',14X,'RPT',13X,'REO',12X,'RCTO',13X,'AE',14X,'APE',
     613X,'AF',7X,'ITER'/' ',7(6X,'E(',I1,')',6X),5X,'  DT  ',6X,'J16'
```

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                     PRINT                        DATE = 75157          11/58/40
      -/' ',132('-'))
       IPAGE=5
  140 WRITE(IOUT,160)T,TSTR,T1,PT,PP,PD,PN,PPT,ND,PCTO,PEO,MCT,MD,MN,
     1MDCT,MDPT,MDD,NN,MDF,MDF,MDPE,MDTSO,MDCTO,TP,TPT,TEO,NCT,TCTO,RP,
     2RPT,REO,RCTO,AREATS,ITER,E,DT,I1
  160 FORMAT(5(/' ',8E16.6,I4))
      IPAGE=IPAGE+6
      RETURN
  300 IF(IPAGE.EQ.0)GO TO 320
      IF(IPAGE.LT.NPAGE)GO TO 360
  320 WRITE(IOUT,340)
  340 FORMAT('1',6X,'T',11X,'PPT',10X,'TSTR',10X,'PT',11X,'PP',11X,
     1'PD',11X,'PN',10X,'PEO',10X,'PCTO'/' ',132('-'))
      IPAGE=2
  360 WRITE(IOUT,380)T,PPT,TSTR,PT,PP,PD,PN,PEO,PCTO
  380 FORMAT(' ',9E13.5)
      IPAGE=IPAGE+1
      IF(NCTL.EQ.10)RETURN 1
      RETURN
      END
```

BINOM DATE = 75157 11/58/40

```
      SUBROUTINE BINOM(*)
      IMPLICIT REAL*8 (A-H,M,O-Z,$)
      COMMON AREA(3,50),AREATS(3),AREAM(3),TV(3,50),A(10),E(7),B(30),
     1 TVF(3),TDELAY(3),RW(7)
      COMMON PC,RC,TC,AC,MDCTC,EAE,EAPE,EAF,MDTSTR,INFIN,TMGOGS,GPO2GS,
     1 SGOR
      COMMON G,GM1,GP1,OOG,GP102,GM102,GP10G,GM10G,GOGP1,GOGM1,
     1 OOGM1,OOGP1,GPOGM1,SGM102,TOGM1,TOG,MGPGM2,TOGP1,GPGM12,
     2 MGPOGM,MSOGM1,R,GR,OOR,PI,PERR,AWOKW,OOA1,OOKF,KF,KW
      COMMON TSL,TSH,TSW,TSP,TSA,TSWA,TSV,CTD,CTA,PV,PVOTSV,TAUW
      COMMON T,T1,DT,TSTR,DTO2,TSTOP,OODT,DTOPV
      COMMON A1,A2,A3,A4,A5,A6,A7,A8,A9,A10,A11,A12,A13,A14,A15,A16,A17
      COMMON    PN ,    PP ,   PPT ,    PD ,    PT ,  PCTO ,   PEO ,  MDE ,
     -  MDD ,  MDF ,  MDPT ,  MDCT ,  MDPE ,MDTSO ,MDCTO ,   TEO ,   TP ,
     -  TPT ,  TCTO ,    RP ,   RPT ,   REO ,  RCTO ,  ACTO,    MCT ,   AE ,
     -  APE ,    AF ,    MN ,    MD
      COMMON    PN1,    PP1,   PPT1,    PD1,    PT1,  PCTO1,   PEO1,  MDE1,
     -  MDD1,  MDF1,  MDPT1,  MDCT1,  MDPE1,MDTSO1,MDCTO1,   TEO1,   TP1,
     -  TPT1,  TCTO1,    RP1,   RPT1,   REO1,  RCTO1,  ACTO1,   MCT1,   AE1,
     -  APE1,    AF1,    MN1,    MD1
      COMMON    PN2,    PP2,   PPT2,    PD2,    PT2,  PCTO2,   PEO2,  MDE2,
     -  MDD2,  MDF2,  MDPT2,  MDCT2,  MDPE2,MDTSO2,MDCTO2,   TEO2,   TP2,
     -  TPT2,  TCTO2,    RP2,   RPT2,   REO2,  RCTO2,  ACTO2,   MCT2,   AE2,
     -  APE2,    AF2,    MN2,    MD2
      COMMON    PN3,    PP3,   PPT3,    PD3,    PT3,  PCTO3,   PEO3,  MDE3,
     -  MDD3,  MDF3,  MDPT3,  MDCT3,  MDPE3,MDTSO3,MDCTO3,   TEO3,   TP3,
     -  TPT3,  TCTO3,    RP3,   RPT3,   REO3,  RCTO3,  ACTO3,   MCT3,   AE3,
     -  APE3,    AF3,    MN3,    MD3
      COMMON PSOPO,TSOTO,RSORO,MSOMO
      COMMON $Y,$Y1,$Y2,$X1,$X2,$DX,$E1,$E2,$EMAX,$EP,$DE
      COMMON INSTR(26),IDEBUG,IIN,IOUT,NP,IP,ITER,NVT(3),I,NT,IPAGE,
     1NPAGE,$N,IT(3),J,IM1,ITIME,ND,NN,NCT,IFLG,IFLG1,IFLG2,IFLG3,IFLG4,
     2IFLG5,IFLG6,IFLG7,IFLG8,IFLG9,I1,I2,I3,I4,I5
      COMMON J1,J2,J3,J4,J5,J6,J7,J8,J9,J10,J11,J12,J13,J14,J15,J16,J17,
     1 J18,J19,J20,J21,J22,J23,J24,J25,J26
      COMMON NCTL
      INTEGER $N
      REAL*8 INFIN,KF,KW
      I=0
      A(1)=1.
   10 I=I+1
      IF(I.GT.6)GO TO 20
      IM1=I-1
      A(I+1)=A(I)*(A(8)-IM1)/I
      WRITE(IDEBUG,15)I,I1,IM1
   15 FORMAT(' I=',I7,'  I1=',I7,'  IM1=',I7)
      GO TO 10
   20 WRITE(IDEBUG,30)A
   30 FORMAT('0BINOM'/' ',10E13.5)
      DO 40 I=1,7
   40 A(I)=A(I)*A(9)**(I-1)
      WRITE(IDEBUG,30)A
      RETURN
      END
```

```
                        REVERT                 DATE = 75157           11/58/40
      SUBROUTINE REVERT(*)
      IMPLICIT REAL*8 (A-H,M,O-Z,$)
      COMMON AREA(3,50),AREATS(3),AREAM(3),TV(3,50),A(10),E(7),B(30),
     1 TVF(3),TDELAY(3),RW(7)
      COMMON PC,RC,TC,AC,MDCTC,EAE,EAPE,EAF,MDTSTR,INFIN,TMGOGS,GPO2GS,
     1 SGOR
      COMMON G,GM1,GP1,OOG,GP1O2,GM1O2,GP1OG,GM1OG,GOGP1,GOGM1,
     1 OOGM1,OOGP1,GPOGM1,SGM1O2,TOGM1,TOG,MGPGM2,TOGP1,GPGM12,
     2 MGPOGM,MGOGM1,R,GR,OOR,PI,PERR,AWOKW,OOA1,OOKF,KF,KW
      COMMON TSL,TSH,TSW,TSP,TSA,TSWA,TSV,CTD,CTA,PV,PVOTSV,TAUW
      COMMON T,T1,DT,TSTR,DTO2,TSTOP,OODT,DTOPV
      COMMON A1,A2,A3,A4,A5,A6,A7,A8,A9,A10,A11,A12,A13,A14,A15,A16,A17
      COMMON     PN ,    PP ,   PPT ,    PD ,    PT , PCT0 ,  PE0 ,  MDE ,
     -  MDD ,  MDF , MDPT , MDCT , MDPE ,MDTS0 ,MDCT0 ,  TE0 ,   TP ,
     -  TPT , TCT0 ,   RP ,   RPT ,  RE0 , RCT0 , ACT0,  MCT ,   AE ,
     -  APE ,   AF ,   MN ,   MD
      COMMON     PN1,    PP1,   PPT1,    PD1,    PT1, PCT01,  PE01,  MDE1,
     -  MDD1,  MDF1, MDPT1, MDCT1, MDPE1,MDTS01,MDCT01,  TE01,   TP1,
     -  TPT1, TCT01,   RP1,   RPT1,  RE01, RCT01, ACT01,  MCT1,   AE1,
     -  APE1,   AF1,   MN1,   MD1
      COMMON     PN2,    PP2,   PPT2,    PD2,    PT2, PCT02,  PE02,  MDE2,
     -  MDD2,  MDF2, MDPT2, MDCT2, MDPE2,MDTS02,MDCT02,  TE02,   TP2,
     -  TPT2, TCT02,   RP2,   RPT2,  RE02, RCT02, ACT02,  MCT2,   AE2,
     -  APE2,   AF2,   MN2,   MD2
      COMMON     PN3,    PP3,   PPT3,    PD3,    PT3, PCT03,  PE03,  MDE3,
     -  MDD3,  MDF3, MDPT3, MDCT3, MDPE3,MDTS03,MDCT03,  TE03,   TP3,
     -  TPT3, TCT03,   RP3,   RPT3,  RE03, RCT03, ACT03,  MCT3,   AE3,
     -  APE3,   AF3,   MN3,   MD3
      COMMON PSOP0,TSOT0,RSOR0,MSOM0
      COMMON $Y,$Y1,$Y2,$X1,$X2,$DX,$E1,$E2,$EMAX,$EP,$DE
      COMMON INSTR(26),IDEBUG,IIN,IOUT,NP,IP,ITER,NVT(3),I,NT,IPAGE,
     1NPAGE,$N,IT(3),J,IM1,ITIME,ND,NN,NCT,IFLG,IFLG1,IFLG2,IFLG3,IFLG4,
     2IFLG5,IFLG6,IFLG7,IFLG8,IFLG9,I1,I2,I3,I4,I5
      COMMON J1,J2,J3,J4,J5,J6,J7,J8,J9,J10,J11,J12,J13,J14,J15,J16,J17,
     1 J18,J19,J20,J21,J22,J23,J24,J25,J26
      COMMON NCTL
      INTEGER $V
      REAL*8 INFIN,KF,KW
      B(1)=1./A(1)
      B(2)=-A(2)/A(1)**3
      B(3)=(2.*A(2)**2-A(1)*A(3))/A(1)**5
      B(4)=(5.*A(1)*A(2)*A(3)-A(1)**2*A(4)-5.*A(2)**3)/A(1)**7
      B(5)=(6.*A(1)**2*A(2)*A(4)+3.*A(1)**2*A(3)**2+14.*A(2)**4-
     A A(1)**3*A(5)-21.*A(1)*A(2)**2*A(3))/A(1)**9
      B(6)=(7.*A(1)**3*A(2)*A(5)+7.*A(1)**3*A(3)*A(4)+84.*A(1)*A(2)**3
     B *A(3)-A(1)**4*A(6)-28.*A(1)**2*A(2)**2*A(4)-28.*A(1)**2*A(2)
     C *A(3)**2-42.*A(2)**5)/A(1)**11
      B(7)=(8.*A(1)**4*A(2)*A(6)+8.*A(1)**4*A(3)*A(5)+4.*A(1)**4*A(4)**2
     A +120.*A(1)**2*A(2)**3*A(4)+180.*A(1)**2*A(2)**2*A(3)**2+
     B 132.*A(2)**6-A(1)**5*A(7)-36.*A(1)**3*A(2)**2*A(5)-
     C 72.*A(1)**3*A(2)*A(3)*A(4)-12.*A(1)**3*A(3)**3-330.*A(1)*A(2)
     D **4*A(3))/A(1)**13
      DO 10 I=1,7
   10 A(I)=B(I)
      WRITE(IDEBUG,20)A
   20 FORMAT('0REVERT'/' ',10E13.5)
      RETURN
      END
```

```
                         SMPERT              DATE = 75157           11/58/40

      SUBROUTINE SMPERT(*)
      IMPLICIT REAL*8 (A-H,M,O-Z,$)
      COMMON AREA(3,50),AREATS(3),AREAM(3),TV(3,50),A(10),F(7),B(30),
     1 TVF(3),TDELAY(3),RW(7)
      COMMON PC,RC,TC,AC,MDCTC,FAF,FAPE,EAF,MDTSTR,INFIN,TMGOGS,GPO2GS,
     1 SGOR
      COMMON G,GM1,GP1,OOG,GP1O2,GM1O2,GP1OG,GM1OG,GOGP1,GOGM1,
     1 OOGM1,OOGP1,GPOGM1,SGM1O2,TOGM1,TOG,MGPGM2,TOGP1,GPGM12,
     2 MGPOGM,MGOGM1,P,GR,OOR,PT,PERR,AWOKW,OOA1,OOKF,KF,KW
      COMMON TSL,TSH,TSW,TSP,TSA,TSWA,TSV,CTD,CTA,PV,PVOTSV,TAUW
      COMMON T,T1,DT,TSTR,DTO2,TSTOP,OODT,DTOPV
      COMMON A1,A2,A3,A4,A5,A6,A7,A8,A9,A10,A11,A12,A13,A14,A15,A16,A17
      COMMON    PN ,    PP ,   PPT ,    PD ,    PT , PCTO ,  PEO ,  MDE ,
     -  MDD ,  MDE , MDPT , MDCT , MDPE ,MDTSO ,MDCTO ,  TEO ,   TP ,
     -  TPT , TCTO ,   RP ,  RPT ,  REO , RCTO , ACTO,   MCT ,   AE ,
     -  APE ,   AF ,   MN ,   MD
      COMMON    PN1,    PP1,   PPT1,    PD1,    PT1, PCTO1,  PEO1,  MDE1,
     -  MDD1,  MDE1, MDPT1, MDCT1, MDPE1,MDTSO1,MDCTO1,  TEO1,   TP1,
     -  TPT1, TCTO1,   RP1,  RPT1,  REO1, RCTO1, ACTO1,  MCT1,   AE1,
     -  APE1,   AF1,   MN1,   MD1
      COMMON    PN2,    PP2,   PPT2,    PD2,    PT2, PCTO2,  PEO2,  MDE2,
     -  MDD2,  MDE2, MDPT2, MDCT2, MDPE2,MDTSO2,MDCTO2,  TEO2,   TP2,
     -  TPT2, TCTO2,   RP2,  RPT2,  REO2, RCTO2, ACTO2,  MCT2,   AE2,
     -  APE2,   AF2,   MN2,   MD2
      COMMON    PN3,    PP3,   PPT3,    PD3,    PT3, PCTO3,  PEO3,  MDE3,
     -  MDD3,  MDE3, MDPT3, MDCT3, MDPE3,MDTSO3,MDCTO3,  TEO3,   TP3,
     -  TPT3, TCTO3,   RP3,  RPT3,  REO3, RCTO3, ACTO3,  MCT3,   AE3,
     -  APE3,   AF3,   MN3,   MD3
      COMMON PSOPO,TSOTO,RSORO,MSOMO
      COMMON $Y,$Y1,$Y2,$X1,$X2,$DX,$E1,$E2,$EMAX,$EP,$DE
      COMMON INSTR(26),IDEBUG,IIN,IOUT,NP,IP,ITER,NVT(3),I,NT,IPAGE,
     1NPAGE,$N,IT(3),J,IM1,ITIME,ND,NN,NCT,IFLG,IFLG1,IFLG2,IFLG3,IFLG4,
     2IFLG5,IFLG6,IFLG7,IFLG8,IFLG9,I1,I2,I3,I4,I5
      COMMON J1,J2,J3,J4,J5,J6,J7,J8,J9,J10,J11,J12,J13,J14,J15,J16,J17,
     1 J18,J19,J20,J21,J22,J23,J24,J25,J26
      COMMON NCTL
      DIMENSION IEXTP(19),EPS(19),Q(19),V(30,4)
      DIMENSION JJ(4)
      EQUIVALENCE (V(1),PN)
      COMPLEX*16 X(4),Y(4)
      INTEGER $N
      REAL*8 NU1,NU2,NU1D,NU2D,NU1N,NU2N,INFIN,KF,KW
C                   1  2  3  4  5  6  7  8  9 10 11 12 13 17 15 16 17 18 19
      DATA IEXTP/ 8,13,10,11,21, 9,12,25, 7,16, 5, 4, 1,14, 0, 0, 2,20,
     # 17/
      MACH(D1) = DSQRT(TOGM1 *((D1 / PCTO) **(-GM1OG)- 1.D0))
      WRITE(IDEBUG,1)
    1 FORMAT('1SMPERT'/' ',6('='))
C-----------------------------------
C COMPUTE CONSTANTS FOR EXPANSIONS
C-----------------------------------
      IF(IFLG2.NE.1)GO TO 90
C EQUATION 1
      CA1 =-1.D0
      A(1) = A1 / DSQRT( TE01 ) * A2
      CB1 = AE1 * A(1)
```

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      CC1 = PE01 * A(1)
      CD1 = 0.5D0 * PE01 * A(1) * AE1 / TE01
C EQUATION 2
   90 CA2 = -1.D0
      A(2) = A1 / DSQRT( TP1 ) * A2
      CB2 = -APE1 * A(2)
      CC2 = -PP1 * A(2)
      CD2 = 0.5D0 * PP1 * A(2) * APE1 / TP1
C EQUATION 3
      CA3 = -1.D0
      CB3 = -(PP1 - PD1 * A16) * DOKF * A2
      CC3 = -AF1 * DOKF * A2
      CD3 = -CC3 * A16
C EQUATION 4
      CA4 = -1.D0
      CB4 = -AWDKW * A2
      CC4 = -CB4 * A15
C EQUATION 5
      CA5 = -1.D0
      CB5 = DTOPV
      CC5 = CB5
      CD5 = CB5
      CE5 = CB5 * ( MDPE1 + MDE1 + MDPT1)
C EQUATION 6
      CA6 = 1.D0
      CB6 = 1.D0
      CC6 = -1.D0
      IF(IFLG2.NE.1)GO TO 91
C EQUATION 7
      CA7 = 1.D0
      CB7 =-1.D0
      CC7 = -1.D0
C EQUATION 8
      CA8 = -1.D0
      A(3) = 1.D0 -MCT1
      A(4) = 1.D0 + GM1O2 * MCT1
      CB8 = MDCTC * A(3) / A(4) ** (GOGM1 * 2.D0)
C EQUATION 9
      CA9 = -1.D0
      A(5) = 1.D0 + GM1O2 * MCT1 ** 2
      CB9 = -G * A(3) * PE01 / A(4) / A(5)
C EQUATION 10
      CA10 = -1.D0
      CB10 = - GM1 * A(3) * TE01 / A(4) / A(5)
C EQUATION 11
   91 CA11 = -1.D0
      IF(IFLG2)99,9999,100
  100 CB11 =  0.5D0
      CC11 = CB11
      GO TO 101
   99 CB11=1.D0-A17
      CC11=A17
C EQUATION 12
  101 A(9) = - GM1 / MDTS01 ** 2
      A(10) = GM1 / MDTS01 ** 3
      CA12 =A(9) * MDD1
```

```
      CB12 = A(10) * MDD1 **2
      IF(IFLG2.EQ.1)A(6)=PD1/PE01
      IF(IFLG2.NE.1)A(6)=PD1/PCT01
      A(7) = A(5) ** TOG
      A(8) = A(6) ** GP1OG
      NU1D = TOG * A(7) - GP1OG * A(8)
      NU2D = TMGOGS * A(7) - GP02GS * A(8)
      IF(IFLG2)94,9999,93
   93 CC12 = NU1D / PD1 / PE01
      CD12 = NU2D / ( PD1 * PE01 ) ** 2
      GO TO 95
   94 CC12= NU1D/PD1/PCT01
      CD12=NU2D/(PD1*PCT01)**2
   95 IF(IFLG2.NE.1)GO TO 92
C EQUATION 13
      CA13 = A(9) * MDCT1
      CB13 = A(10) * MDCT1 ** 2
      B(1) = PN1 / PE01
      B(2) = B(1) ** TOG
      B(3) = B(1) ** GP1OG
      NU1N=TOG*B(2)-GP1OG*B(3)
      NU2N=TMGOGS*B(2)-GP02GS*B(3)
      CC13=NU1N/PN1/PE01
      CD13=NU2N/(PN1*PE01)**2
C EQUATION 14
      CA14 = -1.D0
      CB14 =  TSA * SGOR / DSQRT( TE01 ) * A2
      CC14 = -0.5D0 * PE01 * CB14 / TE01
C EQUATION 17
   92 GO TO(96,98),IFLG9
   98 CA17=A2
      CB17=-R*TCT01
      GO TO 97
   96 CA17 = RP1
      CB17 = - G * PP1
C EQUATION 18
   97 CA18= -1.D0
      CB18 = 0.5D0
      CC18 = RPT1 - RP1
C EQUATION 19
      CA19 = R * RP1
      CB19 = R * TP1
      CC19 = -A2
      IF(IFLG2)2,9999,3
C***********************************************************************
C SUPERSONIC BRANCH
C***********************************************************************
    2 IF(IDEBUG.EQ.03)GO TO 70
      CA1 = INFIN
      CB1 = INFIN
      CC1 = INFIN
      CD1 = INFIN
      CA7 = INFIN
      CB7 = INFIN
      CC7 = INFIN
      CA8 = INFIN
```

```
      CB8 = INFIN
      CA9 = INFIN
      CB9 = INFIN
      CC6 = INFIN
      CA10 = INFIN
      CB10 = INFIN
      CB11 = INFIN
      CB12 = INFIN
      CA13 = INFIN
      CB13 = INFIN
      CC13 = INFIN
      CD13 = INFIN
      CA14 = INFIN
      CB14 = INFIN
      CC14 = INFIN
C EQUATION 11
   70 SALP11 = -CC11 / CA11
C EQUATION 18
      SALP18 = -CB18 / CA18
      SBET18 = -CC18 / CA18
C EQUATION 19
      A(1) = -1.D0 / CA19
      SALP19 = CB19 * SALP18 * A(1)
      SBET19 = CC19 * A(1)
      SGAM19 = CB19 * SBET18 * A(1)
C EQUATION 2
      A(2) = -1.D0 / CA2
      SALP2 = (CB2 + CD2 * SBET19) * A(2)
      SBET2 = CD2 * SALP19 * A(2)
      SGAM2 = (CC2 * EAPE + CD2 * SGAM19) * A(2)
C EQUATION 3
      A(3) = -1.D0 / CA3
      SALP3 = CC3 * A(3)
      SBET3 = CD3 * A(3)
      SGAM3 = CB3 * EAF * A(3)
C EQUATION 17
      A(4) = -CB17 / CA17
      SALP17 = SALP18 * A(4)
      SBET17 = SBET18 * A(4)
C EQUATION 4
      SALP4 = CC4 * SALP11
C EQUATION 5
      SALP5 = CA5 + CB5 * SBET2
      SBET5 = CB5 * SALP2 + CC5 * SALP3
      SGAM5 = CC5 * SBET3
      SEPS5 = CB5 * SGAM2 + CC5 * SGAM3 + CE5
C EQUATION 4 CONTINUED
      SBET4 = CB4 * SALP17
      SGAM4 = CB4 * SBET17
C EQUATION 5 CONTINUED
      SIOT5 = SALP5 + SALP17 * SBET5
      A(5) = -1.D0 / SIOT5
      SZET5 = SGAM5 * A(5)
      SETA5 = CD5 * A(5)
      SKAP5 = (SBET5 * SBET17 + SEPS5) * A(5)
C EQUATION 4 CONTINUED
```

```
      SETA4 = CA4 + SBET4 * SETA5
      SEPS4 = -(SBET4 * SZET5 + SALP4) / SETA4
      SZET4 = -(SBET4 * SKAP5 + SGAM4) / SETA4
C EQUATION 6
      A(6) = -CB6 / CA6
      SALP6 = SEPS4 * A(6)
      SBET6 = SZET4 * A(6)
C EQUATION 12
      SGAM12 = CD12 * PCT01 ** 2
      SALP12 = (CC12 * PCT01 + CA12 * SALP6) /  SGAM12
      SBET12 = CA12 * SBET6 / SGAM12
      IF(IDEBUG.EQ.03)GO TO 80
      SEPS3 = INFIN
      SGAM6 = INFIN
      SEPS6 = INFIN
      SZET6 = INFIN
      SETA6 = INFIN
      SIOT6 = INFIN
      SLAM6 = INFIN
      SMU6  = INFIN
      SNU6  = INFIN
      SALP7 = INFIN
      SBET7 = INFIN
      SGAM7 = INFIN
      SEPS7 = INFIN
      SZET7 = INFIN
      SETA7 = INFIN
      SIOT7 = INFIN
      SKAP7 = INFIN
      SALP8 = INFIN
      SALP9 = INFIN
      SBET9 = INFIN
      SGAM9 = INFIN
      SZET9 = INFIN
      SALP10 = INFIN
      SBET11 = INFIN
      SALP13 = INFIN
      SBET13 = INFIN
      SGAM13 = INFIN
      SALP14 = INFIN
      SBET14 = INFIN
      SGAM14 = INFIN
      SEPS14 = INFIN
      SZET14 = INFIN
      SETA14 = INFIN
      SIOT14 = INFIN
      SGAM17 = INFIN
      SEPS17 = INFIN
   80 A(7) = 0.5D0 * SALP12
      Y(2) = DSQRT(A(7) ** 2 - SBET12)
      Y(1) = -A(7) + Y(2)
      Y(2) = -A(7) - Y(2)
C-----------
C SORT ROOTS
C-----------
      I=0
```

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                          SMPERT              DATE = 75157          11/58/40
      DO 200 K = 1,2
      IF(DABS(DIMAG(Y(K))).GT.1.D-12)GO TO  200
      B(15) = DREAL(Y(K))/PD1
      WRITE(IDEBUG,9)K,Y(1),Y(2),A14,B(15)
    9 FORMAT(' K=',I1,' Y=',4E13.5,' A14=',E13.5,' B(15)=',E13.5)
      IF(DABS(B(15)).GT.DABS(A14))GO TO 200
      I = I +1
      EPS(12) = Y(K)
  200 CONTINUE
      IF(I.LE.1)GO TO 205
      IF(DABS(DREAL(Y(2))).LT.DABS(DREAL(Y(1))))Y(1)=Y(2)
      EPS(12)=Y(1)
      I=1
  205 IFLG8=0
      K = 1
      IF(I.EQ.1)GO TO 230
      WRITE(IOUT,210)I
  210 FORMAT('0SMPERT (SUPERSONIC)!',I3,'  SOLUTIONS FOUND')
      IDEBUG = 06
      IFLG8 = 1
      K = 0
  220 K=K+1
      IF(K.GT.2)GO TO  60
      EPS(12) = Y(K)
C-----------------
C COMPUTE INCREMENTS
C-----------------
  230 EPS(6) = SALP6 * EPS(12) + SBET6
      EPS(4) = SEPS4 * EPS(12) + SZET4
      EPS(5) = SZET5 * EPS(12) + SETA5 * EPS(4) + SKAP5
      EPS(17) = SALP17 * EPS(5) + SBET17
      EPS(3) = SALP3 * EPS(17) + SBET3 * EPS(12) + SGAM3
      EPS(2) = SALP2 * EPS(17) + SBET2 * EPS(5) + SGAM2
      EPS(19) = SALP19 * EPS(5) + SBET19 * EPS(17) + SGAM19
      EPS(18) = SALP18 * EPS(5) + SBET18
      EPS(11) = SALP11 * EPS(12)
      EPS(1) = 0.D0
      EPS(7) = 0.D0
      EPS(8) = 0.D0
      EPS(9) = 0.D0
      EPS(10) = 0.D0
      EPS(13) = 0.D0
      EPS(14) = 0.D0
      WRITE(IDEBUG,20)(I,I=1,24),EPS
C----------------------
C COMPUTE PROPERTY VALUES
C----------------------
      DO 240 I = 1,19
      J = IEXTP(I)
      IF(J.EQ.0)GO TO 240
      V(J,1) = V(J,2) + EPS(I)
  240 CONTINUE
      TE0=TCT0
      MDE = MD0 - MDF
      PE0 = MDE * DSQRT(TE0) / (A1 * A2 * AE)
      GO TO(239,238),IFLG9
```

```
  239 PPT = PPT1 * (RPT / RPT1) ** G
      TPT = PPT * A2 * OOR / RPT
      GO TO 237
  238 TPT=TCTO
      PPT=RPT * R * TPT / A2
  237 REO = PEO * A2 * OOR / TEO
      MD = MACH(PD)
      IF((INSTR(23).NE.2).AND.(INSTR(24).EQ.0))GO TO 241
      J16=J16+1
      CALL PRINT
      J16=J16-1
      WRITE(IOUT,242)
  242 FORMAT('+0')
  241 IF((IFLG8.EQ.0).AND.(IDEBUG.EQ.03))RETURN
      WRITE(IDEBUG,32)V
C-----------------------------
C SMALL PERTURBATION RESIDUALS
C-----------------------------
      DO 250 I = 1,19
  250 Q(I) = INFIN
      Q(2) = CA2 * EPS(2) + CB2 * EPS(17) + CC2 * EAPE + CD2 * EPS(19)
      Q(3) = CA3 * EPS(3) + CB3 * EAF + CC3 * EPS(17) + CD3 * EPS(12)
      Q(4) = CA4 * EPS(4) + CB4 * EPS(17) + CC4 * EPS(11)
      Q(5) = CA5 * EPS(5) + CB5 * EPS(2)  + CC5 * EPS(3) + CD5  * EPS(4)
     # + CE5
      Q(6) = CA6 * EPS(6) + CB6 * EPS(4)
      Q(7) = INFIN
      Q(8) = INFIN
      Q(9) = INFIN
      Q(10) = INFIN
      Q(11) = CA11 * EPS(11) + CC11 * EPS(12)
      Q(12) = CA12 * EPS(6) + CC12 * PCT01 * EPS(12) + CD12 * PCT01 ** 2
     # * EPS(12) ** 2
      Q(13) = INFIN
      Q(14) = INFIN
      Q(17) = CA17 * EPS(17) + CB17 * EPS(18)
      Q(18) = CA18 * EPS(18) + CB18 * EPS(5) + CC18
      Q(19) = CA19 * EPS(19) + CB19 * EPS(18) + CC19 * EPS(17)
      WRITE(IDEBUG,13)(I,I=1,20),Q
C---------------
C EXACT RESIDUALS
C---------------
      DO 40 I=1,19
   40 Q(I)=1.D70
      Q(2)=MDPE+A1*PP*APE/DSQRT(TPT*A2
      Q(3)=MDF+AF*OOKF*(PP-PD*A16)*A2
      Q(4)=MDPT+AWOKW*(PP-PT*A15)*A2
      Q(5)=RPT-RPT1-(MDPE+MDF+MDPT)*DTOPV
      Q(6)=MDD+MDPT-MDCT
      IF(IFLG2)254,9999,255
  254 Q(11)=PT-(1.D0-A17)*PN-A17*PD
      GO TO 256
  255 Q(11)=PT-0.5D0*(PN+PD)
  256 B(12)=1.D0/PCTO
      B(13)=TOGM1*MDTS0**2
      Q(12)=MDD**2-B(13)*((PD*B(12))**TOG-(PD*B(12))**GP1OG)
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        GO TO (251,252),IFLG9
    251 Q(17)=PP-PPT1*(RP/RPT1)**G
        GO TO 253
    252 Q(17)=PP-RP*R*TP/A2
    253 Q(18)=RP-0.5D0*(RPT+RPT1)
        Q(19)=TP-PP*DOR/RP*A2
        GO TO 39
C**************************************************************************
C SUBSONIC BRANCH
C**************************************************************************
C-----------------------------
C COMPUTE CONSTANTS FOR SOLUTION
C-----------------------------
C EQUATION 19
      3 SALP19 = -CB19 / CA19
        SBET19 = -CC19 / CA19
C EQUATION 2
        B(4) = -1.D0 / CA2
        SALP2 = ( CB2 + CD2 * SBET19 ) * B(4)
        SBET2 = CD2 * SALP19 * B(4)
        SGAM2 = CC2 * EAPE * B(4)
C EQUATION 5
        SALP5 = CB5 * SALP2
        SBET5 = CB5 * SBET2
        SGAM5 = CB5 * SGAM2 + CE5
C EQUATION 8
        SALP8 = -CA8 / CB8
C EQUATION 18
        SALP18 = -CA18 / CB18
        SBET18 = -CC18 / CB18
C EQUATION 5 CONTINUED
        SKAP5 = CA5 * SALP18 + SBET5
        B(5) = 1.D0 / SKAP5
        SEPS5 = - SALP5 * B(5)
        SZET5 = - CC5 * B(5)
        SETA5 = - CD5 * B(5)
        SIOT5 = - ( CA5 * SBET18 + SGAM5 ) * B(5)
C EQUATION 10
        SALP10 = - CB10 * SALP8 / CA10
C EQUATION 11
        SALP11 = - CB11 / CA11
        SBET11 = - CC11 / CA11
C EQUATION 17
        SEPS17 = CA17 +CB17 * SEPS5
        B(6) =-CB17 / SEPS17
        SALP17 = SZET5 * B(6)
        SBET17 = SETA5 * B(6)
        SGAM17 = SIOT5 * B(6)
C EQUATION 1
        B(7) = -1.D0 / CA1
        SALP1 = CB1 * B(7)
        SBET1 = CD1 * SALP10 * B(7)
        SGAM1 = CC1 * EAE * B(7)
C EQUATION 3
        SEPS3 = CA3 + CC3 * SALP17
        B(8) = -1.D0 / SEPS3
```

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      SALP3 = CC3 * SBET17 * B(8)
      SBET3 = CD3 * B(8)
      SGAM3 = ( CC3 * SGAM17 + CB3 * EAF ) * B(8)
C EQUATION 4
      SEPS4 = CA4 + CB4 * ( SBET17 + SALP17 * SALP3 )
      B(9) = - 1.D0 / SEPS4
      SALP4 = ( CB4 * SALP17 * SBET3          + CC4 * SBET11 ) * B(9)
      SBET4 = CC4 * SALP11 * B(9)
      SGAM4 = CB4 * ( SALP17 * SGAM3 + SGAM17 ) * B(9)
C EQUATION 6
      B(10) = - CB6 / CA6
      SALP6 = SALP4 * B(10)
      SBET6 = SBET4 * B(10)
      SGAM6 = -CC6 / CA6
      SEPS6 = SGAM4 * B(10)
C EQUATION 7
      SZET7 = CA7 * SGAM6 + CC7 * SBET1
      B(11) = - 1.D0 / SZET7
      SALP7 = ( CA7 * SALP6 + CB7 * ( SBET3 + SALP3 * SALP4  )) * B(11)
      SBET7 = ( CA7 * SBET6 + CB7 * SALP3 * SBET4 ) * B(11)
      SGAM7 = CC7 * SALP1 *B(11)
      SEPS7 = ( CA7 * SEPS6 + CB7 * SGAM3 + CC7 * SGAM1 + CB7 * SALP3 *
     * SGAM4 ) * B (11)
C EQUATION 6 CONTINUED
      SZET6 = SALP6 + SGAM6 * SALP7
      SETA6 = SBET6 + SGAM6 * SBET7
      SIOT6 = SGAM6 * SGAM7
      SKAP6 = SEPS6 + SGAM6 * SEPS7
C EQUATION 14
      B(12) = CC14 * SALP10
      SALP14 = CB14 + B(12) * SGAM7
      SBET14 = B(12) * SALP7
      SGAM14 = B(12) * SBET7
      SEPS14 = B(12) * SEPS7
C EQUATION 9
      B(13) = CB9 * SALP8
      SZET9 = CA9 + B(13) * SGAM7
      SGAM9 =-B(13) / SZET9
      SALP9 = SGAM9 * SALP7
      SBET9 = SGAM9 * SBET7
      SGAM9=SGAM9*SEPS7
C EQUATION 14 CONTINUED
      B(14) = - 1.D0 / CA14
      SZET14 = ( SALP14 * SALP9 + SBET14 ) * B(14)
      SETA14 = ( SALP14 * SBET9 + SGAM14 ) * B (14)
      SIOT14 = ( SALP14 * SGAM9 + SEPS14 ) * B(14)
C EQUATION 6 CONTINUED
      SLAM6 = SZET6 + SIOT6 * SALP9
      SMU6  = SETA6 + SIOT6 * SBET9
      SNU6 = SKAP6 + SIOT6 * SGAM9
C EQUATION 7 CONTINUED
      SETA7 = SALP7 + SGAM7 * SALP9
      SIOT7 = SBET7 + SGAM7 * SBET9
      SKAP7 = SEPS7 + SGAM7 * SGAM9
C EQUATION 12
      SALP12 = PE01 - PD1 * SALP9
```

```
      SBFT12 = -PD1 * SBFT9
      SGAM12 = -PD1 * SGAM9
      SA2 = CD12 * SALP12 ** 2
      SB2 = CA12 * SLAM6 + CB12 * SZET14 + CC12 * SALP12 + 2.D0 * CD12 *
     @ SALP12 * SGAM12
      SC2 = 2.D0 * CD12 * SALP12 * SBET12
      SD2 = CA12 * SMU6 + CB12 * SETA14 + CC12 * SBET12 + 2.D0 * CD12 *
     @ SBET12 * SGAM12
      SE2 = CD12 * SBFT12 ** 2
      SF2 = CA12 * SNU6 + CB12 * SIOT14 + CC12 * SGAM12 + CD12 *
     @ SGAM12 ** 2
C EQUATION 13
      SALP13 = - PN1 * SALP9
      SBFT13 = PE01 - PN1 * SBET9
      SGAM13 = - PN1* SGAM9
      SA3= CD13 * SALP13 ** 2
      SB3 = CA13 * SETA7 + CB13 * SZET14 + CC13 * SALP13 + 2.D0 * CD13 *
     @ SALP13 * SGAM13
      SC3 = 2.D0 * CD13 * SALP13 * SBET13
      SD3 = CA13 * SIOT7 + CB13 * SETA14 + CC13 * SBET13 + 2.D0 * CD13 *
     @ SBET13 * SGAM13
      SE3 = CD13 * SBET13 ** 2
      SF3 = CA13 * SKAP7 +   CB13 * SIOT14 + CC13 * SGAM13 + CD13 *
     @ SGAM13 ** 2
      II=IDEBUG
      CALL QSIMUL(SA2,SB2,SC2,SD2,SE2,SF2,SA3,SB3,SC3,SD3,SE3,SF3,II,X
     1 ,Y)
C-----------
C SORT ROOTS
C-----------
      I=0
      DO 15 K=1,4
      IF((DABS(DIMAG(X(K))).GT.1.D-12).OR.(DABS(DIMAG(Y(K))).GT.1.D-12))
     1 GO TO 15
      B(14)=DREAL(X(K))/PD1
      B(15)=DREAL(Y(K))/PN1
      WRITE(IDEBUG,69)K,X(K),Y(K),A14,B(14),B(15)
   69 FORMAT(' K=',I1,' X=',2E13.5,' Y=',2E13.5,' A14=',E13.5,
     1 ' B(14),B(15)=',2E13.5)
       IF((DABS(B(14)).GT.DABS(A14)).OR.(DABS(B(15)).GT.DABS(A14)))
     1 GO TO 15
      I=I+1
      JJ(I)=K
      EPS(12)=X(K)
      EPS(13)=Y(K)
   15 CONTINUE
      IF(I.LE.1)GO TO 340
      K=I
      B(14)=X(JJ(1))
      B(15)=Y(JJ(1))
      DO 320 I=2,K
      J=JJ(I)
      IF(DABS(DREAL(X(J))).GT.DABS(B(14)))GO TO 300
      I1=J
      B(14)=X(J)
  300 IF(DABS(DREAL(Y(J))).GT.DABS(B(15)))GO TO 320
```

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                    SMPERT                 DATE = 75157          11/58/40
      I2=J
      B(15)=Y(J)
  320 CONTINUE
      IF(I1.NE.I2)GO TO 340
      I=1
      EPS(12)=X(I1)
      EPS(13)=Y(I2)
  340 IFLG8=0
      K=1
      IF(I.EQ.1)GO TO 17
      WRITE(IOUT,16)I
   16 FORMAT('0SMPERT:',I3,'  SOLUTIONS FOUND')
      IDEBUG=06
      IFLG8=1
      K=0
   18 K=K+1
      IF(K.GT.4)GO TO 60
      EPS(12)=X(K)
      EPS(13)=Y(K)
C-------------------
C COMPUTE INCREMENTS
C-------------------
   17 EPS(6) = SLAM6 * EPS(12) + SMU6 * EPS(13) + SNU6
      EPS(7) = SETA7 * EPS(12) + SIOT7 * EPS(13) + SKAP7
      EPS(9) = SALP9 * EPS(12) + SBET9 * EPS(13) + SGAM9
      EPS(14) = SZET14 * EPS(12) + SETA14 * EPS(13) + SIOT14
      EPS(4) = SALP4 * EPS(12) + SBET4 * EPS(13) + SGAM4
      EPS(3) = SALP3 * EPS(4) + SBET3 * EPS(12) + SGAM3
      EPS(1) = SALP1 * EPS(9) + SBET1 * EPS(7) + SGAM1
      EPS(17) = SALP17 * EPS(3) + SBET17 * EPS(4) + SGAM17
      EPS(11) = SALP11 * EPS(13) + SBET11 * EPS(12)
      EPS(10) = SALP10 * EPS(7)
      EPS(18) = SEPS5 * EPS(17) + SZET5 * EPS(3) + SETA5 * EPS(4) +
     @ SIOT5
      EPS(5) = SALP18 * EPS(18) + SBET18
      EPS(8) = SALP8 * EPS(7)
      EPS(2) = SALP2 * EPS(17) + SBET2 * EPS(18) + SGAM2
      EPS(19) = SALP19 * EPS(18) + SBET19 * EPS(17)
      WRITE(IDEBUG,20)(I,I=1,24),EPS
   20 FORMAT(3(/' ',8(5X,'EPS(',I2,')',4X )),3(/' ',8E16.8))
C-----------------------------------------
C COMPUTE SMALL PERTURBATION PROPERTY VALUES
C-----------------------------------------
      DO 30 I=1,19
   25 J=IEXTP(I)
      IF(J.EQ.0)GO TO 30
      V(J,1)=V(J,2)+EPS(I)
   30 CONTINUE
      GO TO(341,342),IFLG9
  341 PPT = PPT1 * (RPT / RPT1) ** G
      TPT = PPT * OOR / RPT * A2
      GO TO 343
  342 TPT=TCT0
      PPT=RPT*R*TPT/A2
  343 PCT0 = PE0
      TCT0 = TE0
```

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                      SMPERT                DATE = 75157           11/58/40
      REO = PEO * OOR / TEO * A2
      RCTO = REO
      ACTO = DSQRT(GR * TCTO)
      MDCTO = RCTO * ACTO * CTA
      MD = MACH(PD)
      MN = MACH(PN)
      IF((INSTR(23).NE.2).AND.(INSTR(24).EQ.0))GO TO 28
      J16=J16+1
      CALL PRINT
      J16=J16-1
      WRITE(IOUT,29)
   29 FORMAT('+0')
   28 IF((IFLG8.EQ.0).AND.(IDEBUG.EQ.03))RETURN
      WRITE(IDEBUG,32)V
   32 FORMAT('0SMALL PERTURBATION PROPERTIES',13(/' ',8E16.8))
C-------------------------------
C SMALL PERTURBATION RESIDUALS
C-------------------------------
      DO 35 I=1,19
   35 Q(I)=1.D70
      Q(1) = CA1 * EPS(1) + CB1 * EPS(9) + CC1 * EAE + CD1 * EPS(10)
      Q(2) = CA2 * EPS(2) + CB2 * EPS(17) + CC2 * EAPE + CD2 * EPS(19)
      Q(3) = CA3 * EPS(3) + CB3 * EAF + CC3 * EPS(17) + CD3 * EPS(12)
      Q(4) = CA4 * EPS(4) + CB4 * EPS(17) + CC4 * EPS(11)
      Q(5) = CA5 * EPS(5) + CB5 * EPS(2) + CC5 * EPS(3) + CD5 * EPS(4) +
     @ CE5
      Q(6) = CA6 * EPS(6) + CB6 * EPS(4) + CC6 * EPS(7)
      Q(7) = CA7*EPS(6) + CB7 * EPS(3) + CC7 * EPS(1)
      Q(8) = CA8 * EPS(7) + CB8 * EPS(8)
      Q(9) = CA9 * EPS(9) + CB9 * EPS(8)
      Q(10) = CA10 * EPS(10) + CB10 * EPS(8)
      Q(11) =CA11 * EPS(11) + CB11 * EPS(13) + CC11 * EPS(12)
      B(15) = PE01 * EPS(12) - PD1 * EPS(9)
      Q(12) = CA12 * EPS(6) + CB12 * EPS(14) + CC12 * B(15) + CD12 *
     @ B(15) ** 2
      B(16) = PE01 * EPS(13) - PN1 * EPS(9)
      Q(13) = CA13 * EPS(7) + CB13 * EPS(14) + CC13 * B(16) + CD13 *
     @ B(16) ** 2
      Q(14) = CA14 * EPS(14) + CB14 * EPS(9) + CC14 * EPS(10)
      Q(17) = CA17 * EPS(17) + CB17 * EPS(18)
      Q(18) = CA18 * EPS(18) + CB18 * EPS(5) + CC18
      Q(19) = CA19 * EPS(19) + CB19 * EPS(18) + CC19 * EPS(17)
      WRITE(IDEBUG,13)(I,I=1,20),Q
   13 FORMAT('0RESIDUALS FROM SMALL PERTURBATION EQUATIONS',
     1 2(/' ',10(6X,I2,5X)),2(/' ',10E13.5))
C----------------
C EXACT RESIDUALS
C----------------
      DO 140 I=1,19
  140 Q(I)=1.D70
      Q(1)=MDE-A1*PEO*AE/DSQRT(TEO)*A2
      Q(2)=MDPE+A1*PP*APE/DSQRT(TP)*A2
      Q(3)=MDF+AF*OOKF*(PP-PD)*A2
      Q(3)=MDF+AF*OOKF*(PP-PD*A16)*A2
      Q(4)=MDPT+AWOKW*(PP-PT*A15)*A2
      Q(5)=RPT-RPT1-(MDPE+MDF+MDPT)*DTOPV
```

```
      Q(6)=MDD+MDPT-MDCT
      Q(7)=MDD-MDF-MDE
      B(9)=1.D0+GM102*MCT
      B(10)=1.D0+GM102*MCT**2
      Q(8)=MDCT-MCT*MDCTC*B(9)**MGROGM
      B(11)=B(10)/B(9)**2
      Q(9)=PE0-PC*B(11)**GOGM1
      Q(10)=TE0-TC*B(11)
      IF(IFLG2)144,9999,145
  144 Q(11)=PT-(1.D0-A17)*PN-A17*PD
      GO TO 146
  145 Q(11)=PT-0.5D0*(PN+PD)
  146 B(12)=1.D0/PE0
      B(13)=TOGM1*MDTS0**2
      Q(12)=MDD**2-B(13)*((PD*B(12))**TOG-(PD*B(12))**GP1OG)
      Q(13)=MDCT**2-B(13)*((PN*B(12))**TOG-(PN*B(12))**GP1OG)
      Q(14)=MDTS0-SGOR*PE0*TS4/DSQRT(TE0)*A2
      GO TO(141,142),IFLG9
  141 Q(17)=PP-PPT1*(RP/RPT1)**G
      GO TO 143
  142 Q(17)=PP-RP*R*TP/A2
  143 Q(18)=RP-0.5D0*(RPT+RPT1)
      Q(19)=TP-PP*OOR/RP*A2
C******************************************************************************
C OUTPUT
C******************************************************************************
C--------------------------------
C CONVERT RESIDUALS TO PERCENTAGES
C--------------------------------
   39 DO 49 I=1,19
      J=IEXTP(I)
      IF(J.EQ.0)GO TO 49
      IF(I.EQ.6)GO TO 45
      IF(I.EQ.7)GO TO 41
      IF(I.EQ.8)GO TO 42
      IF(I.EQ.12)GO TO 43
      IF(I.EQ.13)GO TO 42
      GO TO 46
   41 J=10
      GO TO 46
   42 J=12
      GO TO 46
   43 J=9
      GO TO 46
   45 J=11
   46 IF(V(J,2).NE.0.D0)GO TO 47
      Q(I)=INFIN
      GO TO 49
   47 Q(I)=Q(I)*1.D2/V(J,2)
   49 CONTINUE
      WRITE(IDEBUG,21)(I,I=1,20),Q
   21 FORMAT('0RESIDUALS FROM EXACT EQUATIONS',
     1 2(/' ',10(6X,I2,5X)),2(/' ',10E13.5))
      IF(IFLG8.EQ.0)GO TO 60
      IF(IFLG2)220,9999,18
   60 WRITE(IDEBUG,31)(I,I=1,10),A,(I,I=1,30),B
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 31 FORMAT('0A ARRAY'/' ',10(6X,I2,5X)/' ',10E13.5/'0','B ARRAY',
    13(/' ',10(6X,I2,5X)),3(/' ',10E13.5))
     WRITE(IDEBUG,10) CA1, CB1, CC1, CD1, CA2, CB2, CC2, CD2,
    1  CA3, CB3, CC3, CD3, CA4, CB4, CC4, CA5, CB5, CC5, CD5,
    2  CE5, CA6, CB6, CC6, CA7, CB7, CC7, CA8, CB8, CA9, CB9,
    3 CA10, CB10,CA11,CB11,CC11,CA12,CB12,CC12,CD12,CA13,CB13,
    4 CC13,CD13,CA14,CB14,CC14,CA17,CB17,CA18,CB18,CC18,CA19,
    5 CB19,CC19
 10 FORMAT('1SMPERT'/' ',6('=')/'0',7X,'CA1',13X,'CB1',13X,'CC1',
    1 13X,'CD1'/' ',4E16.8/'0',7X,'CA2',13X,'CB2',13X,'CC2',13X,
    2 'CD2'/' ',4E16.8/'0',7X,'CA3',13X,'CB3',13X,'CC3',13X,'CD3'
    3 /' ',4E16.8/'0',7X,'CA4',13X,'CB4',13X,'CC4'/' ',3E16.8/'0',
    4 7X,'CA5',13X,'CB5',13X,'CC5 ',13X,'CD5',13X,'CE5'/' ',5E16.8
    5 /'0',7X,'CA6',13X,'CB6',13X,'CC6'/' ',3E16.8/'0',7X,'CA7',13X,
    6 'CB7',13X,'CC7'/' ',3E16.8/'0',7X,'CA8',13X,'CB8'/' ',2E16.8
    7 /'0',7X,'CA9',13X,'CB9'/' ',2E16.8/'0',6X,'CA10',12X,'CB10'/' ',
    8 2E 16.8/'0',6X,'CA11',11X,'CB11',12X,'CC11'/' ',3E16.8/'0',
    9 6X,'CA12',12X,'CB12',12X,'CC12',12X,'CD12'/' ',4E16.8/'0',6X,
    A 'CA13',12X,'CB13',12X,'CC13',12X,'CD13'/' ',4E16.8/'0',6X,
    B 'CA14',12X,'CB14',12X,'CC14'/' ',3E16.8/ '0',6X,'CA17',12X,
    C 'CB17'/' ',2E16.8/'0',6X,'CA18',12X,'CB18',12X,'CC18'/' ',
    D 3E16.8/'0',6X,'CA19',12X,'CB19',12X,'CC19'/' ',3E16.8)
     WRITE(IDEBUG,11) SALP1, SBET1, SGAM1, SALP2, SBET2, SGAM2, SALP3
    1 , SBET3, SGAM3, SEPS3, SALP4, SBET4, SGAM4, SEPS4, SALP5, SBET5
    2 , SGAM5, SEPS5, SZET5, SETA5, SIOT5, SKAP5, SALP6, SBET6, SGAM6
    3 , SEPS6, SZET6, SETA6, SIOT6, SKAP6, SLAM6,  SMU6,  SNU6, SALP7
    4 , SBET7, SGAM7, SEPS7, SZET7, SETA7, SIOT7, SKAP7, SALP8, SALP9
    5 , SBET9, SGAM9, SZET9,SALP10,SALP11,SBET11,SALP12,SBET12,SGAM12
    6 ,SALP13,SBET13,SGAM13,SALP14,SBET14,SGAM14,SEPS14,SZET14,SETA14
    7 ,SIOT14,SALP17,SBET17,SGAM17,SEPS17,SALP18,SBET18,SALP19,SBET19
 11 FORMAT('1',6X,'SALP1',11X,'SBET1',11X,'SGAM1'/' ',3F16.8/'0',6X,
    1 'SALP2',11X,'SBET2',11X,'SGAM2'/' ',3E16.8/'0',6X,'SALP3',11X,
    2 'SBET3',11X,'SGAM3',11X,'SEPS3'/' ',4E16.8/'0',6X,'SALP4',11X,
    3 'SBET4',11X,'SGAM4',          11X,'SEPS4'/' ',4E16.8/'0',6X,
    4 'SALP5',11X,'SBET5',11X,'SGAM5',11X,'SEPS5',11X,'SZET5',11X,
    5 'SETA5',11X,'SIOT5',11X,'SKAP5'/' ',8E16.8/'0',6X,'SALP6',11X,
    6 'SBET6',11X,'SGAM6',11X,'SEPS6',11X,'SZET6',11X,'SETA6',11X,
    7 'SIOT6',11X,'SKAP6'/' ',8E16.8/'0',6X,'SLAM6',11X,'SMU6 ',11X,
    8 'SNU6'/' ',3E16.8/'0',6X,'SALP7',11X,'SBET7',11X,'SGAM7',11X,
    9 'SEPS7',11X,'SZET7',11X,'SETA7',11X,'SIOT7',11X,'SKAP7'/' ',
    A 8E16.8/'0', 6X,'SALP8'/' ',F16.8/'0',6X,'SALP9',11X,'SBET9',
    B              11X,'SGAM9',11X,'SZET9'/' ',4E16.8/'0',5X,'SALP10'/
    C ' ', F16.8/'0',5X,'SALP11',10X,'SBET11'/' ',2F16.8/'0',5X,'SALP12
    D ',10X,'SBET12',10X,'SGAM12'/' ',3E16.8/'0',5X,'SALP13',10X,
    E 'SBET13',10X,'SGAM13'/' ',3E16.8/'0',5X,'SALP14',10X,'SBET14',
    F 10X,'SGAM14',10X,'SEPS14',10X,'SZET14',10X,'SETA14',10X,'SIOT14'
    G /' ',7E16.8/'0',5X,'SALP17',10X,'SBET17',10X,'SGAM17',10X,
    H 'SEPS17'/' ',4E16.8/'0',5X, 'SALP18',10X,'SBET18'/' ',2E16.8/
    I '0',5X,'SALP19',10X,'SBET19'/' ',2E16.8 )
     WRITE(IDEBUG,12)SA2,SB2,SC2,SD2,SE2,SF2,SA3,SB3,SC3,SD3,SE3,SF3
    1 ,FAE,FAPE,FAF
 12 FORMAT('1',7X,'SA2',13X,'SB2',13X,'SC2',13X,'SD2',13X,'SE2',
    1 13X,'SF2'/' ',6E16.8/'0',7X,'SA3',13X,'SB3',13X,'SC3',13X,
    2 'SD3',13X,'SE3',13X,'SF3'/' ',6E16.8/'0',7X,'FAE',12X,'FAPE',
    3 13X,'FAF'
    4 /' ',8E16.8)
     IF(IFLGB.EQ.1)STOP
     RETURN
9999 STOP
     END
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                         QSIMUL                DATE = 75157           11/58/40

      SUBROUTINE QSIMUL(A2,B2,C2,D2,E2,F2,A3,B3,C3,D3,E3,F3,IDEBUG,XX,Y)
      IMPLICIT REAL*8(A-H,O-Z)
      COMPLEX*16 X(2,2,4),Y(4),SIGMA,UPSLON,PHI,PSI,OMEGA,ZERO,A1,B1,C1,
     -Y1,Y2,Y3,Y4,ONE,R(2,2,4,2),CINFIN,XX(4)
      COMPLEX*16 SIGMA1,UPSLN1,PHI1,PSI1,OMEGA1
      DIMENSION III(4),JJJ(4)
      DATA ZERO/(0.D0,0.D0)/,ONE/(1.D0,0.D0)/,CINFIN/(1.D70,1.D70)/
C-----------------------------
C COMPUTE QUARTIC COEFFICIENTS
C-----------------------------
      ALPHI=A2*E3-A3*E2
      BETAI=A2*D3-A3*D2
      GAMMI=A2*F3-A3*F2
      ALPHII=A3*B2-A2*B3
      BETAII=A3*C2-A2*C3
      DELTII=ALPHI*BETAII
      EPSLII=ALPHI*ALPHII+BETAI*BETAII
      ZETAII=BETAI*ALPHII+GAMMI*BETAII
      ETAII=GAMMI*ALPHII
      BIISQ=BETAII**2
      ABII=ALPHII*BETAII
      AIISQ=ALPHII**2
      SIGMA=ZERO
      UPSLON=ZERO
      PHI=ZERO
      PSI=ZERO
      OMEGA=ZERO
      DO 8 I=1,2
      DO 7 J=1,2
      DO 6 K=1,4
    6 X(I,J,K)=CINFIN
    7 CONTINUE
    8 CONTINUE
      SIGMA= A2 * ALPHI**2 + C2 * DELTII + E2 * BIISQ
      UPSLON = 2.D0 * A2 * ALPHI * BETAI + B2 * DELTII + C2 * EPSLII +
     * 2.D0 * E2*ABII + D2 * BIISQ
      PHI = A2 * ( BETAI ** 2 + 2.D0 * ALPHI * GAMMI ) + B2 * EPSLII +
     * C2 * ZETAII + E2 * AIISQ + F2 * BIISQ + 2.D0 * D2 * ABII
      PSI = 2.D0 * BETAI * GAMMI *A2 + B2 * ZETAII + C2 * ETAII +
     *   2.D0 * F2 * ABII + D2 * AIISQ
      OMEGA = A2 * GAMMI ** 2 + B2 * ETAII + F2 * AIISQ
      SIGMA1=SIGMA
      UPSLN1=UPSLON
      PSI1=PSI
      PHI1=PHI
      OMEGA1=OMEGA
      IF(IDEBUG.EQ.03)GO TO 9
C------------------
C PRINT COEFFICIENTS
C------------------
      WRITE(IDEBUG,1)A2,B2,C2,D2,E2,F2,A3,B3,C3,D3,E3,F3,ALPHI,BETAI,
     - GAMMI,ALPHII,BETAII,DELTII,EPSLII,ZETAII,ETAII,BIISQ,ABII,AIISQ
    1 FORMAT('1QSIMUL'/' ',6('=')/'0',7X,'A2',14X,'B2',14X,'C2',14X,
     1 'D2',14X,'E2',14X,'F2'/' ',6E16.8/'0',7X,'A3',14X,'B3',14X,'C3',
     2 14X,'D3',14X,'E3',14X,'F3'/' ',6E16.8/'0',6X,'ALPHI',11X,
     3 'BETAI',11X,'GAMMI',10X,'ALPHII',10X,'BETAII',10X,'DELTII',
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     4 10X,'EPSLII'/' ',7E16.8/'0',5X,'ZETAII',11X,'ETAII',11X,
     5 'BIISQ',11X,'ABII',12X,'AIISQ'/' ',5E16.8)
      WRITE(IDEBUG,2)SIGMA,UPSLON,PHI,PSI,OMEGA,ZERO
    2 FORMAT('0',13X,'SIGMA',27X,'UPSLON',28X,'PHI',29X,'PHI'/' ',
     18E16.8/'0',14X,'OMEGA',27X,'ZERO'/' ',4E16.8)
C--------------------
C FIND ROOTS TO QUARTIC
C--------------------
    9 N=4
      IF(DREAL(SIGMA).NE.0.D0)GO TO 40
      N=3
      IF(DREAL(UPSLON).NE.0.D0)GO TO 30
      N=2
      IF(DREAL(PHI).NE.0.D0)GO TO 20
C LINEAR
      N=1
   10 OMEGA=OMEGA/PSI
      PSI=ONE
      CALL QANDC(N,OMEGA,ZERO,ZERO,ZERO,ZERO,Y1,Y2,Y3,Y4)
      GO TO 45
C QUADRATIC
   20 PSI=PSI/PHI
      OMEGA=OMEGA/PHI
      PHI=ONE
      CALL QANDC(N,PSI,OMEGA,ZERO,ZERO,Y1,Y2,Y3,Y4)
      GO TO 45
C CUBIC
   30 PHI=PHI/UPSLON
      PSI=PSI/UPSLON
      OMEGA=OMEGA/UPSLON
      UPSLON=ONE
      CALL QANDC(N,PHI,PSI,OMEGA,ZERO,Y1,Y2,Y3,Y4)
      GO TO 45
C QUARTIC
   40 UPSLON=UPSLON/SIGMA
      PHI=PHI/SIGMA
      PSI=PSI/SIGMA
      OMEGA=OMEGA/SIGMA
      SIGMA=ONE
      CALL QANDC(N,UPSLON,PHI,PSI,OMEGA,Y1,Y2,Y3,Y4)
C---------------------------------
C FIND ALL X VALUES FOR EACH Y ROOT
C---------------------------------
   45 Y(1)=Y1
      Y(2)=Y2
      Y(3)=Y3
      Y(4)=Y4
      DO 100 I=1,4
      IF(I.GT.N)GO TO 100
      B1=-.5*(B2+C2*Y(I))/A2
      C1=CDSQRT(B1**2-(D2*Y(I)+F2*Y(I)**2+F2)/A2)
      X(1,1,I)=B1+C1
      X(2,1,I)=B1-C1
      B1=-.5*(B3+C3*Y(I))/A3
      C1=CDSQRT(B1**2-(D3*Y(I)+F3*Y(I)**2+F3)/A3)
      X(1,2,I)=B1+C1
```

```
      X(2,2,I)=B1-C1
  100 CONTINUE
C----------------------------------
C PRINT ROOTS TO QUARTIC AND CONICS
C----------------------------------
      WRITE(IDEBUG,2)SIGMA,UPSLON,PHI,PSI,OMEGA,ZERO
      WRITE(IDEBUG,3)Y,(I,I=1,2),X
    3 FORMAT('0',15X,'Y1',30X,'Y2',30X,'Y3',30X,'Y4'/' ',8E16.8/'0',
     1 2('|',26('-'),'EQUATION',I2,27('-')),'-|'/' ',2('|',11('-'),
     2 'POSITIVE',11('-'),'|',11('-'),'NEGATIVE',12('-') ,'-|')
     3/'0X ROOTS BASED ON Y1'/' ',8E16.8/'0X ROOTS BASED ON Y2'/' ',8
     4 E16.8/'0X ROOTS BASED ON Y3'/' ',8E16.8/'0X ROOTS BASED ON Y4'/
     6 ' ',8E16.8)
C--------------------------------------------------------------
C CHECK ALL X AND Y VALUES IN ORIGINAL SYSTEM OF CONICS
C--------------------------------------------------------------
      DO 130 L=1,2
      DO 120 I=1,4
      DO 114 J=1,2
      DO 115 K=1,2
      IF(DREAL(Y(I)).GT.1.D69)GO TO 115
      GO TO(108,110),L
  108 R(J,K,I,1)=A2*X(J,K,I)**2+B2*X(J,K,I)+C2*X(J,K,I)*Y(I)+D2*Y(I)+
     1 E2*Y(I)**2+F2
      GO TO 115
  110 R(J,K,I,2)=A3*X(J,K,I)**2+B3*X(J,K,I)+C3*X(J,K,I)*Y(I)+D3*Y(I)+
     1 E3*Y(I)**2+F3
  115 CONTINUE
  114 CONTINUE
  120 CONTINUE
  130 CONTINUE
      WRITE(IDEBUG,4)R
    4 FORMAT('0RESIDUAL ARRAY',4(/' ',8E16.8))
C---------------------------
C SORT OUT EXTRANEOUS ROOTS
C---------------------------
  135 L=0
      DO 160 J=1,4
      DO 180 I=1,2
      DO 140 K=1,2
      IF(CDABS(R(I,1,J,K)).LT.1.D-10)GO TO 140
      GO TO 180
  140 CONTINUE
      L=L+1
      IF(L.LE.4)GO TO 150
      WRITE(IOUT,145)
  145 FORMAT('0QSIMUL: MORE THAN FOUR ROOTS FOUND')
      STOP
  150 III(L)=I
      JJJ(L)=J
  180 CONTINUE
  160 CONTINUE
      LLL=L
      DO 200 L=1,4
      XX(L)=CINFIN
      IF(L.GT.LLL)GO TO 190
      XX(L)=X(III(L),1,JJJ(L))
      GO TO 200
  190 Y(L)=CINFIN
  200 CONTINUE
      WRITE(IDEBUG,220)XX,Y
  220 FORMAT('1SORTED ROOTS: XX/Y',2(/' ',8E16.8))
      WRITE(IDEBUG,240)III,JJJ
  240 FORMAT('0III AND JJJ VALUES FOR R(III,1,JJJ,K)'/' ','III=',4I2/
     1 ' JJJ=',4I2)
      RETURN
      END
```

```
                                   QANDC              DATE = 75157          11/58/40
      SUBROUTINE QANDC(N,B,C,D,E,X1,X2,X3,X4)
      IMPLICIT COMPLEX*16(A-G,O-Z)
      COMPLEX*16I
      DATA I/(0.D0,1.D0)/,CINFIN/(1.D70,1.D70)/
      GO TO(30,20,10,5),N
C QUARTIC
    5 A=((4.D0*C*E-(B**2*E)-D**2)/2.D0)
      A1=(C*(B*D-4.D0*E)/6.D0)
      A2=-((C**3)/27.D0)
      A=A+A1+A2
      BB=CDSQRT((A**2)+((B*D-4.D0*E-((C**2)/3.D0))**3)/27.D0)
      A=-A
      CALL CUBRT(A,BB,R)
      PSTAR=B*D-4.D0*E-C*C/3.D0
      R1=-PSTAR/(3.D0*R)
      R=(R+R1+(C/3.D0))
      P=CDSQRT((B**2/4.D0)-C+R)
      PQ=CDSQRT(0.25D0*R**2-E)
      AB2=.5D0*B*R-D
      PPQ2=2.D0*P*PQ
      IF(CDABS(AB2-PPQ2) .GT. CDABS(AB2+PPQ2))PQ=-PQ
      PP=(CDABS(P))
C     CALCULATING THE ZEROS
      A1=(1.0,0.0)
      B1=(B/2.D0)+P
      C1=(R/2.D0)+PQ
      X1=(-B1+CDSQRT(B1**2-4.D0*A1*C1))/(2.D0*A1)
      X2=(-B1-CDSQRT(B1**2-4.D0*A1*C1))/(2.D0*A1)
      B1=(B/2.D0)-P
      C1=(R/2.D0)-PQ
      X3=(-B1+CDSQRT(B1**2-4.D0*A1*C1))/(2.D0*A1)
      X4=(-B1-CDSQRT(B1**2-4.D0*A1*C1))/(2.D0*A1)
      RETURN
C CUBIC
   10 CONTINUE
      P=C-(B**2/3.D0)
      Q=D-(B*C/3.D0)+((2.D0*B**3)/27.D0)
      Z1=-(Q/2.D0)+(CDSQRT((Q**2/4.D0)+(P**3/27.D0)))
      Z2=-(Q/2.D0)-(CDSQRT((Q**2/4.D0)+(P**3/27.D0)))
      IF(CDABS(Z1).GE.CDABS(Z2))Z=Z1
      IF(CDABS(Z2).GE.CDABS(Z1))Z=Z2
      IF(CDABS(Z) .EQ. 0.0)X1=-(B/3.D0)
      IF(CDABS(Z) .EQ. 0.0)X2=-(B/3.D0)
      IF(CDABS(Z) .EQ. 0.0)X3=-(B/3.D0)
      IF(CDABS(Z) .EQ. 0.0)RETURN
      BBB=(0.D0,0.D0)
      CALL CUBRT(Z,BBB,R1)
      R=-(P/(3.D0*R1))
      W1=-(.5D0)+((3.D0**.5)/2.D0)*I
      W2=-(.5D0)-((3.D0**.5)/2.D0)*I
      X1=-(B/3.D0)+R1+R
      X2=-(B/3.D0)+W1*R1+W2*R
      X3=-(B/3.D0)+W2*R1+W1*R
      X4=CINFIN
      RETURN
C QUADRATIC
   20 A1=.5*B
      R=CDSQRT(A1**2-C)
      X1=A1+R
      X2=A1-R
      X3=CINFIN
      X4=CINFIN
      RETURN
C LINEAR
   30 X1=-B
      X2=CINFIN
      X3=CINFIN
      X4=CINFIN
      RETURN
      END
```

CUBRT DATE = 75157 11/58/40

```
      SUBROUTINE CUBRT(AA,BB,RR)
      IMPLICIT COMPLEX*16(A-G,O-Z)
      REAL*8H,H1A,H1B,HTH
      REAL*8PI,SSSS
      COMPLEX*16I
  990 CONTINUE
      I=(0.,1.)
      II=1
      Z1=AA+BB
      Z2=AA-BB
      IF(CDABS(Z2) .GE. CDABS(Z1))A=Z2
      IF(CDABS(Z1) .GE. CDABS(Z2))A=Z1
      B=DCONJG(A)
      H1A=(A+B)/2.D0
      H1B=-I*(A-B)/2.D0
      HTH=DATAN2(H1B,H1A)
      H=(H1A**2+H1B**2)**.5D0
      PI=3.14159265358979300
      SSSS=3.D0
      RR=(H**(1.D0/3.D0))*( DCOS((HTH+(II-1)*2.D0*PI)/SSSS)+I*( DSIN((HT
     1H+(II-1)*2.D0*PI)/SSSS)))
      RETURN
      END
```

IN IV G LEVEL 21 DREAL DATE = 75157 11/58/40

```
      FUNCTION DREAL(CC)
      COMPLEX*16 C,CC
      REAL*8 D(2),DREAL
      EQUIVALENCE (C,D(1))
      C=CC
      DREAL=D(1)
      RETURN
      END
```

IN IV G LEVEL 21 DIMAG DATE = 75157 11/58/40

```
      FUNCTION DIMAG(II)
      COMPLEX*16 I,II
      REAL*8 D(2),DIMAG
      EQUIVALENCE (I,D(1))
      I=II
      DIMAG=D(2)
      RETURN
      END
```

NOMENCLATURE

A	Area
A_{11}	Solution weighting parameter, Eq. (25)
A_{15}	Momentum correction coefficient in wall crossflow model, Eq. (7)
A_{16}	Flap correction coefficient in the flap flow model, Eq. (8)
A_{17}	Weight used in computing test section pressure, Eq. (10)
A_i, B_i, C_i, D_i, E_i	Arrays of coefficients in the small perturbation equations
E	Computational error
F	Function
k	Flow coefficient, as in k_f and k_w
M	Mach number
M_∞	Steady, asymptotic test section Mach number
$\dot{m}$	Mass flow rate
$\dot{m}_o$	Convenient quantity with units of mass flow rate defined as $\sqrt{\frac{\gamma}{R}} \frac{P_{ct_o}}{\sqrt{T_{ct_o}}} A_{ts}$
$\tilde{m}$	Nondimensional mass flow rate defined as $\sqrt{\frac{\gamma - 1}{2}} \frac{\dot{m}}{\dot{m}_o}$, Eq. (B-3)
$\hat{m}$	Nondimensional mass flow rate defined as $\dot{m}/\dot{m}_c$, Eq. (B-1)
$\dot{m}_c$	Convenient quantity with units of mass flow rate defined as $\sqrt{\frac{\gamma}{R}} \frac{P_c}{\sqrt{T_c}} A_{ct}$
n	Iteration number
P	Pressure
$\tilde{P}$	Nondimensional pressure, P/P_o

R	Perfect gas constant
T	Temperature
t	Time
t*	Midpoint of a time interval
t_F	Final time in an area time curve
V	Volume, as in V_p or V_{ts}
v_i	Scratch variable used to develop small perturbation expansion, Eq. (27)
X,Y	Variables in numerical reversion procedure (Fig. 10)
a	Constant defined as $\sqrt{\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{\gamma-1}} \frac{\gamma}{R}}$, Eqs. (4) and (5)
γ	Ratio of specific heats
δ_f	Flap gap
ϵ_i	Array of small perturbations of the variables from the exact solution (Table A-1)
ϵ_{A_e}	Perturbation in the main valve area
ϵ_{A_f}	Perturbation in the flap area
$\epsilon_{A_{pe}}$	Perturbation in the plenum exhaust valve area
ρ	Density
τ	Porosity, percent of test section wall area drilled out to allow crossflow

SUBSCRIPTS

c	Charge condition
ct	Charge tube (or supply tube)
d	Diffuser end of test section
e	Main tunnel exit, main valves

f	Flaps
i	Array index
max	Maximum value as in $A_{pe_{max}}$
n	Nozzle end of test section
p	Plenum
pe	Plenum exhaust
pt	Plenum - Test Section
t, ts	Test section, as in P_t or A_{ts}
tsw	Test section wall, as in A_{tsw}, the total wall area
w	Test section wall, as in A_w, the effective flow area
0	Stagnation condition
1	Test value in numerical reversion (Fig. 10)

SUPERSCRIPT

*	Sonic conditions