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STABILITY CHARACTERIZATION OF ADVANCED INJECTORS

Design Guide, Volume 2
Operation of the Computer Program

Report 20672-P2D

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STABILITY CHARACTERIZATION OF ADVANCED INJECTORS

DESIGN GUIDE

Volume 2, Operation of the Computer Program

Report 20672-P2D

Prepared by:

Aerojet-General Corporation
Liquid Rocket Division

Contract NAS 8-20672

Phase II, Final Report

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FOREWORD

This volume is submitted as partial fulfillment of contract provisions of Contract NAS 8-20672 and meets the requirements of Supplement No. 10 of that contract. The NASA project engineer was Mr. R. J. Richmond.

Volume I of this report is written specifically for the designer with the intent of providing combustion stability information which may be applied directly during a program's design phase. This volume (Volume II), on the other hand, is to provide the tools by which the analyst may characterize the combustion stability of a system. The combustion model which provided the basis for this analytical technique is the Sensitive Time Lag theory first developed by Dr. L. H. Crocco and later extended by Dr. F. H. Reardon. This volume provides description of a computer program, written in FORTRAN V, which may be utilized in characterizing a variety of combustion systems.

The work was conducted by the Thrust Chamber Engineering Section of the Liquid Rocket Division under Dr. N. E. Van Huff, acting manager; Mr. J. M. McBride, project manager; and Mr. W. W. Howard, project engineer.

Special acknowledgement is given to Mr. R. C. Waugh for his contribution in the development of analytical models, Mr. D. P. Dudley for programming and and conversion of the computer program, Mr. R. K. Turner for the reduction of combustion stability theory into design criteria and analysis and correlations of test data, and Mr. W. J. Nord for organizing and editing the material contained in these reports.

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I. PROBLEM

A. ABSTRACT

This program solves the combustion instability problem using the sensitive time lag theory. This amounts basically to solving the inhomogeneous Helmholtz equation for the condition of neutral stability. The inhomogeneous terms in the Helmholtz equation account for the mean flow and combustion effects. The program considers longitudinal and transverse modes of oscillation. It includes effects of non-uniform injection, velocity effects, and non-linear combustion response.

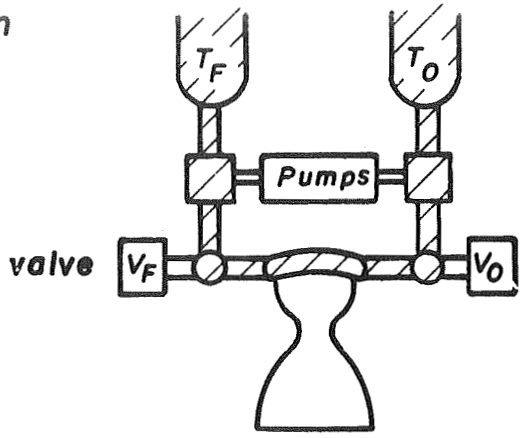
The program is divided into several subprograms which can either be run together or separately. These subprograms include nozzle admittance, longitudinal mode analysis, transverse mode analysis, describing functions for combustion response, and nonuniform injection parameters.

B. TECHNICAL DESCRIPTION

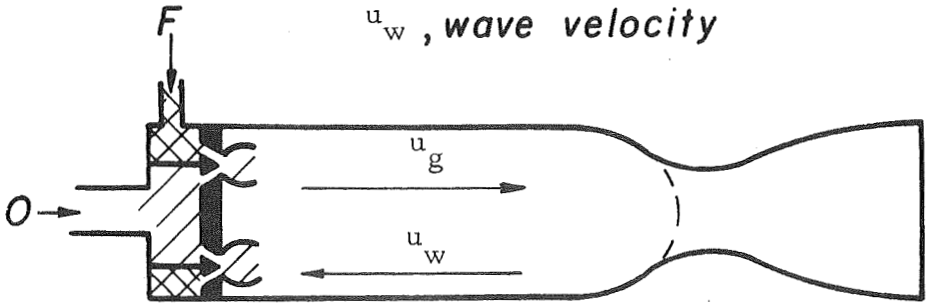
1. The Nature of Combustion Instability

It is well known that the processes occurring within a liquid rocket combustion chamber are never entirely smooth. Even when the mean operating conditions are constant, fluctuations around these mean values occur in all of the quantities that characterize the flow. The nature of the fluctuations can vary widely from one combustor to another and in a single combustor for different operating conditions. If the fluctuations are random and of small amplitude, this unsteadiness is referred to as "combustion noise". With random fluctuations of large amplitude, the operation of the rocket is said to be "rough", and the functioning of the system of which the rocket is a part may be impaired.

Type	Characteristic coupling
1. Chugging (low frequency)	(1) feed system (2) combustion chamber



2. Entropy wave
(1) injector (mixture ratio)
(2) chamber ; u_g , gas velocity ; u_w , wave velocity



3. Hi-frequency
(1) combustion process
(2) chamber geometry (wave travel time)

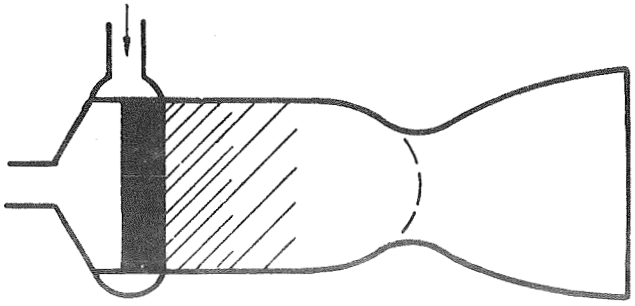


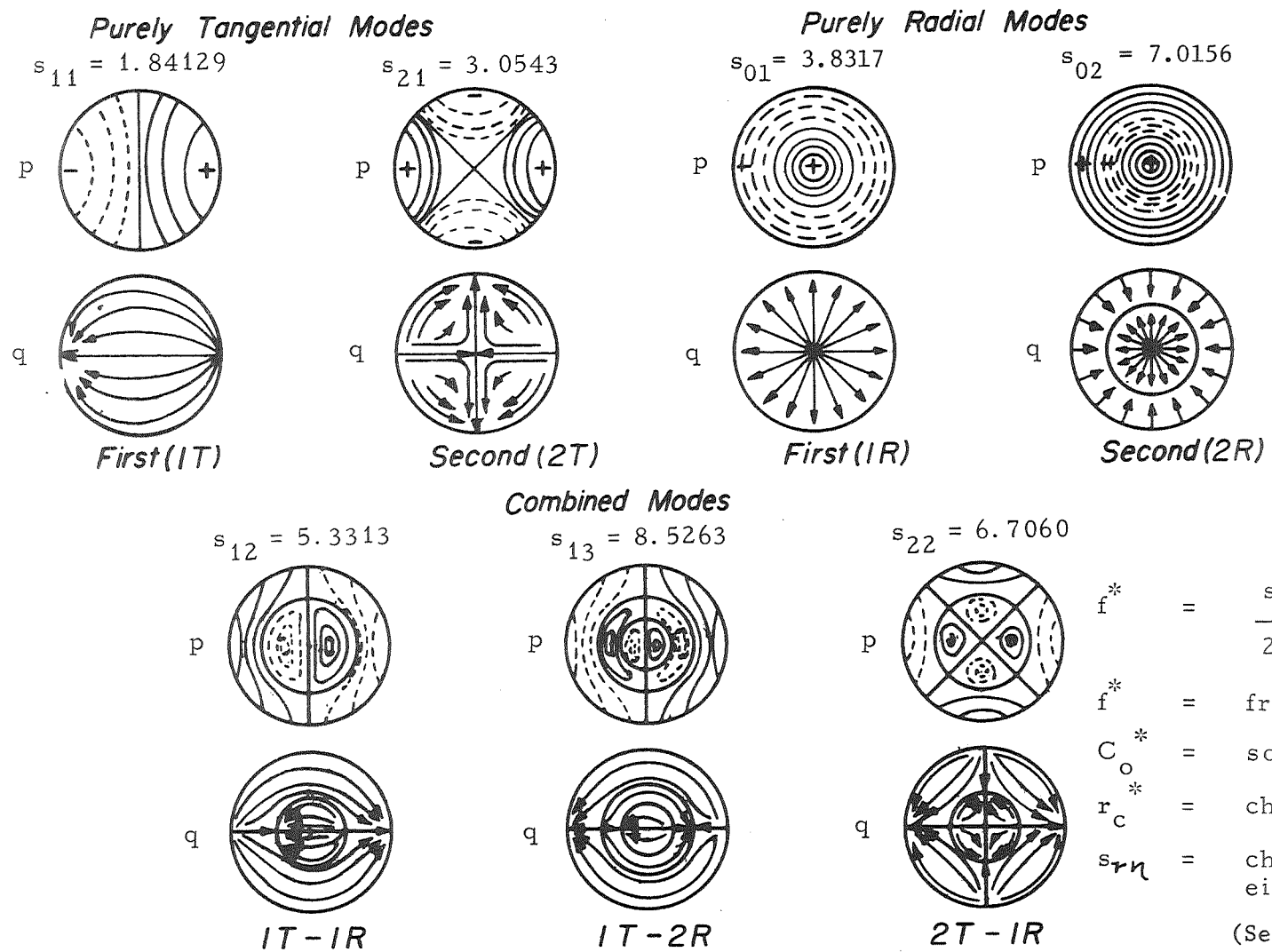
Figure 1 -- Liquid Propellant Combustion Instability

I, B, Technical Description (cont.)

Much more serious than rough operation is the problem of combustion instability, also termed unstable combustion, oscillatory combustion, or resonant combustion. Whereas rough combustion refers to random fluctuations, combustion instability consists of organized oscillations that are maintained and amplified by the combustion process itself. The various types of combustion instability can be classified roughly into three categories: low frequency, intermediate frequency, and high frequency. However, the classification is not based simply on frequency alone. Just as electrical and mechanical systems respond to specific frequencies depending on the type of coupling, so also liquid rocket systems exhibit representative frequency and amplitude patterns.

The basic coupling mechanisms for the three general types of combustion instability found in liquid propellant rocket engines are illustrated in Figure 1. For the low frequency ("chugging") type, interaction between the propellant feed system and the combustion chamber places the frequency generally less than 200 Hertz. The coupling is effected by the oscillating propellant feed rates. In the case of intermediate frequency combustion instability (sometimes referred to as entropy wave instability), the injector characteristics (especially the internal injector manifolding and orifice impedances) account for part of the interaction, with the mean gas flow and pressure wave propagation in the combustion chamber completing the process. Typical frequencies are in the several hundred Hertz range.

In this report, attention will be focused on the third type of combustion instability, namely, high frequency instability. This type depends upon a coupling between the combustion processes and flow oscillations in the combustion chamber. Such coupling requires no input from the feed system, although it is possible for the feed system to have an effect when the combustion chamber is large and acoustic frequencies are reduced to several hundred cycles per second. Normally, the frequencies to be expected are in the thousand Hertz range for most current engines.



$$f^* = \frac{s_{rn}\, C_o^*}{2\pi\, r_c^*}$$

f^* = frequency

C_o^* = sound speed

r_c^* = chamber radius

s_{rn} = characteristic eigen value

(See Table I)

Figure 2 -- Pressure, p, and Velocity, q, Characteristics of Several Transverse Modes

TABLE I

$s_{\nu\eta}$ FOR A CYLINDRICAL CHAMBER

For transverse modes the frequency of oscillation is given by:

$$f^* = \frac{s_{\nu\eta} \; C_o^* \times 12}{2 \pi r_c^*}$$

Mode	ν	η	$s_{\nu\eta}$
1st radial	0	1	3.8317
2nd radial	0	2	7.0156
3rd radial	0	3	10.1734
1st tangential	1	1	1.8413
2nd tangential	2	1	3.0543
3rd tangential	3	1	4.2012
4th tangential	4	1	5.3175
5th tangential	5	1	6.4154
6th tangential	6	1	7.5013
1T, 1R combined	1	2	5.3313
2T, 1R combined	2	2	6.7060
3T, 1R combined	3	2	8.0151
4T, 1R combined	4	2	9.2825
1T, 2R combined	1	3	8.5263

For a longitudinal mode the frequency can be estimated by:

$$f^* = \frac{C_o^* \times 12}{2 \, (L_c^* + 2/3 \, L_N^*)} \, (1 - M_m^2)$$

where: L_N^* = length of nozzle in inches.

M_m = average Mach number in nozzle-chamber combination

I, B, Technical Description (cont.)

The combustion chamber geometry is an important factor in high frequency combustion instability because the possible frequencies depend on the internal geometry. Since it is effectively closed at one end by the injector and has a choked-flow exhaust nozzle at the other end, the chamber acts acoustically much as a double closed-end cavity. For instance, for purely longitudinal modes, an approximate point of effective reflection in the nozzle can be determined theoretically; between that point and the injector face standing patterns of acoustic waves can be established. Similarly in the transverse plane, tangential modes of the spinning or standing types as well as radial modes may be established. Frequencies correspond approximately to those of the acoustic modes, either the fundamental or higher harmonics. Modes containing combinations of tangential, radial and longitudinal oscillations may also exist, each characterized by its own frequency. Pressure and velocity patterns for several transverse modes are illustrated in Figure 2. However, despite the similarity of the modes and the closeness of frequencies, the continuous generation of gases produces effects that do not exist in a closed chamber. In a closed chamber, the only source of damping originates from the friction on the walls. This source of damping is active of course also in the combustion chamber, but it plays a very modest role compared to other, more powerful sources of damping. Indeed, the very existence of the nozzle produces damping in the case of pure or combined longitudinal modes because the reflection of waves from the convergent (subsonic) portion of the nozzle departs from that of the ideal closed end. For purely transverse waves this source of damping is missing, and actually is replaced by a slight source of amplification.

The most important source of damping, however, is related to the process of gas generation itself, and consists of two parts of approximately equal importance. The most obvious comes from the fact that, from the conditions of the steady propellant injection flow (steady, of course, only if the feed system perturbations are disregarded) the combustion gases must have

I, B, Technical Description (cont.)

acquired, at the moment of generation, the perturbed momentum corresponding to the oscillatory flow. The acquisition of this momentum demands a certain work which must be absorbed from the system. The fact that momentum exchanges due to the drag of the droplets can take place prior to the moment of generation can only add additional damping.

The other, more subtle source of damping comes from the fact that at the moment of generation the volume of the propellant must change from its practically negligible liquid volume, to the full volume of the burned gases. To this change of volume corresponds a certain "pumping work" proportional to the local instantaneous pressure. Hence, more work must be absorbed from the system when the pressure is higher, and less when it is lower, thus providing an effective damping mechanism.

The significance of the preceding discussion is that, from the point of view of instability, each combustion system is characterized by certain well-defined proper frequencies at which the gases can oscillate in well-defined modes, and by certain damping mechanisms which absorb energy from the oscillating system. It is clear that self-sustained oscillations can exist (and instability appear) only if the combustion process is able to generate, at any one of the proper frequencies, enough feedback combustion energy (in excess of the steady-state conditions) to restore continually the amount which is being lost.

Suppose, for a moment, that the amount of combustion feedback energy is independent of frequency. Then the only important factor in the balance would be the energy damping corresponding to each mode, that (or those) mode(s) becoming unstable which correspond(s) to the lowest level of damping. Experience shows that this is not the case, and that, for a given injector, the selection of the unstable mode is rather governed by its proper frequency than by its damping level. This has been shown to be the case both for

I, B, Technical Description (cont.)

longitudinal and for transverse forms of instability. In both it has been possible to observe the switch from one unstable mode to another (for instance from the fundamental to the second mode) when the geometrical (or other) conditions are gradually changed. It is not our purpose to discuss here the details of the transition from one mode to the other (it does not take place suddenly), but rather to point out that the transition occurs in such a way as to maintain the oscillation frequency within a well-defined narrow range.

The only logical interpretation of this observation is that not only the combustion feedback energy must depend on frequency, but that actually only in a narrow range around one, well defined, frequency (determined in a complicated way by the various geometrical, physical and chemical conditions on which the combustion process depends), can the combustion feedback energy reach a level sufficient to balance the damping.

The empirically observed existence for a given combustion system of one narrow frequency range in which instability can appear can be interpreted by stating that, among the features characterizing the response of a given combustion system to oscillatory conditions, one can single out a "characteristic time" simply proportional to the reciprocal of frequency, such that only when its ratio to the oscillation period is around a certain value, maximum feedback can be generated and, possibly, instability produced.

This behavior has similarities to that of a resonant system, which is able to oscillate at certain natural frequencies with amplitudes that depend on the value of the frequency of the exciting forces compared to those of the natural frequencies. In the combustion instability problem also the exciting force due to the unsteady combustion processes is characterized by its own frequency (or its characteristic time), and maximum amplitudes are to be expected where there is coincidence with one of the proper frequencies.

I, B, Technical Description (cont.)

However, there is an important difference, residing in the fact that the exciting force is not independently applied from the outside, but is produced (in a sort of feedback loop) by the oscillations themselves, with the result that considerations of stability appear and take fundamental importance, and that the eventual oscillatory situation is determined by nonlinear effects. Nevertheless the terms "resonance" and "resonant" are often applied also to this case.

It appears that the knowledge of the characteristic time associated with a particular combustion system would be of primary importance in the design of new rockets, since it determines in which mode instability is able to appear. Such a knowledge could, for instance, allow the choice of the chamber and injector geometry in such a way that all of the proper frequencies would be too high to become unstable. Unfortunately, even assuming the characteristic time to be known, the choice of the propellant combination, as well as the chamber and basic injection system geometry, has always been fixed in the past during the early stages of development programs based on other stringent requirements of size, weight and performance, and there is very little chance that even in the future the designers may base their designs only on stability requirements. Therefore, a more sophisticated approach to the problem of stability is necessary, in which the second condition for appearance of instability, that of the energy balance, is also taken into consideration. In other words, even if it is impossible to avoid having some of the proper frequencies fall in the range where they may become unstable for the given combustion system one should make sure that for the corresponding modes the combustion feedback is not sufficient to balance the damping.

Clearly there are two ways in which this balance can be improved in favor of stability: one is the depression of the combustion feedback, the other the increase of the damping. Of the two solutions, the

I, B, Technical Description (cont.)

second has been favored in recent times because it is better understood and hence easily controlled. Such damping devices as baffles or acoustic liners have been introduced, to the cost of more or less profound design complications, and have been very effective in producing substantial levels of damping, due to the dissipation caused by the devices. At the same time these devices also entail a change of the proper frequencies, and, in view of the previous discussion, this change can also have an effect on the balance.

On the other hand, the solution of depressing the combustion feedback has not been used in any consistent and systematic fashion, but only by looking for injector designs which, fortuitously or nearly so, result in the most stable operation on the test stand.

It may be added that a third, and the most effective solution, clearly consists in applying simultaneously the two solutions above, by (1) using an injector as stable as possible, and (2) adding a certain amount of extra damping to attain whatever safety margin is required.

The difficulty with a systematic application of the second (or the third) solution has been that the behavior of the combustion systems under oscillatory conditions is still very incompletely understood, so that it is impossible today, starting from the fundamental consideration of the basic physico-chemical processes involved, not only to predict the value of the characteristic time or the magnitude of the energy feedback, but often even the very direction in which these quantities are affected by a change in design.

However, a less fundamental approach exists, which may still help the designer considerably, that is based upon the idea of establishing empirical correlations between the characteristic time and the energy feedback on one side and, on the other side, a certain number of appropriate combinations of parameters characterizing the injector geometry, the propellant mixture and the

I, B, Technical Description (cont.)

operating conditions. The feasibility of such an approach is offered by the sensitive time lag concept, introduced by Crocco in 1951 (Ref. 1). Although originally formulated with the sole intent of gaining an insight into the essential features of the high frequency instability phenomenon, the sensitive time lag combustion model was later found to predict accurately the quantitative behavior of the system in quite a few cases. In fact, this was beyond the expectations for such a heuristic approach.

This is indeed the primary advantage of the sensitive time lag concept, that the complexity of the actual combustion process can be avoided through the use of a very small number of lumped parameters. This is not to say that phenomena, such as droplet breakup, vaporization, mixing, chemical reactions, etc., are not important in determining stability and performance characteristics, but rather that, lacking such specific knowledge, the general nature of the coupling between the chamber conditions and the combustion process may still be described.

According to the Crocco model, the dynamic aspects of the injection-combustion process that are of significance in high frequency instability are characterized by a time lag, which is sensitive to the local, instantaneous values of pressure, temperature, gas velocity, etc. The degree of sensitivity is measured by one or more interaction indices. The sensitive time lag, then, plays the role of the above discussed characteristic time, while the interaction indices, properly combined, hold the key to the magnitude of the energy feedback. Thus, the occurrence of high frequency combustion instability is seen to result from the matching of the sensitive combustion time lag with one of the proper frequencies of the combustion chamber, provided that the degree of sensitivity of the combustion is sufficiently large to offset the damping effects present in the chamber. The stability conditions can then be expressed only in terms of the time lag and the interaction indices, and the ways to stabilization are easily discussed.

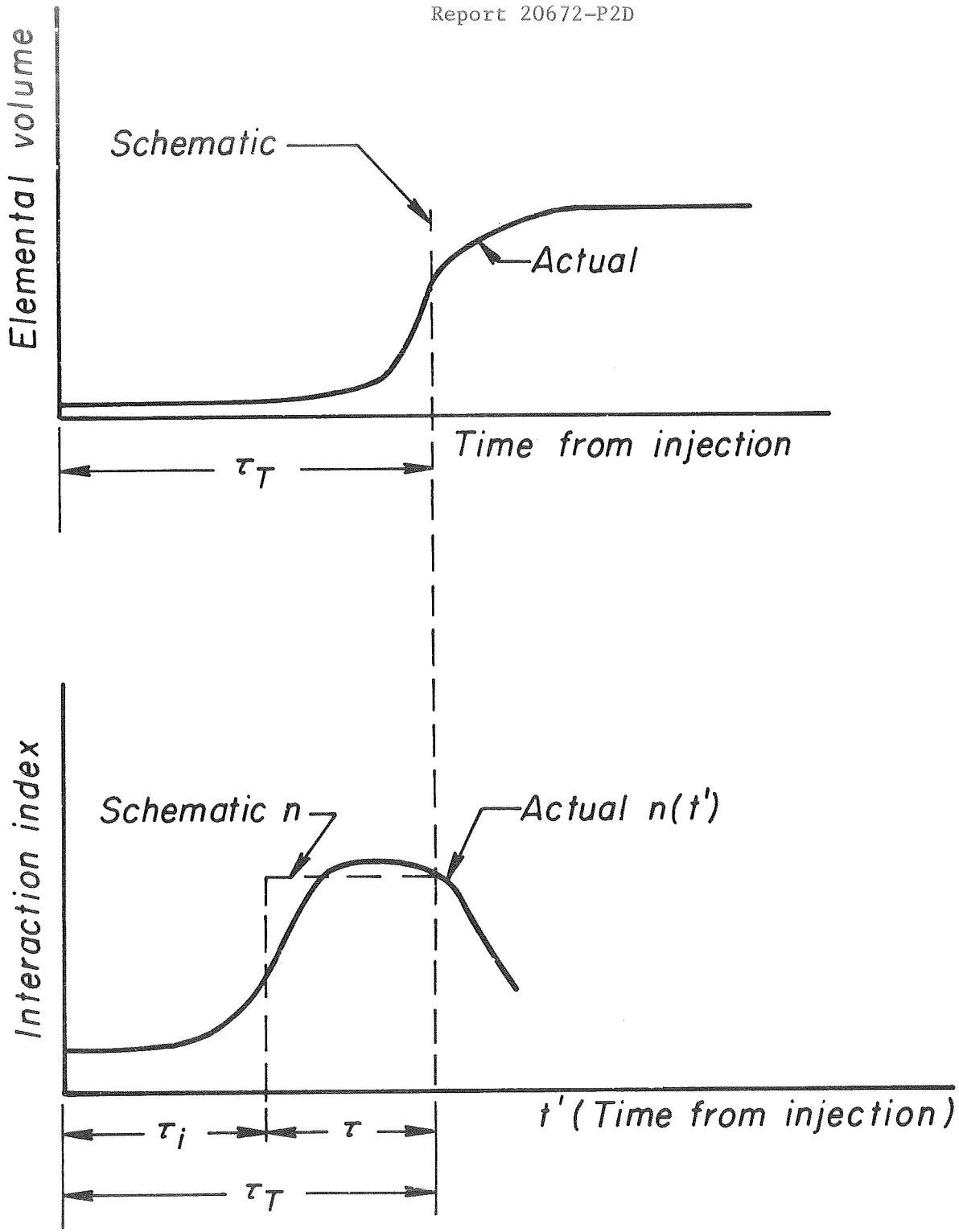


Figure 3 -- Time Lag Schematization

I, B, Technical Description (cont.)

2. The Sensitive Time Lag Concept

The liquid propellant combustion process may be represented schematically as in Figure 3, which shows the volume of a propellant element from the instant of injection until conversion to final combustion products is accomplished. Initially, in the liquid state, the volume is small. The conversion to gaseous products takes place more or less gradually, depending on the degree of atomization, the intensity of mixing, the chemical nature of the reactants, and so on. This gradual change is replaced, for analytical simplicity, by a step function, as shown in Figure 3. This is not to say that the combustion process is thought to occur instantaneously, but that such simplification may reasonably describe the essential nature of the combustion process from a dynamic point of view. The step function approximation of the overall combustion process defines a characteristic time, called the "total time lag" for the propellant element considered and denoted by τ_T. This time, of the order of a few milliseconds, is not representative of the characteristic times of high frequency instability. Rather, the total time lag is basic to the low frequency type of combustion instability. However, the total time lag, together with the velocity history of the injected propellants, determines the space lag, that is, the location in the chamber at which combustion of the particular propellant element is taking place. It is this aspect of the total time lag that cannot be disregarded when considering high frequency instability. This point will be discussed further in a later section. It suffices to say here that the step function approximation is compatible with any combustion distribution in the chamber, since τ_T can be different for different propellant elements.

The lower diagram of Figure 3 illustrates the important concept that not all of the processes that occur during the combustion of liquid propellants are equally affected by the combustion environment. Consider first only the effect of pressure (and correlated temperature) oscillations.

I, B, Technical Description (cont.)

Initially, only liquid streams, ligaments, or relatively large droplets are available in conditions unfavorable to combustion. It is to be expected that pressure perturbations interact only slightly with propellants in that degree of preparation. In the later portion of the preparation phase (as the nominal τ_T value is approached), droplets are small and interspersed; moreover fuel and oxidizer species are mixed. Hence, burning rates are readily influenced by instantaneous pressure changes. This increased sensitivity to disturbances in pressure and temperature is represented on the figure by a higher instantaneous "pressure interaction index", n. The portion of the total time lag that is associated with this high sensitivity can be attributed an approximately constant mean value of the interaction index and is called the "sensitive time lag", denoted by τ. The early portion is referred to as the "insensitive time lag", τ_i, and the corresponding interaction index is taken to be zero. Again, the step-function approximation is useful to reach a simple analytical description. The sensitive time lag is of the order of a few tenths of a millisecond (an order of magnitude smaller than the total time lag). It plays the role in the frequency combustion instability of the "characteristic time" discussed previously. The energy feedback resulting from pressure oscillations can be calculated in terms of τ and the interaction index, n. Similarly the energy feedback resulting from gas velocity oscillations can be calculated in terms of a velocity-sensitive time lag (which may coincide with the one already defined) and of an appropriate "velocity interaction index", and the same would apply to the interaction with other possible physical quantities.

In the schematic representation just discussed two (or more) combustion parameters have been defined that are of key importance to further discussions of high frequency instability. The first is the sensitive time lag, τ, which places the combustion process in proper perspective with the times corresponding to the various acoustic modes associated with the chamber geometry. The second parameter, the interaction index, n (and, possibly, other parameters, representing the additional interaction indices of relevance), must exceed a certain minimum level if the damping is to be balanced and self amplifying or sustained oscillations are to be generated.

I, B, Technical Description (cont.)

These points are further clarified (where only one interaction index is relevant) by a stability diagram using τ as the abscissa and n as the ordinate (Figure 4), relative to the first tangential (1T) mode. As already observed, the resonant behavior of the system is such that the maximum amount of energy feedback is obtained when the ratio of the characteristic time to the oscillation period (in this case of the 1T mode) is around a certain value (which for the present simple combustion model is 1/2). At the corresponding value of τ, evidently, the damping processes can be balanced with the minimum value of n_{min}. At other values of τ the effectiveness of the feedback process decreases, and hence larger values of n are required to reach the balance, the values increasing with increasing deviations of τ from the value of maximum effectiveness. The curve of Figure 4 represents, for the given mode, the n-τ combinations for which a balance between feedback and damping is obtained. If, for given τ, n is smaller than the value which produces the balance, perturbations will decay as a result of the excessive damping; if on the contrary n is larger, perturbations will amplify as a result of the excessive feedback. Hence the curve provides the stability boundary between the stable region of Figure 4 (under the curve) and the unstable region (above the curve).

A given combustion system is characterized by a certain value of the interaction index. If this value is less than n_{min} no instability at all is possible. If the interaction index is just equal to n_{min}, then instability is possible, but only if the matching of the proper time of the chamber and the characteristic combustion time is perfect. For $n > n_{min}$ the time-matching requirement is less stringent, i.e., a certain mismatch of the times will still result in instability. As the value of n increases, the amount of allowable mismatching also increases.

For other modes than the 1T mode, the stability boundary can be represented in a similar way, the scale of τ properly shifted. Putting the stability boundaries corresponding to different modes on the same plot results

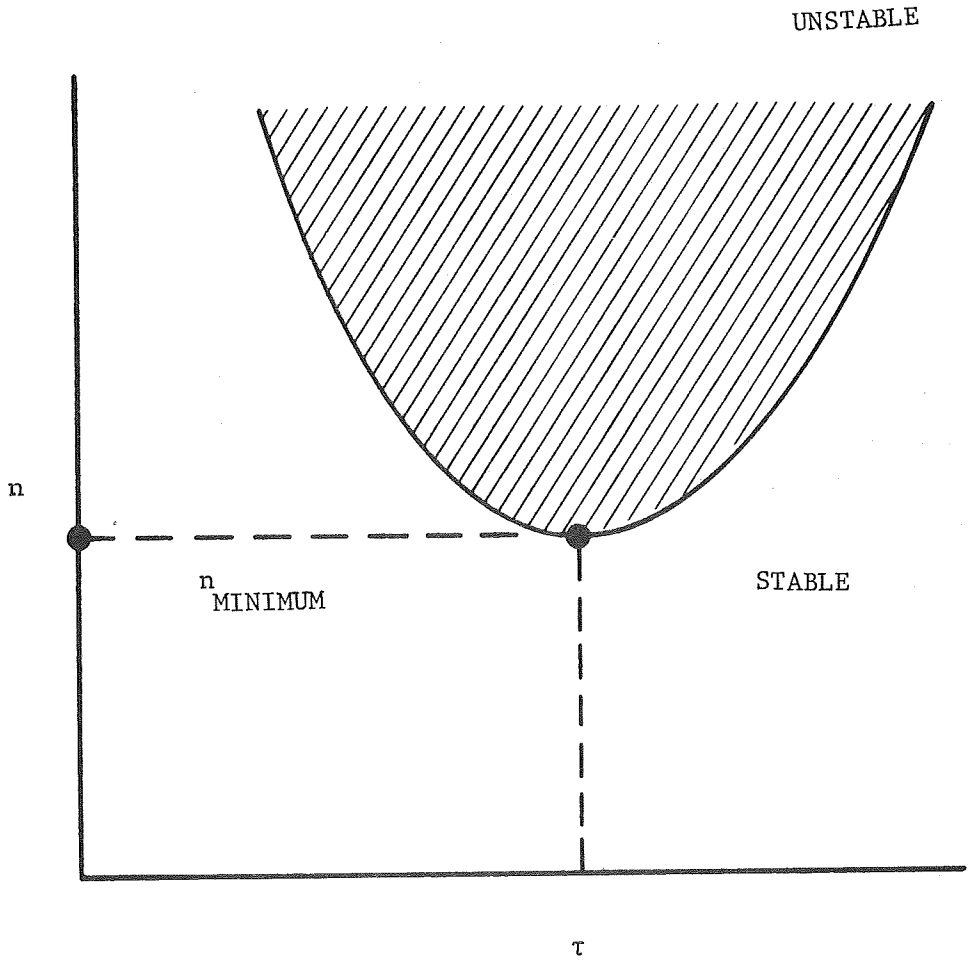


Figure 4 -- Stability Diagram, n, τ, - Plane

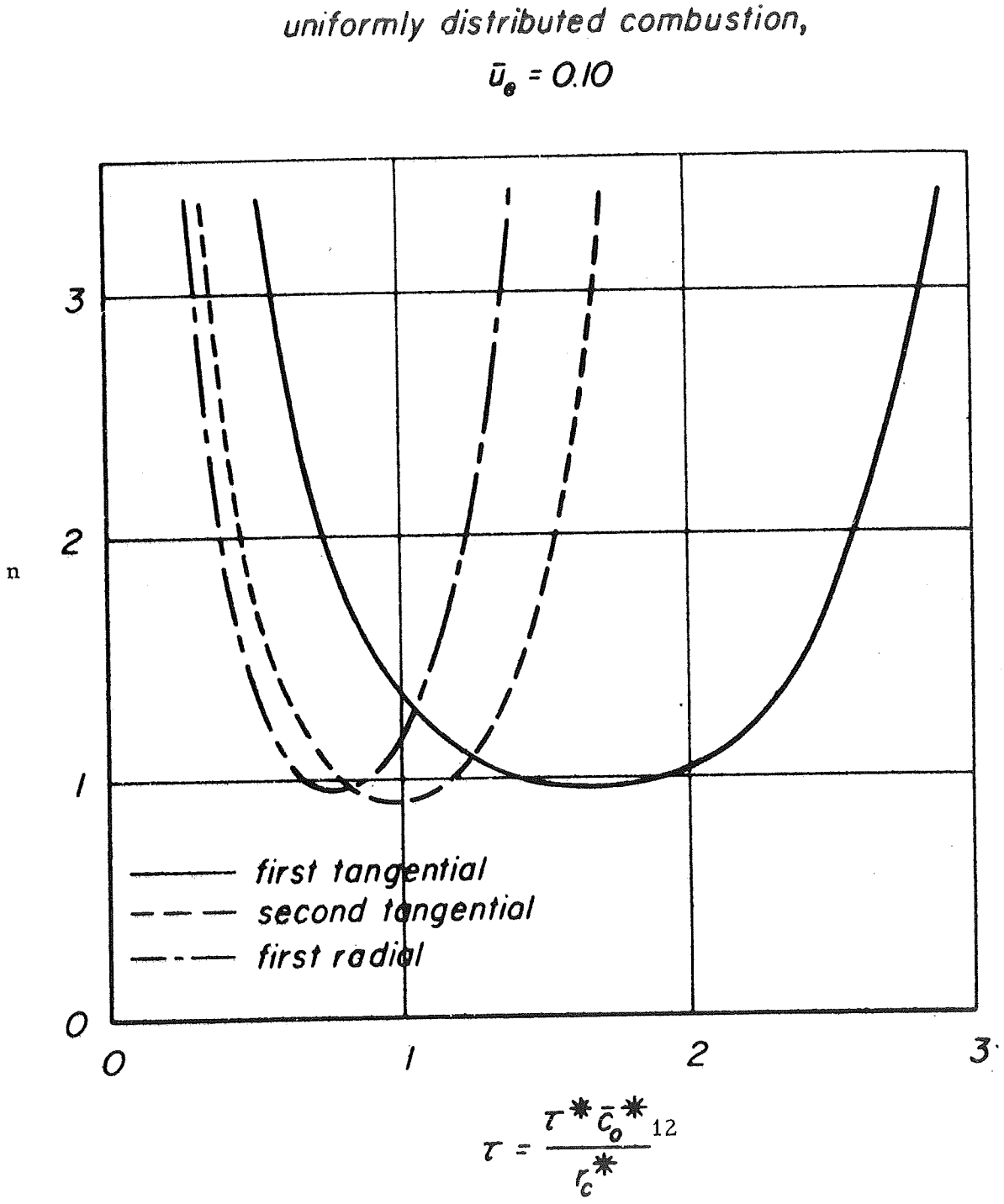


Figure 5 -- Theoretical Stability Limits for Several Purely Transverse Modes

I, B, Technical Description (cont.)

in Figure 5, where an overall stability region, regardless of mode, is now evident. Plots of this kind are fundamental to the methods to be discussed extensively in this report. However, two remarks, to be substantiated later, should be made.

The first remark is that such a clearcut boundary between stability and instability is obtained only if the perturbations are assumed to be of small amplitude. This is indeed the assumption on which most of the theoretical developments on combustion instability have been based. Within this assumption all effects of the perturbations can be assumed to vary linearly with the perturbation amplitudes, the mathematical treatment is accordingly substantially simpler, and the (linear) stability boundary unequivocally defined, the linearly unstable region being practically interpreted as that in which oscillations grow spontaneously out of the random combustion noise. However, in real practice the perturbations are not necessarily limited to the range where all of their effects vary linearly with the amplitude, and when the contrary happens important nonlinear effects may appear. Some effects of nonlinearity can be derived theoretically, at the cost of substantial mathematical complexities. But what is important to the present qualitative discussion is that, while the linearly unstable region always remains a region of instability, the corresponding statement for the linearly stable region is not true. In other words, a system corresponding in the n-τ plane to a point of the linearly stable region may be triggered into amplifying or self-sustaining oscillations by a perturbation (for instance, a pulse) of sufficiently large amplitude. Only if the pulse remains under a certain critical level do the resulting oscillations decay - in agreement with the predictions of the linear theory. This nonlinear behavior plays an important role in rockets, and has to be taken into account when interpreting the experimental results.

I, B, Technical Description (cont.)

The second remark is that the curves of Figures 4 and 5 depend not only on the chamber and nozzle geometries, but also on the transverse and longitudinal distributions of combustion, the first being substantially determined by the distribution of the injection flux across the injector, the second by the details of the individual combustion processes (such as atomization, evaporation, mixing and chemical reactions, recirculation flow, etc.). The significance of the total time lag τ_T in this connection has been mentioned already. Large values of τ_T, other factors being equal, will spread the combustion toward the nozzle end of the chamber. If the total time lag is too large for the chamber in question, performance will suffer because of incomplete burning prior to the nozzle entrance. Since the region of maximum combustion is closely associated with the region where propellants have reached the sensitive state in the preparation process, it is in this general location that interaction between the combustion process and the acoustic modes reaches a maximum level.

For the fundamental longitudinal mode, pressure antinodes are found at the injector and the nozzle end of the chamber, as shown in Figure 6. Higher harmonics will have additional pressure antinode locations. If combustion is uniformly distributed from one end of the chamber to the other, maximum instability coupling cannot take place since there is a region (or regions, in the harmonics) in which a pressure nodal environment is approached. If the wave is sinusoidal, a true node is found; otherwise, only an oscillation with reduced amplitude will be observed. The limiting case of a non-sinusoidal wave is that of a shock wave, the amplitude variation of which is shown in Figure 6. In the nodal region, even with proper time phasing, too little energy is available from the increased burning rate to cause the pressure oscillations to be amplified. However, if combustion is concentrated at the injector end, the best environment for energy transfer to the pressure oscillations is provided.

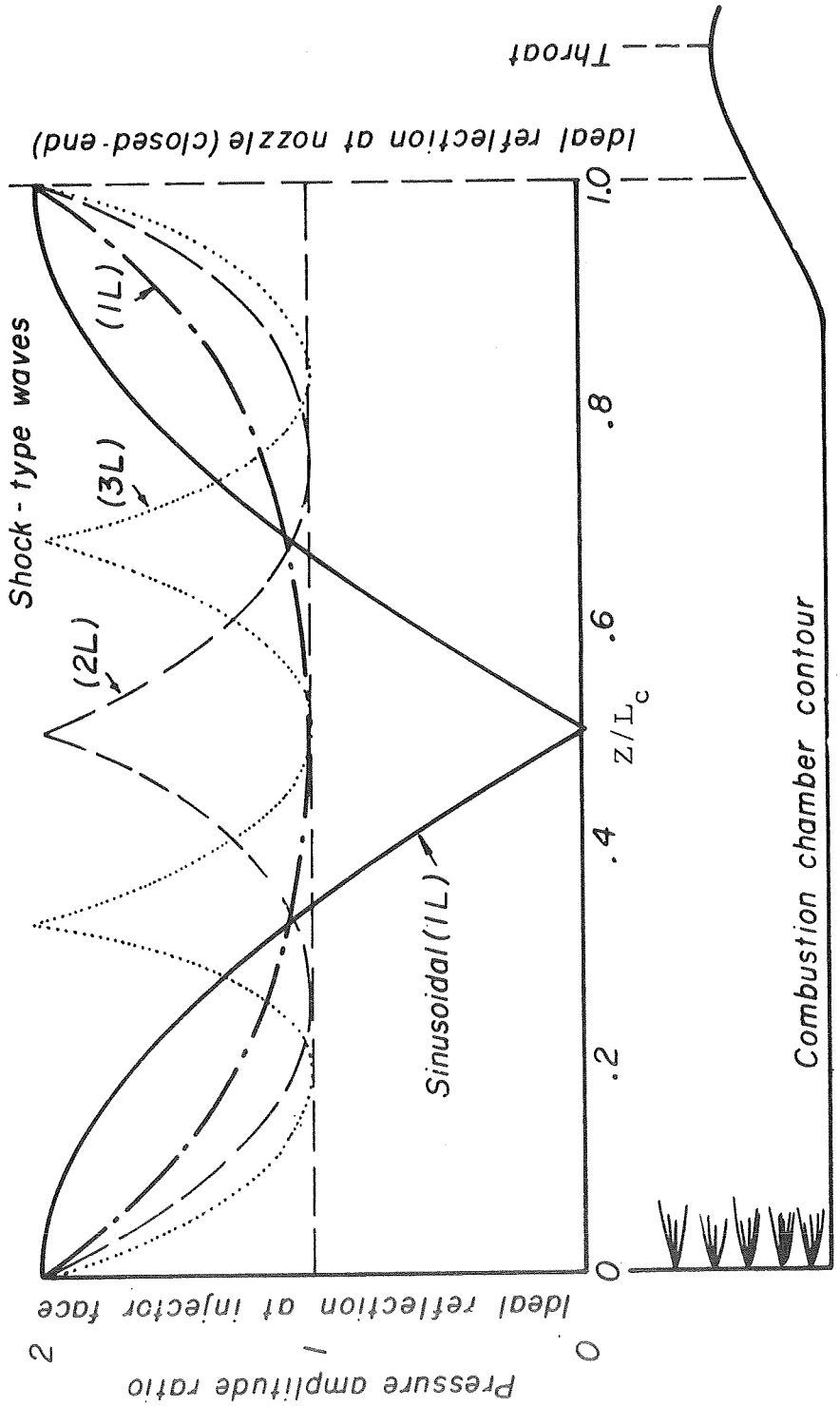


Figure 6 -- Axial Pressure Variations for Several Longitudinal Modes

I, B, Technical Description (cont.)

The steady state combustion rate is approximately proportional to the rate of change of axial gas velocity with distance from the injector. Typical velocity profiles are shown in Figure 7. Two extremes are apparent: (1) the concentrated combustion case in which near-maximum gas velocities are produced within a short distance from the injector, as shown by curve "A", and (2) the nearly uniform combustion case in which the axial velocity curve is nearly linear, as represented by curve "B". Rocket experience has shown that the actual velocity distributions fall within these extremes. Thus, combustion concentrated near the nodal point and combustion concentrated near the antinode at the nozzle end are both unrealistic situations.

The transverse modes may also be discussed on a somewhat similar basis. Experimental measurements at a number of laboratories have shown that maximum amplitudes for the tangential modes are always found at the injector end. Thus, to reduce coupling, axially distributed combustion can offer considerable improvement as compared to the concentrated combustion case, just as was found for the longitudinal mode. In the radial direction the combustion distribution picture is more complicated. As shown in Figure 8, pressure oscillation amplitudes vary radially, and the vibration is strongly dependent on the mode. The first and second tangential modes are similar to each other but quite different from the first radial mode. To promote instability in the first tangential mode, assuming that the n, τ values are suitable, one would choose an injector design that would provide rapid burning (i.e., small τ_T, to keep the combustion near the injector face) and would have the injection orifices concentrated at the outer radii. Either spreading the combustion axially or moving the injection toward the center of the chamber would reduce the degree of coupling. If the first radial mode is also considered, then a compromise location near the half-radius point would prove to be the best injection point. This principle has been verified in an investigation of a number of injection distributions by the Aerojet-General Corporation using high-thrust hardware (Ref 2).

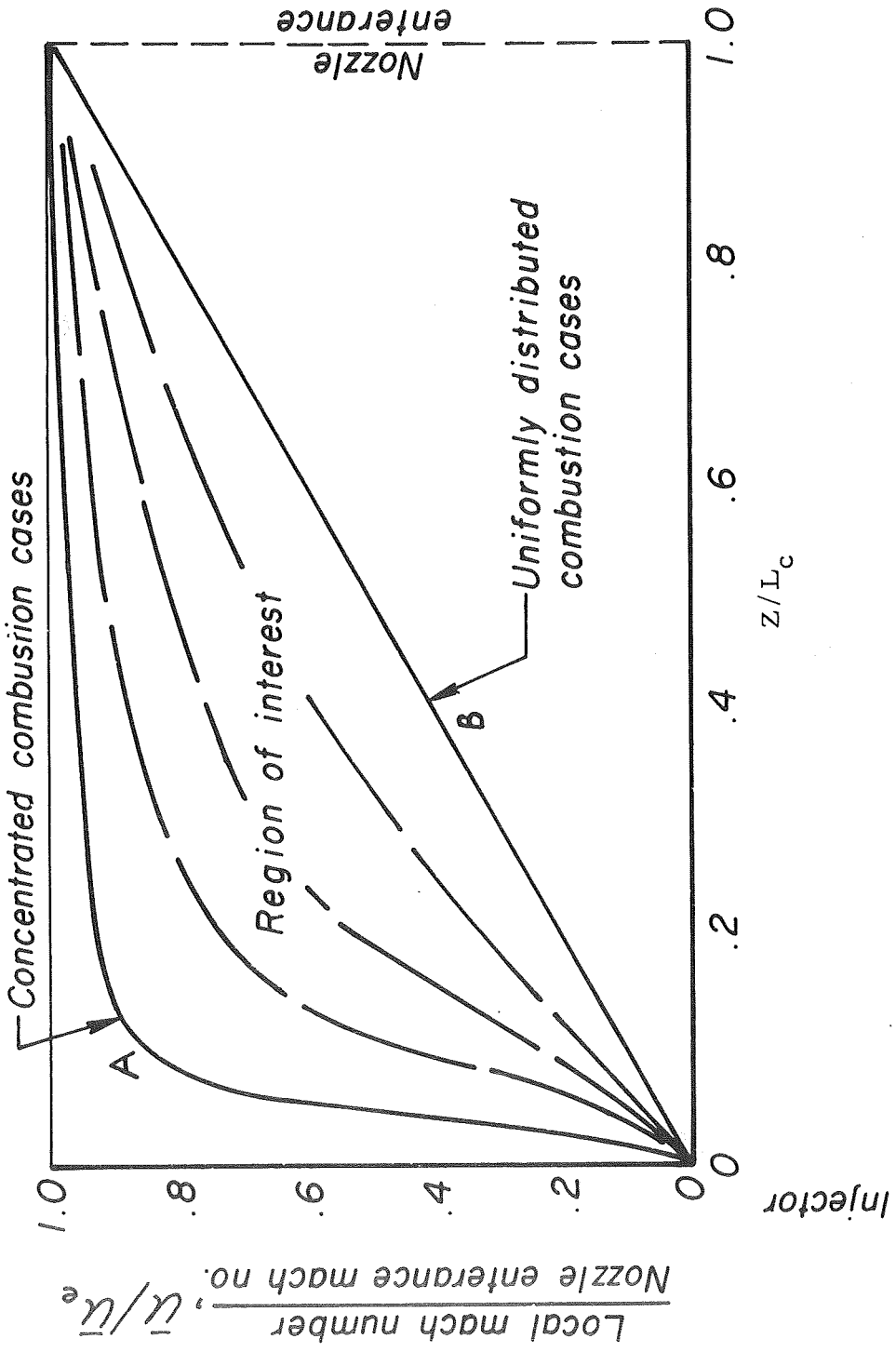


Figure 7 -- Typical Combustion Distributions

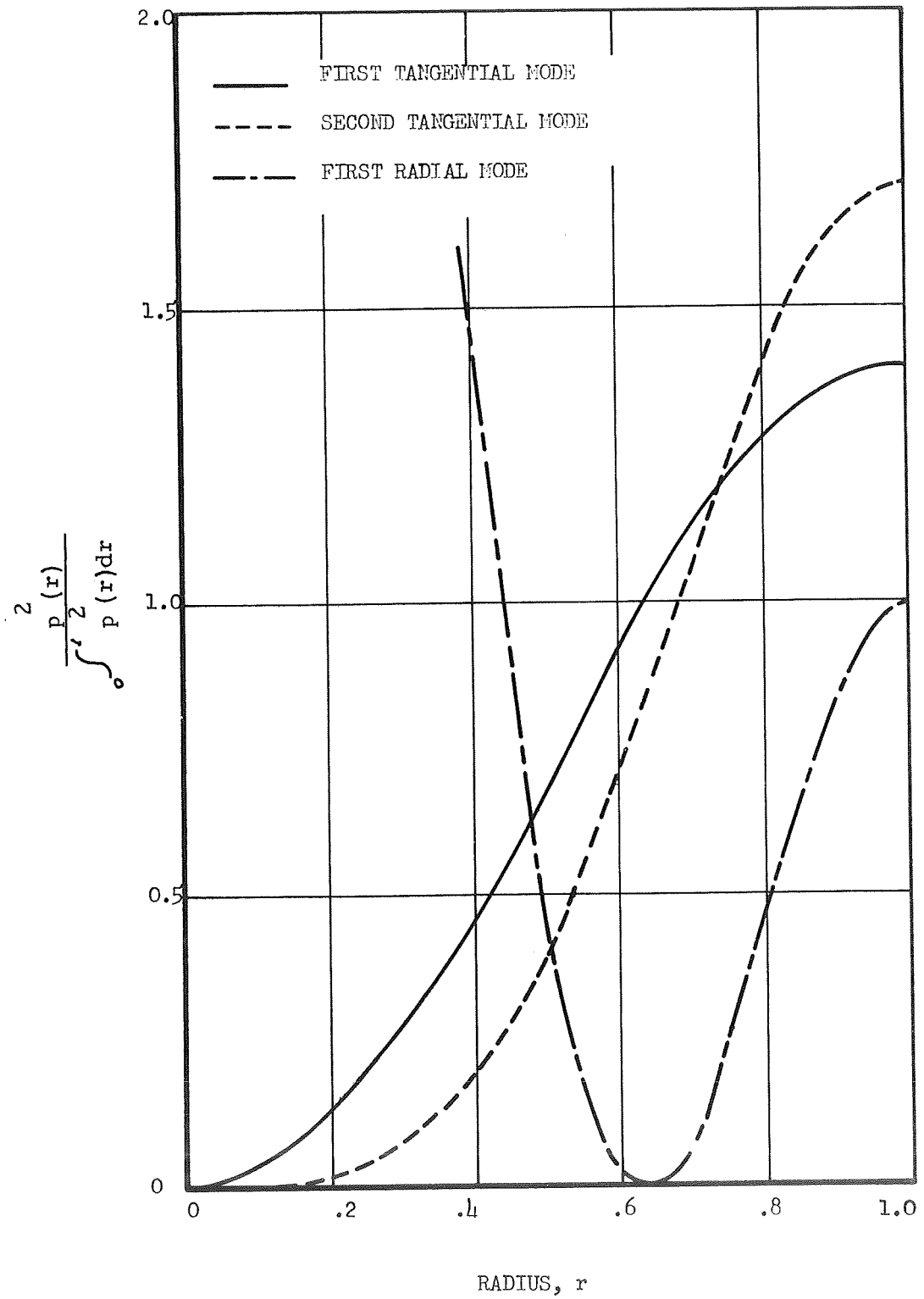


Figure 8 -- Pressure Non-Uniformity Coefficient for Concentrated Combustion

I, B, Technical Description (cont.)

The qualitative discussion just given is based on the assumption that there is only one relevant interaction index. When more than one has to be taken into account, the effect of each additional interaction index produces a displacement of the stability boundaries in the n-τ plane, and the interpretation becomes correspondingly more difficult. Effects of this kind are found, for instance, when the combustion rates are sensitive to the transverse velocity perturbations characteristic of transverse oscillations. One can visualize important coupling mechanisms related to the inequalities in the displacements of liquid drops and propellant vapors that are produced by such oscillations. The local mixture ratio can be altered, with resulting changes in the burning rate, if one of the propellants is displaced with respect to the other. Even with unlike-impinging injector elements such an effect exists, but it may be especially significant in like-on-like designs, where the fact that a certain level of displacement must be reached before significant alterations of mixture ratio occur, may result in a particular type of triggering into nonlinear instability.

It is interesting in this connection to observe that this effect may be particularly intense in the region immediately adjacent to the injector where one can expect droplets and vapors to be present in abundance, and in very unmixed conditions. Thus, it is clear that in the use of baffles and liners there must be a consideration of the combustion distribution in the chamber. In general, it has been found that for tangential modes the oscillation amplitudes are greatest at the injection end of the chamber, combustion rates are maximum a few inches from the injector and coupling between the combustion process and tangential waves is greatest in the outer regions of the injector face. If the chamber volume is subdivided by baffles, the dimensions of the cavities between baffles determine the period of oscillation. Combining these principles, it is concluded that if baffles are to be used to control tangential modes they must be placed at the injector end, they must

I, B, Technical Description (cont.)

protect the preparation zone found in the first few inches downstream of the injector, they must extend as close as possible to the chamber wall, and the circumferential blade spacing must be small enough to prevent cavity modes from existing. Similarly, acoustic liner orifices are most effective near the injector end of the chamber, and liner absorption characteristics must be designed to match the resonance properties of the chamber and the combustion process, as described by the sensitive time lag theory.

3. Development of the Sensitive Time Lag Theory

The historical background of the development of the sensitive time lag theory is important to the understanding of the concepts described in the preceding section. The earliest published paper on combustion instability theory was that of Gunder and Friant (Ref 3) in 1950, with a subsequent discussion by Yachter (Ref 4). Probably the most important contribution of these early treatments was the introduction of the concept of a combustion time lag (conceived independently, but not published, by other groups) between the instant of injection of a propellant element and the succeeding instant of burning, in which the propellant element is transformed into hot gas capable of contributing to the chamber pressure.

Interest at Princeton University in the problem of combustion instability in liquid propellant rocket motors was given impetus by a Bureau of Aeronautics Symposium held at the Naval Research Laboratory in December, 1950. This interest resulted in theoretical analyses by Professors Summerfield and Crocco.

Professor Summerfield's work (Ref 5) considered the effects of inertia in the propellant feed lines and the capacitance of the combustion chamber, assuming a constant combustion time lag. His analysis treated the case of low frequency oscillations for frequencies up to about 200 cps.

I, B, Technical Description (cont.)

Professor Crocco advanced the concept of the pressure dependence of the combustion time lag. His paper (Ref 1) presented the fundamentals resulting from this concept. In his paper, Crocco treated the case of low frequency instability in a bipropellant rocket, and also the case of high frequency instability with combustion concentrated at the injector end of the combustion chamber.

The analytical work on the high frequency case was continued by S. I. Cheng under the direction of Professor Crocco. His studies of the effects of the axial distribution of combustion (on the longitudinal modes) were published as his Ph.D. thesis. A thorough discussion of these and other aspects of the theory was published by Crocco and Cheng in 1956 as an AGARD monograph (Ref 6). The general theories of low and longitudinal high frequency instability, the effects of the combustion distribution, the influence of the exhaust nozzle, as well as the (scarce) experimental evidence substantiating the analyses were all discussed at length. A brief discussion of the transverse modes of combustion instability was included, and general adherence to the sensitive time lag model was predicted.

The extension to the transverse modes was initiated by S. M. Scala (Ref 7). Following Crocco's pressure dependence model, he determined the fundamental behavior of the transverse modes, including the influence of the nozzle. In addition, Scala treated the case of intermediate frequency instability, in which the coupling mechanism consists of entropy perturbations, generated by off-design mixture ratio combustion, which reflect from the nozzle as pressure waves and propagate back to the injector to cause perturbations in the injection rates.

I, B, Technical Description (cont.)

The study of transverse instability was continued by F. H. Reardon (Ref 8), who developed several extensions to the basic theory to explain certain experimental results (which are discussed in the following section). The sensitive time lag concept was extended to include sensitivity to the transverse components of the oscillating gas velocity. The effect on the combustion rate was visualized in the oscillatory displacement of the vapors of one propellant with respect to the liquid droplets of the other. In addition, Reardon introduced an approximate treatment of the effects of nonuniform distribution of propellant injection on the transverse modes, and applied the modified theory to a sector-shaped combustor, which simulates the "pocket-mode" behavior of a baffled chamber.

I, B, Technical Description (cont.)

4. Theory

a. General Approach

The simplifying assumptions on which the mathematical treatment of combustion instability is based are the following:

(1) The substance contained in the combustion chamber is either in the form of liquid propellants, of practically zero volume, or in the form of complete combustion gases. It will be noticed that this assumption disregards the contribution of the propellants in vapor form, and of the intermediate products of combustion. Hence the assumption is equivalent to saying that not only the liquids, but also the vapors and the intermediates occupy a negligible volume compared to the final products of combustion. This assumption (first used by Crocco in Ref. 1) is actually in agreement with the step-function combustion model discussed in Section I. Even more important, it represents quite well the actual conditions in rockets where indeed, with the exception of the region immediately adjacent to the injector, practically the same gas temperature is observed throughout the chamber. Of course, it is clear that the above is true when using liquid propellants, and not for the combustion of gaseous propellants. The difference is that while in the latter case there is a constant mass flux with energy addition, in the case of liquid propellants the gas flow has a variable mass flux with energy addition being produced through an addition of mass to the gaseous flow.

(2) The combustion gases are of constant composition, they obey the perfect gas law and have constant specific heats.

(3) Frictional effects on the walls are neglected, and only those are taken into account which result in the liquid droplet drag.

I, B, Technical Description (cont.)

Also, Reynolds stresses associated with the high turbulence level caused by combustion are neglected, in spite of the fact that they may play an important role with respect to the uniformity assumption (Assumption 5).

(4) The flow of injected propellants is unaffected by oscillations in the chamber, and hence the injection flux and velocity are always the same as in steady conditions. This assumption is not necessarily verified in actual rockets where, especially for large rockets, the possibility of matching the wave propagation times in the feed lines and in the chamber may lead to interactions. However, the assumption is rather good if matching is avoided, and substantially simplifies the treatment by making the chamber behavior independent of the feed system varieties and complexities. The resulting instability problem has been termed "intrinsic instability" of the combustion chamber.

(5) The steady-state gas flow is uniform across any chamber section. This is possible partly because the previous assumption allows the boundary layer formation on the walls to be disregarded. However, it involves more. For instance, it would require the injected propellants to be uniformly distributed so as to produce no recirculation. Of course, this is not the actual situation, and the uniform flow considered in the theory should be interpreted as an average flow from which the actual flow can depart substantially if the injection is far from being uniform. For large rockets the injection systems are generally rather uniform, and hence the uniformity assumption can be quite accurate. However, it will be seen in the following that transverse stability conditions can be improved by using particular non-uniform injection systems. It is felt that the contradiction that results in these cases is not very important for not too large flow Mach numbers because of the strongly equalizing effects of the high turbulence due to combustion.

I, B, Technical Description (cont.)

(6) In steady-state, the total energy (internal and kinetic) of the droplets remains constant. Obviously this is not exactly true, because of the heat exchanges affecting the internal energy and the droplet drag affecting the kinetic energy in ways that are not so simply related. The assumption has, however, the advantage of providing a substantial simplification of the treatment, and it is believed not to hide any of the fundamental effects.

(7) The steady-state flow in the nozzle is one-dimensional. Although not true, this assumption is known to result in very accurate predictions concerning the steady flow itself. Here, however, the same assumption is extended to the treatment of the oscillatory nozzle flow obtained when the steady flow is perturbed. It should be observed that this assumption is consistent with that of uniform steady flow in the chamber (Assumption 5).

(8) The unsteady, oscillatory quantities in the chamber and in the nozzle can be obtained by superposing small perturbations to the steady-state quantities. By "small" is meant as usual, that only "linear" (first order) terms in the perturbations are to be retained, while terms containing products or powers of perturbations (second and higher order) are to be neglected. The great advantage of this assumption is of a mathematical nature, since the resulting equations, being linear, can be treated in a much simpler way. One of the simplications is that a harmonic time dependence can be chosen, as discussed under Assumption 10. But, of course, the disadvantage is that only the linear effects can be accounted for, all the nonlinear effects being left out. Under the small perturbation assumption only the "linear" stability problem can be attacked.

(9) The gas flow Mach number is always sufficiently small so that the square can be neglected compared to unity. Because of this assumption, the analysis cannot be applied to thrust chambers in which the Mach

number exceeds 0.3. Such is not an essential assumption; its relaxation leads only to complexity. This assumption does not apply to the longitudinal analysis.

(10) The time dependence of the perturbations can be expressed in complex form as exp (σt) where $\sigma = \lambda + i\omega$ is the same complex quantity for all perturbations. Here ω is the angular frequency and λ the amplification coefficient. As usual when using the complex representation each perturbation is obtained by multiplying the above exponential by a corresponding complex amplitude factor which is a function of the space coordinates only, and by taking the real part of the result. The assumption of exponential time dependence is common in problems of linear stability. It does not affect the generality of the result, since within the linear framework the development of the most general perturbation can be obtained from the superposition of independent components each behaving exponentially, and since, from the point of view of stability, the only thing that matters is that no single component should show amplification. Hence all the information required is the behavior of exponentially varying perturbations when the frequency is made to change over all possible values.

b. Governing Equations

(1) General Equations

The equations governing the unsteady, two-phase flow in the combustion chamber are derived from the principles of conservation of mass, momentum, and energy, and the equation of state, according to the assumptions discussed in the previous section. It is convenient to work with the equations in nondimensional form. The reference quantities for the nondimensionalization are taken as the stagnation gas properties at the injector face (pressure, temperature, density, and speed of sound) together with a

I, B, Technical Description (cont.)

reference length, which is the chamber radius for transverse modes. (The chamber length is generally used for longitudinal modes). The governing equations take the following forms:

Conservation of mass,

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{q}) = Q = -\frac{\partial \rho_L}{\partial t} - \nabla \cdot (\rho_L \vec{q}_L) \tag{1}$$

Conservation of momentum,

$$\rho \frac{\partial \vec{q}}{\partial \tau} + \rho \vec{q} \cdot \nabla \vec{q} + \frac{1}{\gamma} \nabla p = (Q + \kappa \rho_L)(\vec{q}_L - \vec{q}) \tag{2}$$

Conservation of energy,

$$\rho \frac{\partial h_s}{\partial t} + \rho \vec{q} \cdot \nabla h_s - \frac{\gamma - 1}{\gamma} \frac{\partial p}{\partial t} = Q (h_{Ls} - h_s) \tag{3}$$

Equation of state for the gas,

$$p = \rho T \tag{4}$$

Droplet drag (gas/liquid momentum interchange) using Stokes law,

$$\frac{\partial \vec{q}_L}{\partial t} + \vec{q}_L \cdot \nabla \vec{q}_L = \kappa (\vec{q} - \vec{q}_L) \tag{5}$$

And droplet energy,

$$\frac{\partial h_{Ls}}{\partial t} + \vec{q}_L \cdot \nabla h_{Ls} = 0 \tag{6}$$

I, B, Technical Description (cont.)

The symbols used in these equations are defined in Section I.D.

It is necessary to express the governing equations, (1) to (6), in steady state form and perturbed form. The separation is accomplished by writing all the dependent variables, as the sum of a steady state solution and an unsteady solution. For example,

$$p = \bar{p} + p' \, e^{\sigma t} \tag{7}$$

$$u = \bar{u} + u' \, e^{\sigma t}$$

It is noted that the perturbed portion of each parameter is harmonic with respect to time.

(2) Steady State Equations

The steady state solution is assumed to be one dimensional although the perturbations are considered in three dimensions. Therefore, the steady state vectorial components of gas velocity, q and liquid velocity, q_L are given by the following relationships:

$$\bar{\vec{q}} = \bar{u} \; , \; \bar{\vec{q}}_L = \bar{u}_L$$

$$\bar{v} = \bar{w} = \bar{v}_L = \bar{w}_L = 0 \tag{8}$$

where u, u_L are the axial components, v, v_L are the radial components, and w, w_L are the tangential components of $\vec{q}$, $\vec{q}_L$.

I, B, Technical Description (cont.)

Substituting the relationships given by (7) and (8) into (1) to (6) and neglecting the time dependence yields the following system of steady state equations:

Conservation of mass

$$\frac{d}{dZ} (\bar{\rho}\ \bar{u}) = \bar{Q} = - \frac{d}{dZ} (\bar{\rho}_L\ \bar{u}_L) \tag{9a}$$

Conservation of momentum

$$\frac{d}{dZ} (\bar{\rho}\ \bar{u}^2) + \frac{d}{dZ} (\bar{\rho}_L\ \bar{u}_L{}^2) = - \frac{1}{\gamma} \frac{d\bar{p}}{dZ} \tag{9b}$$

Conservation of energy

$$\bar{\rho}\ \bar{u}\ \frac{d\bar{h}_s}{dZ} = - \bar{Q}\ (\bar{h}_s - \bar{h}_{Ls}) \tag{9c}$$

Equation of state (gas)

$$\bar{p} = \bar{\rho}\ \bar{T} \tag{9d}$$

Droplet drag

$$\bar{u}_L\ \frac{d\bar{u}_L}{dZ} = \kappa\ (\bar{u} - \bar{u}_L) \tag{9e}$$

Droplet energy

$$\frac{d\bar{h}_{Ls}}{dZ} = 0 \tag{9f}$$

I, B, Technical Description (cont.)

It should be noted that at $Z = 0$, $u = 0$ and $\bar{p} = \bar{\rho} = 1$ because of the nondimensionalizing scheme. At $Z = L_c$, combustion is assumed to be complete so that $\bar{\rho}_L = 0$ and $\bar{Q} = 0$.

(3) The Perturbation Equations: Wave Equations

The perturbed equations are considered in three dimensional form in cylindrical coordinates and the resulting system of equations is linearized. That is, the perturbed quantities are considered to be small, and therefore, all products of two or more perturbed terms are considered to be zero. Substituting equations (7) and (8) into equations (1) to (6) yields the following system of equations.

$$(\sigma + \frac{d\bar{u}}{dZ})\ \rho' + \bar{u}\ \frac{\partial \rho'}{\partial Z} + \frac{d\bar{\rho}}{dZ}\ u' + \bar{\rho}\ (\frac{\partial v'}{\partial r} + \frac{v'}{r}$$

$$+ \frac{1}{r}\ \frac{\partial w'}{\partial \theta} + \frac{\partial u'}{\partial Z}) = \bar{Q}\ (Pp' + Rv' + Tw') \qquad (11a)^*$$

where

$$P = n\ (1-e^{-\sigma\tau}),\ R = 1_r\ (1-e^{-\sigma\tau}) = \frac{1_r}{n}\ P, \text{ and } T = 1_\theta\ (1-e^{-\sigma\tau}) = \frac{1_\theta}{n}\ P$$

Conservation of axial momentum

$$(\sigma\bar{u} + 2\bar{u}\ \frac{d\bar{u}}{dZ})\ \rho' + (\sigma\bar{u}_L + 2\bar{u}_L\ \frac{d\bar{u}_L}{dZ})\ \rho_L' + \bar{u}^2\ \frac{\partial \rho'}{\partial Z} + \bar{u}^2_L\ \frac{\partial \rho'_L}{\partial Z}$$

$$+ (\sigma\bar{\rho} + 2\bar{\rho}\ \frac{d\bar{u}}{dZ} + 2\bar{u}\ \frac{d\bar{\rho}}{dZ})\ u' + (\sigma\bar{\rho}_L + 2\bar{\rho}\ \frac{d\bar{u}_L}{dZ} + 2\bar{u}_L\ \frac{d\bar{\rho}_L}{dZ})\ u_L'$$

$$+ 2\bar{\rho}\ \bar{u}\ \frac{\partial u'}{\partial Z} + 2\bar{\rho}_L\ \bar{u}_L\ \frac{\partial u_L'}{\partial Z} + \bar{\rho}\ \bar{u}\ (\frac{\partial v'}{\partial r} + \frac{v'}{r} + \frac{1}{r}\ \frac{\partial w'}{\partial \theta})$$

$$+ \bar{\rho}_L\ \bar{u}_L\ (\frac{\partial v_L'}{\partial r} + \frac{v_L'}{r} + \frac{1}{r}\ \frac{\partial w_L'}{\partial \theta}) = -\frac{1}{\gamma}\ \frac{\partial p'}{\partial Z} \qquad (11b)$$

*Equation 10 is an intermediate step deleted during revision.

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Conservation of radial momentum

$$(\sigma\bar{\rho} + \bar{\rho}\,\frac{d\bar{u}}{dZ} + \bar{u}\,\frac{d\bar{\rho}}{dZ})\ v' + (\sigma\bar{\rho}_L + \bar{\rho}_L\,\frac{d\bar{u}}{dZ} + \bar{u}_L\,\frac{d\bar{\rho}_L}{dZ})\ v'_L$$

$$+ \bar{\rho}\,\bar{u}\,\frac{\partial v'}{\partial Z} + \bar{\rho}_L\,\bar{u}_L\,\frac{\partial v'_L}{\partial Z} = -\frac{1}{\gamma}\,\frac{\partial p'}{\partial r} \qquad (11c)$$

Conservation of tangential momentum

$$(\sigma\bar{\rho} + \bar{\rho}\,\frac{d\bar{u}}{dZ} + \bar{u}\,\frac{d\bar{\rho}}{dZ})\ w' + (\sigma\bar{\rho}_L + \bar{\rho}_L\,\frac{d\bar{u}_L}{dZ} + \bar{u}_L\,\frac{d\bar{\rho}_L}{dZ})\ w'_L$$

$$+ \bar{\rho}\,\bar{u}\,\frac{\partial w'}{\partial Z} + \bar{\rho}_L\,\bar{u}_L\,\frac{\partial w'_L}{\partial Z} = -\frac{1}{\gamma r}\,\frac{\partial p'}{\partial \theta} \qquad (11d)$$

Conservation of energy and equation of state, combined

$$(\sigma\bar{\rho} + \bar{Q} - u\,\frac{d\bar{\rho}}{dZ})\ \rho' + \bar{\rho}\,\bar{u}\,\frac{\partial \rho'}{\partial Z} - (\gamma-1)\ \bar{\rho}\,\bar{u}\ (\sigma\bar{\rho} + \bar{Q} + \bar{\rho}\,\frac{d\bar{u}}{dZ})\ u'$$

$$- (\gamma-1)\ (\bar{\rho}\,\bar{u})^2\,\frac{\partial u'}{\partial Z} = (\sigma\,\frac{\bar{\rho}}{\gamma} + \bar{Q} - \bar{u}\,\frac{d\bar{\rho}}{dZ})\ p' + \bar{\rho}\,\bar{u}\,\frac{\partial p'}{\partial Z} \qquad (11e)$$

Droplet dynamics

defining $\quad K = \dfrac{\kappa}{\kappa+\sigma}$

and $\quad \xi = (\kappa+\sigma) \int \dfrac{dZ}{\bar{u}_L}$

then

$$u'_L = Ku' - \frac{K}{\bar{u}_L}\,e^{-\xi}\left[\int_0^Z \frac{d\bar{u}_L}{dZ}\,e^{\xi}u'\ dZ + \int_0^Z \bar{u}_L\,e^{\xi}\,\frac{\partial u'}{\partial Z}\ dZ\right] \qquad (11f)$$

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$$v_L' = K\,(1-e^{-\xi})\,v' - K\,e^{-\xi}\int_0^Z e^{\xi}\,\frac{\partial v'}{\partial Z}\,dZ \tag{11g}$$

$$w_L' = K\,(1-e^{-\xi})\,w' - K\,e^{-\xi}\int_0^Z e^{\xi}\,\frac{\partial w'}{\partial Z}\,dZ \tag{11h}$$

$$\begin{aligned}&\left(\sigma + \frac{d\bar{u}}{dZ}\right)\rho' + \left(\sigma + \frac{d\bar{u}_L}{dZ}\right)\rho_L' + \bar{u}\,\frac{\partial \rho'}{\partial Z} + \bar{u}_L\,\frac{\partial \rho_L'}{\partial Z}\\ &+ \bar{\rho}\left(\frac{\partial v'}{\partial r} + \frac{v'}{r} + \frac{1}{r}\frac{\partial w'}{\partial \theta} + \frac{\partial u'}{\partial Z}\right) + \bar{\rho}_L\left(\frac{\partial v_L'}{\partial r} + \frac{v_L'}{r}\right.\\ &\left. + \frac{1}{r}\frac{\partial w_L'}{\partial \theta} + \frac{\partial v_L'}{\partial Z}\right) + \frac{d\bar{\rho}}{dZ}\,u' + \frac{d\bar{\rho}_L}{dZ}\,u_L' = 0\end{aligned} \tag{11i}$$

In general, separation of variables is not possible with these equations. A solution can be obtained by writing each quantity in a series such that each successive term in the series is less than its predecessor. Therefore, the pressure perturbation is written in the form

$$p' = p_0 + p_1 + p_2 + p_3 + \ldots p_n + \ldots \tag{12}$$

where p_0 can assume any magnitude within the restrictions of the analysis. Then $p_1 = 0\,(u_e \cdot p_0)$* , $p_2 = 0\,(\bar{u}_e^2 \cdot p_0)$ and $p_n = 0\,(\bar{u}_e^n \cdot p_0)$ where $\bar{u}_e$ is essentially the chamber Mach number. Applying this approach to equations (11a) through (11i), collecting terms of like order, and solving for the pressure results in wave equations for p_0 and p_1:

$$\sigma^2\,p_0 - \nabla^2\,p_0 = 0 \tag{13a}$$

* This notation is used to indicate the order of magnitude of a given parameter.

I, B, Technical Description (cont.)

$$\sigma^2 p_1 - \nabla^2 p_1 = \sigma\gamma \bar{Q} \left(P p_0 - R \frac{1}{\sigma\gamma\bar{\rho}} \frac{\partial p_0}{\partial r} - T \frac{1}{\sigma\gamma\bar{\rho}\theta} \frac{\partial p_0}{\partial \theta}\right) - \sigma \left[2 \frac{d\bar{u}}{dZ} + (\gamma-1) \frac{\bar{Q}}{\bar{\rho}} + \sigma \frac{\kappa}{\kappa+\sigma} \frac{\rho_L}{\bar{\rho}}\right] p_0 \qquad (13b)$$

For a cylindrical chamber the solutions of (13a) and (13b) are given by

$$p_0 (z, r, \theta) = P_{oo} \cosh (\Omega Z) \psi (r) \Theta (\Theta) \qquad (15a)^*$$

$$p_1 (z, r, \theta) = P_{oo} (\Gamma_{11} P + \Gamma_{10}) \psi (r) \Theta (\Theta) \qquad (15b)$$

where

$$\psi (r) = J_\nu (s_{\nu\eta} \cdot r) \qquad (15c)$$

$$\Theta (\Theta) \begin{cases} \cos \nu \theta & \text{STANDING MODE} \\ e^{-\nu\theta} & \text{SPINNING MODE} \end{cases} \qquad (15d)$$

and J_ν represents the Bessel function of the first kind of order ν (see Table I)

Also,

$$\Gamma_{11} = \frac{1}{\Omega} \left(-\sigma\gamma A_{\nu\eta} + \frac{1_r}{n} B_{\nu\eta} + \frac{1_\theta}{n} C_{\nu\eta}\right) \int_0^Z \bar{Q} (\zeta) \sinh [\Omega (Z-\zeta)] d\zeta \qquad (15e)$$

where

$$\Omega^2 = \sigma^2 + s_{\nu\eta}^2$$

the factors $A_{\nu\eta}$, $B_{\nu\eta}$ and $C_{\nu\eta}$ are discussed in Section B.4.b.(5).

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* Equation 14 is an intermediate step deleted during revision.

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$$\Gamma_{10} = \frac{\sigma}{\Omega} \left\{ (\gamma-1) \int_0^Z \overline{Q}(\zeta) \sinh [\Omega (Z-\zeta)] \, d\zeta \right. \tag{15f}$$

$$+ 2 \int_0^Z \frac{d\overline{u}}{dZ}(\zeta) \sinh [\Omega (Z-\zeta)] \, d\zeta$$

$$\left. + \frac{\kappa\sigma}{\kappa+\sigma} \int_0^Z \frac{\overline{\rho}_L}{\overline{\rho}}(\zeta) \sinh [\Omega (Z-\zeta)] \, d\zeta \right\}$$

These solutions depend on the following boundary conditions:

$Z = 0, \quad u' = 0$

$r = 1, \quad v' = 0$

$r = 0, \quad v' < oo$

To complete the analysis, the combustion terms must be considered in detail, and the boundary condition at the nozzle entrance (viz., the nozzle admittance condition) must be specified.

For an annular chamber the modification to the cylindrical chamber analysis imposed by the annular geometry enters through the solution for ψ (r). The differential equation for ψ (r) is the classic Bessel equation which results in the following general solution:

$$\psi_{\nu\eta}(r) = C_1 J_\nu (s_{\nu\eta} \cdot r) + C_2 Y_\nu (s_{\nu\eta} \cdot r) \tag{16}$$

where J_ν is the Bessel function of the first kind, Y_ν is the Bessel function of the second kind, and $s_{\nu\eta}$ (where ν specifies the order of the Bessel equation) is the transverse acoustic mode number. Specifically, this means that at all chamber walls

I, B, Technical Description (cont.)

$$\frac{d\psi_\nu}{dr} = 0 \tag{16a}$$

Applying this condition to (16) yields

$$\psi'_\nu = 0 = J'_\nu\ (s_{\nu\eta} \cdot r_c) + \frac{C_2}{C_1} Y'_\nu\ (s_{\nu\eta} \cdot r_c) \tag{17}$$

at the outer wall, $r_c = 1$, equation (17) reduces to

$$J'_\nu\ (s_{\nu\eta}) + \frac{C_2}{C_1} . Y'_\nu\ (s_{\nu\eta}) = 0\ . \tag{18}$$

For the cylindrical chamber case, equation (18) reduces to

$$J'\ (s_{\nu\eta}) = 0 \tag{19}$$

since B must be zero because Y_ν becomes infinite at $r = 0$. The solution of equation (19) serves to define the transverse acoustic mode number, $s_{\nu\eta}$, for cylindrical combustion chambers.

The annular chamber has its inner wall located in the range $0<r_i<1$. Therefore, for the inner wall, equation (17) is written:

$$J'_\nu\ (s_{\nu\eta} \cdot r) + \frac{C_2}{C_1} Y'_\nu\ (s_{\nu\eta} \cdot r) = 0,\ @\ r = r_i \tag{20}$$

whereas at the outer wall, $r = 1$ and equation (18) is still applicable. Solution of (18) and (20) simultaneously yields

$$J'_\nu\ (s_{\nu\eta})\ Y'_\nu\ (s_{\nu\eta} \cdot R) - J'_\nu\ (s_{\nu\eta} \cdot R)\ Y'_\nu\ (s_{\nu\eta}) = 0 \tag{21}$$

I, B, Technical Description (cont.)

The solution of equation (21) defines the transverse acoustic mode number, $s_{\nu\eta}$, for annular chambers. Fortunately, equation (21) has been solved in Reference (9) and the values of $s_{\nu\eta}$ are listed as a function of R, where $R = r_i/r_o$, on Table II.

Thus the use of an annular chamber will alter the frequencies of the transverse modes. The extent of the alteration is illustrated in Figure 9. In addition, radial injection distribution effects will be minimized by the use of the annular chamber so that in most cases the distribution coefficients $A_{\nu\eta}$, $B_{\nu\eta}$, and $C_{\nu\eta}$ can be assumed to be unity.

TABLE II

BESSEL FUNCTION VALUE $(s_{\nu\eta})_{ann}$ FOR TANGENTIAL MODES IN ANNULAR CHAMBERS

Annular Chamber Geometry (Radius) Inner / (Radius) Outer		Tangential Modes 1T	2T	3T	4T	5T	6T
0.910	$(s_{\nu\eta})_{ann}$ =	1.04802	2.09602	3.14401	4.19197	5.23989	6.28778
0.833		1.092	2.1846	3.27672	4.368	5.4588	6.5496
0.667		1.209	2.412	3.61	4.80	5.98	7.14
0.500		1.35	2.68	3.98	5.18	6.34	7.45
0.400		1.41	2.85	4.10	5.27	6.40	7.5
0.333		1.54	2.91	4.17	5.31	6.42	7.5
0.286		1.60	2.99	4.18	5.31	6.42	7.5
0.250		1.64	3.00	4.18	5.31	6.42	7.5
0.222		1.67	3.02	4.18	5.31	6.42	7.5
0.200		1.70	3.025	4.18	5.31	6.42	7.5

NOTE: 1. Figure 9 gives the frequency ratio viz. $\frac{(s_{\nu\eta})_{annular}}{(s_{\nu\eta})_{cylindrical}}$ for different chamber geometries.

2. Calculation of annular chamber tangential frequencies

$$\left[f^* = \frac{C_o^* \, (s_{\nu\eta})_{annular}^{12}}{2\pi \, r_c^*} \right]$$

Reference: Bridge and Angrist, "Math. of Computation, 16, 78," April 1962.

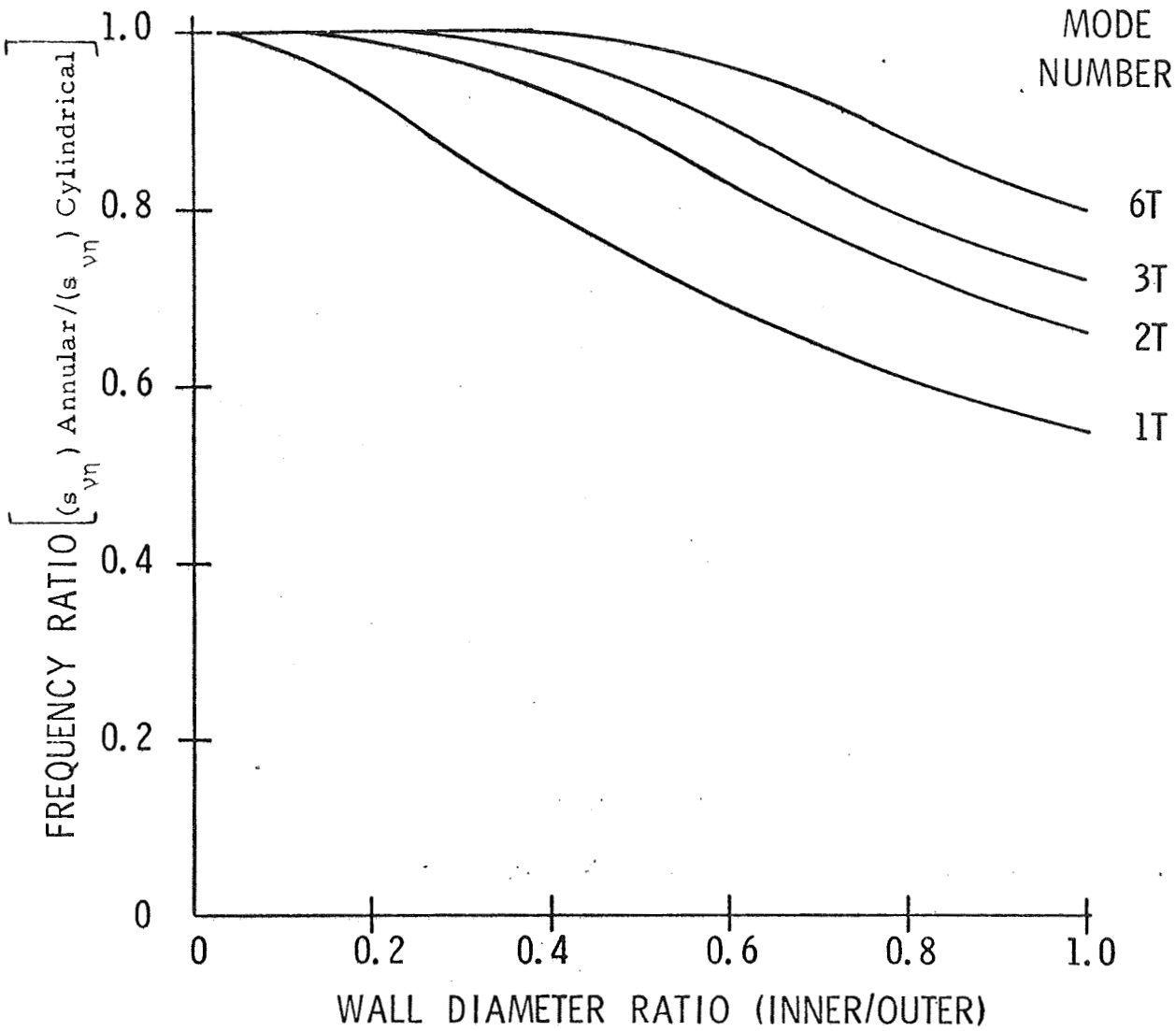


Figure 9 -- Tangential Mode Acoustic Frequencies for Annular Chambers

I, B, Technical Description (cont.)

(4) Combustion Response

(a) General Formulation

In Equation 11a combustion terms are written. It is necessary now to provide a mathematical formulation for the combustion terms in the flow equations in terms of the chamber conditions. As discussed previously our quantitative understanding of the actual combustion processes is not sufficient to provide a mathematical model. Fortunately the heuristic formulation based on the sensitive time lag concept seems to provide a good representation of the actual combustion response. The relation between time lag and burning rate is immediately found by considering that the fraction of propellant burning at a certain station in a time interval dt must have been injected during the interval $d(t - \tau_T)$. If, then $\dot{m}_b$ and $\dot{m}_i$ are the corresponding burning and injection rates we must have

$$\dot{m}_b dt = \dot{m}_i \, d(t - \tau_T)$$

In steady-state τ_T does not vary with time, and hence, if the injection rate is unaffected by the oscillations

$$\bar{\dot{m}}_b = \bar{\dot{m}}_i$$

From these two relations we obtain the fractional perturbation of the burning rate in the form

$$\frac{\dot{m}_b'}{\bar{\dot{m}}_b} = \frac{\dot{m}_b - \bar{\dot{m}}_b}{\bar{\dot{m}}_b} = -\frac{\partial \tau_T}{\partial t} = \frac{-d\tau}{dt} \qquad (22)$$

I, B, Technical Description (cont.)

where, in accordance with the definition of sensitive time lag, the variation of τ_T with time is entirely due to the variation of τ, and where τ has been assumed to be the same for all propellant elements, and hence independent of the space coordinates.

Turning to the evaluation of $d\tau/dt$, a satisfactory mathematical description is obtained if one imagines that during the sensitive time lag certain preparatory processes, which need not be more precisely defined, take place at a rate depending on the local, instantaneous values of quantities representing the state and the motion of the gas and droplets. When these preparatory processes, integrated over the duration of the sensitive time lag, reach a certain fixed level, the conversion into hot gases takes place abruptly. It is clear, then, that when the state and the motion conditions vary, also the duration of the sensitive (and hence, the total) time lag will vary, resulting in a variable rate of gas production.

The quantitative formulation follows at once. If the rate of the preparatory processes is given by a function f (p, T, v,....) of the pertinent values of the pressure, temperature, any representative velocity v (for instance the radial gas velocity) and possibly other quantities representing the conditions in the chamber, the sensitive time lag τ for an element burning at time t will be given by the equation

$$\int_{t-\tau}^{t} f\,(p,\ T,\ v,\ \ldots.)dt_1 = \text{const.}$$

where t_1 represents the burning time. Here the values of p, T, v, ... must be evaluated not only at time t_1, but also at the position where the particular propellant element finds itself at that time. Since the above relation must be satisfied also in steady operation, indicating the steady-state quantities with a superimposed bar we must have

I, B, Technical Description (cont.)

$$\int_{t-\tau}^{t} f\,(p,\ T,\ v,\ \ldots.)\ dt_1 = \int_{t-\bar{\tau}}^{t} f(\bar{p},\ \bar{T},\ \bar{v},\ \ldots.)dt_1\ . \quad (23)$$

Now we introduce the perturbations, such that

$$p = \bar{p} + p',\ T = \bar{T} + T',\ v = \bar{v} + v'\ \ldots.$$

and expand the rate function in a Taylor series

$$f(p,\ T,\ v,\ \ldots.) = \bar{f} + \bar{f}_p\ p' + \bar{f}_T T' + \bar{f}_v\ v' + \ldots.$$

where $\bar{f} = f(\bar{p},\ \bar{T},\ \bar{v},\ \ldots.)$ and similarly for the partial derivatives $\bar{f}_p$, $\bar{f}_T$, $\bar{f}_v$ of f with respect to the subscripts. Observe that, under the small perturbations assumption, the Taylor series must be stopped after the first order terms.

If it is assumed that the temperature is a function only of the pressure (for instance, through the isentropic defining relation) $T' = p'\ (dT/dp)$. Then, defining the nondimensional interaction indices n, l, ... as

$$n = \frac{\bar{f}_p + \bar{f}_T\ (dT/dp)}{\bar{f}},\ l = \frac{\bar{f}_v}{\bar{f}},\ \ldots. \quad (24)$$

$$f(p,\ T,\ v,\ \ldots.) = \bar{f}\ (1 + n\ p' + lv' + \ldots.)$$

and Equation (23) can be written in the form

I, B, Technical Description (cont.)

$$\int_{t-\tau}^{t-\bar{\tau}} \bar{f}\,(1 + np' + lv' + \ldots,)dt_1 + \int_{t-\bar{\tau}}^{t} \bar{f}(1 + np' + lv' + \ldots)dt_1$$

$$= \int_{t-\tau}^{t} \bar{f}\, dt_1$$

Here the integration interval at the L.H.S. of Equation (23) has been split into two parts. The first interval, from $t - \tau$ to $t - \bar{\tau}$ is of duration $\bar{\tau} - \tau$ and hence of the order of the perturbation of the time lag. Hence, compared with the other two integrals, the first integral is of the order of a perturbation. As a result in its evaluation one can disregard in the integrand the terms containing the perturbations which, in view of the small perturbation assumption, would result in a negligible second order contribution. Then, simplifying, the above equation becomes

$$\int_{t-\tau}^{t} \bar{f}\, dt_1 = \int_{t-\bar{\tau}}^{t} \bar{f}(np' + lv' + \ldots)dt_1$$

In the combustion zone $\bar{p}$ is approximately constant, and if v is the radial gas velocity, so that $\bar{v} = 0$ then $\bar{f}\,(\bar{p}, \bar{v})$ is a constant, and so are n and l.

Then we obtain simply

$$\bar{\tau} - \tau = n \int_{t-\bar{\tau}}^{t} p'\, dt_1 + l \int_{t-\bar{\tau}}^{t} v' dt_1 + \ldots$$

or, differentiating with respect to t

I, B, Technical Description (cont.)

$$-\frac{d\tau}{dt} = n\left[p'(t) - p'(t-\bar{\tau})\right] + l\left[v'(t) - v'(t-\bar{\tau})\right] + \ldots \quad (25)$$

Again, it must be specified that while $p'(t)$ is evaluated at the conversion instant t at the location where the conversion takes place, $p'(t - \bar{\tau})$ must be evaluated not only at time $t - \bar{\tau}$, but also at the location where the propellant was at that time. However, the displacement of the propellant during the time $\bar{\tau}$ produces an effect of second order in the expression (25). As a reasonable approximation, therefore, both $p'(t)$ and $p'(t - \bar{\tau})$ can be evaluated at the station when the conversion into burned gases takes place. And, of course, the same applies to the velocity effect in Equation (25), and to other possible effects.

In Equation (25) only the pressure sensitivity and the radial velocity sensitivity are explicitly considered. Concerning the last it must be added that other components of the gas velocity can be treated in exactly the same fashion. If one is interested, for instance, in the effect of the transverse non-uniformity of the gas composition, then also the tangential velocity component is relevant, and correspondingly another velocity sensitive term must appear in Equation (25), which becomes, in the absence of other interactions

$$-\frac{d\tau}{dt} = n\left[p'(t) - p'(t-\bar{\tau})\right] + l_r\left[v'(t) - v'(t-\bar{\tau})\right] \quad (26)$$

$$+ l_\theta\left[w'(t) - w'(t-\bar{\tau})\right]$$

It must be observed that, actually, when only the effects of the nonuniform gas composition on the burning rate are sought, what counts is the displacement of the gases with respect to the droplets,

I, B, Technical Description (cont.)

rather than the relative velocity. This can be formalized by writing, for instance, instead of (26),

$$-\frac{d\tau}{dt} = n\left[p'(t) - p'(t-\bar{\tau})\right] + m_r\left[\delta'_r(t) - \delta'_r(t-\bar{\tau})\right]$$

$$+ m_\theta\left[\delta'_\theta(t) - \delta'_\theta(t-\bar{\tau})\right] \qquad (27)$$

where m_r and m_θ are two displacement indices relative to the radial and tangential displacements δ_r, δ_θ respectively. The two formulations (26) and (27) are closely correlated, because of the relations existing between velocities and displacements.

If the time dependence of the perturbations in Equations (26) and (27) is taken to be exp (st), the combined effect is:

$$-\frac{d\tau}{dt} = -(P\,p' + R_v\,v' + T_v w') \text{ or } -(Pp' + R_\delta\,\delta'_r + T_\delta\,\delta'_\theta) \qquad (28)$$

where the quantities defined by

$$\frac{P}{n} = \frac{R}{1_r} = \frac{T}{1_\theta} = \frac{R_\delta}{m_r} = \frac{T_\delta}{m_\theta} = 1 - e^{-\sigma\bar{\tau}}, \quad (\sigma = \lambda + i\omega) \qquad (29)$$

are, in view of (22), to be interpreted as feedback factors. In this case the relation between velocities and displacements is simply $v' = \sigma\delta'_r$, $w' = \sigma\delta'_\theta$ so that the same expression can be used for $-\frac{d\tau}{dt}$ for velocity or displacement effects if R_δ is equivalent to σR and T_δ is equivalent to σT.

(b) Velocity Sensitive Combustion

It is desirable to take a closer look at the dynamic aspects of velocity sensitive combustion. The most significant

I, B, Technical Description (cont.)

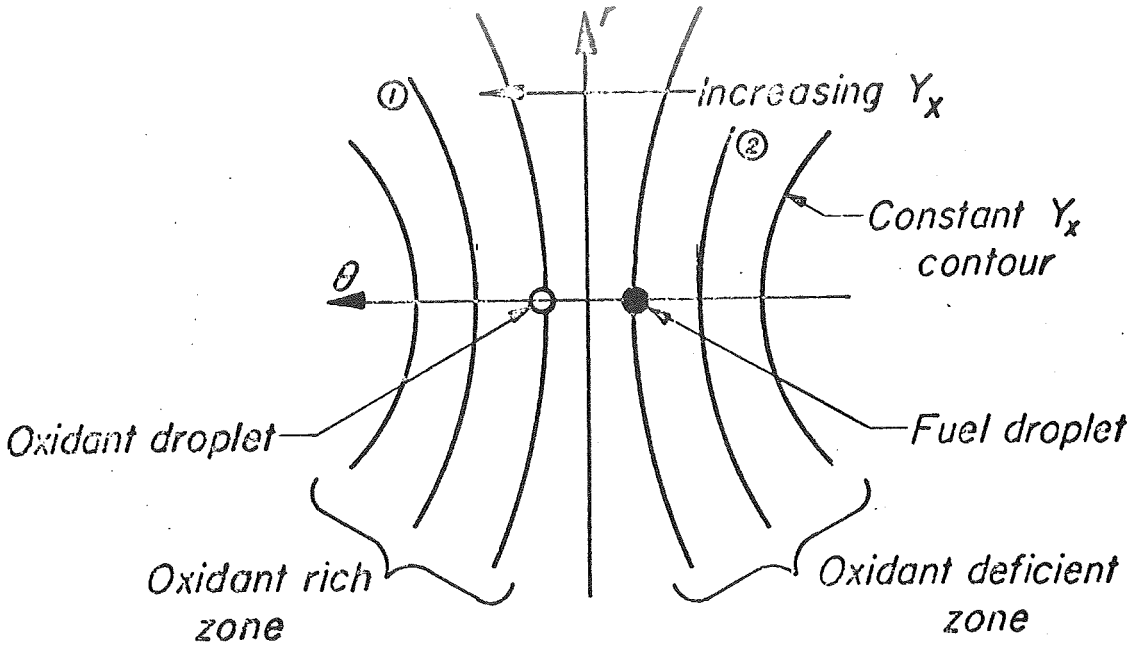
velocity effects are those resulting from the radial and tangential components of the gas velocity perturbation. In the case of purely transverse modes, the longitudinal velocity perturbation component is always much smaller than the transverse components. In addition, the longitudinal component vanishes at the injector face and has its smallest magnitude in the early combustion zone, the region which appears to have the greatest significance for transverse modes. It is possible that in certain combustion chambers the axial spreading of the combustion will result in sizable longitudinal velocity oscillations for higher order longitudinal or combined transverse-longitudinal modes. However, in such cases the pressure perturbation will become correspondingly small in that region, thus, the decreased pressure effect will cancel the increased velocity effect. In the present analysis, therefore, only the effects of the transverse velocity oscillations will be considered in the combustion response.

Of the various intermediate processes occurring during the combustion of liquid bipropellants, those most sensitive to velocity are the vaporization of the liquid droplets and the mixing of the vaporized propellants that must precede chemical reaction. The theoretical study of unsteady vaporization by Wieber and Mickelsen (Ref. 10) indicates that the evaporation rate is dependent on the absolute magnitude of the relative velocity between droplet and gas; therefore, the vaporization velocity effect is seen to be essentially nonlinear, and cannot be treated within the framework of a linearized theory. On the other hand, the mixing of the propellants by the oscillating velocities may be linearized, and gives rise to important modifications of the stability behavior of a combustor. Although no detailed description of such a complex phenomenon is now possible, the following discussion illustrates one process by which the burning rate may be caused to oscillate by an oscillating transverse gas velocity.

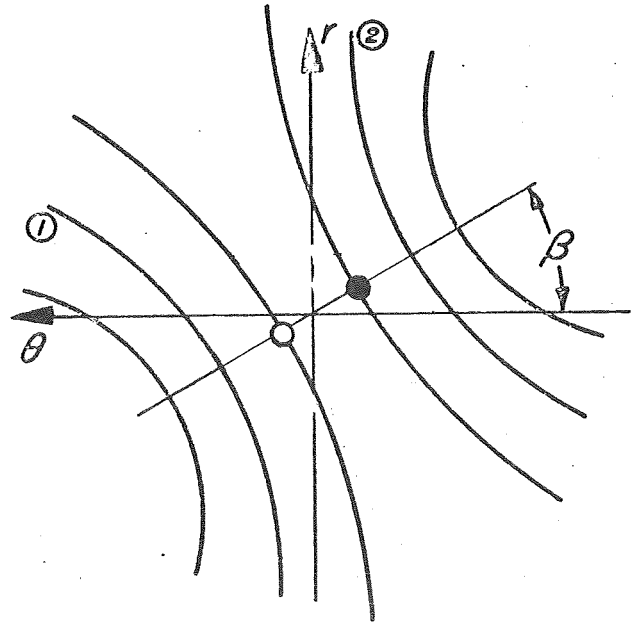
I, B, Technical Description (cont.)

Consider first the mixture of gaseous combustion products, vaporized propellants (oxidizer and fuel), and liquid propellant droplets at some axial station downstream from a fuel-on-oxidizer impinging doublet injector element. Since liquid mixing is imperfect, some stratification will exist in the mixture. For concreteness, assume that the line of centers of the doublet is aligned tangentially (i.e., normal to a radius). Then the stratification is almost entirely in the tangential direction, as shown schematically in Figure 10 by the lines of constant mass fraction of vaporized oxidizer in the mixture Y_x. The exact shape of the constant Y_x contours will be dependent on the injector design, operating conditions, and propellant characteristics. Because of the turbulence in the combustion chamber, the stratification pattern shown represents only a mean condition.

As a droplet evaporates, the vapor diffuses away and must mix with the other vaporized propellant in the propellant proportions for chemical reaction. In a rocket combustor, the transport and mixing are most likely to be carried out by turbulence rather than by molecular diffusion. The overall burning rate of a fuel-rich droplet will, therefore, be a function of the amount of oxidizer vapor near the droplet. In the presence of small, periodic tangential gas velocity oscillations ($w'_e{}^{i\omega t}$) the gaseous mixture will be displaced relative to the droplets, causing oscillations of the local mass fractions of both oxidizer and fuel. Since a fuel droplet is in an oxidant-deficient region, a velocity perturbation which increases the oxidizer fraction in the vicinity of the droplet will increase the contribution of that droplet to the overall burning rate. The opposite is true for an oxidizer-rich droplet subject to the same perturbation, since an oxidizer fraction increase corresponds to a fuel fraction decrease. Thus, the effects of the same velocity perturbation on the two droplets will tend to cancel, unless the propellants have significantly different vaporization rates. In the latter case, at any axial station, there will be a greater number of droplets of the less-volatile propellant, and summation



(a) Spray produced by tangentially oriented injector spud



(b) Spray produced by rotated spud

Figure 10 -- Sprays Produced by Various Orientations of the Injector Spud

I, B, Technical Description (cont.)

of the velocity effect over all of the droplets in the spray will result in a net contribution to the burning rate. This contribution will clearly depend on the amplitude of the velocity as well as its direction. For small perturbations, and for the doublet spray shown in Figure 10a, the burning rate contribution can be written in the form

$$f' = lw'e^{i\omega t}$$

where l is a velocity interaction index analogous to the pressure interaction index defined by Crocco. In the case of an arbitrarily oriented spray, such as shown in Figure 10b, the burning rate perturbation due to velocity effects becomes

$$f' = (l_r v' + l_\theta w')e^{i\omega t} \tag{30}$$

so that, in general, two velocity indices are necessary.

It is clear that this linearized expression will not be valid for all types of injection patterns. For example, approximately linear effects can be expected with a fuel-on-oxidizer doublet and for a like-on-like pattern if the spacing between unlike fans is sufficiently small. However, for large spacings, nonlinear velocity effects must be taken into consideration.

At present, the magnitudes of the velocity indices cannot be calculated because of the lack of quantitative knowledge of the processes involved in liquid propellant combustion under turbulent conditions.

I, B, Technical Description (cont.)

It is also possible to formulate the above discussion in terms of displacement interaction indices. Letting the radial and transverse components of the displacements be $\delta'_r e^{i\omega t}$ and $\delta'\theta e^{i\omega t}$, the net combustion process rate perturbation can be written

$$f' = (m_r \delta'_r + m_\theta \delta'_\theta) e^{i\omega t} \tag{31}$$

It is clear that $m_r = i\omega l_r$ $m_\theta = i\omega l_\theta$. Thus, the displacement indices present at 90° phase shift with respect to the velocity indices.

The analysis of the effects of velocity (or displacement) sensitivity on the stability of a combustor is considerably simplified by assuming that the velocity effects occur during the same time interval (the sensitive time lag) as the pressure effects. In this case, the burning rate perturbation becomes

$$Q' = \overline{Q}(\mathcal{P}p' + \mathcal{R}v' + \mathcal{T}w') \tag{32}$$

where

$$\mathcal{P} = n\,(1-e^{-\sigma\tau})$$
$$\mathcal{R} = l_r\,(1-e^{-\sigma\tau})$$
$$\mathcal{T} = l_\theta\,(1-e^{-\sigma\tau})$$

In equation (32), additional simplifications have been introduced by assuming that all propellant elements have equal mean sensitive time lags, and that the space lag associated with the sensitive time lag is a negligible fraction of the wave length. In general, of course, the mean sensitive time lag varies from one propellant element to another. Crocco and Cheng have shown that this nonuniformity of the sensitive time lag leads to increased stability of the combustor. Therefore, the assumption of a uniform time lag produces a conservative stability prediction.

I, B, Technical Description (cont.)

It would be possible to generalize the burning rate expression to allow for different time lags for pressure and velocity effects. However, both mathematical and physical considerations indicate the desirability of the simpler formulation.

(c) Approximate Treatment of Nonlinear Combustion Response

Nonlinearities associated with oscillatory combustion chamber operation can derive from two sources: (1) the fluid mechanical behavior of the gases in the chamber, and (2) the dynamics of the combustion process. It is clear that significant interactions between the two kinds can also occur. The studies of Priem and Guentert have shown that combustion process nonlinearities can be important even for oscillation amplitudes less than 20% of the mean chamber pressure. Thus, it is worthwhile to consider nonlinearity of the combustion response while retaining the linearized fluid mechanical analysis with its attendant simplification.

To insert the nonlinear combustion dynamics into the framework of the linear theory, some method of equivalent linearization must be used. The method selected in this analysis is the "describing function" method.

When a sinusoidal signal is input to a nonlinear element, the output will not, in general, be sinusoidal. Fourier analysis of the output will reveal many frequency components, among which is one (the fundamental) that corresponds to the frequency of the input signal.

I, B, Technical Description (cont.)

For the analysis of stability, only the fundamental frequency component is required, as shown by Reardon (Ref 8). An equivalent linear transfer function for the nonlinear element can be defined as the ratio of the fundamental component of the output to the input. Thus, if

$$I(t) = Ie^{i\omega_f t}$$

is the input, and

$$O(t) = O_1(\omega_f)e^{i\omega_f t} + \sum_{j \neq 1} O_j e^{ij\omega_f t} \tag{33}$$

is the output, the equivalent linear transfer function is

$$TF = \frac{O_1(\omega_f)}{I}$$

For nonlinearities that can be treated by this method, linear behavior is obtained for limiting values of the input (e.g., $I \to 0$ or $I \to \infty$). It is convenient to define a "describing function" F as

$$F(\omega) = TF/(TF)_{LIM} \tag{34}$$

where $(TF)_{LIM}$ is the limiting linear transfer function. Thus, a linear analysis can be extended to include isolated nonlinear effects by replacing the linear transfer function of the nonlinear element by $F(\omega) \cdot (TF)_{LIM}$.

In applying this approach to the combustion instability problem, it is assumed that the only significant nonlinearities

I, B, Technical Description (cont.)

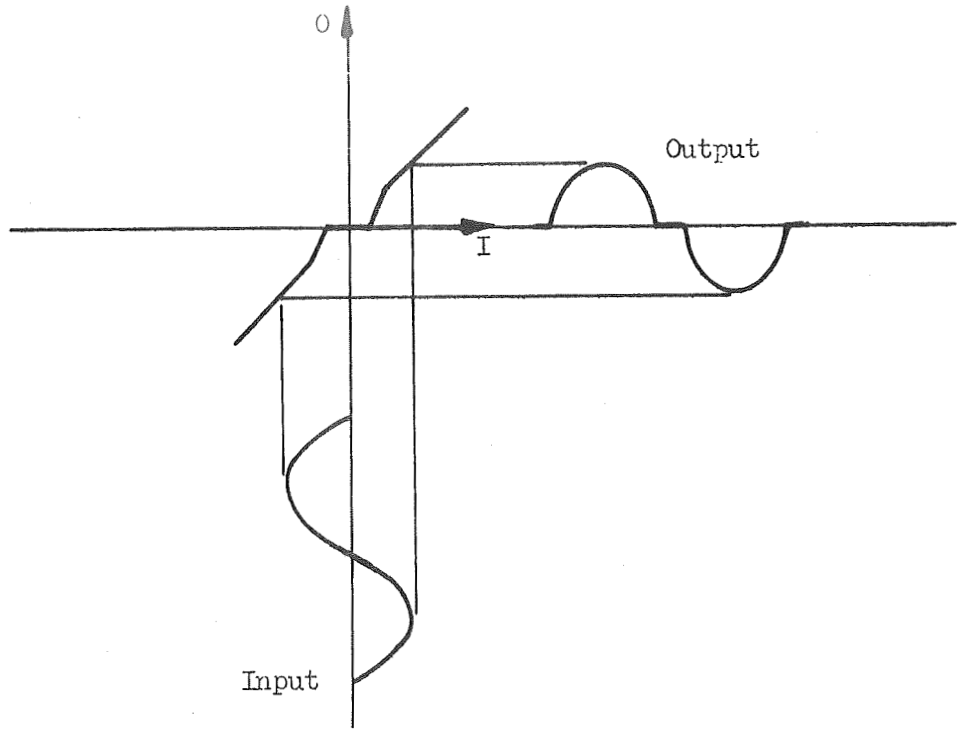
are those associated with the response of the combustion process to pressure and velocity perturbations. Three describing functions are required, corresponding to the combustion response to pressure, radial velocity, and tangential velocity perturbations. Thus, the combustion rate perturbation becomes

$$Q' = \overline{Q} \left[F_P(p')\ \mathcal{P}p' + F_R(v')\ \mathcal{R}v' + F_T\ (w')\ \mathcal{T}w' \right] \qquad (35)$$

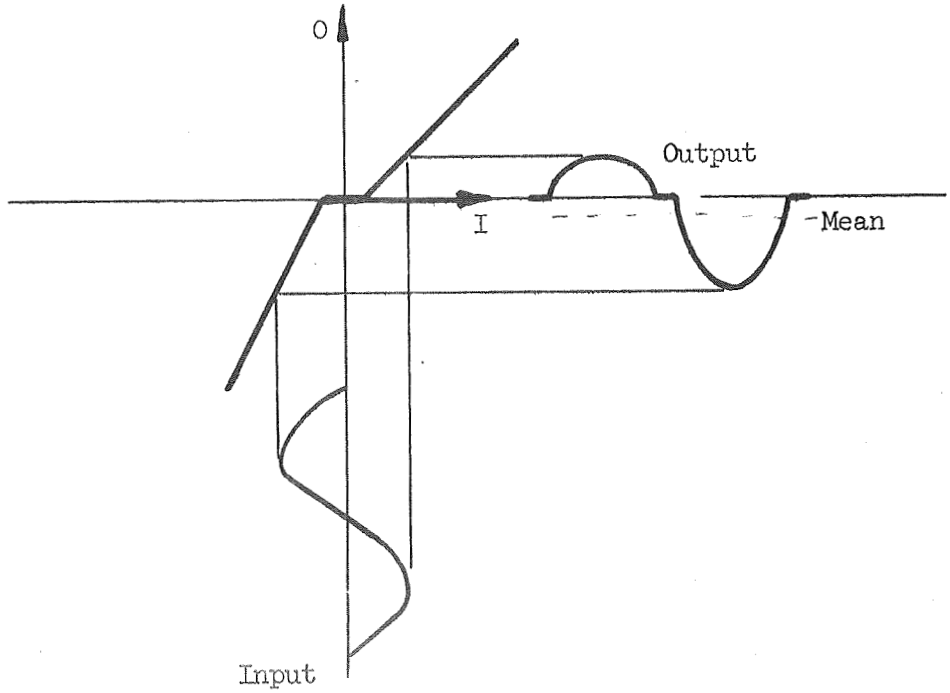
In the above expression, the dependence of the describing functions on the perturbation (input) amplitude is shown explicitly. This dependence on amplitude introduces complications into the solution of the perturbation equations. In general, the input amplitude is a function of the axial, as well as the transverse, space coordinate. To obtain a solution, it is necessary to introduce the additional simplification of neglecting the axial variation of perturbation amplitude in the evaluation of the describing function. For purely transverse modes, this is not an unreasonable approximation, and it breaks down significantly only for higher-order longitudinal modes. The error made by using the perturbation amplitudes at the injector face will be small.

To calculate the describing functions, it is necessary to know the shape of the combustion response to each perturbation. Since it is assumed that the effects are independent of each other, the burning rate perturbation can be written

$$\frac{Q'}{\overline{Q}} = \phi_p\ (P') + \phi_R\ (v') + \phi_T(w')$$



(a) Response Function with Odd-Symmetry



(b) Asymmetric Response Function

Figure 11 -- Examples of Nonlinear Response Functions

I, B, Technical Description (cont.)

The procedure for calculating each describing function is the same; therefore, it is necessary only to discuss one, say, the pressure-effect describing function.

The input perturbation is $p' = Po \cos\chi$ where $\chi = \omega t$ and, from Fourier analysis the fundamental term of the output series is

$$\phi_P (P_o) = \frac{1}{\pi} \int_{C-}^{C+\pi} \phi_P(P_o \cos\chi) e^{-i\chi} d\chi$$

Thus, the describing function is given by

$$F_P = \frac{1}{\pi P_o (TF)_{LIM}} \int_{C-\pi}^{C+\pi} \phi_P(P_o \cos\chi) e^{-i\chi} d\chi \qquad (36)$$

In the expressions above, C is an arbitrary constant, and $(TF)_{LIM}$ is a suitable normalizing factor, such that $F \to 1$ for equivalent linear operation. The choice of $(TF)_{LIM}$ depends on the characteristics of each nonlinear response function, and a general rule does not appear feasible.

The describing function method applies well to nonlinearities with odd symmetry (Figure 11a). It is not applicable to response functions with even symmetry, such as the velocity effect on vaporization, since there is no contribution to the fundamental term of the Fourier series. An intermediate case is that of asymmetric response function (Figure 11b). In this case, there will be a significant contribution to the fundamental oscillation, but a change in the mean burning rate as well. This change in the mean burning rate occurs only during the sensitive portion of the total time lag and so will have a negligible influence on the steady state solution.

I, B, Technical Description (cont.)

In general, the describing function is complex; that is, the nonlinear combustion response introduces a phase shift as well as an amplitude change. However, for response functions with odd symmetry, the fundamental component of the output is in phase with the input, so that the describing function is real.

(5) Effect of Non-Uniform Injection

The non-uniformity of mass injection in the r and θ direction can be characterized by a burning rate distribution function $\mu(r, \theta)$ which is the ratio of the local injection density to the mean injection density so that

$$\pi = \int_0^1 \int_0^{2\pi} \mu r dr d\theta .$$

When μ is multiplied by $\overline{Q}$ in equations 13b terms on the right hand side are known functions of r and θ as well as Z. The solution of this type of inhomogeneous differential equation can be expressed as a Bessel-Fourier series as follows:

$$P_1 = (A_{\nu\eta} P_{a\nu\eta} + B_{\nu\eta} P_{b\nu\eta} + C_{\nu\eta} P_{c\nu\eta} + P_d) \Psi_{\nu\eta} \theta_\nu +$$

$$\sum_{\substack{p \neq \nu \\ q \neq \eta}} \sum (A_{pq} P_{apq} + B_{pq} P_{bpq} + C_{pq} P_{cpq}) \Psi_{pq} \theta_p$$

where the subscript a indicates pressure effects (associated with P) b radial velocity effects (associated with R), c tangential velocity effects (associated with T) and d damping effects (which are independent of r and θ).

I, B, Technical Description (cont.)

When the orthogonality property of the functions Ψ and θ is used on the system characteristic equation the coefficients $A_{\nu\eta}$, $B_{\nu\eta}$ and $C_{\nu\eta}$ are found to be:

$$A_{vn} = \frac{\int_0^1 \int_0^{2\pi} \mu(r,\theta)\ \Psi^2_{\nu\eta}\ \theta_\nu \theta_\nu^*\ r\ dr\ d\theta}{\int_0^1 \int_0^{2\pi} \Psi_{\nu\eta}^2\ \theta_\nu\ \theta_\nu^*\ r\ dr\ d\theta}$$

$$B_{vn} = \frac{\int_0^1 \int_0^{2\pi} \mu(r,\theta)\ \frac{d\Psi_{\nu\eta}}{dr}\ \Psi_{\nu\eta}\ \theta_\nu\ \theta_\nu^*\ r\ dr\ d\theta}{\int_0^1 \int_0^{2\pi} \Psi_{\nu\eta}^2\ \theta_\nu\ \theta_\nu^*\ r\ dr\ d\theta} \qquad (37)$$

$$C_{vn} = \frac{\int_0^1 \int_0^{2\pi} \mu(r,\theta)\ \Psi^2(r,\theta)\ \frac{d\theta_\nu}{d\theta}\ \theta_\nu^*\ dr\ d\theta}{\int_0^1 \int_0^{2\pi} \Psi_{\nu\eta}^2\ \theta_\nu\ \theta_\nu^*\ r\ dr\ d\theta}$$

In section I,B,7 it is seen how these coefficients affect the characteristic equation. It should be noted that if the energy addition follows a non-linear relationship a describing function must also be included in the above coefficients.

I, B, Technical Description (cont.)

(6) Nozzle Admittance

In any rocket combustion instability analysis, it is desirable to apply a boundary condition at the nozzle entrance to describe the effect of the nozzle upon wave motion in the combustion chamber. In a linearized analysis, this boundary condition is written in the form of an admittance relation; that is, a linear relation between the perturbations of two thermodynamic properties and of the velocity components. The coefficients in this relation are termed admittance coefficients and are calculated by means of an analysis of the oscillatory flow in the nozzle. In this section, the analysis and numerical integration which lead to the determination of these coefficients are discussed.

The divergent portion of the supercritical nozzle need not be analyzed; all that is pertinent is the subsonic flow in the convergent portion since any disturbances to the supersonic flow cannot propagate upstream through the throat. Therefore, disturbances in the subsonic portion of the nozzle and in the chamber are neither affected nor caused by disturbances in the supersonic region. (The opposite, however, is not true.)

To date, two types of nozzles have been analyzed: axisymmetric designs and two-dimensional designs. The axisymmetric case is presently the one of the most practical significance and is the one to be discussed here. The two-dimensional case applies to thin annular chambers and to certain experimental configurations. The analyses of the two cases are similar; details of both are given in References 11 and 12.

The unperturbed, or steady-state, flow is considered to be one-dimensional in order to simplify the analysis. The perturbed flow, however, may be three-dimensional. The combustion process is

I, B, Technical Description (cont.)

assumed to be completed before the flow enters the nozzle so that there are no source terms in the differential equations of motion. The equations do allow for the occurrence of entropy waves and vorticity waves in the nozzle due to the combustion chamber.

The three-dimensional coordinate system (Figure 12) employs the values of the velocity potential ϕ and the stream function ψ of the unperturbed flow in addition to the azimuthal angle, with

$$\bar{q} = \frac{\partial \phi}{\partial s}$$

$$r \rho \bar{q} = \frac{\partial \psi}{\partial n}$$

where s is the streamline direction and n is the direction normal to the streamline. Since the value of the stream function is a constant at the nozzle walls where the boundary conditions are applied, separation of variables is allowed.

Under the usual assumption of small-amplitude oscillations, linear partial differential equations are obtained that govern the perturbations. These equations are separated under the assumption that the nozzle is sufficiently long that the cosine of the semi-angle of convergence may be approximated by unity. The time and azimuthal dependencies are given by sinusoidal functions. The radial dependencies are given in terms of Bessel functions of the first kind and their derivatives. The axial dependencies are related to the solution to a certain second-order linear ordinary differential equation with complex-variable coefficients which can only be obtained in exact form by numerical integration.

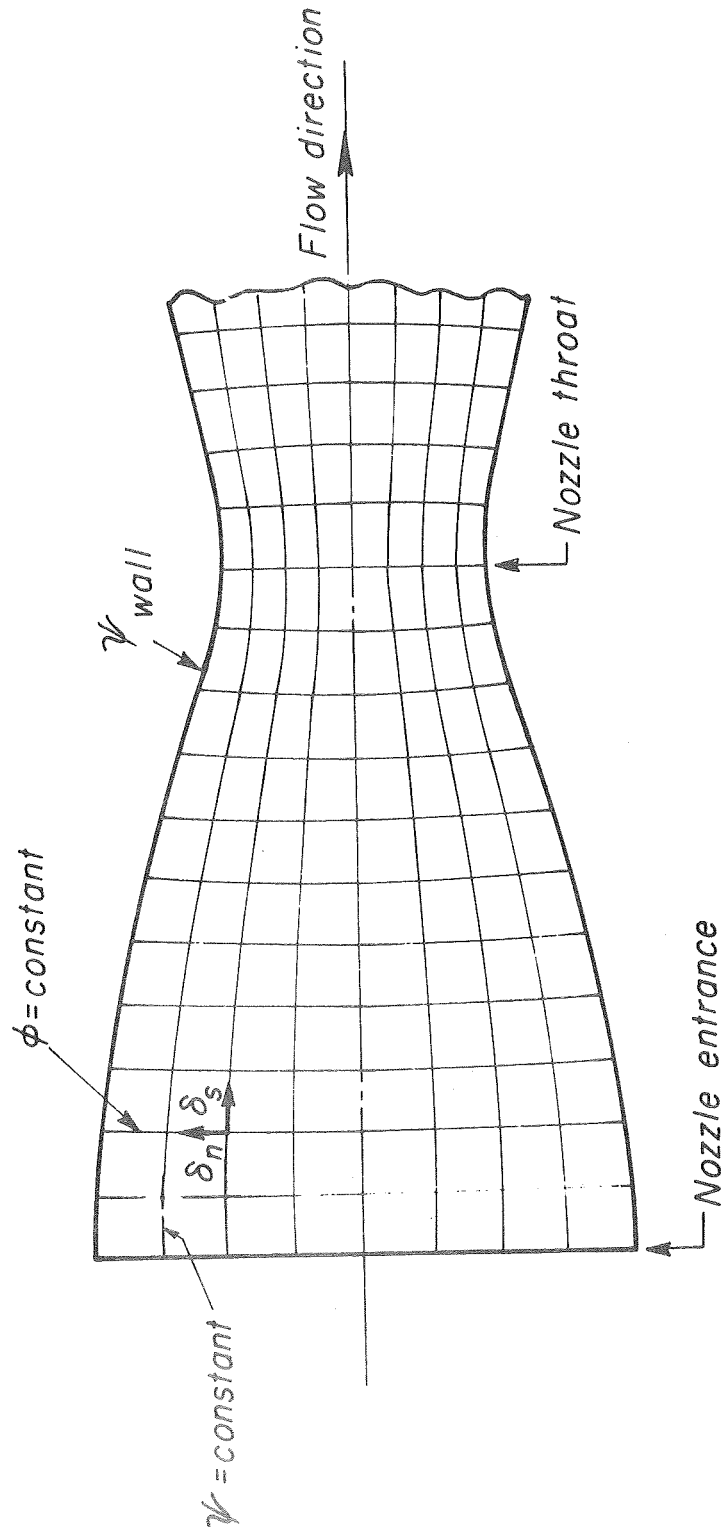


Figure 12 -- Exhaust Nozzle Coordinate System

I, B, Technical Description (cont.)

This second order differential equation is singular at the throat; one of the homogeneous solutions will be regular there and the other one will be singular. The singular solution is cast away. This procedure has been demonstrated to be equivalent to disallowing perturbations to propagate upstream from the supersonic portion of the nozzle (Ref 6).

It has been shown that the admittance coefficients are functions of the solutions to certain first order equations that are obtained by reduction of the original second order equation. So, while it would be necessary to integrate the second-order equation in order to determine the variation of the flow properties, it is not necessary for the purpose of determining the admittance coefficients. Since the interest lies in the prediction of global stability characteristics and not in the details of the flow itself, only the equations immediately needed to determine the admittance coefficient will be presented. The derivations and additional analyses may be found in Reference 11.

The admittance coefficients for a given geometry are determined as functions of the axial coordinate or, equivalently, of the local mean-flow Mach number. This implies that, when the admittance coefficient at the nozzle entrance is desired, the axial coordinate at the entrance or the entrance Mach number must be known before the admittance coefficients can be determined.

The linear admittance condition is given by

$$\gamma U + A P + \gamma B \, s_{\nu\eta} \, V + \gamma \, C S = 0 \qquad (38)$$

I, B, Technical Description (cont.)

where U, P, V, and S are the axial dependencies of the nondimensional perturbations of axial velocity, pressure, radial velocity, and entropy, respectively.

The annular nozzle analysis used in this program is based on Reference 11. It contains certain inconsistencies which should be aired. The current analysis is an approximation to an annular nozzle analysis which is expected to be exact for a certain case.

The cylindrical nozzle analysis postulates the existence of streamlines and a velocity potential. The equations of motion are written in terms of stream functions and velocity potentials. The limits of integration in the radial direction must be written in terms of these streamlines. For a conventional nozzle these limits are the nozzle centerline and the outer wall which are both streamlines. To make an annular analysis from the conventional nozzle analysis with a minimum of fuss a different streamline can be chosen for the inner boundary. A new corresponding value of $s_{\nu\eta}$ can also be determined. It is clear that once the outer boundary is chosen the number of possible inner boundaries is severely limited to one which is a constant fraction of the outer radius.

The nozzle admittance analysis requires a table of the square of the velocity versus the velocity potential. For a general annular nozzle inner and outer contour this can be calculated by first calculating area ratios versus distance then velocities versus distance and the velocity potential from velocity and distances. As this program is written the table of velocity squared versus velocity potential is calculated for a very general annular nozzle configuration. It should be clear from the discussion above that the configuration for which the admittance is obtained is not in general the configuration assumed.

I, B, Technical Description (cont.)

Basic changes to the nozzle admittance analysis are needed to rectify this limitation.

(7) Characteristic Equation

Solution of the perturbation equations gives the pressure perturbation in the form of a Bessel-Fourier series:

$$p' = P_{oo} \left[P_{\nu\eta} (Z) \Psi_{\nu\eta} (r) \theta_{\nu}(\theta) + \sum_{\substack{p \neq \nu \\ q \neq \eta}} \sum P_{pq} (Z) \Psi_{pf} (r) \theta_{p}(\theta) \right]$$

In this expression the indices ν and η refer to the fundamental term, that is, to the oscillatory mode under consideration. The other terms in the series account for the distortion introduced by flow, injection distribution, velocity effects, and nonlinear combustion response. For values of the indices p, q different from ν, η, each term in the series includes an integration constant. However, the integration constant for the fundamental term can be shown to be of order M^3, and so can be neglected in the present analysis. The constant P_{oo} represents the perturbation amplitude level; in this linearized analysis, the amplitude has no effect on the stability solution.

Since the perturbation solution is obtained in the form of a series, the nozzle admittance boundary condition must be applied term by term. For each p, q $\neq \nu, \eta$, the nozzle boundary condition can be used to determine the integration constant. Application of the remaining condition,

$$\gamma U_{\nu\eta} (Z_e) + AP_{\nu\eta} (Z_e) + Bs_{\nu\eta} \gamma V_{\nu\eta} (Z_e) + C \gamma s_{\nu\eta} (Z_e) = 0 \qquad (39)$$

results in an eigenvalue problem. That is, this equation is the characteristic equation for the eigenvalues $\sigma = \lambda + i\omega$. For a given combustor geometry

I, B, Technical Description (cont.)

and for a given value of the combustion parameters n, τ, l_r and l_θ, the characteristic equation can, in principle, be used to determine the frequency of oscillation ω and the growth rate λ of the perturbation amplitude.

However, since the coefficients of the characteristic equation are function of the variable σ, it is more convenient to regard σ as one of the independent variables. Considerable simplification results if $\lambda = 0$, that is, $\sigma = i\omega$, which is interpreted physically as an oscillation, the amplitude of which neither grows nor decays with time. The neutral condition is clearly the boundary between stable and unstable operation, and is sometimes referred to as the stability limit.

For neutral oscillations, regarding the frequency as an independent variable, the characteristic equation becomes a relation between the combustion parameters. Since the equation is complex, two of the combustion parameters can be determined in terms of the other two. It is natural to select the sensitive time lag τ and the pressure interaction index n as the dependent variables, because these parameters are significant to all modes of oscillation. Following this procedure, the characteristic equation can be written in the form:

$$n\,(1 - e^{-i\omega\tau}) = \frac{h\,(\omega)}{A_{\nu\eta} + \frac{i}{\gamma\omega}\left(B_{\nu\eta}\,\frac{l_r}{n} + C_{\nu\eta}\,\frac{l_\theta}{n}\right)} = \tilde{h}_r + i\,\tilde{h}_i \;. \qquad (40)$$

The solution is

$$n\left(\omega, \frac{l_r}{n}, \frac{l_\theta}{n}\right) = \frac{\tilde{h}_r^{\,2} + \tilde{h}_i^{\,2}}{2\,\tilde{h}_r} \qquad (41)$$

I, B, Technical Description (cont.)

$$\tau\left(\omega, \frac{l_r}{n}, \frac{l_\theta}{n}\right) = \tan^{-1}\left(\frac{\tilde{h}_i}{n - \tilde{h}_r}\right) \tag{42}$$

where τ is determined to within an additive constant $\frac{2\pi}{\omega}$.

A typical solution for n (ω) and τ (ω) for assumed values of the velocity indices is shown in Figure 13. This solution applies at the stability limits, where $\lambda = 0$. It can be seen that for any value of τ only one value of n is consistent with neutral oscillations. For the same τ, a larger n corresponds to instability ($\lambda > 0$) and a smaller n to stability ($\lambda < 0$). In the case of transverse modes, for values of n in the range of interest (≤ 2), the frequency varies over a very narrow range, and is very nearly equal to the corresponding acoustic frequency. For longitudinal modes, both the frequency range and the departure from the acoustic-mode frequency are somewhat larger. The narrow frequency range result is related directly to the fact that high frequency instability involves the interaction of the combustion chamber. The chamber acoustics are somewhat modified by the presence of the exhaust nozzle and the mean gas flow, but a good approximation of the resonant frequencies can be made without reference to the combustion effects.

(8) Longitudinal Mode Analysis

The preceding discussion is valid generally for any mode but applies more specifically for the transverse mode analysis of this program. The analysis of longitudinal modes is simplified considerably, without losing the essential features, by assuming that the combustion is concentrated at a single axial station, ξ_1. If the steady-state velocity profile $\bar{u}$ (Z) is given, a combustion front location can be defined by:

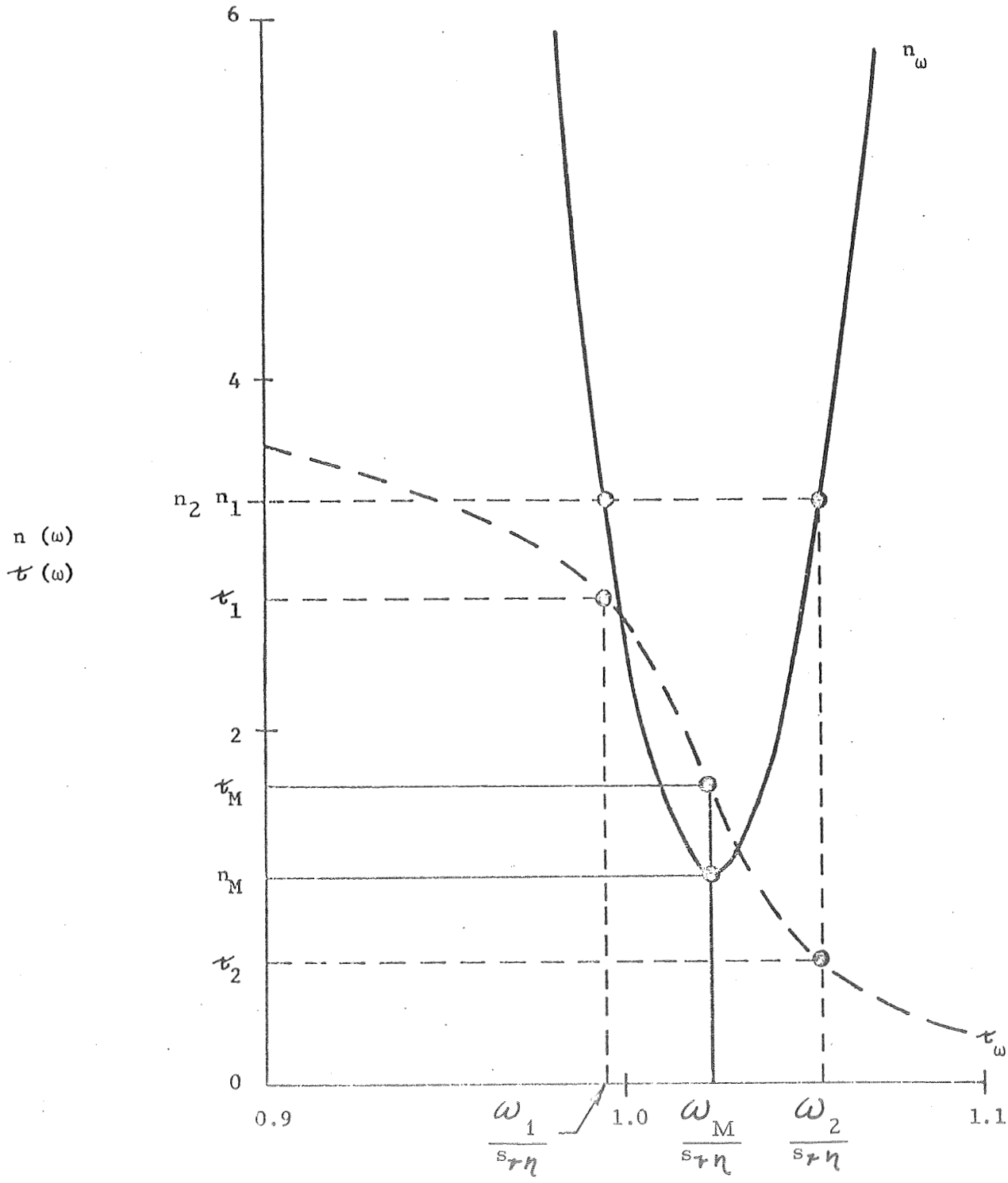


Figure 13 -- Typical Solutions of $\eta(\omega)$ and $\tau(\omega)$

I, B, Technical Description (cont.)

$$\xi_1 = 1 - \frac{1}{\bar{u}_e} \int_o^1 \bar{u}\ (Z)\ dZ$$

where $\bar{u}_e = \bar{u}\ (Z = 1)$ is the gas velocity at the nozzle entrance.

In this analysis the combustion chamber is separated into two regions by the combustion front. Between the injector and the front (Region "0" where $0 \leq Z \leq \xi_1$) there is no mean gas velocity. Liquid propellant droplets, assumed to have negligible volume compared to the total volume by Region "0", travel through the gases and burst instantaneously into gaseous products at the combustion front. The (dimensionless) liquid velocity $\bar{u}_{Lo}$ is assumed to be small, so that its square is negligible, even through the gas velocity in Region "1" is <u>not</u> restricted.

Downstream of the combustion front, in Region "1", the steady-state gas velocity is constant and equal to the nozzle entrance velocity. The gases in Region "0" and Region "1" are assumed to have the same stagnation properties. Assuming that any kinetic energy lost by the droplets while traveling through Region "0" is transferred into thermal energy of the droplets, and neglecting heat transfer and viscous effects, the combustion front appears as a planar mass source, and the stagnation enthalpy is constant in Regions "0" and "1".

The steady state equations in Region "0" yield:

$$\bar{P} = 1,\ \bar{T} = 1,\ \bar{\rho} = 1$$

I, B, Technical Description (cont.)

In Region "1" these equation give:

$$\bar{P} = \frac{1}{1 - \dfrac{\gamma\, \bar{u}_e\, (\bar{u}_L - \bar{u}_e)}{1 - \frac{\gamma-1}{2}\, \bar{u}_e^{\,2}}}$$

$$\bar{T} = 1 - \frac{\gamma-1}{2}\, \bar{u}_e^{\,2}$$

$$\bar{\rho} = \frac{1}{1 - \frac{\gamma-1}{2}\, \bar{u}_e^{\,2} - \gamma\, \bar{u}_e\, (\bar{u}_L - \bar{u}_e)}$$

The liquid velocity in Region "0" is given by:

$$\bar{u}_L = \bar{u}_{Lo} - \kappa\, Z$$

The unsteady equations, with pressure and density related by assuming constant entropy reduce to:

$$\sigma\rho' + \frac{\partial u'}{\partial Z} = 0$$

$$\sigma u' + \frac{1}{\gamma}\frac{\partial p'}{\partial Z} = 0 \qquad (0 \leq Z \leq \xi_1)$$

$$p' = \gamma\rho'$$

I, B, Technical Description (cont.)

Region "1"

$$\sigma\rho' + \bar{u}_e \frac{\partial\rho'}{\partial Z} + \bar{\rho} \frac{\partial u'}{\partial Z} = 0$$

$$\sigma\bar{\rho}\, u' + \bar{\rho}\, \bar{u}_e \frac{\partial u'}{\partial Z} + \frac{1}{\gamma} \frac{\partial p'}{\partial Z} = 0 \qquad (\xi < Z \leq 1)$$

$$p' = \gamma\, \bar{T}\, \rho'$$

These equations have the general periodic solutions

Region "0"

$$u' = C_{ro}\, e^{-\sigma Z} + C_{so}\, e^{-\sigma Z}$$

$$(0 \leq Z \leq \xi_1)$$

$$p' = C_{ro}\, e^{-\sigma Z} - C_{so}\, e^{-\sigma Z}$$

Region "1"

$$u' = C_{r1}\, e^{-a_{r1}\, \sigma Z} + C_{s1}\, e^{-a_{s1}\, \sigma Z}$$

$$(\xi_1 < Z \leq 1)$$

$$p' = \frac{\bar{P}}{\bar{C}}\, C_{r1}\, e^{-a_{r1}\, \sigma Z} - C_{s1}\, e^{-a_{s1}\, \sigma Z}$$

I, B, Technical Description (cont.)

where

$$a_{r1} = \frac{1}{\bar{C} + \bar{u}} \quad \text{and} \quad a_{s1} = -\frac{1}{\bar{C} - \bar{u}}$$

The coefficients C_{ro}, C_{so}, C_{r1}, C_{s1} must be determined by the boundary conditions. Two of these boundary conditions are that $u' = 0$ at $Z = 0$ and the nozzle admittance condition:

$$\frac{u'}{p'} = \frac{\bar{u}_e}{\gamma \bar{p}} \alpha_N \quad (Z = 1)$$

where α is the longitudinal nozzle admittance coefficient and is in general complex.

The remaining two boundary conditions are the matching conditions across the combustion front. These are obtained by writing the mass and momentum conservation equations across the combustion front under oscillatory conditions assuming the burning rate perturbation, Q', is given by:

$$Q' = \bar{Q}n \ (1 - e^{-\sigma\tau}).$$

The details of this procedure are given in Ref. 1. Once these coefficients are obtained a characteristic equation can be written in terms of the parameters n, τ and σ. The neutral stability boundaries can then be obtained using the same procedure as that used for a transverse mode.

I, Problem (cont.)

C. EQUATIONS

1. Program A - Longitudinal Mode Analysis

Input = $M(Z^*)$, $\overline{M}_e$, $\overline{C}_o^*$, κ, γ, $\bar{u}^*_{LO}$, L_c^*, α_N

$$\xi_1 = 1 - \frac{\int_o^{L_c^*} M(Z^*)\, dZ^*}{M_e\, L_c^*}$$

$$\bar{c} = \left[1 - \frac{\gamma-1}{2} M_e^{\,2}\right]^{1/2}$$

$$\phi_1 = \frac{2\omega\, \bar{c}}{\bar{c}^2 - M_e^{\,2}} (1 - \xi_1)$$

$$\bar{u}_{LO} = \frac{\bar{u}^*_{Lo}}{\bar{C}_o^{\,*}}$$

$$\bar{u}_L = \bar{u}_{Lo} - \kappa\, \xi_1$$

$$\xi_L = \frac{\overline{M}_e}{\bar{u}_L} \quad \frac{1}{1 - \frac{\gamma-1}{2} \overline{M}_e^{\,2} - \gamma\, \overline{M}_e^2 (\kappa - 1)}$$

$$\theta_1 = 2\omega\, \xi_1$$

I, C, Equations (cont.)

$$B = \frac{1 + \frac{\bar{M}_e}{\bar{c}} \alpha_N}{1 - \frac{\bar{M}_e}{\bar{c}} \alpha_N}$$

$$C = 1 + B\, e^{i\phi_1}$$

$$D = 1 - B\, e^{i\phi_1}$$

$$E = 1 - e^{-i\theta_1}$$

$$F = 1 + e^{-i\theta_1}$$

$$I_1 + iJ = \frac{F}{\gamma} (\bar{M}_e C - \bar{c} D) + \left[\left(\frac{1 - \frac{\gamma-1}{2} \bar{M}_e^{\,2}}{\gamma} + \frac{\bar{M}_e^{\,2}}{\gamma} \right) \left(1 + \frac{\xi_L \kappa}{\omega} \right) \right.$$

$$\left. - \frac{2 \bar{M}_e^{\,2} \gamma \kappa}{\left(1 - \frac{\gamma-1}{2} \bar{M}_e^{\,2} - \gamma \bar{M}_e^{\,2} (\kappa - 1) \right) \omega} \right] CE + ED \left[\frac{2 \bar{M}_e \bar{c} \gamma \kappa}{\left(1 - \gamma \bar{M}_e^{\,2} (\kappa - 1) \right) \omega} \right.$$

$$\left. - \left(\frac{2 \bar{M}_e \bar{c}}{\gamma} \right) \left(1 + \frac{\xi_L \kappa}{\omega} \right) \right]$$

$$K_1 + iL = F \left[\left(\frac{1 - \frac{\gamma-1}{2} \bar{M}_e^{\,2}}{\gamma} + \frac{\bar{M}_e^{\,2}}{\gamma} \right) C - \frac{2 \bar{M}_e \bar{c}}{\gamma} D \right]$$

$$M_1 + iN = \frac{I_1 + iJ}{K_1 + iL}$$

I, C, Equations (cont.)

$$T_1 = \frac{M_1^{\ 2} + N^{\ 2}}{2\ M_1}$$

$$\delta_m = \tan^{-1}\left(\frac{N}{T_1 - M_1}\right)$$

$$\delta = \frac{\delta_m}{\omega}$$

$$\tau = \frac{\delta\ L_c^*}{\overline{C}_o^*}$$

$$n = \frac{T_1}{\bar{u}_L\ \gamma\left(1 + \xi_L - \dfrac{1}{1 - \frac{\gamma-1}{2}\overline{M}_e^{\ 2} - \gamma\ \overline{M}_e^{\ 2}\ (\kappa-1)}\right)}$$

Evaluate n and τ over a range of ω.

I, C, Equations (cont.)

2. Program B Transverse Mode Analysis

$$\text{Input} = s_{\nu\eta},\ \gamma,\ D_1(Z),\ r_c^*,\ L_c^*,\ C_o^*,\ \bar{u}_{Lo}^*,\ \kappa,\ \bar{u}_e,\ \frac{1_R}{n},\ \frac{1_\theta}{n},\ E$$

$$\bar{u} = \frac{D_1\ \bar{u}_e}{D_1(Z=L_c)}$$

solve $$\frac{d\ \bar{u}_L}{dZ} = \frac{\kappa[\bar{u} - \bar{u}_L]}{\bar{u}_L} \quad \text{for } \bar{u}_L$$

$$\bar{\rho} = [1 + \frac{\gamma-1}{2}\ \bar{u}^2]^{-\frac{1}{\gamma-1}}$$

$$\rho_L = [\bar{u}_e\ (1 + \frac{\gamma-1}{2}\ \bar{u}_e^{\ 2})^{-\frac{1}{\gamma-1}} - \frac{\bar{\rho}\ \bar{u}}{\bar{u}_L}\ ]$$

$$\bar{Q} = \frac{[(1-\gamma\bar{u}^2)\bar{\rho}\ \frac{d\bar{u}}{dZ} - \gamma\bar{u}\ \bar{\rho}_L\ \kappa\ (\bar{u}-\bar{u}_L)]}{1 + \gamma\bar{u}(\bar{u} - \bar{u}_L)}$$

$$\Omega = (s_{\nu\eta}^{\ 2} - \omega^2)^{1/2}$$

$$Y_1 = (\gamma-1)\int_o^{L_c} \bar{Q}\ \cosh\ [\Omega(L_c-Z)]dZ + \int_o^{L_c} 2\ \frac{d\bar{u}}{dZ}\ \cosh\ [\Omega(L_c-Z)]\ dZ$$

$$+ \frac{(\omega+i\kappa)\kappa\omega}{\kappa^2 + \omega^2}\ \int_o^{L_c}\ \frac{\rho_L}{\bar{\rho}}\ \cosh\ [\Omega(L_c-Z)]\ dZ$$

$$Y_2 = -\ \frac{s_{\nu\eta}\ E}{\omega}\ \cosh\ (\Omega\ L_c) - \frac{i\Omega}{\omega\sinh(\Omega\ L_c)}$$

I, C, Equations (cont.)

$$Y_2 = -\frac{s_{\nu\eta} E}{\omega} \cosh(\Omega L_c) - \frac{i\,\Omega}{\omega \sinh(\Omega L_c)} \quad \frac{i\Omega}{\omega} \sinh(\Omega L_c)$$

$$Y_3 = \frac{E\, s_{\nu\eta}}{\Omega} \frac{\kappa^2 \omega}{\kappa^2 + \omega^2} \int_0^{L_c} \frac{\rho_L}{\rho} \sinh[\Omega(L_c - Z)]\, dZ$$

$$- \frac{i\, E\, s_{\nu\eta}}{\Omega} \left[(\gamma - 1) \int_0^{L_c} \bar{Q} \sinh[\Omega(L_c - Z)]\, dZ \right.$$

$$+ \int_0^{L_c} 2 \frac{d\bar{u}}{dZ} \sinh[\Omega(L_c - Z)]\, dZ$$

$$\left. + \frac{\omega^2 \kappa}{\kappa^2 + \omega^2} \int_0^{L_c} \frac{\bar{\rho}_L}{\bar{\rho}} \sinh[\Omega(L_c - Z)]\, dZ \right]$$

$$Y_6 = \frac{iE\, s_{\nu\eta}}{\Omega} \int_0^{L_c} \bar{Q} \sinh[\Omega(L_c - Z)]\, dZ$$

$$+ \int_0^{L_c} \bar{Q} \cosh[\Omega(L_c - Z)]\, dZ$$

$$h = \frac{Y_1 + Y_2 + Y_3}{Y_6}$$

evaluate h over a range of ω

I, C, Equations (cont.)

3. Program C - Nozzle Admittance

Nozzle admittance is calculated for an axisymmetric conventional or annular nozzle with an inner wall radius r_i and outer wall radius r_o. These radii are functions of axial distance Z from the nozzle throat which are defined as follows:

$$r_o^* (Z^*) = R_{ATo}^* + R_{CTo}^* - \sqrt{R_{CTo}^{*2} - Z^{*2}} \quad , \quad 0 \leq Z^* \leq Z^*_{1o}$$

where $Z^*_{1o} = R_{CTo}^* \sin \alpha_o$

$$r_o^* (Z^*) = R_{ST1o}^* + \frac{Z^* - Z_{1o}^*}{Z_{2o}^* - Z_{1o}^*} (R_{ST2o}^* - R_{ST1o}^*), \quad Z_{1o}^* < Z^* \leq Z_{2o}^*$$

where $R_{ST1o}^* = R_{ATo}^* + R_{CTo}^* (1 - \cos \alpha_o)$

$$Z_{2o}^* = Z_{1o}^* + (R_{ST2o}^* - R_{ST1o}^*) \cot \alpha_o$$

$$R_{ST2o}^* = R_{ACo}^* - R_{CCo}^* (1 - \cos \alpha_o)$$

$$r_o^*(Z^*) = R_{ACo}^* - R_{CCo}^* + \sqrt{R_{CCo}^{*2} - (Z_{3o}^* - Z^*)^2} \quad , \quad Z_{2o}^* < Z^* \leq Z_{3o}^*$$

where $Z_{3o}^* = Z_{2o}^* + R_{CCo}^* \sin \alpha_o$

I, C, Equations (cont.)

$$r_o^* (Z^*) = R^*_{ACo} \quad , \quad Z^*_{3o} \leq Z^*$$

$$r_i^* (Z^*) = R^*_{ATi} + R^*_{CTi} - \sqrt{R^{*2}_{CTi} - Z^{*2}} \quad , \quad 0 \leq Z^* \leq Z^*_{1i}$$

$$R^*_{CTi} > 0$$

$$r_i^* (Z) = R^*_{ATi} + R^*_{CTi} + \sqrt{R^{*2}_{CTi} - Z^{*2}} \quad , \quad 0 \leq Z^* \leq Z^*_{2i}$$

$$R^*_{CTo} < 0$$

$$r_i^* (Z^*) = 0 \ , \qquad R^*_{ATi} = 0$$

$$R^*_{ACi} = 0$$

where $Z^*_{1i} = R^*_{CTi} \sin \alpha_i$

$$r_i^* (Z^*) = R^*_{ST1i} + \frac{Z^* - Z^*_{1i}}{Z^*_{2i} - Z^*_{1i}} (R^*_{ST2i} - R^*_{ST1i}) \quad Z^*_{1i} < Z^* \leq Z^*_{2i}$$

where $R^*_{ST1i} = R^*_{ATi} + R^*_{CTi} (1 - \text{Cos} \ \alpha_i)$

$$Z^*_{2i} = Z^*_{1i} + (R^*_{ST2i} - R^*_{ST1i}) \text{ Cot } \alpha_i$$

$$R^*_{ST2i} = R^*_{ACi} - R^*_{CCi} (1 - \text{Cos } \alpha_i)$$

I, C, Equations (cont.)

$$r_i^*(Z^*) = R_{ACi}^* - R_{CCi}^* + \sqrt{R_{CCi}^{*2} - (Z_{3i}^* - Z^*)^2} \quad , \qquad Z_{2i}^* < Z^* \leq Z_{3i}^*$$

$$R_{CCi}^* > 0$$

$$r_i^*(Z^*) = R_{ACi}^* - \sqrt{R_{CCi}^{*2} - (Z_{3i}^* - Z^*)^2} \quad , \qquad Z_{2i}^* < Z^* \leq Z_{3i}^*$$

$$R_{CCi}^* < 0$$

where $Z_{3i}^* = Z_{2i}^* + R_{CCi}^* \sin \alpha_i$

R_{ATo}^*, R_{ATi}^*, R_{CTo}^*, R_{CTi}^*, R_{ACo}^*, R_{ACi}^*, R_{CCo}^*, R_{CCi}^*, α_o and α_i are input data defined by Figures 14 and 15.

From the nozzle radius calculate the nozzle area a^*.

$$a^*(Z^*) = \pi \left[r_o^{*2}(Z^*) - r_i^{*2}(Z^*)\right]$$

Mach number, M(Z), can be obtained by creating a table of M versus a^* from the equation.

$$\frac{a^*(Z)}{a^*(Z^*=0)} = \frac{1}{M(Z^*)} \left[\left(\frac{2}{\gamma+1}\right)\left(1 + \frac{\gamma-1}{2} M^2(Z^*)\right)\right]^{\frac{\gamma+1}{2(\gamma-1)}}$$

The velocity divided by the speed of sound at the throat, $\bar{q}$, (commonly called M^*) is given by

$$\bar{q}(Z)^2 = \frac{\frac{\gamma+1}{2} M^2(Z^*)}{1 + \frac{\gamma-1}{2} M^2(Z^*)}$$

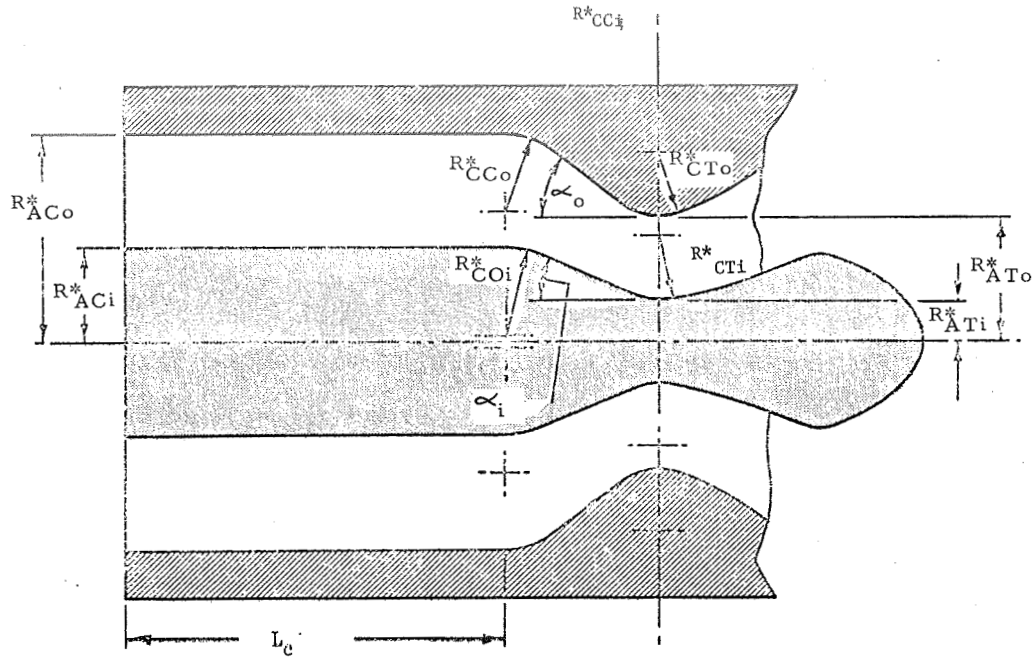


Figure 14 -- Computer Input Parameters -- Annular Chamber

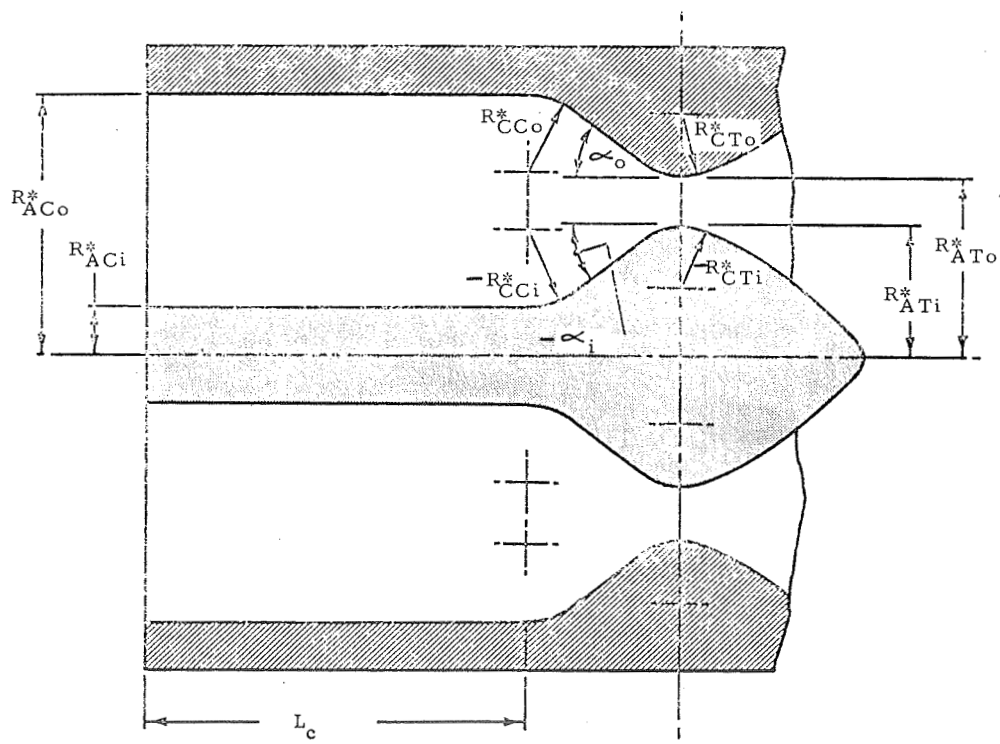


Figure 15 -- Computer Input Parameters -- Annular Chamber

I, C, Equations (cont.)

The velocity potential, which is the independent variable for the equations of motion in the nozzle, is given by

$$\hat{\phi}\ (Z^*) = \frac{2\ K}{R_{AT_o}} \int_o^Z \bar{q}\ (Z^*)\ dZ^* \tag{43}$$

Auxiliary functions $\hat{\zeta}$, $\hat{\xi}^{(1)}$, $\hat{\xi}^{(2)}$, f_3 which are required to define the admittance coefficients in the nozzle are given by the following differential equations

$$b\left(\frac{d\hat{\zeta}}{d\hat{\phi}} + \hat{\zeta}^2\right) = (g + ih)\ \hat{\zeta} - (j + i\ k)$$

$$\frac{d}{d\hat{\phi}}\left[(1 - \bar{q}^2)\ \hat{\xi}^{(1)}\right] = -\left[\hat{\zeta} - i\ \hat{\omega}\ \left(\frac{1}{2\bar{q}^2} + \frac{2}{(\gamma+1)(1-\bar{q}^2)}\right)\right](1-\bar{q}^2)\ \hat{\xi}^{(1)}$$

$$+ \frac{2}{\gamma+1}\ \frac{\hat{s}_{\nu\eta}^{\ 2}}{4}\ \frac{(\bar{c})^{\frac{2}{\gamma-1}}}{\bar{q}}$$

$$\frac{d}{d\hat{\phi}}\left[(-\bar{q})^2\ \xi^{(2)}\right] = -\left[\hat{\zeta} - i\hat{\omega}\ \left(\frac{1}{2\bar{q}^2} + \frac{2}{(\gamma+1)(1-\bar{q}^2)}\right)\right](1-\bar{q}^2)\ \hat{\xi}^{(2)}$$

$$+ \frac{2}{\gamma+1}\left[\frac{df_3}{d\hat{\phi}} + \frac{\hat{s}_{\nu\eta}^{\ 2}\ \bar{c}^{\frac{2}{\gamma-1}}\ \bar{q}}{2i\hat{\omega}}\left(\frac{1-\bar{q}^2}{2\bar{q}^2} + \frac{\hat{c}^2}{\bar{q}^2}\ f_3\right)\right]$$

$$\frac{d}{d\hat{\phi}}\ (\bar{c}^2\ f_3) - \frac{i\hat{\omega}}{2\bar{q}^2}\ (\bar{c}^2\ f_3) = \frac{1}{2}\ \frac{d\bar{q}^2}{d\hat{\phi}}$$

where $\quad b = \bar{q}^2\ (\bar{c}^2 - \bar{q}^2)$

I, C, Equations (cont.)

$$g = \frac{\gamma+1}{2} \frac{(\bar{q})^2}{\bar{c}^2} \frac{d(\bar{q})^2}{d\hat{\phi}}$$

$$h = \hat{\omega}(\bar{q})$$

$$j = \frac{\hat{\omega}^2}{4} - \frac{\bar{q}(\bar{c})^{\frac{2}{\gamma-1}}}{4} (\hat{s}_{\nu\eta})^2$$

$$k = \frac{\gamma-1}{4} \frac{(\bar{q})^2}{\bar{c}^2} \frac{d(\bar{q})^2}{d\hat{\phi}} \hat{\omega}$$

$$\hat{\omega} = \omega/\hat{K} \tag{44}$$

$$\hat{s}_{\nu\eta} = s_{\nu\eta}/\hat{K} \tag{45}$$

$$\hat{K} = \left(\frac{d\bar{q}}{dZ}\right)_{Z=i} = R^*_{ATo} \left[\frac{2}{\gamma+1} \left(\frac{R^*_{ATo}}{R^*_{CTo}} - \frac{R^*_{ATi}}{R^*_{CTi}} \right) \Big/ \left(R^{*2}_{ATo} - R^{*2}_{ATi} \right) \right]^{1/2}$$

The initial values of the auxiliary functions are given as follows:

$$\hat{\xi}^{(1)}(0) = 0$$

$$\hat{\xi}^{(2)}(0) = 0$$

$$f_3(0) = 0$$

$$\hat{\zeta}(0) = \hat{\alpha}_o + i\,\hat{\beta}_o$$

I, C, Equations (cont.)

where $$\hat{\alpha}_o = \frac{\frac{\gamma+1}{2}\left(\frac{\hat{\omega}^2 - \hat{s}_{\nu\eta}^{\,2}}{4}\right) - \frac{\gamma-1}{4}\hat{\omega}^2}{\hat{\omega}^2 + \left(\frac{\gamma+1}{2}\right)^2}$$

$$\hat{\beta}_o = -\frac{\frac{\gamma^2-1}{8} + \frac{\hat{\omega}^2 - (\hat{s}_{\nu\eta})^2}{4}}{\hat{\omega}^2 + \left(\frac{\gamma+1}{2}\right)^2}$$

The equation for $\hat{\zeta}$ is singular at Z = 0 so in the region of the throat $\hat{\zeta}$ is defined from its derivative at the throat

$$\left.\frac{d\hat{\zeta}}{d\hat{\phi}}\right|_{Z=0} = \alpha_i + i\,\beta_1$$

where $$\alpha_1 = \frac{1}{\left(\frac{\gamma+1}{2}\right)^2 + \hat{\omega}^2}\left\{\alpha_o\left[\left(\frac{\gamma+1}{2}\right)^3 + \hat{\omega}^2\right]\right.$$

$$- \frac{\gamma+1}{2}\beta_o\left[1 - \frac{\gamma+1}{2}\hat{\omega}\right]$$

$$+ \frac{\gamma^2-1}{8}\left(\hat{\omega}^2 - \hat{s}_{\nu\eta}^{\,2}\right) + \left(\frac{\gamma+1}{2}\right)^2\left(\alpha_o^2 - \beta_o^2\right)$$

$$\left. + 2\left(\frac{\gamma+1}{2}\right)\hat{\omega}\,\alpha_o\beta_o\right\}$$

I, C, Equations (cont.)

$$\beta_1 = \frac{1}{\left(\frac{\gamma+1}{2}\right)^2 + \hat{\omega}^2} \left\{ \frac{(\gamma+1)(3-\gamma)}{4} \hat{\omega}\, \alpha_o + \beta_o \left[\left(\frac{\gamma+1}{2}\right)^3 + \hat{\omega}^2 \right] \right.$$

$$\left. + \frac{\gamma-1}{8} \hat{\omega} \left[\left(\frac{\gamma+1}{2}\right)^2 - (\hat{s}_{\nu\eta})^2 \right] - \frac{\gamma+1}{2} \hat{\omega} \left(\alpha_o^2 - \beta_o^2\right) + 2 \left(\frac{\gamma+1}{2}\right)^2 \alpha_o \beta_o \right\}$$

The nozzle admittance coefficients can be defined from the auxiliary functions at the desired value of Z.

$$A = \frac{\left(\frac{2}{\gamma+1}\right)^{1/2} \bar{q}\, \bar{c}^2 \left(\hat{\xi}^{(1)} \bar{c}^2 - \hat{\zeta}\right)}{\bar{q}^2 \left(\hat{\xi}^{(1)} \bar{c}^2 - \hat{\zeta}\right) - i \frac{\hat{\omega}}{2}} \left(\frac{\gamma+1}{2\bar{c}^2}\right)^{\frac{\gamma}{\gamma-1}} \tag{46}$$

$$B = \frac{\frac{i\hat{\omega}}{s_{\nu\eta}} \sqrt{\bar{c}\, \frac{2}{\gamma-1}}\, \bar{q}\, \hat{\xi}^{(1)} \bar{c}^2}{\bar{q}^2 \hat{\xi}^{(1)} \bar{c}^2 - \hat{\zeta} - \frac{i\hat{\omega}}{2}} \tag{47}$$

$$C = \frac{\left(\frac{2}{\gamma+1}\right)^{\frac{1}{2}} \bar{q}\, \bar{c}^2 \left(f_3 \hat{\zeta} + \frac{1-\bar{q}^2}{2} \hat{\xi}^{(1)} - i \frac{\hat{\omega}}{2} \hat{\xi}^{(2)}\right)}{\bar{q}^2 \left(\hat{\xi}^{(1)} \bar{c}^2 - \hat{\zeta}\right) - i \frac{\hat{\omega}}{2}} \tag{48}$$

I, C, Equations (cont.)

$$\alpha = -\frac{A}{\overline{M}\,(Z_3)} \tag{49}$$

$$E = Af' + iB \tag{50}$$

$$f' = \frac{\hat{\omega}}{\hat{s}_{\nu\eta}\left(\frac{\gamma+1}{2}\right)^{\frac{1}{2}}\left[\bar{q}\left(\frac{\gamma+1}{2} - (\bar{q})^2\,\frac{\gamma-1}{2}\right)^{\frac{1}{\gamma-1}}\right]^{1/2}}$$

I, C, Equations (cont.)

4. Program D

Take h from Program B

$$\tilde{h}_T = \frac{h}{A_{\nu\eta} + i\left(\frac{B_{\nu\eta}\frac{1_R}{n}}{\gamma\omega} + \frac{C_{\nu\eta}\frac{1_\theta}{n}}{\gamma\omega}\right)}$$

5. Program E

For standing mode

$$A_{\nu\eta} = \frac{\int_0^{2\pi}\int_0^1 \mu(r,\theta)\, F_P(r,\theta)\, J_\nu^2\,(s_{\nu\eta}\, r)\, \mathrm{Cos}^2\, \nu\theta\; r\, dr\, d\theta}{\int_0^{2\pi}\int_0^1 J_\nu^2(s_{\nu\eta} r)\, \mathrm{Cos}^2\, \nu\theta\; r\, dr\, d\theta} \qquad (51)$$

$$B_{\nu\eta} = \frac{\int_0^{2\pi}\int_0^1 \mu(r,\theta)\, F_R\,(\omega,r,\theta)\, J_\nu'\,(s_{\nu\eta}\, r)\, J(s_{\nu\eta} r)\, \mathrm{Cos}^2\, \nu\theta\; r\, dr\, d\theta}{\int_0^{2\pi}\int_0^1 J_\nu^2\,(s_{\nu\eta}\, r)\, \mathrm{Cos}^2\, \nu\theta\; r\, dr\, d\theta} \qquad (52)$$

$$C_{\nu\eta} = -\frac{\int_0^{2\pi}\int_0^1 \mu(r,\theta)\, \frac{F_T(r,\theta,\omega)}{r}\, J_\nu^2\,(S_{\nu\eta}\, r)\, \nu\, \sin\nu\theta\, \mathrm{Cos}\, \nu\theta\; r\, dr\, d\theta}{\int_0^{2\pi}\int_0^1 J_\nu^2\,(s_{\nu\eta}\, r)\, \mathrm{Cos}^2\, \nu\theta\; r\, dr\, d\theta} \qquad (53)$$

for a spinning mode replace

$$A_{\nu\eta} = \frac{A_{\nu\eta}}{2}$$

$$B_{\nu\eta} = \frac{B_{\nu\eta}}{2}$$

$$C_{\nu\eta} = \frac{i\, C_{\nu\eta}}{2}$$

I, C, Equations (cont.)

$$\mu(r,\theta) = \frac{\sigma(r,\theta)}{\sigma_{ave}} \tag{54}$$

$\sigma(r,\theta)$ is the injection density (weight flow per unit area)

σ_{ave} is the total weight flow divided by the total injector area

6. Program F

$$n\ (1 - e^{-i\omega\tau}) = h_T$$

7. Program I

For non-linear combustion response, input tables of burning rate versus pressure, radial velocity, and tangential velocity, ϕ_P, ϕ_R, ϕ_1. Additional data needed are: P_{oo} (amplitude of pressure oscillation being considered divided by the mean chamber pressure) TFLP, TFLR, and TFLT (the linear transfer functions for equivalent linear operation associated with the pressure, radial velocity and tangential velocity dependent nonlinear element.) A describing function is calculated at each point on the injector.

$$f_p(r,\theta) = \frac{1}{\pi\ P_o\ (TF_{LP})} \int_{-\pi}^{\pi} \phi_P(\omega\tau, r, \theta)\ \mathrm{Cos}\ (\omega\tau)\ d(\omega\tau) \tag{55}$$

where

$$\phi_P(\omega\tau, r, \theta) = \phi_P(P')$$

$$P' = P_o \cos \omega\tau$$

$$P_o = \left| P_{oo}\ J_\nu(s_{\nu\eta}\ r)\ \mathrm{Cos}\ \nu\ \theta \right|$$

$$F_R(r,\theta,\omega) = \frac{1}{\pi\ V_o(TF_{LR})} \int_{-\pi}^{\pi} \phi_R(\omega\tau, r, \theta)\ \mathrm{Cos}\ (\omega\tau)\ d(\omega\tau)$$

I, C, Equations (cont.)

where

$$\phi_R(\omega\tau, r, \theta) = \phi_R(v')$$

$$v' = V_o \text{ Cos } \omega\tau$$

$$V_o = \left| V_{oo} \left[\frac{\nu J_\nu(s_{\nu\eta} r) - s_{\nu\eta} J_{\nu+1}(s_{\nu\eta} r)}{r} \right] \cos \nu\theta \right|$$

$$V_{oo} = \frac{P_{oo}}{\gamma\omega}$$

$$f_T(r, \theta, \omega) = \frac{1}{\pi W_o (TF_{LT})} \int_{-\pi}^{\pi} \phi_T(\omega\tau, r, \theta) \text{ Cos } (\omega\tau) \, d(\omega\tau)$$

where

$$\phi_T(\omega\tau, r, \theta) = \phi_T(w')$$

$$w' = W_o \text{ Cos } \omega\tau$$

$$W_o = \left| \frac{V_{oo} J_\nu(s_{\nu\eta} r) \nu \sin \nu\theta}{r} \right|$$

8. Program J, Injected Mass Distribution Effects

This program calculates mass flow distribution $\mu(r,\theta)$ used in the program for calculating the $A_{\nu\eta}$, $B_{\nu\eta}$ and $C_{\nu\eta}$. It also calculates useful design parameters such as pressure drops, injection velocities, mixture ratios, and flow areas. Input consists of type and location of elements, description of each element type in terms of orifice diameters and number of orifices, and overall information including propellant densities, orifice discharge coefficients, amount of film cooling, injector radius, total flow rates and total mixture ratio.

First the total orifice area, A_T, for each propellant is calculated:

$$A_T = \sum_i 0.7853891 \, d_i^2$$

I, C, Equations (cont.)

Then the area of the film coolant orifices, A_{FCT}, is calculated

$$A_{FCT} = \sum_i 0.7853891\ d_{FC_i}^2$$

Total flows of oxidizer and fuel are then calculated. The equations used depend on how the information on the film coolant is input.

If percent film coolant is given; P_{ffc}, percent fuel film coolant; P_{xfc} percent oxidizer film coolant, the total fuel flow rate in injector matrix, W_{fT}, is given by:

$$W_{fT} = \frac{W_T}{MR+1} (1 - P_{ffc})$$

The total oxidizer flow rate in the injector matrix, W_{XT}, is given by:

$$W_{XT} = W_T - \frac{W_T}{MR+1} (1 - P_{xfc})$$

If the number and size of the film cooling orifices are given in terms of the fuel hole area in the matrix A_F, oxidizer hole area in the matrix A_X, fuel film coolant hole area A_{FFC}, and oxidizer film coolant area A_{XFC}.

$$W_{fT} = \frac{W_T}{MR+1} \frac{A_{FT}}{A_{FT} + A_{FFC}}$$

$$W_{XT} = W_T - \frac{W_T}{MR+1} \frac{A_{XT}}{A_{XT} + A_{XFC}}$$

The total weight flow per element is given by:

$$W_{E_i} = \frac{A_{Fi}}{A_{FT}} W_{fT} + \frac{A_{xi}}{A_{XT}} W_{XT}$$

I, C, Equations (cont.)

W_{E_i} is used in Program E as follows:

$$\frac{W_{Ei}}{W_T} \quad XM\ XN = \mu_i \text{ for each element.}$$

See equations 51 to 53.

This program also calculates injector pressure drop ΔP:

$$\Delta P = \frac{W^2}{C_d^2\ A^2} \frac{144}{g\ 64.4}$$

where C_d is the orifice discharge coefficient, A is the orifice area, W is the orifice flow rate and ρ is the propellant density. Injection velocity V is calculated from ΔP.

$$V = \frac{(144)(64.4)\ \Delta P}{\rho g}$$

I, Problem (cont.)

D. DEFINITION OF TERMS

$a^*(z^*)$	Area of annular nozzle
A_{Fi}	Area of the ith fuel element, in.^{2}
A_{xi}	Area of the ith oxidizer element, in.^{2}
A_{XFC}	Total area of oxidizer film coolant orifices, in.^{2}
A_{FFC}	Total area of fuel film coolant orifices, in.^{2}
A_{XT}	Total area of oxidizer orifices excluding film coolant, in.^{2}
A_{FT}	Total area of fuel orifices excluding film coolant, in.^{2}
A_{FCT}	Total film coolant area, in.^{2}
A_T	Total orifice area, in.^{2}
$A_{\nu\eta}$	Factor measuring the effect of nonuniform injection on stability (see Equation 37)
b	Variable used in nozzle analysis
B	Term used in longitudinal analysis
$B_{\nu\eta}$	Factor measuring the effect of nonuniform injection on stability (see Equation 37)
c	Speed of sound nondimensionalized by the stagnation speed of sound in the chamber analysis or the throat speed of sound in the nozzle analysis
C	Term used in longitudinal analysis
C_d	Injector orifice discharge coefficient
C_o^*	Dimensional stagnation gas speed of sound in feet per second
C_{th}^*	Dimensional speed of sound at the nozzle throat in feet per second
C_1, C_2	Constants in radial dependent factor of pressure in an annular chamber
$C_{\nu\eta}$	Factor measuring the effect of nonuniform injection on stability (see Equation 37) Complex $C_{\nu\eta R} + i\, C_{\nu\eta I}$
d_i	Diameter of the ith orifice
d_{FC_i}	Diameter of the ith film in coolant orifice
D	Term used in longitudinal analysis
$D_1(z)$	Combustion distribution used in transverse analysis

I, D, Definition of Terms (cont.)

e		Base the natural logarithms
E		Term used in longitudinal analysis
f^*		Dimensional frequency in Hertz
f_3		Auxiliary function in nozzle analysis, complex
f_p	$= \frac{\partial f}{\partial p}$	
f_T	$= \frac{\partial f}{\partial T}$	
f_v	$= \frac{\partial f}{\partial v}$	
$f(\ )$		Rate of preparatory processes before burning
f'		A nozzle frequency defined by Equation 50
F		Term used in longitudinal analysis
$F(\omega)$		Describing function defined by Equation 34
F_p		Describing function for pressure oscillations
F_R		Describing function for velocity oscillations in the radial direction
F_T		Describing function for velocity oscillations in the tangential direction
g		Variable used in nozzle analysis
$\hat{h}$		Variable used in nozzle analysis
h		Part of characteristic equation which includes all acoustic effects (Equation 40) can also be viewed as a chamber admittance complex number $h = h_r + i\, h_i$
h_i		Imaginary part of h
h_r		Real part of h
$\tilde{h}$		Includes acoustic and nonuniform injection effects in the characteristic equation (see Equation 40)
$\tilde{h}_i$		Imaginary part of $\tilde{h}$
$\tilde{h}_r$		Real part of $\tilde{h}$
h_s		Total enthalpy of gas nondimensionalized by $R^*\ T_o^*$
i		Unit imaginary number $\sqrt{-1}$
I		Input to a nonlinear element
I_1		Term used in longitudinal analysis

I, D, Definition of Terms (cont.)

j	Variable used in nozzle analysis
J	Term used in the longitudinal analysis
$J_\nu(\ )$	Bessel function of the first kind of order ν
$J'_\nu(\ )$	Derivative with respect to the argument of the Bessel function of the first kind of order ν
k	Variable used in nozzle analysis
$\hat{K}$	Velocity gradient at the throat nondimensional (see Equation 45)
K	Factor involving droplet drag on frequency defined in Equation 11
K_1	Term used in longitudinal analysis
l_r	Velocity interaction index measuring the amount of interaction between gas velocity in the radial direction and the burning rate
l_θ	Velocity interaction index measuring the amount of interaction between gas velocity in the tangential direction and the burning rate
L	Term used in longitudinal analysis
L_c^*	Chamber length, in.
$\dot{m}_b$	Mass burning rate
$\dot{m}_i$	Mass injection rate
m_r	Displacement interaction index measuring the amount of interaction between gas displacement in the radial direction and the burning rate
m_θ	Displacement interaction index measuring the amount of interaction between gas displacement in the tangential direction and the burning rate
M	Mach number
M_1	Term used in longitudinal analysis
M_e	Mach number at nozzle entrance
MR	Mixture ratio
n	Pressure interaction index measuring the amount of interaction between pressure oscillations and burning rate oscillations
n_{min}	Minimum value of the pressure interaction index for a particular mode
N	Term used in the longitudinal analysis

I, D, Definition of Terms (cont.)

0	Output of a nonlinear element
0_1	Component of output of a nonlinear element at the input frequency ω_f
0_j	Component of output of a nonlinear element of a frequency $j\omega_f$: $j = 2, 3, 4$, etc.
p	Pressure nondimensionalized by the stagnation gas pressure
p_o	Zeroth order solution for pressure. Defined by Equations 12 and 13a
p_1	First order solution for pressure defined by Equations 12 and 13b
P	Z dependent factor in pressure perturbation
P_o	Amplitude of pressure oscillation
P_{oo}	Constant coefficient measuring amplitude of pressure defined in Equation 15a
P_{ffc}	Percent fuel film coolant
P_{xfc}	Percent oxidizer film coolant
$\vec{q}$	Velocity nondimensionalized by the stagnation gas speed of sound, C_o^* in chamber. In the nozzle it is nondimensionalized by the speed of sound at the throat
Q	Burning rate per unit volume nondimensionalized by $\frac{\rho_o^* C_o^*}{r_c^*}$ or $\frac{\rho_o^* C_o^*}{L_c^*}$ for transverse or longitudinal modes.
r	Coordinate in the radial direction. Nondimensionalized by the chamber radius r_c^*
r_c^*	Dimensional chamber radius in inches
r_d^*	Droplet radius in feet
r_i^*	Inner radius of an annular chamber in feet
r_o^*	Outer radius of an annular chamber in feet
R^*	Gas constant
R	Ratio of inner radius and outer radius of an annular nozzle
R^*_{ACi}	Radius of inner contour of an annular chamber at the chamber entrance in inches (see Figures 14,15)
R^*_{ACo}	Radius of outer contour of an annular chamber at the chamber entrance in inches (see Figures 14,15)

I, D, Definition of Terms (cont.)

R^*_{ATi}	Radius of the throat of the inner contour of an annular nozzle in inches (see figure)
R^*_{ATo}	Radius of the throat of the outer contour of an annular nozzle in inches (see figure)
R^*_{CCi}	Radius of curvature at the chamber entrance of the inner contour of an annular nozzle in inches (see Figure
R^*_{CCo}	Radius of curvature at the chamber entrance of the outer contour of an annular nozzle in inches (see Figure
$R^*_{C\ i}$	Radius of curvature at the throat of an inner contour of an annular nozzle in inches (see Figure
R^*_{CTo}	Radius of curvature at the throat of the outer contour of an annular nozzle in inches (see Figure
R^*_{ST1i}	Radius of inner contour of annular nozzle at transition between throat curvature and tangent in inches r_i^* (Z^{k*}_{1i})
R^*_{ST1o}	Radius of outer contour of annular nozzle at transition between throat curvature and tangent in inches r_o^* (Z^*_{10})
R^*_{ST2i}	Radius of inner contour of annular nozzle at transition between chamber curvature and tangent in inches r_i^* (Z^*_{2i})
R^*_{ST2o}	Radius of outer contour of annular nozzle at transition between chamber curvature and tangent in inches r_o^* (Z^*_{20})
S	Z dependent factor in entropy perturbation
$s_{\nu\eta}$	Mode number for a transverse mode defined by Equations 19 thru 21 tabulated for a cylindrical chamber on page
$\hat{s}_{\nu\eta}$	Mode number used in nozzle analysis (see Equation 45)
t	time nondimensional as τ_i
T	Temperature nondimensionalized by T_o^*
T_1	Term in longitudinal analysis
T_o^*	Stagnation gas temperature
TF	Equivalent linear transfer function (see Equation 33)
$(TF)_{LIM}$	Limiting linear transfer function
u	Gas velocity in the axial direction nondimensionalized by C_o^*
$\bar{u}_e$	Mean value of the gas velocity at the nozzle entrance nondimensionalized by the stagnation gas speed of sound
u_L	Axial velocity of liquid drops
$\bar{u}^*_{Lo}$	Liquid injection velocity, ft/sec (see Equation 56)
U	Z dependent factor in axial velocity perturbation

I, D, Definition of Terms (cont.)

v	Gas velocity in the radial direction nondimensionalized by C_o^*
V_o	Amplitude of radial velocity oscillation
V_{oo}	Constant coefficient measuring the amplitude of radial velocity
V	Z dependent factor is radial velocity perturbation
w	Gas velocity in the tangential direction nondimensionalized by C_o^*
W_o	Amplitude of tangential velocity oscillation
W_T	Total propellant weight flow rate, lb/sec
W_{fT}	Total fuel flow rate excluding film coolant, lb/sec
W_{XT}	Total oxidizer flow rate excluding film coolant, lb/sec
W_{E_i}	Flow rate of the ith element, lb/sec
$Y_\nu(\ )$	Bessel function of the second kind of order ν
$Y'_\nu(\ )$	Derivative with respect to the argument of the Bessel function of the second kind of order ν
Y_x	Mass fraction of vaporized oxidizer
Y_1, Y_2, Y_3, Y_6	Variables used in transverse analysis
Z	Length along the chamber axis nondimensionalized by the chamber length L_c^* for a longitudinal mode or by the chamber radius r_c^* for a transverse mode
Z_e	At nozzle entrance
Z^*_{1i}	Axial distance from throat to first transition from curve to tangent for inner contour of an annular nozzle in feet
Z^*_{1o}	Axial distance from throat to first transition from curve to tangent for outer contour of an annular nozzle in feet
Z^*_{2i}	Axial distance from throat to second transition from tangent to curve for inner contour of an annular nozzle in feet
Z^*_{2o}	Axial distance from throat to second transition from tangent to curve for outer contour of an annular nozzle in feet
Z^*_{3i}	Axial distance from throat to transition from chamber to nozzle of the inner contour of an annular nozzle in feet
Z^*_{3o}	Axial distance from throat to transition from chamber to nozzle in feet

I, D, Definition of Terms (cont.)

α_N	Longitudinal nozzle admittance coefficient (see Equation 49)
α_o	Convergence angle of outer contour of an annular nozzle (see Figure 14)
α_i	Convergence angle of inner contour of an annular nozzle (see Figure 14)
α_1	Real part of derivative of ζ at throat
α_o	Real part of ζ at throat
β	Angle of orientation relative to the θ coordinate. See Figure 10
β_1	Imaginary part of derivative of ζ at throat
β_N	Longitudinal admittance coefficient for entropy, complex, $\beta_N = \beta_{N_r} + i\,\beta_{N_i}$
β_o	Imaginary part of ζ at throat
γ	Ratio of specific heats
Γ	Z dependent factor in the first order solution for pressure defined by Equation 15
δ_r	Displacement of gas in the radial direction due to pressure oscillations
δ_θ	Displacement of gas in the tangential direction due to pressure oscillations
δ	Term used in longitudinal analysis
δ_m	Term used in longitudinal analysis
ΔP	Injector pressure drop, lb/in.^{2}
ζ	Variable in Z direction used in various integrals
$\hat{\zeta}$	Auxiliary function in nozzle analysis complex
η	Index numbering the zeros in the derivative of the Bessel function
θ	Coordinate in the tangential direction
θ_1	Term used in longitudinal analysis
θ_F	Fuel angle of injection measured from Z axis
θ_x	Oxidizer angle of injection measured from Z axis
Θ	θ dependent factor in the solution for pressure defined in Equation 15
Θ^*	Complex conjugate of Θ
κ	Momentum interchange coefficient between droplets and gas $\kappa^* = \frac{9}{2}\,\frac{\mu^*}{r_d^{*2}\,\rho_L^*}$ nondimensionalized by $\frac{C_o^*}{r_c^*}$ or $\frac{C_o^*}{L_c^*}$ for transverse or longitudinal modes

I, D, Definition of Terms (cont.)

λ	Real part of complex frequency σ
μ	Burning rate distribution function $= \frac{\sigma}{\sigma_{mean}}$
μ^*	Viscosity in lb-sec/ft^2
ν	Order of the Bessel function which indicates the number of cycles of pressure oscillation when traversing in the tangential direction at a fixed radius, axial length and time
ν_F	Fuel injection velocity, ft/sec
ν_x	Oxidizer injection velocity ft/sec
ξ	Factor involving droplet drag, frequency and liquid inertance defined in Equation 11
ξ_1	Distance from injector to concentrated combustion front nondimensionalized by chamber length
ξ_L	Term used in longitudinal analysis
$\xi^{(1)}$	Auxiliary function in nozzle analysis, complex
$\xi^{(2)}$	Auxiliary function in nozzle analysis, complex
ρ	Density of chamber gases nondimensionalized by the stagnation gas density ρ_o^*
ρ_L^*	Density of liquid droplets, lb-sec^2/ft^4
σ	Complex frequency nondimensionalized as the reciprocal of τ_i
σ	Injection density
σ_{mean}	Mean injection density
τ_i	Portion of time lag which is insensitive to pressure oscillations nondimensionalized by $\frac{L_c^*}{C_o^*}$ for a longitudinal mode and $\frac{r_c^*}{C_o^*}$ for a transverse mode
τ	Mean sensitive time lag nondimensional as τ_i
τ_T	Total time delay between injection of propellant and burning of that same propellant nondimensional as τ_i
τ^*	Sensitive time lag in milliseconds
ϕ	Velocity potential in the exhaust nozzle
ϕ_P	Function relating input pressure to the combustion to the output (burning rate)

I, D, Definition of Terms (cont.)

ϕ_R	Function relating input radial velocity to the combustion to the output (burning rate)
ϕ_T	Function relating input tangential velocity to the combustion to the output (burning rate)
ϕ_1	Term used in longitudinal analysis
χ	ωt
ψ	Stream function in the exhaust nozzle
Ψ	r dependent factor in the solution for pressure defined by Equation 15
ω	Imaginary part of complex Laplace variable σ
	For a transverse mode in chamber $\omega = \frac{2 f^* r_c^*}{C_o^* 12}$
	For a longitudinal mode in chamber $\omega = \frac{2 f^* L_c^*}{C_o^* 12}$
	For the nozzle $\omega \quad \frac{2 f^* R^*_{AT_o}}{C^*_{th} 12}$
ω_f	Frequency of input signal to a nonlinear element
$\hat{\omega}$	Nondimensional frequency used in nozzle analysis (see Equation 44)
Ω	$(s_{\nu\eta}^2 - \omega^2)^{1/2}$
A	Nozzle admittance coefficient (see Equation 38). Complex number $A = A_r + i A_i$
B	Nozzle admittance coefficient (see Equation 38). Complex number $B = B_r + i B_i$
C	Nozzle admittance coefficient (see Equation 38). Complex number $C = C_r + i C_i$
E	Combined nozzle admittance coefficient defined by Equation 50. Complex number $E_r + i E_i$
P	Pressure sensitive combustion response define as $n(1-e^{-\sigma\tau})$
R	Radial velocity sensitive combustion response defined by $1_r(1-e^{-\sigma\tau})$
R_δ	Radial displacement sensitive combustion response defined by $m_r(1-e^{-\sigma\tau})$
T_δ	Tangential displacement sensitive combustion response defined by $m_\theta(1-e^{-\sigma\tau})$

I, D, Definition of Terms (cont.)

T	Tangential velocity sensitive combustion response defined by $1_\theta(1-e^{-\sigma\tau})$
—	A bar over a variable indicates it is a mean quantity and does not depend on time
'	A prime on a variable indicates it is a perturbation quantity

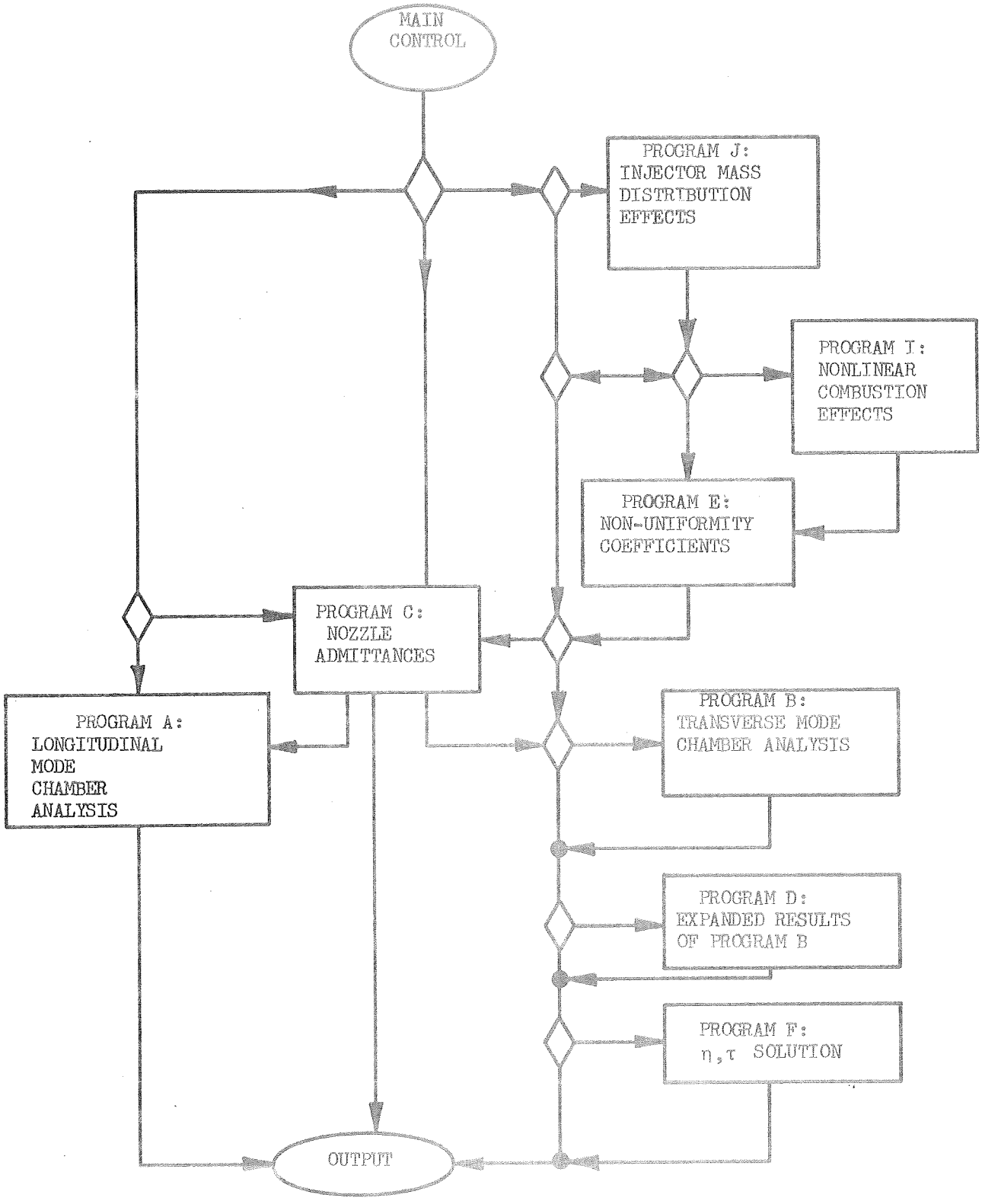


Figure 16 -- General Flow Diagram of the Computer Program

I, Problem (cont.)

E. SPECIAL OPTIONS

The stability solution of any given liquid rocket engine must consider the three main portions of that engine: (1) the injector, (2) the combustion chamber, and (3) the exhaust nozzle. Furthermore, oscillatory conditions can exist along the longitudinal direction as well as the transverse (i.e., tangential and radial) directions. It is clear that these considerations serve as the basis for building the computer program.

The complete program consists of nine separate subprograms which may be used independently or in various combinations depending upon the data available and the information required by the designer. Figure 16 shows the interrelationships of the programs and the optional routes for proceeding with the calculation. The individual programs are:

A. Longitudinal Mode Chamber Analysis, used to obtain n, τ stability mapping for longitudinal modes.

B. Transverse Mode Chamber Analysis. For simplicity only the analysis is performed; the n, τ mapping is done later in Program F.

C. Nozzle Admittance. Here the resistive effects of the nozzle are calculated for both longitudinal and transverse modes.

D. Expansion of Results from Program B by interpolation and add nonuniformity and velocity effects.

E. Injector Nonuniformity Coefficients. Calculates modulating coefficients for the effects resulting from uneven injection distribution and nonlinear combustion response.

F. Stability Mapping (n, τ) for Transverse Modes

G. Not in use

H. High Combustion Chamber Mach Number Analysis (not operational)

I. Nonlinear Combustion Response. Input to Program E.

J. Injected Mass Distribution Effects

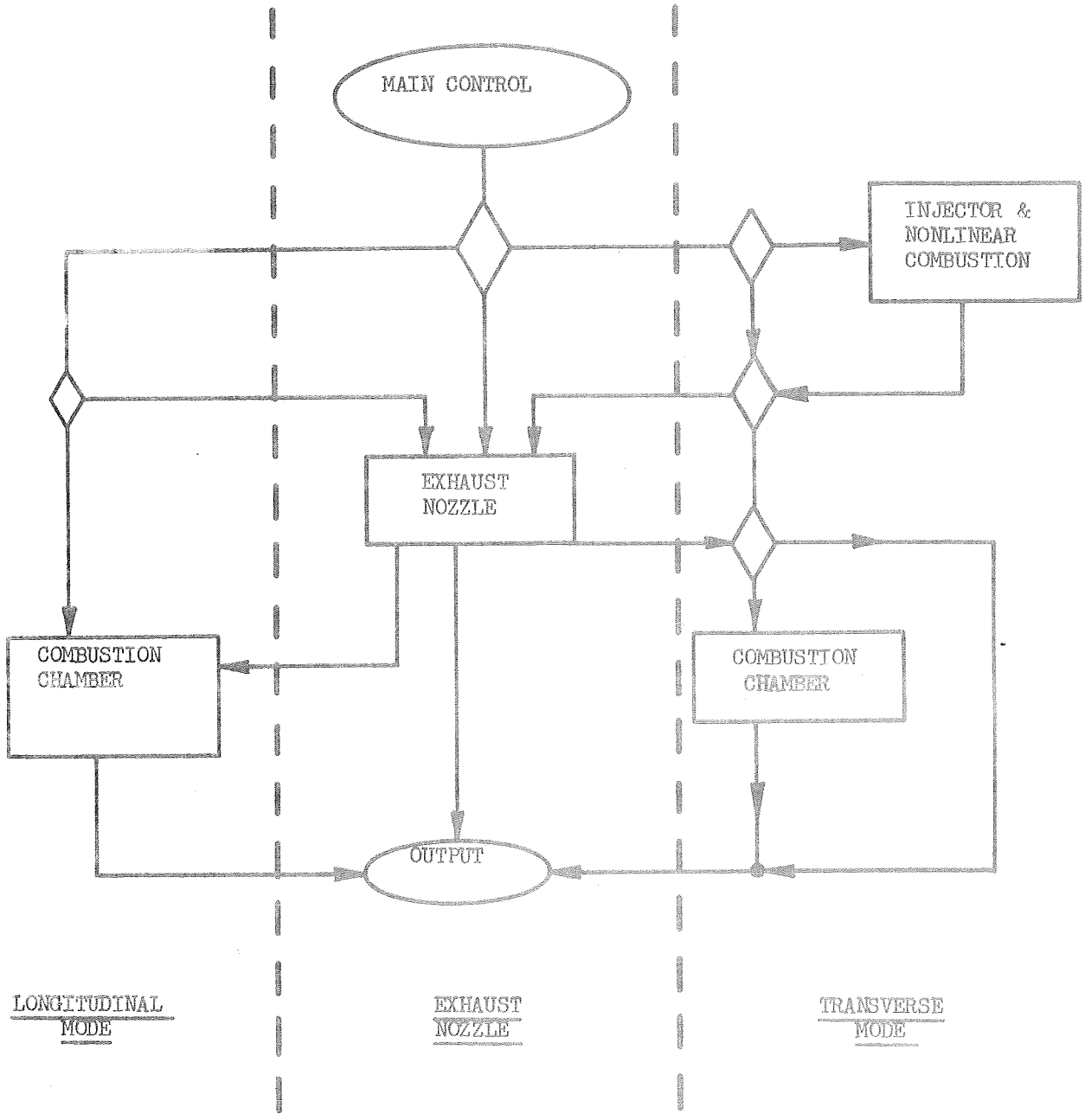


Figure 17 -- Overall Schematic of Computer Program

I, E, Special Options (cont.)

To assure that the proper subprograms are requested it is necessary to introduce a regulatory device that monitors the course of the entire program as it proceeds from one portion of the engine to another. This regulatory device is called MAIN CONTROL and serves to direct the flow of the solution in a consistent manner. Figure 16 illustrates the basic framework of the computer program. The diamond-shaped symbols can be considered as switches that are turned on if the particular item is to be analyzed by the program or turned off if the item is not needed. It is the function of MAIN CONTROL to turn these switches on or off according to the dictates of the problem.

It can be seen in Figure 17 that the program is divided into 3 parts: (1) longitudinal modes, (2) transverse modes, and (3) exhaust nozzle. The exhaust nozzle portion has been carried over from the program's early development when nozzle parametric studies were conducted.

The versatility of the program is illustrated in Figure 16 by the various flow-paths that can be constructed. For example, if the required injector and nozzle data were known beforehand, one could determine the transverse stability of the engine by merely running the combustion chamber program. If, on the other hand, all the data were unknown, proper use of MAIN CONTROL would initiate the injector, nozzle, and chamber programs. Therefore, the program is as suitable for parametric studies as it is for analysis of specific designs.

It can be seen that the transverse portion of the program is more detailed than the longitudinal portion. The injector requires programs, J, I, and E to evaluate the injector parameters that affect stability. The chamber analysis requires B, D, and F. It should be noted that program D is more of a convenience than a necessity while program F determines the solution of n and τ.

I, E, Special Options (cont.)

Following is an outline which will help determine which programs are to be run when evaluating an engine design.

I. Longitudinal Modes

A.* Is the nozzle admittance coefficient (α_N) known?

1. YES: Input this datum
2. NO: Run Program C

B. Run Program A

II. Transverse Modes

A.* Are the nozzle admittances (A, B, C) known?

1. YES: Input the data
2. NO: Run Program C

B.* Are the injector non-uniformity coefficients ($A_{\nu\eta}$, $B_{\nu\eta}$, $C_{\nu\eta}$)** known?

1. YES: Input the data
2. NO: Run Program E

a. Is the mass distribution (μ) around the face known?

(1) YES: Input the data
(2) NO: Run Program J (Usual Case)

b.* Is the combustion response linear [F_P, F_R, F_T = 1]?

(1) YES: DO NOT RUN PROGRAM I (Usual Case)
(2) NO: RUN Program I

C. Do you want more than 10 points on the stability plane?

1. YES: Run Program D (RECOMMENDED)
2. NO: Do not run Program D

*Changes with mode (e.g., first tangential, second radial, etc.)
**If the injector has a uniform injection profile, $A_{\nu\eta} = B_{\nu\eta} = C_{\nu\eta} = 1.0$.

I, E, Special Options (cont.)

D. Do you want n, τ points?

1. YES: Run Program F
2. NO: Do not run Program F

If the instruction given is to "input the data", the proper L-numbers can be obtained from the section on input data.

I, E, Special Options (cont.)

In addition to evaluating specific designs parametric surveys can be run to evaluate the effect of particular portions of the program. The following outline may be helpful for this purpose:

I. NOZZLE EFFECTS: Run Program C

II. VARIATION OF NON-UNIFORMITY COEFFICIENTS WITH RESPECT TO:

a. Mass Distribution

(1) Input the data (μ) to Program E
(2) Run Programs J and E

b. Nonlinear combustion response

(1) Input the data (F_P, F_R, F_T) to Program E
(2) Run Programs I and E

c. Both mass distribution and nonlinear combustion response

(1) Input the data (μ, F_P, F_R, F_T) to Program E
(2) Run Programs E, I, and J as needed.

III. Variation of the stability zones with respect to:

a. Nozzle effects

(1) Input the data (A, B, C)
(2) Run Programs C and A or B, C, D, and F

b. Non-uniformity coefficients

(1) Input the data ($A_{\nu\eta}$, $B_{\nu\eta}$, $C_{\nu\eta}$) and run B
(2) Run B, D, E, and F

c. et al

No further extension of the parametric study outline is necessary. The ones that have been presented serve as a guide to the others. There are countless other variations that might be considered.

I, Problem (cont.)

F. NUMERICAL METHODS OF SOLUTION*

As seen in Section C the nozzle admittance coefficients are defined in terms of a system of non-linear differential equations which must be integrated from the throat to the nozzle entrance. These equations are integrated using Adams integration. Adams integration, as developed at Aerojet, uses several subroutines: ADSET, ADINT, ADCOR, ADRES and ADPAR. A description of Adams integration, which is reproduced from an Aerojet manual, follows:

PURPOSE

To integrate a system of N simultaneous first order differential equations.

RESTRICTIONS

$N \leq 200$

METHOD

Adam's method of integration as described in Computing Services Report #13, "Adam's Method of Integration of Differential Equations", by Dr. R. D. Glauz, is used. Accurate computation of functional values between integration steps is possible using partial step integration. The set of differential equations must be written as a system of first order equations in the form:

$$\frac{dy_1}{dx} = f_1 (x, y_1, y_2, \ldots, y_n)$$

- - - - -

$$\frac{dy_n}{dx} = f_n (x, y_1, y_2, \ldots, y_n)$$

*Nomenclature in this section does not correspond to the rest of the report.

I, F, Numerical Methods of Solution (cont.)

USAGE

This subroutine has five separate entries:

1. The initial setup of the integration which specified number of equations and storage locations is done at the beginning of the program with the statement:

CALL ADSET (N, F, D, P, T, X, H, E)

with

N = number of first order differential equations to be integrated.

F = location of integrated y_1, y_2, y_n.

D = location of derivatives $\frac{dy_1}{dx}$, $\frac{dy_2}{dx}$, $\frac{dy_n}{dx}$

P = location of interpolated or partial step

y_1^p, y_2^p, ..., y_n^p.

T = temporary storage having 8N cells

X = independent variable

H = integration step (initially set at approximate value)

E = location of desired accuracy, E (1) = accuracy of y_1 ...

E (n) = accuracy of y_n. If E (I) = 0 then program sets

E(I) = 10^{-8}

I, F, Numerical Methods of Solution (cont.)

2. To integrate forward a single integration step use:

```
        CALL ADINT
100     D(1) = ...
        D(2) = ...
          .
          .
          .
        D(N) = ...
        CALL ADCOR (& 100)
```

The ADINT entry will predict values of $y_1, \ldots, y_n$ at x+h and the ADCOR corrects these values. After the CALL ADCOR statement one has available the values of y_1, y_2, y_n at the new value of x.

3. To obtain functional values $y_1, \ldots y_n$ at a discontinuity or print point x_p use the statement:

```
        CALL ADPAR (XP)
```

This will compute $y_1{}^P, \ldots y_n{}^P$ and put these values in the P(N) array. This will not affect the values in F, D, T.

4. To restart the integration such as at a discontinuity:

```
        CALL ADRES
```

This will zero out the difference table, compute new values for desired accuracy (e.g., if numbers in E have been changed) and set a flag to restart the integration.

The following two equations are the predicter and connector equations written in terms of the backward difference operator $\nabla_n = y_n\ (x_k) - y_n\ (x_{k-1})$:

$$y_n{}^P\ (x_{k+1}) = y_n\ (x_k) + H \left(1 + \frac{1}{2} \nabla + \frac{5}{12} \nabla^2 + \frac{3}{8} \nabla^3 + \frac{251}{720} \nabla^4 \right) \frac{dy_n\ (x_k)}{dx}$$

I, F, Numerical Methods of Solution (cont.)

$$y_n^{\,c}\,(x_{k+1}) = y_n\,(x_k) + H\left[\frac{251}{720}\,\frac{dy_n\,(x_{k+1})}{dx} + \left(\frac{469}{720} + \frac{109}{720}\,\nabla + \frac{49}{720}\,\nabla^2 + \frac{32}{720}\,\nabla^3\right)\frac{dy_n\,(x_k)}{dx}\right]$$

In these equations the integration error is controlled by changing H, the integration step size. The table of backward differences is modified whenever the integration step is changed. This table of backward differences is also used to interpolate for intermediate values of the function by using a 4th order interpolating polynomial.

Also in the nozzle admittance calculation a table of velocity potential is calculated by integrating the steady state velocity profile (Equation 43). Simpson's one third rule is used to evaluate this integral. This method approximates the curve to be integrated by a parabola.

In calculating the sensitive time lag τ an inverse tangent function of a fraction is required (Eq. 42). The inverse tangent in the computer library picks an angle between plus ninety degrees and minus ninety degrees. The correct quadrant of τ is determined by the signs of the numerator and denominator of the fraction. Subroutine QUAD calculates the correct quadrant.

I, F, Numerical Methods of Solution (cont.)

Boole's Integration

The Boole's integration subroutine for evaluating a definite integral in program A uses two entries: INTGR, INTGS. This subroutine uses Boole's formula and Simpson's rule to find the integral of a function between known limits. Boole's formula is used to extrapolate two Simpson's rule values with H = ΔX and 2 ΔX to obtain an answer for the integral which is more accurate than either of the two alone.

$$\int_a^b y\,dx = I_H = \frac{H}{3}\left[y(x_o) + 4\,y(x_1) + 2\,y(x_2) + 4\,y(x_3) + - - - - - - - - - y(x_k)\right]$$

$$I_{Boole} = I_{H = \Delta X} + \frac{I_{H = \Delta X} - I_{H = 2\Delta X}}{15}$$

I, F, Numerical Methods of Solution (cont.)

Bessel Functions

The BESJ subroutine computes the J Bessel function for a given argument and integer order by using the recurrence relationship:

$$F_{n+1}(x) + F_{n-1}(x) = \left(\frac{2n}{x}\right) F_n(x)$$

The desired Bessel function is:

$$J_n(x) = \frac{F_n(x)}{\alpha}$$

where

$$\alpha = F_0(x) + 2 \sum_{M-1}^{M-2} F_{2m}(x)$$

M is initialized at M_0.

M_0 is the greater of M_A and M_B where:

$M_A = [x+6]$ if $x < 5$ and $M_A = [1.4x+60/x]$ if $x \geq 5$.

$M_B = [n+x/4+2]$

$F_{M-2}, F_{M-3}, \ldots, F_2, F_1, F_0$ is evaluated using the recurrence relationship above with $F_M = 0$ and $F_{M-1} = 10^{-30}$.

I, F, Numerical Methods of Solution (cont.)

α and $J_n(x)$ are then computed

The computation is repeated for M+3.

The values of $J_n(x)$ for M and M+3 are compared:

If $| J_n(x)_M - J_n(x)_{M+3} | \leq \delta | J_n(x)_{M+3} |$

this value is accepted as $J_n(x)$; if not, the computation is repeated by adding 3 to M and using this as a new value for M. If M reaches M_{MAX} before the desired accuracy is obtained, execution is terminated. M_{MAX} is defined as:

$$M_{MAX} = \begin{cases} [20 + 10x - \frac{x^2}{3}] & \text{for } x \leq 15 \\ [90 + x/2] & \text{for } x > 15 \end{cases}$$

The BESY subroutine computes the Y Bessel function for a given argument x and order n. The recurrence relation:

$$Y_{n+1}(x) = (\frac{2n}{x}) . \quad Y_n(x) - Y_{n-1}(x)$$

is used for this evaluation.

I, F, Numerical Methods of Solution (cont.)

For $x > 4$

$$Y_0(x) = \left(\frac{2}{\pi x}\right)^{1/2} \left(P_0(x) \sin\left(x - \frac{\pi}{4}\right) + Q_0(x) \cos\left(x - \frac{\pi}{4}\right)\right)$$

$$Y_1(x) = \left(\frac{2}{\pi x}\right)^{1/2} \left(-P_1(x) \cos\left(x - \frac{\pi}{4}\right) + Q_1(x) \sin\left(x - \frac{\pi}{4}\right)\right)$$

$P_0(x)$, $Q_0(x)$, $P_1(x)$, and $Q_1(x)$ are:

$$\frac{1}{\sqrt{2\pi}} P_0\left(\frac{4}{t}\right) = 0.3989422793 - 0.0017530620t^2 + 0.0001734300t^4 - 0.0000487613t^6 + 0.0000173565t^8 - 0.0000037043t^{10}$$

$$\frac{1}{t\sqrt{2\pi}} Q_0\left(\frac{4}{t}\right) = -0.124669441 + 0.0004564324t^2 - 0.0000869791t^4 + 0.0000342468t^6 - 0.0000142078t^8 + 0.0000032312t^{10}$$

$$\frac{1}{\sqrt{2\pi}} P_1\left(\frac{4}{t}\right) = 0.3989422819 + 0.0029218256t^2 - 0.0002232030t^4 + 0.0000580759t^6 - 0.0000200920t^8 + 0.0000042414t^{10}$$

I, F, Numerical Methods of Solution (cont.)

$$\frac{1}{t\sqrt{2\pi}} \quad Q_1\left(\frac{4}{t}\right) = \begin{aligned} & 0.0374008364 - 0.0006390400t^2 \\ & +0.0001064741t^4 - 0.0000398708t^6 \\ & +0.0000162200t - 0.0000036594t^{10} \end{aligned}$$

where $t = \frac{4}{x}$

For $x \leq 4$

$$Y_0(x) = \frac{2}{\pi} \sum_{m=0}^{15} (-1)^m \left(\frac{x}{2}\right)^{2m} \frac{1}{(m!)^2}$$

$$\left[\log \frac{x}{2} + \gamma - H_m\right]$$

where

$$H_m = \sum_{r=1}^{m} \frac{1}{r} \text{ if } m \geq 1 \text{ or } = 0 \quad \text{if } m = 0$$

and γ = Euler's constant = 0.5772156649

$$Y_1(x) = -\frac{2}{\pi x} + \frac{2}{\pi} \sum_{m=1}^{16} (-1)^{M+1} \left(\frac{x}{2}\right)^{2m-1}$$

$$\frac{1}{m!\,(m-1)!} \cdot \left[\log \frac{x}{2} + \gamma - H_m + \frac{1}{2m}\right]$$

I, Problem (cont.)

G. TECHNICAL REFERENCES

1. Crocco, L., "Aspects of Combustion Instability in Liquid Propellant Rockets," J. Amer. Rocket Soc., Part I: vol. 21, November 1951, Part II: vol. 22, January 1952.

2. Reardon, F. H., Mc Bride, J. M., and Smith, A. J., Jr., Effect of Injection Distribution on Combustion Stability, AIAA Paper No. 65-613, AIAA Propulsion Joint Specialist Conference, Colorado Springs, Colorado, June 1965.

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4. Yachter, M., "Discussion of the Paper by Gunder and Friant," J. Appl. Mech., vol. 18, p. 114, 1951.

5. Summerfield, M., "A Theory of Unstable Combustion in Liquid Propellant Rocket Systems," J. Amer. Rocket Soc., vol. 21, p. 108, 1951.

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7. Scala, S. M., Transverse Wave and Entropy Wave Combustion Instability in Liquid Propellant Rockets, Princeton University Aeronautical Engineering Report No. 380, April 1957.

8. Reardon, F. H., An Investigation of Transverse Mode Combustion Instability in Liquid Propellant Rocket Motors, Princeton University Aeronautical Engineering Report No. 550, June 1961.

9. Bridge, J. F., and Angrist, S. W., "An Extended Table of Roots of $J_n'(x)\ Y_n'(\beta x) - J_n'(\beta x)\ Y_n'(x) = 0$", Mathematics of Computation, vol. 16, no. 78, p. 168, 1962.

10. Wieber, P. R., and Mickelsen, W., Effect of Transverse Acoustic Oscillations on the Vaporization of a Liquid-Fuel Droplet, NASA TN D-287, May 1960.

11. Crocco, L., and Sirignano, W. A., Behavior of Supercritical Nozzles Under Three Dimensional Oscillatory Conditions, AGARDograph 117, 1967.

12. Culick, F. E. C., Stability of High Frequency Pressure Oscillations in Gas and Liquid Rocket Combustion Chambers, M. I. T. Aerophysics Laboratory Report No. 480, June 1961.

I, Problem (cont.)

H. RELATED PROJECTS

This program and its predecessors have been used to analyze many engines and proposed engines. The parts of the program concerned with velocity effects and non-linear response have not been used since not enough is known about either of these effects to define the parameters involved. These parts of the program are intended to be research tools.

The major programs on which this program has been used are the following: Gemini Stability Improvement Program (AF 04(695)-517) demonstrated the effect of nonuniform injection on combustion stability. A series of contracts (NAS8-4008, NAS8-11741, NAS8-20672) which were concerned with the stability characteristics of hydrogen-oxygen at high chamber pressures (500 to 2500 psi) used this program to help correlate stability data. The program was also used on Apollo (NAAI-M6J7XAA-400000A), M-1 (NAS3-2555) and Transtage (F04695-68-C-0297)

Report 20672-P2D

Section II, Programming

II, Programming

A. BLOCK DIAGRAM

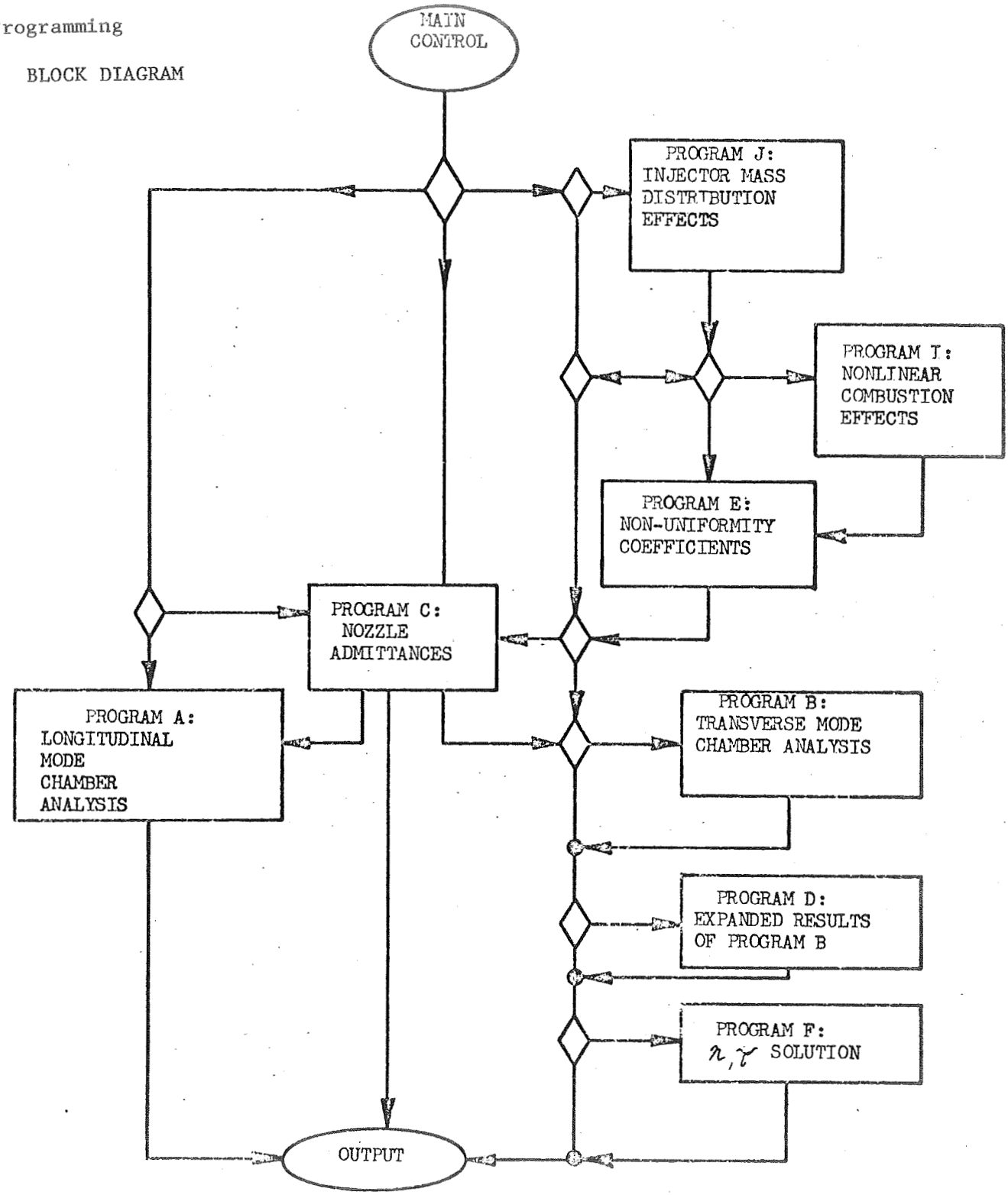


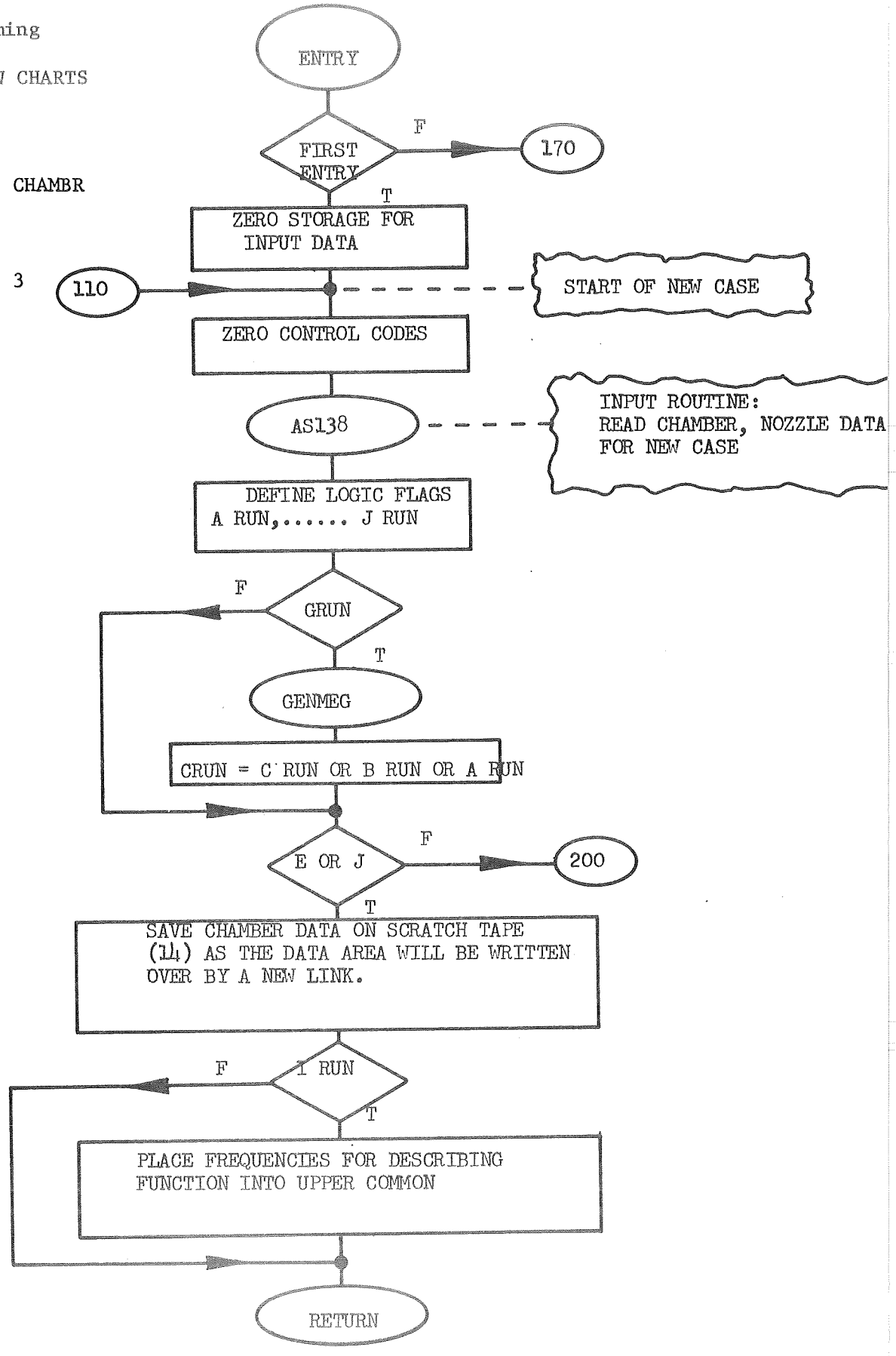
Figure 18 -- Block Diagram of Computer Program

II, Programming

B. FLOW CHARTS

ENTRY = CHAMBR

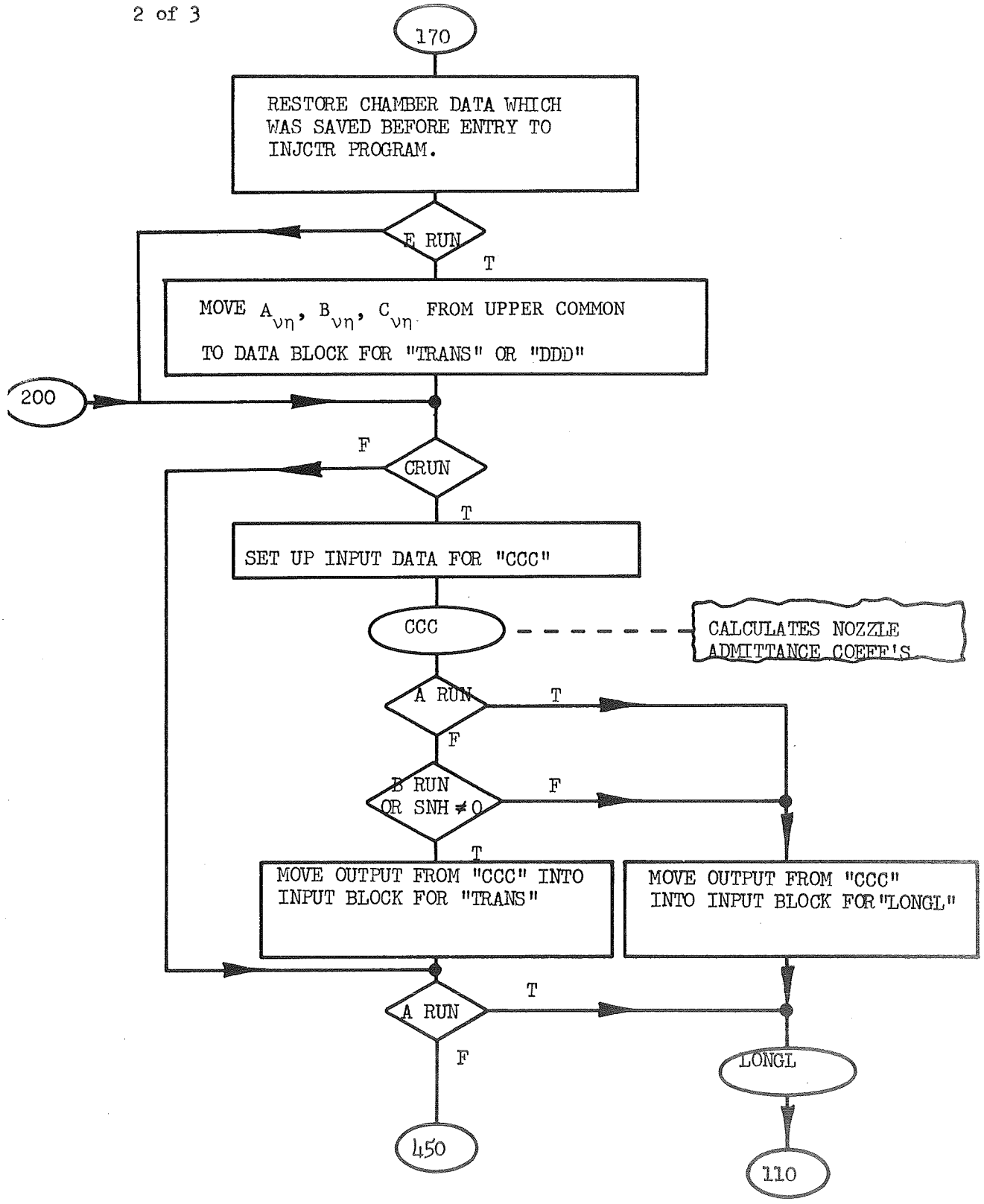
1 of 3



II, B, Flow Charts (cont.)

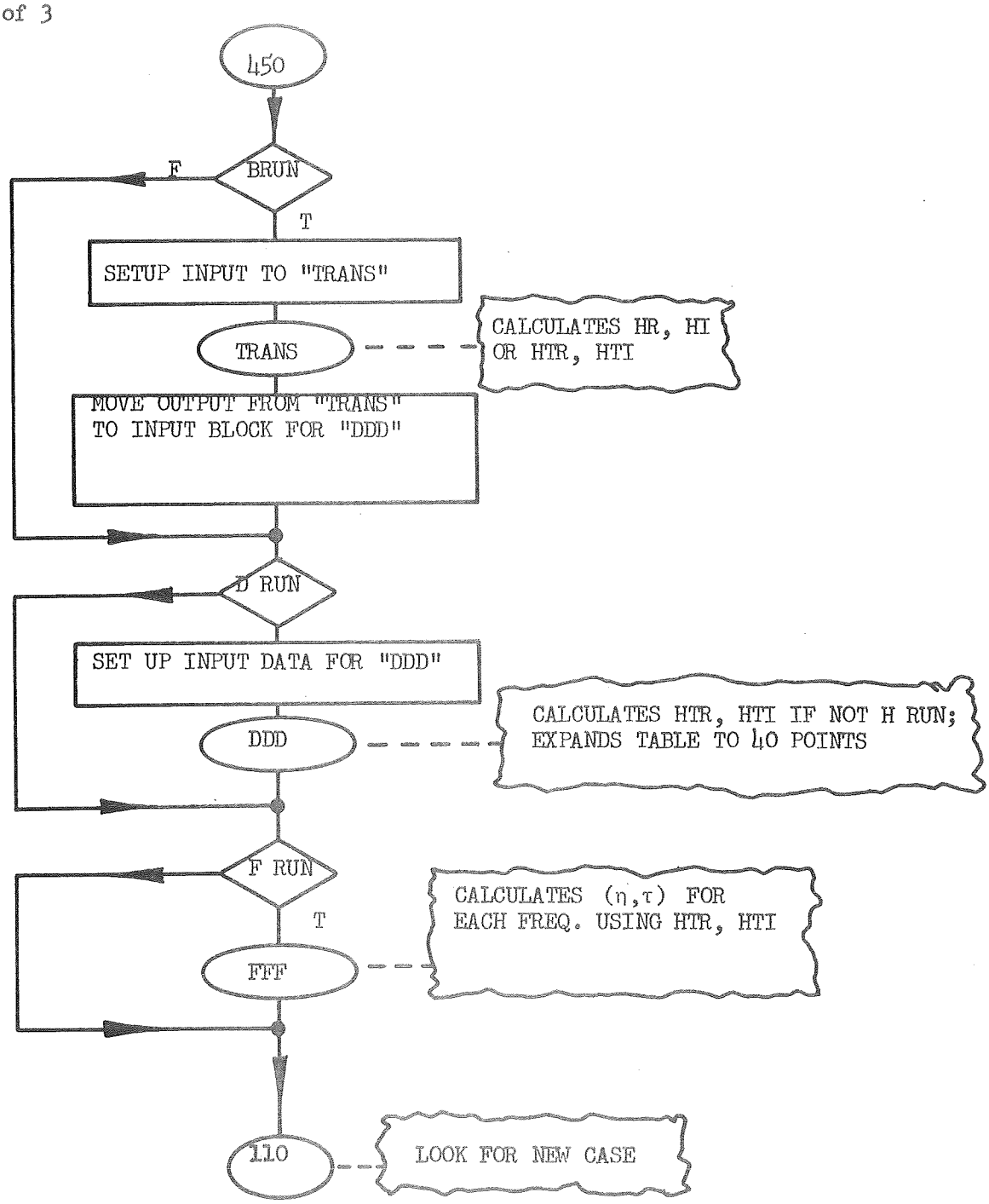
ENTRY = CHAMBER

2 of 3



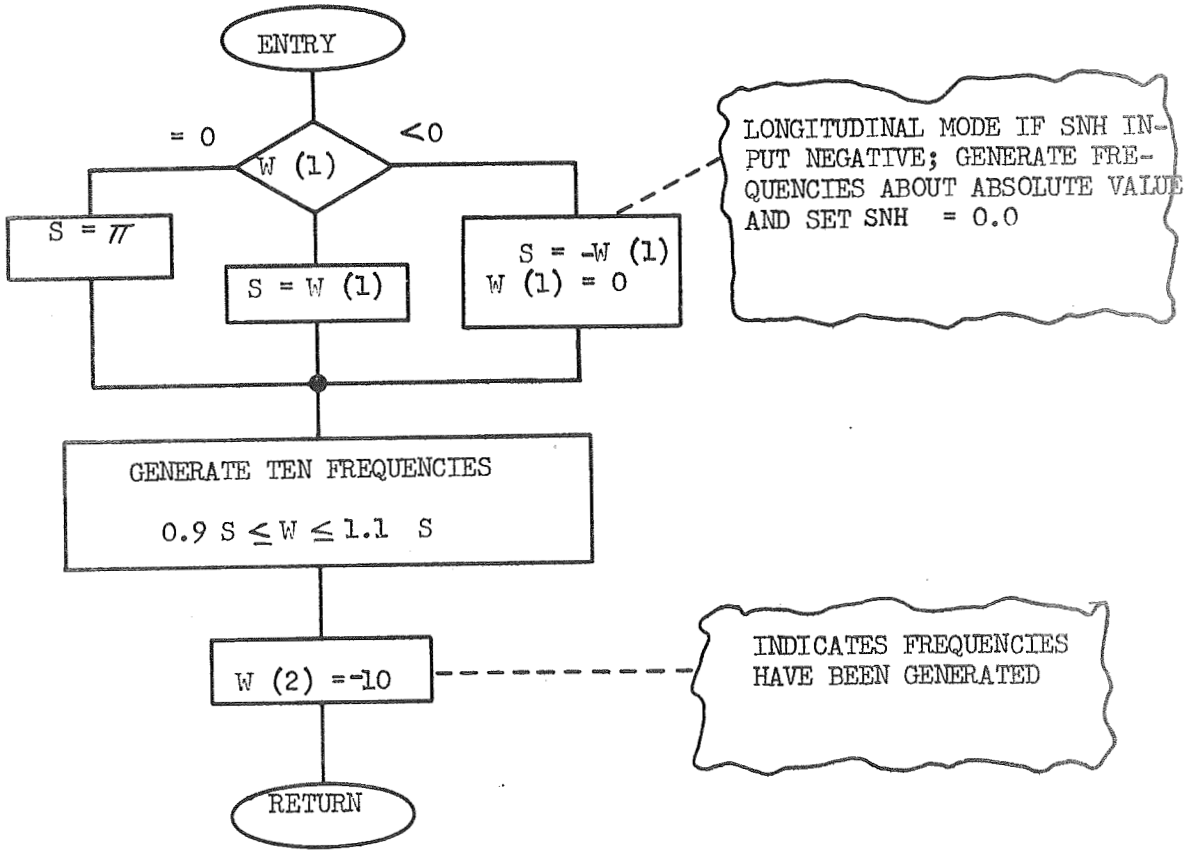
II, B, Flow Charts (cont.)

3 of 3



II, B, Flow Charts (cont.)

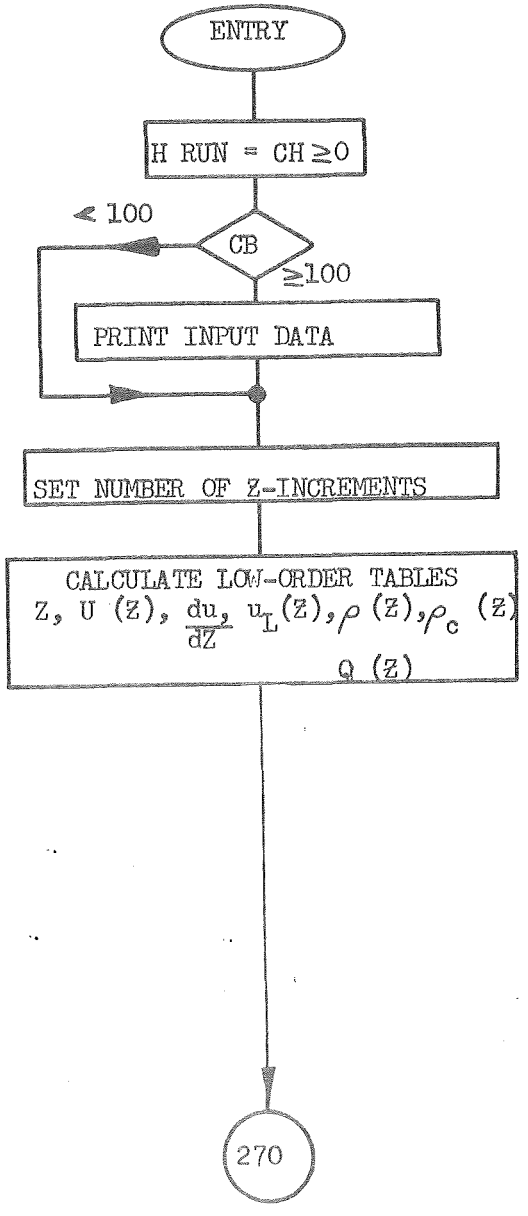
ENTRY = GEMMEG

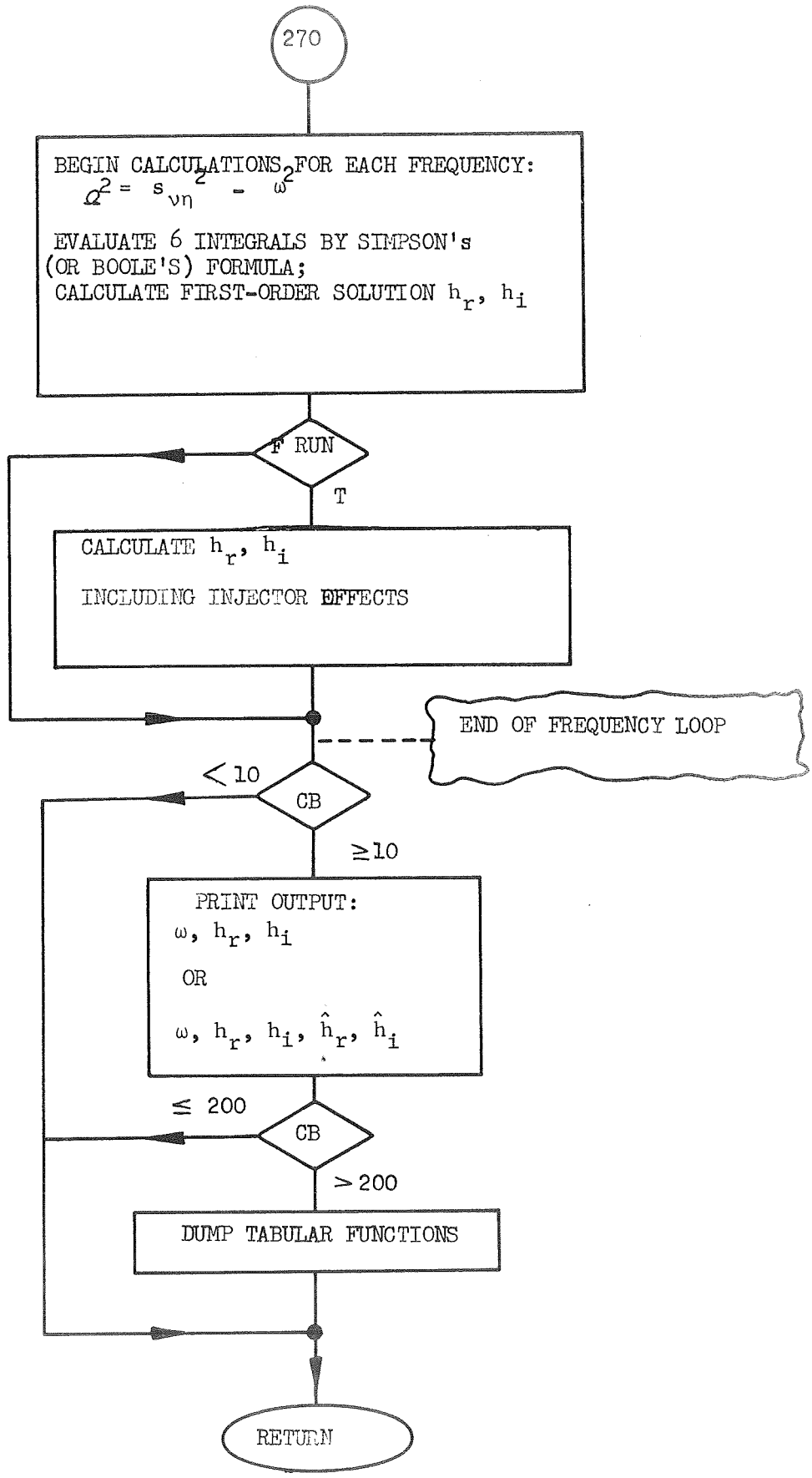


II, B, Flow Charts (cont.)

ENTRY = TRANS

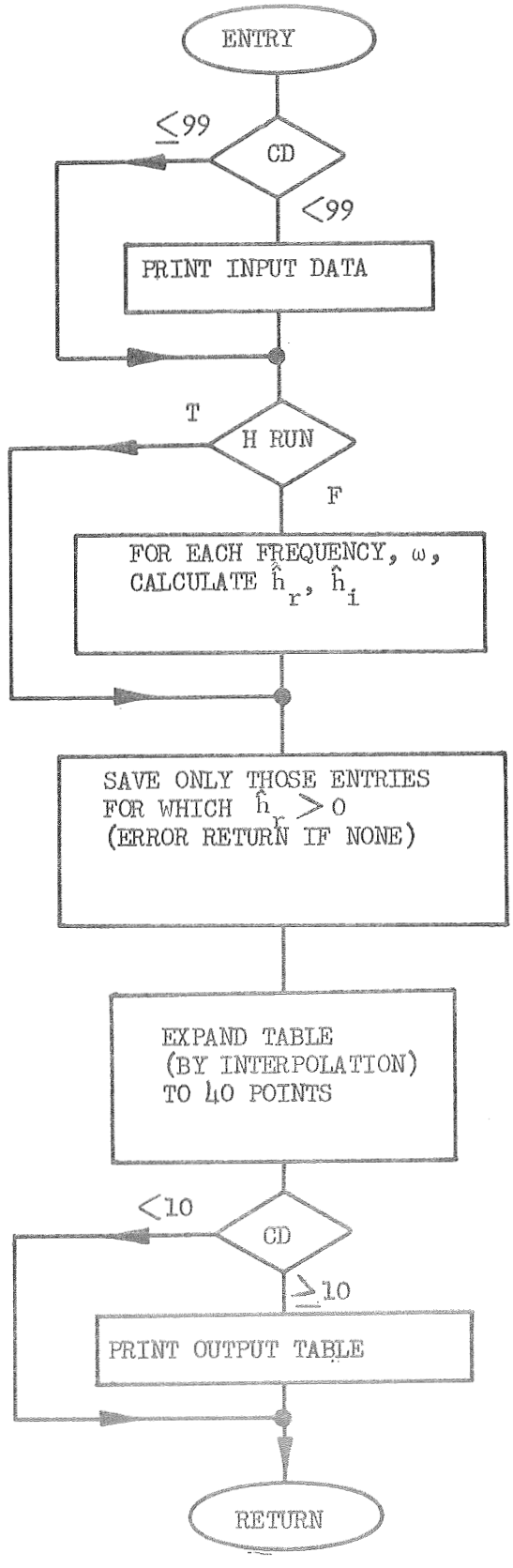
1 of 2



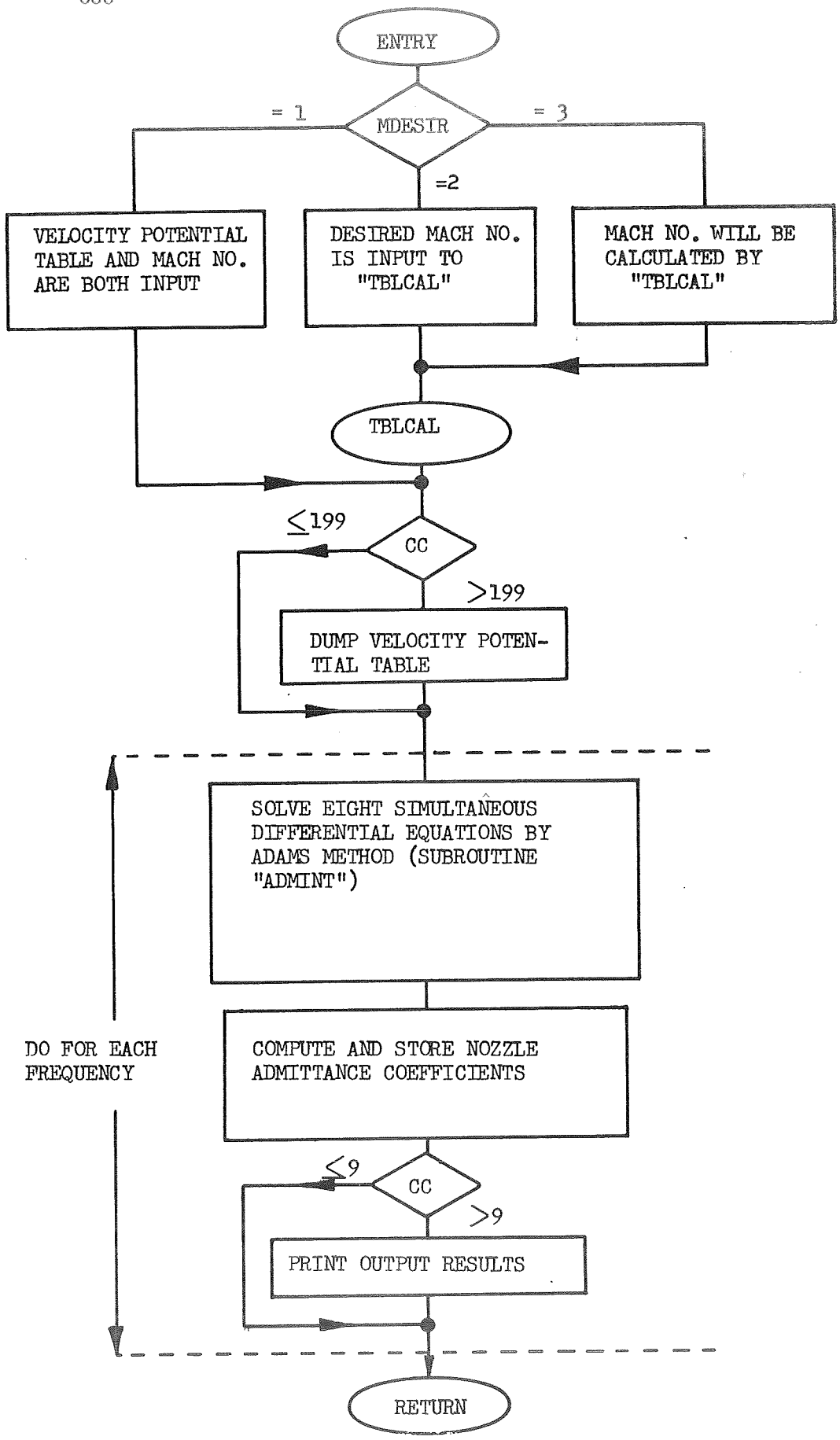

270
BEGIN CALCULATIONS FOR EACH FREQUENCY:
$\alpha^2 = s_{\nu\eta}^2 - \omega^2$
EVALUATE 6 INTEGRALS BY SIMPSON's (OR BOOLE'S) FORMULA;
CALCULATE FIRST-ORDER SOLUTION h_r, h_i
F RUN
T
CALCULATE h_r, h_i
INCLUDING INJECTOR EFFECTS
END OF FREQUENCY LOOP
< 10
CB
≥ 10
PRINT OUTPUT:
ω, h_r, h_i
OR
ω, h_r, h_i, $\hat{h}_r$, $\hat{h}_i$
≤ 200
CB
> 200
DUMP TABULAR FUNCTIONS
RETURN

II, B, Flow Charts (cont.)

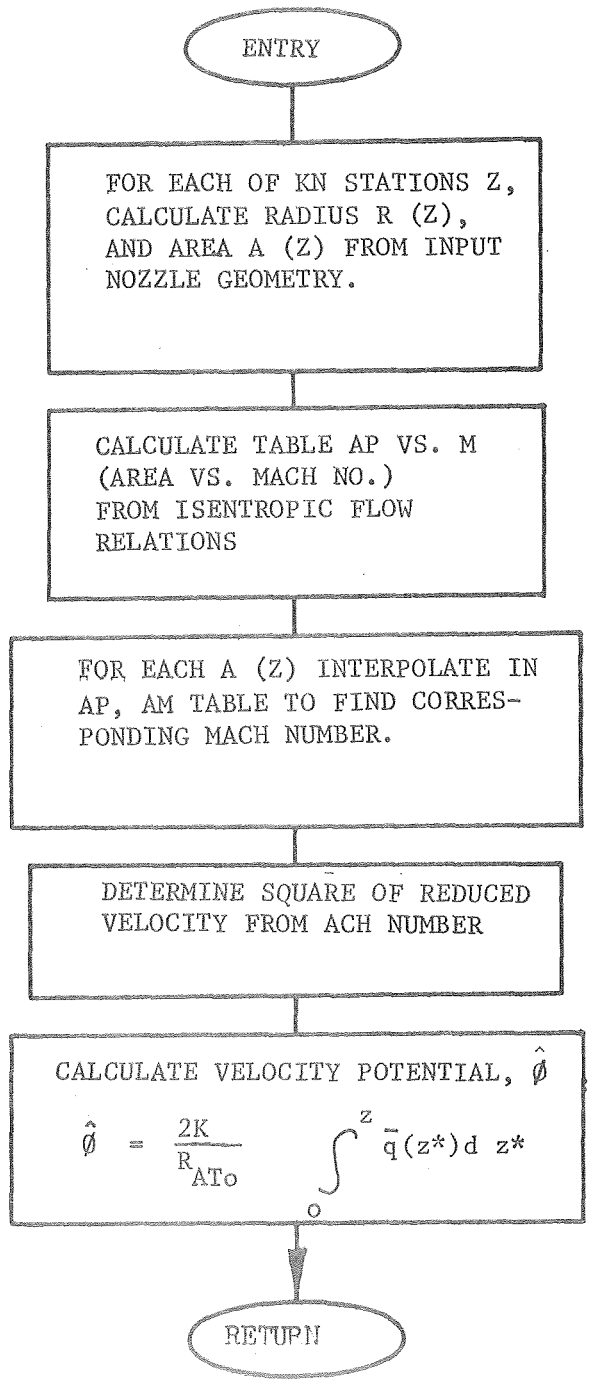
ENTRY = DDD

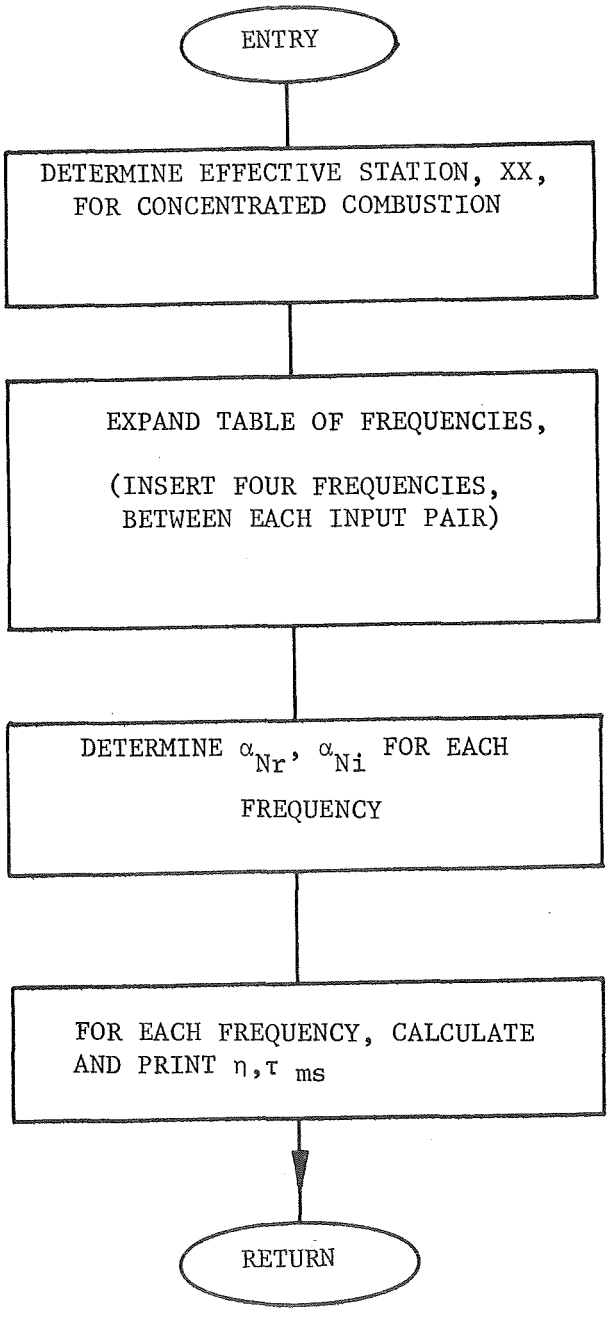


ENTRY = CCC

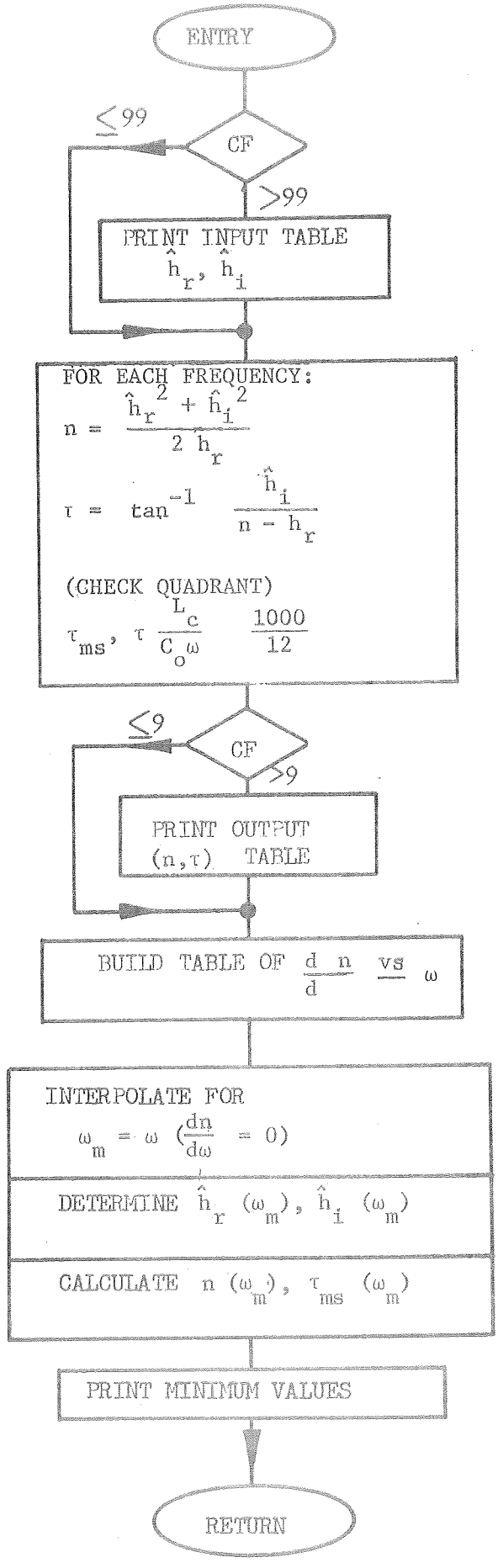

ENTRY
MDESIR
= 1
=2
= 3
VELOCITY POTENTIAL TABLE AND MACH NO. ARE BOTH INPUT
DESIRED MACH NO. IS INPUT TO "TBLCAL"
MACH NO. WILL BE CALCULATED BY "TBLCAL"
TBLCAL
≤199
CC
>199
DUMP VELOCITY POTENTIAL TABLE
SOLVE EIGHT SIMULTANEOUS DIFFERENTIAL EQUATIONS BY ADAMS METHOD (SUBROUTINE "ADMINT")
DO FOR EACH FREQUENCY
COMPUTE AND STORE NOZZLE ADMITTANCE COEFFICIENTS
≤9
CC
>9
PRINT OUTPUT RESULTS
RETURN

ENTRY = TBLCAL

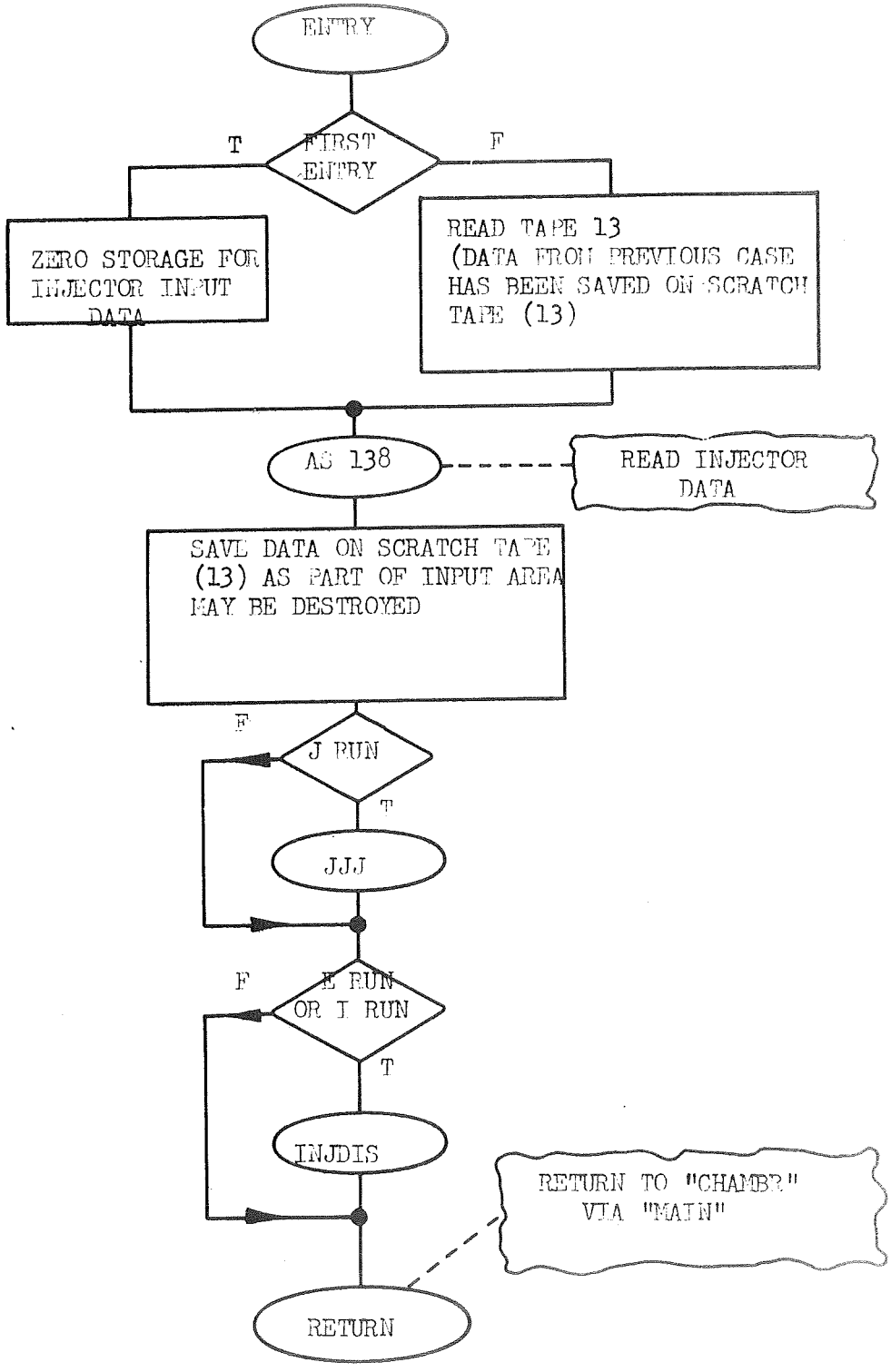



ENTRY
DETERMINE EFFECTIVE STATION, XX, FOR CONCENTRATED COMBUSTION
EXPAND TABLE OF FREQUENCIES,
(INSERT FOUR FREQUENCIES, BETWEEN EACH INPUT PAIR)
DETERMINE α_{Nr}, α_{Ni} FOR EACH FREQUENCY
FOR EACH FREQUENCY, CALCULATE AND PRINT η, τ_{ms}
RETURN

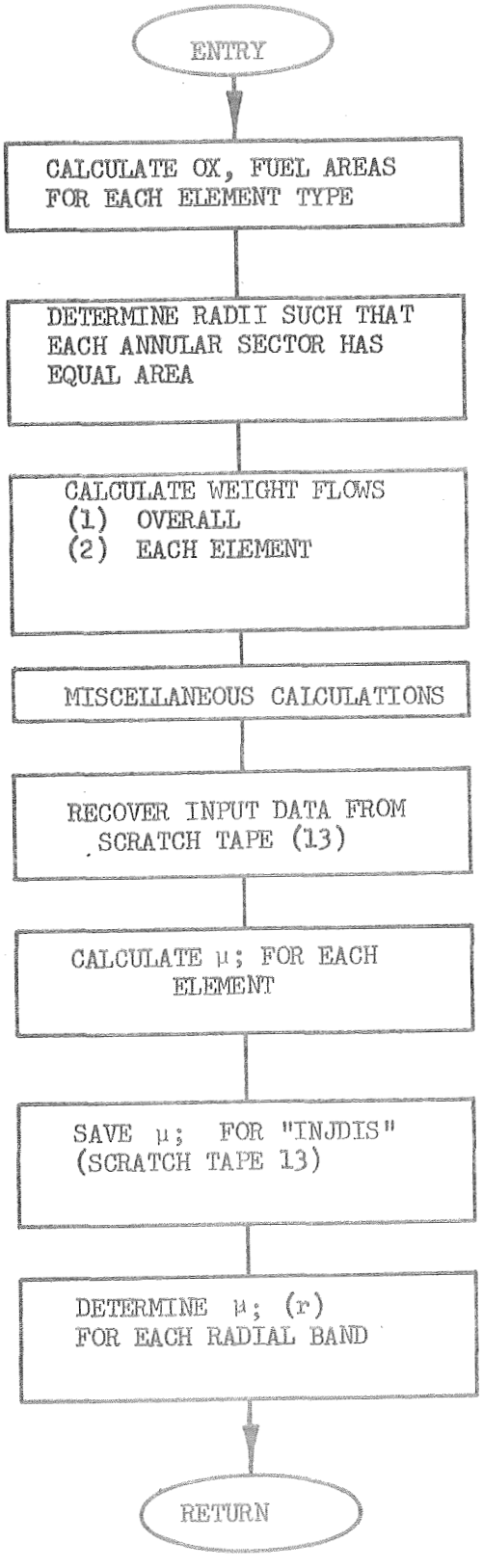
ENTRY = FFF


ENTRY
≤99
CF
>99
PRINT INPUT TABLE
$\hat{h}_r$, $\hat{h}_i$
FOR EACH FREQUENCY:
$n = \frac{\hat{h}_r^2 + \hat{h}_i^2}{2\,h_r}$
$\tau = \tan^{-1} \frac{\hat{h}_i}{n - h_r}$
(CHECK QUADRANT)
τ_{ms}, $\tau \frac{L_c}{C_o \omega}$ $\frac{1000}{12}$
≤9
CF
>9
PRINT OUTPUT
(n,τ) TABLE
BUILD TABLE OF $\frac{d\,n}{d}$ vs ω
INTERPOLATE FOR
$\omega_m = \omega \left(\frac{dn}{d\omega} = 0\right)$
DETERMINE $\hat{h}_r(\omega_m)$, $\hat{h}_i(\omega_m)$
CALCULATE $n(\omega_m)$, $\tau_{ms}(\omega_m)$
PRINT MINIMUM VALUES
RETURN

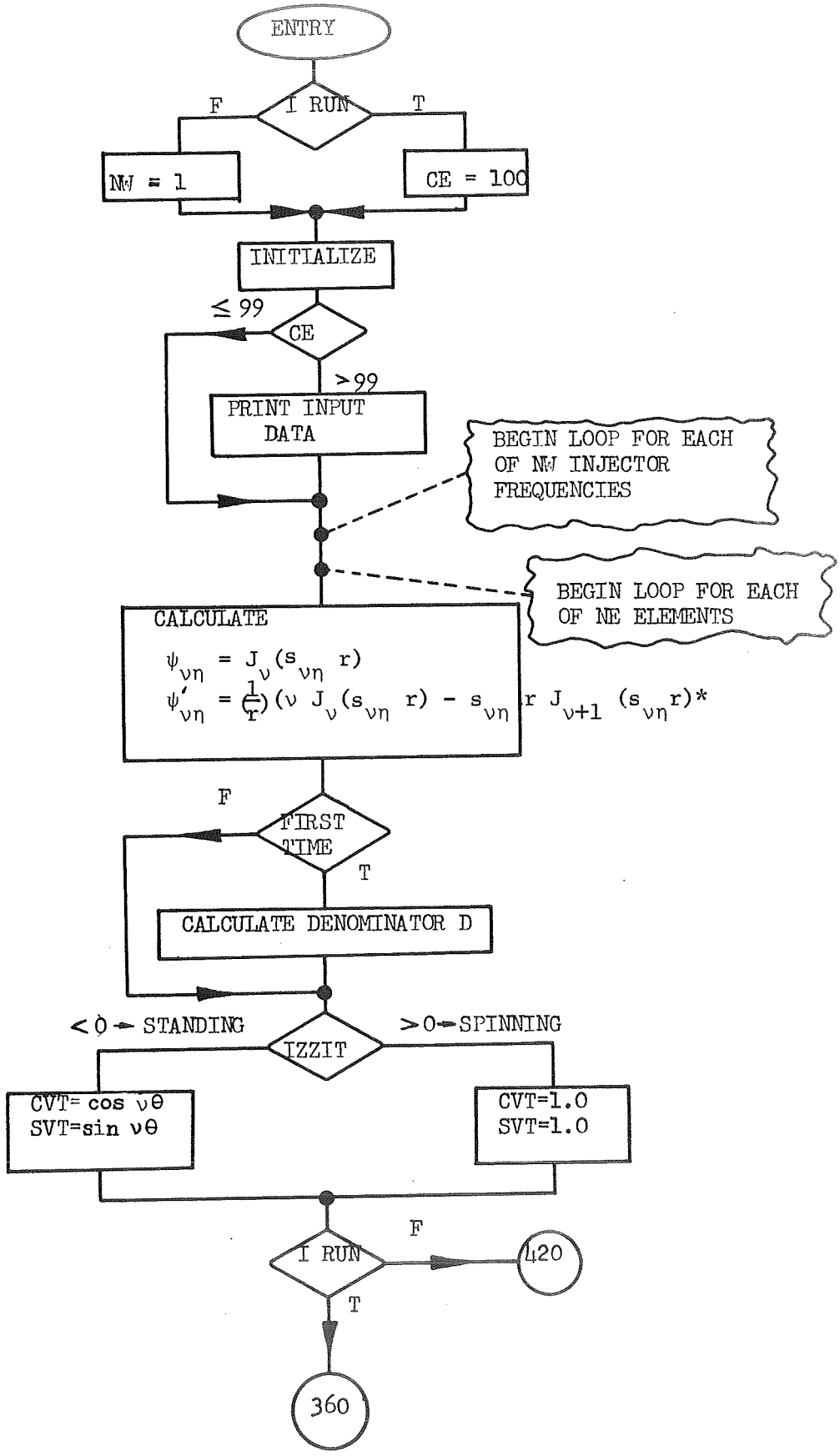
ENTRY = INJCTR



ENTRY = JJJ

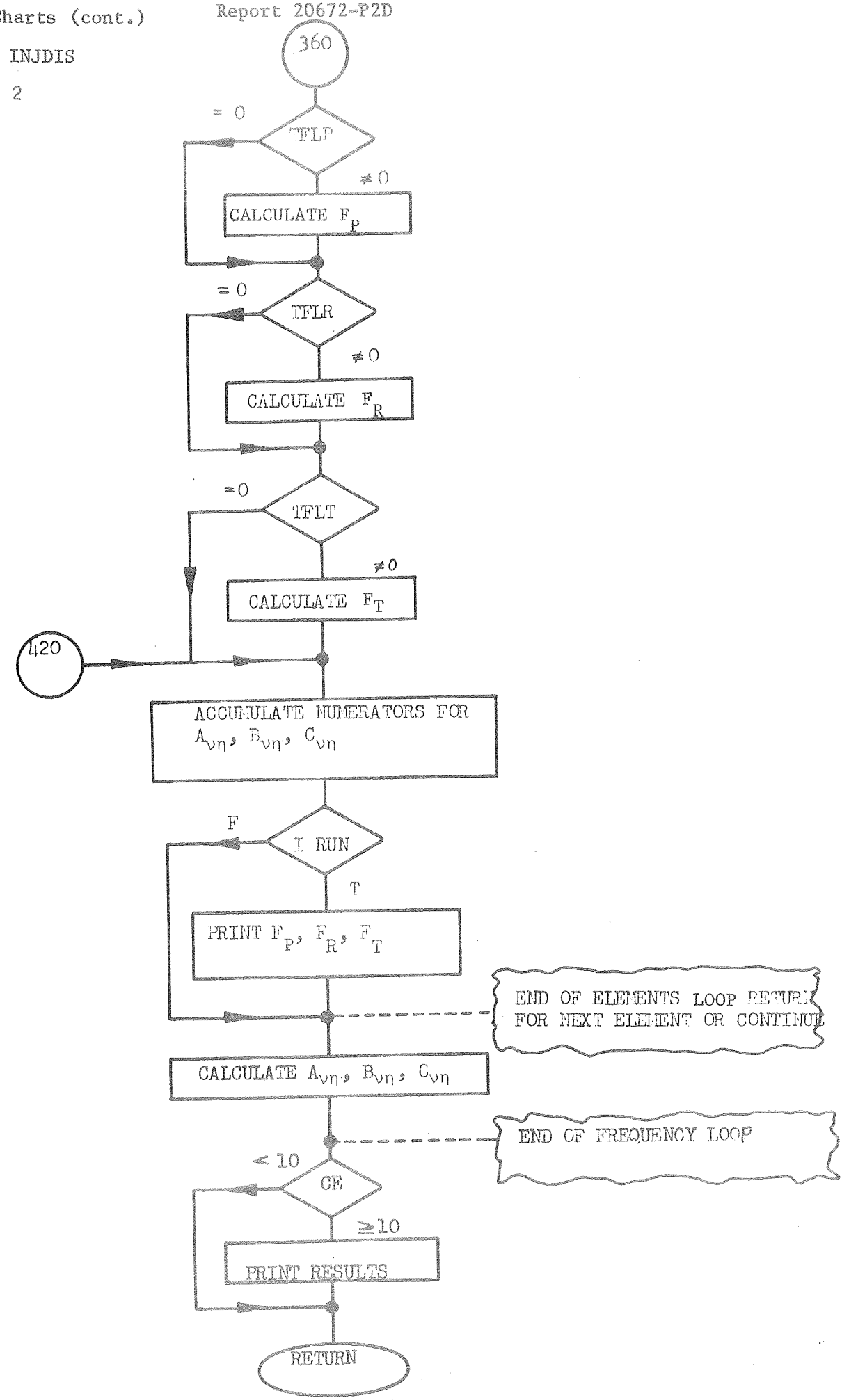

ENTRY
CALCULATE OX, FUEL AREAS FOR EACH ELEMENT TYPE
DETERMINE RADII SUCH THAT EACH ANNULAR SECTOR HAS EQUAL AREA
CALCULATE WEIGHT FLOWS
(1) OVERALL
(2) EACH ELEMENT
MISCELLANEOUS CALCULATIONS
RECOVER INPUT DATA FROM SCRATCH TAPE (13)
CALCULATE μ; FOR EACH ELEMENT
SAVE μ; FOR "INJDIS" (SCRATCH TAPE 13)
DETERMINE μ; (r) FOR EACH RADIAL BAND
RETURN

ENTRY = INJDIS



ENTRY = INJDIS

2 of 2



PROGRAM SUBROUTINES

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```
@ ELT MAIN,1,690702, 33249

000001                COMMON  /PROLOG/  LOGIK(50), SL1, SL2, EORJ                    ....  10
000002                LOGICAL  LOGIK,  SL1,  SL2,  EORJ                              ....  20
000003          C                                                                    ....  30
000004             10 CALL  CHAMBR                                                   ....  40
000005          C                                                                    ....  50
000006          C         RETURNS FROM MAJOR PROGRAM IF AND ONLY IF AN INJECTOR PROGRAM ....  60
000007          C          IS TO BE CALLED... INJCTR DETERMINES WHICH, WRITES SCRATCH ....  70
000008          C          TAPE, AND CALLS PROPER ROUTINE.                           ....  80
000009          C                                                                    ....  90
000010                CALL  INJCTR                                                   .... 100
000011          C                                                                    .... 110
000012                GO TO 10                                                       .... 120
000013                   END                                                         .... 130
```

```
@ ELT SUB01,1,690702, 33250

000001                BLOCK DATA                                          BLOK  30
000002          C                                                         BLOK  40
000003                COMMON  /PROLOG/  LOGIK(50), SL1, SL2, EORJ         BLOK  50
000004                LOGICAL  LOGIK,  SL1,  SL2,  EORJ                   BLOK  60
000005          C                                                         BLOK  70
000006                DATA  SL1, SL2  /  .FALSE., .FALSE.  /              BLOK  80
000007                END                                                 BLOK  90
```

```
@ ELT SUB02,1,690702, 33250

000001          SUBROUTINE OUTAS8(A,K)                                  OUT   10
000002          DIMENSION A(12)                                         OUT   20
000003          WRITE(6,10)(A(I),I=1,K)                                 OUT   30
000004       10 FORMAT(1X,12A6)                                         OUT   40
000005          RETURN                                                  OUT   50
000006          END                                                     OUT   60
```

```
@ ELT SUB03.1,690702, 33251

      SUBROUTINE INAS58(A)                                              IN    10
      DIMENSION A(12)                                                   IN    20
      READ(5,10)A                                                       IN    30
   10 FORMAT(12A6)                                                      IN    40
      RETURN                                                            IN    50
      END                                                               IN    60
```

```
@ ELT SUBD4,1,690717, 38451

      SUBROUTINE INT4(X,Y,X1,YO)                                        INT4  10
      DIMENSION X(9),Y(9),XC(4),YC(4)                                   INT4  20
      EQUIVALENCE (XC(1),X1),(XC(2),X2),(XC(3),X3),(XC(4),X4),(YC(1),Y1)INT4  30
     1,(YC(2),Y2),(YC(3),Y3),(YC(4),Y4)                                 INT4  40
10    NA=1
      J=2                                                               INT4  60
      B=X1                                                              INT4  70
20    IF(X(J).NE.0..OR.Y(J).NE.0.) GO TO (90,160),NA
      IF(J.GT.2) GO TO 70
      YE=0.
      GO TO 180                                                                *NEW
70    NB=1                                                                     **-1
      J=J-1                                                             INT4 150
   80 X1=X(J)                                                           INT4 160
      X2=X(J-1)                                                         INT4 170
      X3=X(J-2)                                                         INT4 180
      Y1=Y(J)                                                           INT4 190
      Y2=Y(J-1)                                                         INT4 200
      Y3=Y(J-2)                                                         INT4 210
      GO TO (150,170),NB
   90 IF(X(J)-B)120,100,100                                             INT4 230
100   IF(J.LE.2) GO TO 130
110   NA=2
  120 J=J+1                                                             INT4 260
      GO TO 20                                                          INT4 270
  130 DO 140 J=1,3                                                      INT4 280
      XC(J)=X(J)                                                        INT4 290
  140 YC(J)=Y(J)                                                        INT4 300
  150 D=X2-X1                                                           INT4 310
      A1=B-X1                                                           INT4 320
      A2=B-X2                                                           INT4 330
      YE=A1*A2/2.0/D*((Y3-Y2)/(X3-X2)-(Y2-Y1)/D)-A2/D*Y1+A1/D*Y2        INT4 340
      GO TO 180                                                         INT4 350
160   NB=2
      GO TO 80                                                          INT4 370
  170 X4=X(J-3)                                                         INT4 380
      Y4=Y(J-3)                                                         INT4 390
      D=X3-X2                                                           INT4 400
      A1=B-X2                                                           INT4 410
      A2=B-X3                                                           INT4 420
      XM12=(Y2-Y1)/(X2-X1)                                              INT4 430
      XM23=(Y3-Y2)/D                                                    INT4 440
      XM34=(Y4-Y3)/(X4-X3)                                              INT4 450
      YE=A1*A2**2/2.0/D**2*(XM12-XM23)+A2*A1**2/2.0/D**2*(XM34-XM23)-A2*INT4 460
     1Y2/D+A1*Y3/D                                                      INT4 470
  180 YO=YE                                                             INT4 480
      RETURN                                                            INT4 490
      END                                                               INT4 500
```

```
@ ELT SUB05,1,690717, 33453

      SUBROUTINE INT4D(X,Y,X1,YO,DY)                                    INT4D 10
      DIMENSION X(9),Y(9),XC(4),YC(4)                                   INT4D 20
      EQUIVALENCE (XC(1),X1),(XC(2),X2),(XC(3),X3),(XC(4),X4),(YC(1),Y1)INT4D 30
     1,(YC(2),Y2),(YC(3),Y3),(YC(4),Y4)                                 INT4D 40
   10 NA=1
      J=2                                                               INT4D 60
      B=XI                                                              INT4D 70
   20 IF(X(J).NE.0..OR.Y(J).NE.0.) GO TO (90,160),NA
      IF(J.GT.2) GO TO 70
      YE=0.
      GO TO 180                                                                *NEW
   70 NB=1                                                                     **-1
      J=J-1                                                             INT4D150
   80 X1=X(J)                                                           INT4D160
      X2=X(J-1)                                                         INT4D170
      X3=X(J-2)                                                         INT4D180
      Y1=Y(J)                                                           INT4D190
      Y2=Y(J-1)                                                         INT4D200
      Y3=Y(J-2)                                                         INT4D210
      GO TO (150,170),NB
   90 IF(X(J)-B)120,100,100                                             INT4D230
  100 IF(J.LE.2) GO TO 130
  110 NA=2
  120 J=J+1                                                             INT4D260
      GO TO 20                                                          INT4D270
  130 DO 140 J=1,3                                                      INT4D280
      XC(J)=X(J)                                                        INT4D290
  140 YC(J)=Y(J)                                                        INT4D300
  150 D=X2-X1                                                           INT4D310
      A1=B-X1                                                           INT4D320
      A2=B-X2                                                           INT4D330
      XM23=(Y3-Y2)/(X3-X2)                                              INT4D340
      XM12=(Y2-Y1)/(X2-X1)                                              INT4D350
      XM2B=(XM23-XM12)/2.0/D                                            INT4D360
      YO=A1*A2*XM2B-A2*Y1/D+A1*Y2/D                                     INT4D370
      DY=XM2B*(A1+A2)+XM12                                              INT4D380
      GO TO 180                                                         INT4D390
  160 NB=2
      GO TO 80                                                          INT4D410
  170 X4=X(J-3)                                                         INT4D420
      Y4=Y(J-3)                                                         INT4D430
      D=X3-X2                                                           INT4D440
      A1=B-X2                                                           INT4D450
      A2=B-X3                                                           INT4D460
      XM12=(Y2-Y1)/(X2-X1)                                              INT4D470
      XM23=(Y3-Y2)/D                                                    INT4D480
      XM34=(Y4-Y3)/(X4-X3)                                              INT4D490
      AM2=A2*(XM12-XM23)                                                INT4D500
      AM1=A1*(XM34-XM23)                                                INT4D510
      YO=(A1*A2/2.0/D*(AM2+AM1)-A2*Y2+A1*Y3)/D                          INT4D520
      DY=(AM2*(2.0*A1+A2)+AM1*(2.0*A2+A1))/2.0/D**2+XM23                INT4D530
  180 RETURN                                                            INT4D540
      END                                                               INT4D550
```

```
@ ELT SUB06,1,690807. 35835

000001                SUBROUTINE PAGE(LINES)                                    PAGE  10
000002          C                                                               PAGE  20
000003          C     HEAD MOVED TO /PROLOG/ AND PAGE MODIFIED TO PRINT HEAD 25JUL 67  PAGE  30
000004          C                                                               PAGE  40
000005                COMMON  /PROLOG/  LOGIK(38), HEAD(12), SL1, SL2, EORJ     PAGE  50
000006                DIMENSION  TODAY (2)                                      PAGE  60
000007                DATA  KPG / 0 /                                           PAGE  70
000008          C                                                               PAGE  80
000009                IF(LINES-60)20,10,10                                      PAGE  90
000010             10 L=2                                                       PAGE 100
000011                GO TO 60                                                  PAGE 110
000012             20 K=L+LINES                                                 PAGE 120
000013                IF(K-60)30,30,50                                          PAGE 130
000014             30 L=K                                                       PAGE 140
000015             40 RETURN                                                    PAGE 150
000016          C                                                               PAGE 160
000017             50 L=LINES+2                                                 PAGE 170
000018             60 IF  (KPG.EQ.0) GO TO 90                                      *NEW
000019             70 KPG = KPG + 1                                             PAGE 190**-1
000020                WRITE (6,80)  TODAY, HEAD, KPG                            PAGE 200
000021             80 FORMAT ( 1H1 3X 6HDATE   2A6, 12X 12A6, 11X 5HPAGE  I5 )  PAGE 210
000022                GO TO 40                                                  PAGE 220
000023          90    TODAY(1)=6H                                                  *NEW
000024                TODAY(2)=6H                                                  *NEW
000025                CALL DATE  (12,TODAY)                                        *NEW
000026                GO TO 70                                                     *NEW
000027                END                                                       PAGE 230
```

```
@ ELT SUB07,1,691029, 50054

      SUBROUTINE  CHAMBR                                                CHAM  10
C                                                                       CHAM  20
C           20 SEP 67  MODIFIED FOR TABULAR INJECTOR COEFFICIENTS       CHAM  30
C                                                                       CHAM  40
      LOGICAL  LOGIK, ARUN,BRUN,CRUN,DRUN,ERUN,FRUN,GRUN,HRUN,IRUN,JRUN CHAM  50
      LOGICAL  SL1, SL2, EORJ                                           CHAM  60
      REAL  MACH                                                        CHAM  70
      COMMON  / /                                                       CHAM  80
     1   GAM, NWI, WIT(30), AVN(30), BVN(30), CVNR(30), CVNI(30), EE,DSCCHAM  90
      COMMON  /PROLOG/  LOGIK(38), HEAD(12), SL1, SL2, EORJ             CHAM 100
      COMMON/ABCDF/ DINP,STOW                                           CHAM 110
      DIMENSION  EXTRA(100),                    WC(75)                  CHAM 120
      DIMENSION DINP(4300),A(1),B(1),C(1),D(1)                          CHAM 130
      DIMENSION  X(133),Y(133),Q(134),STOW(222),STODAT(4607)            CHAM 140
      DIMENSION ZZ(205)                                                 CHAM 150
      DIMENSION G(1),DISTL(20),DISTM(20)                                CHAM 160
      DIMENSION  AMIT(90)                                               CHAM 170
      EQUIVALENCE ( EXTRA, DINP, STODAT )                               CHAM 180
      EQUIVALENCE                                                       CHAM 190
     1   (LOGIK(1) , ARUN),   (LOGIK(2) , BRUN),   (LOGIK(3) , CRUN),   CHAM 200
     2   (LOGIK(4) , DRUN),   (LOGIK(5) , ERUN),   (LOGIK(6) , FRUN),   CHAM 210
     3   (LOGIK(7) , GRUN),   (LOGIK(8) , HRUN),   (LOGIK(9) , IRUN),   CHAM 220
     4   (LOGIK(10), JRUN)                                              CHAM 230
      EQUIVALENCE (EXTRA(1),CA),(EXTRA(2),CB),(EXTRA(3),CC),(EXTRA(4),  CHAM 240
     1CD),(EXTRA(5),CE),(EXTRA(6),CF),(EXTRA(7),CG),(EXTRA(8),CH)       CHAM 250
      EQUIVALENCE (EXTRA(9),CI)                                         CHAM 260
      EQUIVALENCE (DINP(1),A),(DINP(3001),B),(DINP(3401),D),            CHAM 270
     1(DINP(3501),G),(DINP(3801),C),(EXTRA(21),WC) , (B(4),UE)          CHAM 280
      EQUIVALENCE  (DINP(601),AMIT),(DINP(2813),Q),(DINP(3501),X),      CHAM 290
     1      (DINP(3651),Y)                                              CHAM 300
      EQUIVALENCE                                                       CHAM 310
     1  (STOW(1),ZZ), (STOW(213),YH)                                    CHAM 320
     2  ,  (STOW(214),J), (STOW(215),NE), (STOW(216),YL), (STOW(217),K1)CHAM 330
     3  ,  (STOW(218),N), (STOW(219),KER), (STOW(220),XH)               CHAM 340
     4  ,  (STOW(221),KQUAD), (STOW(222),XL)                            CHAM 350
     5   ,   (EXTRA(51), DISTL), (EXTRA(71), DISTM )                    CHAM 360
     6   ,  (EXTRA(10),CJ), (EXTRA(21),SNH ), (EXTRA(12), MACH )        CHAM 370
     7   ,   (DINP(107),U1BAR)                                          CHAM 380
C                                                                       CHAM 390
C*********************************************************************** CHAM 400
C                                                                       CHAM 410
   10 FORMAT(1H0,60H     A     B     C     D     E     F     G     H    CHAM 420
     1 I     J   // 3X,(10F6.0))                                        CHAM 430
   20 FORMAT(///,9X,108H************************ THE FOLLOWING MAIN CONTCHAM 440
     1ROL DATA WILL BE USED IN THIS CASE ************************  ,///,CHAM 450
     245X,33HRATIO OF SPECIFIC HEAT (GAMMA) = ,F7.4,//,45X,22HDESIRED NACHAM 460
     3CH NUMBER = ,E12.5,26H (=0 IF BEING CALCULATED) //45X        17HCHCHAM 470
     5AMBER RADIUS = ,F7.3, 9H (INCHES),//,45X,17HCHAMBER LENGTH = ,F7.3CHAM 480
     6, 9H (INCHES),//,45X, 17HSPEED OF SOUND = ,F10.3,  9H (FT/SEC),//,CHAM 490
     745X, 27HCHAMBER MODE DESCRIPTION = ,F8.5, 28H (=0 FOR LONGITUDINALCHAM 500
     8 MODES),/,)                                                       CHAM 510
   30 FORMAT(///,33X,48H********** CHAMBER FREQUENCIES (WC) **********  CHAM 520
     1   ,//,)                                                          CHAM 530
   40 FORMAT(5F20.5,/ )                                                 CHAM 540
   50 FORMAT(30X, 64H***** MACH DISTRIBUTION IN CHAMBER AS A FUNCTION OFCHAM 550
```

```
000056          1 LENGTH *****,//,11X,7HCHAMBER,15X,4HMACH,14X,7HCHAMBER,15X,4HMACHCHAM 560
000057          2,14X,7HCHAMBER,15X,4HMACH,/,12X,6HLENGTH,11X,12HDISTRIBUTION,11X, CHAM 570
000058          36HLENGTH,11X,12HDISTRIBUTION,11X,6HLENGTH,11X,12HDISTRIBUTION,/,) CHAM 580
000059       60 FORMAT(6(10X,F10.5))                                              CHAM 590
000060    C*********************************************************************** CHAM 600
000061    C*********************************************************************** CHAM 610
000062    C                                                                       CHAM 620
000063          IF ( SL2 )              GO TO 170                                 CHAM 630
000064    C                                                                       CHAM 640
000065          SL2 = .TRUE.                                                      CHAM 650
000066          DO 70 I = 1, 4300                                                 CHAM 660
000067       70    DINP (I) = 0.0                                                 CHAM 670
000068          GO TO 110                                                         CHAM 680
000069    C                                                                       CHAM 690
000070    C*********************************************************************** CHAM 700
000071    C                                                                       CHAM 710
000072       80 WRITE (6,100)   NE                                                CHAM 720
000073       90 CALL EXIT                                                         CHAM 730
000074      100 FORMAT (1H010X17HINPUT ERROR, NE = I3, 19H, HENCE TERMINATION )   CHAM 740
000075    C                                                                       CHAM 750
000076    C*********************************************************************** CHAM 760
000077    C*********************************************************************** CHAM 770
000078    C                                                                       CHAM 780
000079      110 KER = 0                                                           CHAM 790
000080          CALL  DVCHK  (KCHK)                                               CHAM 800
000081    C                                                                       CHAM 810
000082          DO 120 I = 1, 10                                                  CHAM 820
000083      120    DINP(I) = 0.0                                                  CHAM 830
000084          CALL  AS138  ( DINP(1), HEAD(1), NE )                             CHAM 840
000085          IF ( NE .NE. 1 )   GO TO 80                                       CHAM 850
000086          ARUN = CA .NE. 0.0                                                CHAM 860
000087          BRUN = CB .NE. 0.0                                                CHAM 870
000088          CRUN = CC .NE. 0.0                                                CHAM 880
000089          DRUN = CD .NE. 0.0                                                CHAM 890
000090          ERUN = CE .NE. 0.0                                                CHAM 900
000091          FRUN = CF .NE. 0.0                                                CHAM 910
000092          IRUN = CI .NE. 0.0                                                CHAM 920
000093          JRUN = CJ .NE. 0.0                                                CHAM 930
000094         OGRUN =       DINP(22) .LE. 0.0                                    CHAM 940
000095         1       .AND. ( ARUN .OR. BRUN .OR. CRUN .OR. IRUN )               CHAM 950
000096    C                                                                       CHAM 960
000097    C     PRINT NEW MAIN CONTROL DATA                                       CHAM 970
000098    C*********************************************************************** CHAM 980
000099          CALL  PAGE  ( 60 )                                                CHAM 990
000100          WRITE (6,10)  (DINP(I), I=1,10)                                   CHAM1000
000101          WRITE (6,20)  DINP(11), MACH, DINP(14), DINP(15), DINP(16), SNH   CHAM1010
000102    C*********************************************************************** CHAM1020
000103    C     ARE FREQUENCIES TO BE CALCULATED... IF SO, CALCULATE AND PRINT.   CHAM1030
000104    C*********************************************************************** CHAM1040
000105          IF ( .NOT. GRUN )        GO TO 130                                CHAM1050
000106          CALL  GENMEG  ( WC(1) )                                           CHAM1060
000107          IF ( BRUN .OR. ARUN )            CRUN = .TRUE.                    CHAM1070
000108          IF ( CRUN )      CC = CC + 11.0                                   CHAM1080
000109      130 JOMEGA=ABS(EXTRA(22))+22.0001                                    CHAM1090
000110          WRITE (6,30)                                                      CHAM1100
000111          WRITE (6,40)(EXTRA(I),I=23,JOMEGA)                                CHAM1110
000112          WRITE (6,50)                                                      CHAM1120
000113          WRITE (6,60)( DISTL(I), DISTM(I), DISTL(I+7),           DISTM(I+7)CHAM1130
000114         1, DISTL(I+14), DISTM(I+14), I=1,6 ), DISTL(7),          DISTM(7), CHAM1140
```

```
      2DISTL(14), DISTM(14)                                              CHAM1150
C*********************************************************************** CHAM1160
C                                                                        CHAM1170
      EORJ = ERUN .OR. JRUN .OR. IRUN                                    CHAM1180
      IF ( CRUN .OR. EORJ )   CALL  PAGE  ( 60 )                         CHAM1190
  140 IF ( .NOT. EORJ )        GO TO 200                                 CHAM1200
      WRITE (14)      STODAT                                             CHAM1210
      BACKSPACE  14                                                      CHAM1220
      EE  = CE                                                           CHAM1230
      DSC = CI                                                           CHAM1240
      GAM = DINP(11)                                                     CHAM1250
      IF ( .NOT. IRUN )       GO TO 160                                  CHAM1260
      NWI = ( JOMEGA-22 )/2 +1                                           CHAM1270
      DO 150 I = 1, NWI                                                  CHAM1280
  150    WIT(I) = DINP( 2*I+21 )                                         CHAM1290
      WIT(NWI) = DINP( JOMEGA )                                          CHAM1300
C                                                                        CHAM1310
  160 RETURN                                                             CHAM1320
C     ******                                                             CHAM1330
C          PROGRAM RETURNS IF AND ONLY IF INJECTOR PROGRAM IS TO BE RUN  CHAM1340
C                                                                        CHAM1350
C*********************************************************************** CHAM1360
C*********************************************************************** CHAM1370
C                                                                        CHAM1380
C                                                                        CHAM1390
  170 READ (14)  STODAT                                                  CHAM1400
      BACKSPACE  14                                                      CHAM1410
      IF ( .NOT. ERUN )       GO TO 200                                  CHAM1420
C                                                                        CHAM1430
      DINP(3408) = NWI                                                   CHAM1440
      DO 180 I = 1, NWI                                                  CHAM1450
         DINP(I+4522) = WIT(I)                                           CHAM1460
         DINP(I+4539) = AVN (I)                                          CHAM1470
         DINP(I+4556) = BVN (I)                                          CHAM1480
         DINP(I+4573) = CVNR(I)                                          CHAM1490
  180    DINP(I+4590) = CVNI(I)                                          CHAM1500
      DO 190 I = NWI, 84, 17                                             CHAM1510
  190    DINP(I+4523) = 0.0                                              CHAM1520
C                                                                        CHAM1530
C*********************************************************************** CHAM1540
C                                                                        CHAM1550
  200 WC(2) = ABS( WC(2) )                                               CHAM1560
C*********************************************************************** CHAM1570
C     FIX NUMBER OF FREQUENCIES AND TEST DESIRE FOR INTERNAL C FLAG      CHAM1580
C*********************************************************************** CHAM1590
  210 NOMEG=WC(2)+.0001                                                  CHAM1600
      IF(EXTRA(12))230,220,230                                           CHAM1610
  220 DINP(3802)=3.0                                                     CHAM1620
      GO TO 240                                                          CHAM1630
  230 U1BAR = MACH                                                       CHAM1640
      UE = MACH                                                          CHAM1650
  240 IF ( .NOT. CRUN )            GO TO 390                             CHAM1660
C*********************************************************************** CHAM1670
C     SET UP DATA FOR PROGRAM  C.                                        CHAM1680
C*********************************************************************** CHAM1690
  250 DINP(3801)=EXTRA(11)                                               CHAM1700
      NMHAF = NOMEG/2 + 1                                                CHAM1710
      ZZ(1)=EXTRA(14)                                                    CHAM1720
      ZZ(2)=EXTRA(15)                                                    CHAM1730
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000174          ZZ(3)=EXTRA(16)                                                 CHAM1740
000175           DINP(3805) = EXTRA(14)                                         CHAM1750
000176          DINP(3803)=NMHAF                                                CHAM1760
000177          IF ( DINP(3809) .EQ. 0.0 )        DINP(3809) = 131.0            CHAM1770
000178          K = 0                                                           CHAM1780
000179          RATO=DINP(3804)                                                         *NEW
000180          RACO=DINP(3805)                                                         *NEW
000181          RCCO=DINP(3806)                                                         *NEW
000182          RCTO=DINP(3807)                                                         *NEW
000183          RATI=DINP(91)                                                           *NEW
000184          RCTI=DINP(92)                                                           *NEW
000185          RACI=DINP( 93)                                                          *NEW
000186          RCCI=DINP(94)                                                           *NEW
000187          IF(RCTI.EQ.0.) RCTI=1.                                                  *NEW
000188          GRAD=RATO*SQRT(2./(1.+EXTRA(11))*(RATO/RCTO-RATI/RCTI)/(RATO*           *NEW
000189         1RATO-RATI*RATI))                                                        *NEW
000190          ZAVE=SQRT((1.+EXTRA(11))/2.)*RATO/GRAD                                  *NEW
000191          ZZ(4)=ZAVE                                                              *NEW
000192          IF(EXTRA(21))270,260,270                                        CHAM1800**-1
000193      260 SNOZ = 0.0                                                      CHAM1810
000194    C******************************************************************* CHAM1820
000195    C     USING HALF OF CHAMBER FREQUENCIES, CALCULATE NOZZLE FREQUENCIES CHAM1830
000196    C       FOR USE IN PROG C.                                            CHAM1840
000197    C******************************************************************* CHAM1850
000198          RORL = EXTRA(15)                                                CHAM1860
000199          GO TO 280                                                       CHAM1870
000200      270 RORL = EXTRA(14)                                                CHAM1880
000201          SNOZ = SNH/GRAD                                                 CHAM1900**-1
000202      280 DO 290 I=1,NMHAF                                                CHAM1910
000203          KN=(2*I)+1                                                      CHAM1920
000204          NN=4210+K                                                       CHAM1930
000205          DINP(NN) = ZAVE*WC(KN)/RORL                                     CHAM1940
000206          DINP(NN+1) = SNOZ                                               CHAM1950
000207          DINP(NN+2) = MACH                                               CHAM1960
000208          K=K+3                                                           CHAM1970
000209      290 CONTINUE                                                        CHAM1980
000210          DINP(NN)=ZAVE*(WC(NOMEG+2)/EXTRA(14))                           CHAM1990
000211      300 CALL CCC(C(1),ZZ(1),WC(1),CC,KER)                               CHAM2000
000212    C     SET UP NOZZ ADM FOR A,B                                         CHAM2010
000213          IF(KER) 310,330,310                                             CHAM2020
000214      310 WRITE (6,320)                                                   CHAM2030
000215      320 FORMAT (1H0 30X39H ERROR PROGRAM C,  ALL CASES TERMINATED )     CHAM2040
000216          CALL CORE(C(1),420,CC)                                          CHAM2050
000217          GO TO 90                                                        CHAM2060
000218      330 IF ( .NOT. ARUN )         GO TO 360                             CHAM2070
000219    C******************************************************************* CHAM2080
000220    C     MOVE OUTPUT FROM C INTO INPUT BLOCK TO A                        CHAM2090
000221    C******************************************************************* CHAM2100
000222      340 NP = C(3)                                                       CHAM2110
000223          IWO = 0                                                         CHAM2120
000224          DO 350 I = 1, NP                                                CHAM2130
000225             IWO = IWO + 2                                                CHAM2140
000226             AMIT(I    ) = ZZ(IWO     )                                   CHAM2150
000227             AMIT(I+30) = ZZ(IWO+  1)                                     CHAM2160
000228             AMIT(I+60) = ZZ(IWO+101)                                     CHAM2170
000229      350    CONTINUE                                                     CHAM2180
000230    C                    ZEROES TO END TABLES                             CHAM2190
000231          AMIT(NP+ 1) = 0.0                                               CHAM2200
000232          AMIT(NP+31) = 0.0                                               CHAM2210
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      AMIT(NP+61) = 0.0                                                 CHAM2220
      IF ( MACH .LE. 0.0 )   U1BAR = ZZ(205)                            CHAM2230
      GO TO 410                                                         CHAM2240
C                                                                       CHAM2250
  360 IF ( .NOT. BRUN .AND. SNH .EQ. 0.0 )     GO TO 340                CHAM2260
C*********************************************************************** CHAM2270
C     MOVE OUTPUT FROM PROG C INTO INPUT BLOCK FOR PROG B.              CHAM2280
C*********************************************************************** CHAM2290
  370 DO 380 I=18,200                                                   CHAM2300
  380 B(I)=ZZ(I)                                                        CHAM2310
      B(4)=ZZ(205)                                                      CHAM2320
C                                                                       CHAM2330
  390 CONTINUE                                                          CHAM2340
      HRUN = (CH.GT. 0.0) .OR. BRUN .AND.(UE.GE.0.1) .AND.(CH.EQ.0.0)   CHAM2350
C     NOZZLE ADMITTANCE IS INPUT TO PROGS A, B.                         CHAM2360
C*********************************************************************** CHAM2370
C                                                                       CHAM2380
  400 IF ( .NOT. ARUN )            GO TO 450                            CHAM2390
C                                                                       CHAM2400
  410 CALL  LONGL                                                       CHAM2410
C                                                                       CHAM2420
      IF(KER)420,440,420                                                CHAM2430
  420 WRITE (6,430)                                                     CHAM2440
  430 FORMAT(1H0,40X,18H ERROR PROGRAM A  )                             CHAM2450
      CALL  CORE  ( A(1), 700, CA )                                     CHAM2460
  440 CONTINUE                                                          CHAM2470
      GO TO 110                                                         CHAM2480
C*********************************************************************** CHAM2490
C     SET UP MAIN CONTROL DATA FOR USE IN B                             CHAM2500
C*********************************************************************** CHAM2510
  450 IF ( .NOT. BRUN )         GO TO 530                               CHAM2520
      B(1)=WC(1)                                                        CHAM2530
      B(2)=EXTRA(15)/EXTRA(14)                                          CHAM2540
      B(3)=EXTRA(11)                                                    CHAM2550
      B(5)=EXTRA(16)                                                    CHAM2560
      B(6) = DINP(17)                                                   CHAM2570
      B(7) = DINP(18)                                                   CHAM2580
      B(8) = DINP(19)                                                   CHAM2590
      B(19)=WC(2)                                                       CHAM2600
      DO 460 I=1,NOMEG                                                  CHAM2610
      B(I+169)=WC(I+2)                                                  CHAM2620
  460 CONTINUE                                                          CHAM2630
      B(200) = DISTL(1) / DINP(14)                                      CHAM2640
      B(220) = DISTM(1)                                                 CHAM2650
      B(17) = 1.0                                                       CHAM2660
      DO 480 I = 2, 20                                                  CHAM2670
      IF(DISTM(I))490,490,470                                           CHAM2680
  470 B(I+199)=DISTL(I)/EXTRA(14)                                       CHAM2690
      B(I+219)=DISTM(I)                                                 CHAM2700
      B(17)=B(17)+1.0                                                   CHAM2710
  480 CONTINUE                                                          CHAM2720
  490 CONTINUE                                                          CHAM2730
      CALL  TRANS  ( B, X, CB, KER )                                    CHAM2740
      DO 500 I = 9, 100                                                 CHAM2750
  500    B(I) = X(I)                                                    CHAM2760
      IF(KER)530,510,530                                                CHAM2770
  510 WRITE (6,520)                                                     CHAM2780
  520 FORMAT (1H0,40X,18H ERROR PROGRAM B  )                            CHAM2790
      CALL CORE(B(1),400,CB)                                            CHAM2800
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      GO TO 110                                                         CHAM2810
C*********************************************************************** CHAM2820
  530 IF ( .NOT. DRUN )       GO TO 620                                 CHAM2830
  540 DO 550 I=1,8                                                      CHAM2840
      X(I)=D(I)                                                         CHAM2850
  550 CONTINUE                                                          CHAM2860
  560 X(5)=EXTRA(11)                                                    CHAM2870
      DO 570 I = 9, 100                                                 CHAM2880
  570    X(I) = D(I)                                                    CHAM2890
      CALL  DDD  ( X(1), Y(1), CD, KER, ERR )                           CHAM2900
      IF ( ERR )                110,580,580                             CHAM2910
  580 IF ( KER )                610,590,610                             CHAM2920
  590 WRITE (6,600)                                                     CHAM2930
  600 FORMAT (1H0,40X,18H ERROR PROGRAM D  )                            CHAM2940
      CALL CORE(X(1),100,CD)                                            CHAM2950
      GO TO 110                                                         CHAM2960
  610 CONTINUE                                                          CHAM2970
  620 IF ( .NOT. FRUN )       GO TO 670                                 CHAM2980
C*********************************************************************** CHAM2990
C     SET UP DATA FOR PROG F   (N, TAU )                                CHAM3000
C*********************************************************************** CHAM3010
  630 Y(1)=EXTRA(14)                                                    CHAM3020
      Q(101) = EXTRA(16)/Y(1) * 12.0/6.2831853                          CHAM3030
  640 Y(2)=EXTRA(16)                                                    CHAM3040
      CALL  FFF  ( Y(1), Q(1), CF, KER, WC(1) )                         CHAM3050
      IF ( KER )                670,650,670                             CHAM3060
  650 WRITE (6,660)                                                     CHAM3070
  660 FORMAT (1H0,40X,18H ERROR PROGRAM F  )                            CHAM3080
      CALL CORE(Y(1),100,CF)                                            CHAM3090
  670 GO TO 110                                                         CHAM3100
C                                                                       CHAM3110
C                                                                       CHAM3120
C*********************************************************************** CHAM3130
C*********************************************************************** CHAM3140
C*********************************************************************** CHAM3150
       END                                                              CHAM3160
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@ ELT SUB08,1,690702, 33259

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      SUBROUTINE GENMEG(W)                                              WGEN  10
C                                                                       WGEN  20
C*********************************************************************** WGEN  30
      DIMENSION W(1)                                                    WGEN  40
C                                                                       WGEN  50
C   LONGITUDINAL WILL HAVE NEG SNH WHICH WILL BE SET TO ZERO BEFOR RETURWGEN  60
C  IF SNH 0 LONGITIDUNIAL AND GENERATE + OR - 10 PERCENT OF PIE         WGEN  70
C*********************************************************************** WGEN  80
      IF(W(1))40,50,10                                                  WGEN  90
C*********************************************************************** WGEN 100
C   FOR TRANSVERSE GENERATE 10 VALUES AROUND SNH 9 PERCENT BELOW AND    WGEN 110
C   11 PERCENT ABOVE                                                    WGEN 120
C*********************************************************************** WGEN 130
   10 SNH=W(1)                                                          WGEN 140
   20 DELMEG=.1*SNH                                                     WGEN 150
      W(3)=SNH-DELMEG                                                   WGEN 160
      DELMEG=DELMEG/5.0                                                 WGEN 170
      W(3)=W(3)+DELMEG                                                  WGEN 180
      DO 30 I=4,12                                                      WGEN 190
      W(I)=W(I-1)+DELMEG                                                WGEN 200
   30 CONTINUE                                                          WGEN 210
C*********************************************************************** WGEN 220
C  NEGITIVE 10 INDICATES TO PROGRAM THAT FREQUENCES ARE GENERATED INTERNWGEN 230
C*********************************************************************** WGEN 240
      W(2)=-10.0                                                        WGEN 250
      RETURN                                                            WGEN 260
C*********************************************************************** WGEN 270
C   IF NEG GENERATE + OR - 10 PERCENT OF POSITIVE INITIAL GUESS         WGEN 280
C*********************************************************************** WGEN 290
   40 SNH=-W(1)                                                         WGEN 300
      W(1)=0.0                                                          WGEN 310
      GO TO 20                                                          WGEN 320
   50 SNH=3.141592                                                      WGEN 330
      GO TO 20                                                          WGEN 340
      END                                                               WGEN 350
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@ ELT SUB09,1,690708, 48726

      SUBROUTINE  TRANS  ( BIN, XOUT, CB, KER )                         HYMN  20
C                                                                       HYMN  30
C     CALCULATES COMBUSTION PARAMETERS  HR, HI                          HYMN  40
C        PROGRAM BY  LW VERNON  FROM  11MAY67 ANALYSIS OF  AJ SMITH, JR HYMN  50
C           INCORPORATES CORRECTIONS TO ANALYSIS THRU  1 JUN 67         HYMN  60
C           BOOLE INTEGRATION AS OF  12 JUNE 67                         HYMN  70
C           RHO, RHOL CONVENTIONS CORRECTED  22JUN 67                   HYMN  80
C           20 SEP 67  MODIFIED FOR TABULAR INJECTOR COEFFICIENTS       HYMN  90
C                                                                       HYMN 100
C***********************************************************************HYMN 110
C                                                                       HYMN 120
      REAL  IAR, IAI, IBR, IBI                                          HYMN 130
      LOGICAL  LOGIK, HRUN, CKOUT, SIMPL, KNOT, LIMIT, TABLR            HYMN 140
C                                                                       HYMN 150
      COMMON  /PROLOG/  LOGIK(38), HEAD(12), SL1, SL2, EORJ             HYMN 160
      COMMON  /ABCDF / DIN (4300)                                       HYMN 170
     1   , SPACE(222), WIT(17), AVN(17), BVN(17), CVNR(17), CVNI(17)    HYMN 180
      DIMENSION          B    ( 240 ) ,  GS    (  6, 102 ) ,            HYMN 190
     1   ZZ    ( 102 ) ,  STAB ( 102 ) ,  GL    ( 12, 3 )   ,            HYMN 200
     2   U     ( 102 ) ,  CTAB ( 102 ) ,  SLAM  ( 12 )      ,            HYMN 210
     3   DU    ( 102 ) ,  D2U  ( 102 ) ,  ZAP   ( 12 )      ,            HYMN 220
     4   UL    ( 102 ) ,  DUL  ( 102 ) ,  G     ( 12 )      ,            HYMN 230
     5   RHO   ( 102 ) ,  DRHO ( 102 ) ,  OLD   ( 12 )      ,            HYMN 240
     6   RHOL  ( 102 ) ,  DROL ( 102 ) ,  ZING  (  6 )      ,            HYMN 250
     7   QBAR  ( 102 ) ,  DQ   ( 102 ) ,  SIMP  (  6 )      ,            HYMN 260
     8   ZIP3  ( 102 ) ,  V1   ( 102 ) ,  ERRZ  (  6 )      ,            HYMN 270
     9   ZIP5  ( 102 ) ,  V2   ( 102 ) ,  ZF    (  6 )                  HYMN 280
      DIMENSION                                                         HYMN 290
     1   THR   (  30 ) ,  THI  (  30 ) ,  THTR (  30 ) ,  THTI (  30 )  HYMN 300
      DIMENSION AL(6),                                                                *NEW
     1   BIN   ( 240 ) ,  XOUT ( 100 ) ,  WC    ( 28 )      ,            HYMN 320**-1
     2   WET   (  30 ) ,  ERT  (  30 ) ,  EIT   ( 30 )      ,            HYMN 330
     3   ZDIST(  20 ) ,  CRT  (  30 ) ,  CIT   ( 30 )      ,            HYMN 340
     4   DISTM(  20 )                                                   HYMN 350
      EQUIVALENCE                                                       HYMN 360
     1   ( HRUN , LOGIK( 8)),( CKOUT, LOGIK(13)),( SIMPL, LOGIK(14)),   HYMN 370
     2   ( KNOT , LOGIK(15)),( LIMIT, LOGIK(16)),( TABLR, LOGIK(17))   HYMN 380
      EQUIVALENCE                                                       HYMN 390
     1   ( B(1) , SNH   ),( B( 10) , ZINC  ),( DIN( 14) , RCH   ),      HYMN 400
     2   ( B(2) , ZE    ),( B( 18) , XNE   ),( UL(1)    , ULO   ),      HYMN 410
     3   ( B(3) , GAM   ),( B( 19) , XNW   ),( RHOL(1)  , RHOLO ),      HYMN 420
     4   ( B(4) , UE    ),( B(170) , WC    ),( B(20)    , WET   ),      HYMN 430
     5   ( B(5) , SOUND ),( B(200) , ZDIST ),( B(50)    , ERT   ),      HYMN 440
     6   ( B(6) , ULM   ),( B(220) , DISTM ),( B(80)    , EIT   ),      HYMN 450
     7   ( B(7) , XK    ),( B(110) , CRT   ),                            HYMN 460
     8   ( B(8) , XCMPL ),( B(140) , CIT   )                            HYMN 470
      EQUIVALENCE                                                       HYMN 480
     1   ( DIN(3406), RLON ),( DIN(3407), TLON )                        HYMN 490
      EQUIVALENCE                                                       HYMN 500
     1   ( A1R  , AL  ( 1) ),( A2R  , AL  ( 3) ),( A4R  , AL  ( 5) ),   HYMN 510
     2   ( A1I  , AL  ( 2) ),( A2I  , AL  ( 4) ),( A4I  , AL  ( 6) ),   HYMN 520
     3   ( G20R , SLAM( 9) ),( DG20R , SLAM(10) ),                      HYMN 530
     4   ( G20I , SLAM(11) ),( DG20I , SLAM(12) )                       HYMN 540
C***********************************************************************HYMN 550
C                                                                       HYMN 560
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000056          10 FORMAT ( / 65H TRANSVERSE STABILITY PROGRAM... CALCULATES  HR, HI HYMN 570
000057            1 OR  HTR, HTI )                                                   HYMN 580
000058          20 FORMAT ( // 11H INPUT DATA// 9X3HSNH12X2HZE10X5HGAMMA9X2HUE9X     HYMN 590
000059            1   14HSOUND (FT/SEC) 2X13H ULM (FT/SEC) 5X 9HXK (DRAG)4X11HXCOMPL HYMN 600
000060            2(IN)  //   F15.8, F14.8, F12.5, F14.8, F16.2, 2X 3F15.6   //     HYMN 610
000061            3 5X10HINCREMENTS 8X4HLR/N 11X4HLT/N / 5XF8.1, 2F15.7 // )         HYMN 620
000062          30 FORMAT ( // 25H NOZZLE ADMITTANCES INPUT//  15X9HOMEGA(CH) 12X    HYMN 630
000063            1   3HERT 17X3HEIT 17X3HCRT 17X3HCIT // )                         HYMN 640
000064          40 FORMAT ( ////22H CALCULATED RESULTS... 10X 29HFIRST-ORDER SOLN ( UHYMN 650
000065            1NIF INJ ) 15X21HSECOND-ORDER SOLUTION // 17X5HOMEGA 12X6HH REAL   HYMN 660
000066            2 14X6HH IMAG 13X7HHT REAL 13X7HHT IMAG  )                         HYMN 670
000067          50 FORMAT ( 9XF15.7,2E20.8 )                                         HYMN 680
000068          60 FORMAT ( 9XF15.7,4E20.8 )                                         HYMN 690
000069          70 FORMAT ( // 31H INJECTOR COEFFICIENTS INPUT... // )               HYMN 700
000070          80 FORMAT ( 11X3HANH 17X3HBNH 16X6HCNH RE 14X6HCNH IM / 4E20.8 )     HYMN 710
000071          90 FORMAT (10X5HOMEGA16X3HANH17X3HBNH16X6HCNH RE14X6HCNH IM/(5E20.8))HYMN 720
000072         100 FORMAT ( 12H0INTEGRALS   6E18.8 )                                 HYMN 730
000073         110 FORMAT ( 6H ERROR 6X6E18.8 )                                      HYMN 740
000074         120 FORMAT ( 29H0DUMP OF TABULAR FUNCTIONS... // 6X2HZZ12X1HU11X2HDU  HYMN 750
000075            1   11X2HUL11X3HRHO9X4HRHOL9X4HQBAR9X4HZIP39X4HZIP5 // (1H 9E13.5))HYMN 760
000076         130 FORMAT ( 18H0TABLES FOR HIMACH//6X2HZZ11X3HD2U11X3HDUL9X4HDRHO9X  HYMN 770
000077            1 4HDROL10X2HDQ11X2HV111X2HV2//)                                  HYMN 780
000078         140 FORMAT ( 1H 8E13.5 )                                              HYMN 790
000079         150 FORMAT (/10X1HW16X3HIAR15X3HIAI15X3HIBR15X3HIBI14X5HERCON13X5HEICOHYMN 800
000080            1N/8X4HG20R14X4HG21R14X5HDG20R13X5HDG21R14X3HH1R15X3HH2R15X2HCR    HYMN 810
000081            2 /8X4HG20I14X4HG21I14X5HDG20I13X5HDG21I14X3HH1I15X3HH2I15X2HCI//) HYMN 820
000082         160 FORMAT ( 7E18.8 )                                                HYMN 830
000083       C                                                                      HYMN 840
000084       C*********************************************************************** HYMN 850
000085       C*********************************************************************** HYMN 860
000086             HRUN = DIN(8) .GE. 0.0                                           HYMN 870
000087             CALL  DVCHK  ( KCHK )                                            HYMN 880
000088             NWI = DIN(3408) + 0.01                                           HYMN 890
000089             TABLR = NWI .GE. 3                                               HYMN 900
000090             DO 170 I = 1, 240                                                HYMN 910
000091         170    B(I) = BIN(I)                                                 HYMN 920
000092         180 IF ( CB-10.0 )          220,190,190                              HYMN 930
000093         190 CALL  PAGE  (  70 )                                              HYMN 940
000094             KOUT = 2                                                         HYMN 950
000095             NET = XNE                                                        HYMN 960
000096             WRITE (6,10)                                                     HYMN 970
000097             IF ( CB-100.0 )          220,200,200                             HYMN 980
000098         200 WRITE (6,20)  ( B(I), I = 1, 8 ),  ZINC, RLON, TLON              HYMN 990
000099             WRITE (6,30)                                                     HYMN1000
000100             WRITE (6,60)  ( WET(I), ERT(I),EIT(I), CRT(I),CIT(I), I=1,NET )  HYMN1010
000101             CKOUT = ( CB .GT. 200.0 )                                        HYMN1020
000102             IF ( .NOT. HRUN )       GO TO 220                                HYMN1030
000103             WRITE (6,70)                                                     HYMN1040
000104             IF ( TABLR )             GO TO 210                               HYMN1050
000105             WRITE (6,80)    AVN(1),.BVN(1), CVNR(1), CVNI(1)                 HYMN1060
000106             GO TO 220                                                        HYMN1070
000107         210 WRITE (6,90)  ( WIT(I), AVN(I), BVN(I), CVNR(I), CVNI(I),        HYMN1080
000108            1                I = 1, NWI  )                                   HYMN1090
000109       C                                                                      HYMN1100
000110       C     GENERATE NORMALIZED DISTRIBUTION AND OTHER TABULAR FUNCTIONS     HYMN1110
000111       C                                                                      HYMN1120
000112         220 ZC  = XCMPL / RCH                                                HYMN1130
000113             ZC = ZE                                                          HYMN1140
000114             DZ = ZINC + 0.001                                                HYMN1150
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      CALL  INT4  ( ZDIST, DISTM, ZC, UENRM )                          HYMN1160
      SCALE = UE / UENRM                                               HYMN1170
      SIMPL = IDZ .LE. 0                                               HYMN1180
      IF ( SIMPL )            GO TO 230                                HYMN1190
      INT = 2                                                          HYMN1200
      IDZ = IDZ/4 * 4                                                  HYMN1210
C            MUST BE POSITIVE MULTIPLE OF FOUR,  LESS THAN  101        HYMN1220
      GO TO 240                                                        HYMN1230
C                                                                      HYMN1240
  230 INT = 1                                                          HYMN1250
      IDZ = -IDZ/2 * 2                                                 HYMN1260
C                                                                      HYMN1270
  240 IF ( ( IDZ .EQ. 0 ) .OR. ( IDZ .GT. 100 ) )  IDZ = 80            HYMN1280
C                                                                      HYMN1290
C          IDZ  IS NUMBER OF Z-INCREMENTS.                             HYMN1300
C                                                                      HYMN1310
      IDZP = IDZ + 1                                                   HYMN1320
      DZ  = ZC / FLOAT(IDZ)                                            HYMN1330
C                                                                      HYMN1340
      ZZ(1) = 0.0                                                      HYMN1350
      U(1)  = 1.0E-10                                                  HYMN1360
      DU(1) = 0.0                                                      HYMN1370
      RHO(1)= 1.0                                                      HYMN1380
      ULO   = ULM/SOUND                                                HYMN1390
      GF1 = -1.0 / (GAM-1.0)                                           HYMN1400
      GF2 = (GAM-1.0) / 2.0                                            HYMN1410
      RHOZE = ( 1.0 + GF2*UE*UE ) **GF1                                HYMN1420
      RHOLO = RHOZE * UE / ULO                                         HYMN1430
      QBAR(1) = 0.0                                                    HYMN1440
      ZIP3(1) = 0.0                                                    HYMN1450
      ZIP5(1) = RHOLO                                                  HYMN1460
C                    ABOVE ARE FIRST TABULAR ENTRIES.                  HYMN1470
C                                                                      HYMN1480
      Z = 0.0                                                          HYMN1490
C                                                                      HYMN1500
      DO 250 IZ = 2, IDZP                                              HYMN1510
         Z = Z + DZ                                                    HYMN1520
         CALL  INT4D  ( ZDIST, DISTM, Z, U(IZ), DU(IZ) )               HYMN1530
         ZZ(IZ) = Z                                                    HYMN1540
         U (IZ) =  U(IZ)*SCALE                                         HYMN1550
         DU(IZ) = DU(IZ)*SCALE                                         HYMN1560
         UL(IZ) = UL(IZ-1) + XK*DZ*( U(IZ-1)-UL(IZ-1) )/UL(IZ-1)       HYMN1570
         TEMP = 1.0 + GAM*( U(IZ)-UL(IZ) )*U(IZ)                       HYMN1580
         RHO(IZ) = ( 1.0 + GF2*U(IZ)*U(IZ) ) **GF1                     HYMN1590
         RHOL(IZ) = ( RHOZE*UE - RHO(IZ)*U(IZ) ) / UL(IZ)              HYMN1600
     0   QBAR(IZ) = ( ( 1.0 - GAM*U(IZ)*U(IZ) )*RHO(IZ)*DU(IZ)         HYMN1610
     1              - GAM*U(IZ)*RHOL(IZ)*XK*( U(IZ)-UL(IZ) ) ) / TEMP   HYMN1620
         ZIP3(IZ) = DU(IZ) + DU(IZ)                                    HYMN1630
         ZIP5(IZ) = RHOL(IZ) / RHO(IZ)                                 HYMN1640
  250    CONTINUE                                                      HYMN1650
      ZZ(IDZP) = ZC                                                    HYMN1660
      U (IDZP) = UE                                                    HYMN1670
      DU(IDZP) = 0.0                                                   HYMN1680
      RHO(IDZP) = RHOZE                                                HYMN1690
      RHOL(IDZP) = 0.0                                                 HYMN1700
      QBAR(IDZP) = 0.0                                                 HYMN1710
      ZIP3(IDZP) = 0.0                                                 HYMN1720
      ZIP5(IDZP) = 0.0                                                 HYMN1730
C                                                                      HYMN1740
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000174          C     QBAR, ZIP3, ZIP5  AS TABULATED ABOVE ARE FREQ-INDEPENDENT PARTS   HYMN1750
000175          C        OF INTEGRANDS.                                                  HYMN1760
000176          C                                                                        HYMN1770
000177          C*************************************************************************HYMN1780
000178                IF ( .NOT. HRUN )        GO TO 270                                 HYMN1790
000179          C                                                                        HYMN1800
000180          C          INITIAL VALUES FOR  HI-ORDER TABLES                           HYMN1810
000181                HDZ = 0.5 * DZ                                                     HYMN1820
000182                D2U (1) = 0.0                                                      HYMN1830
000183                DRHO(1) = 0.0                                                      HYMN1840
000184                DROL(1) = 0.0                                                      HYMN1850
000185                DQ  (1) = 0.0                                                      HYMN1860
000186                DUL (1) = -XK                                                      HYMN1870
000187                V1  (1) = 0.0                                                      HYMN1880
000188                V2  (1) = 1.0                                                      HYMN1890
000189          C                                                                        HYMN1900
000190                HDZR = 0.5/DZ                                                      HYMN1910
000191                A1 = HDZ/ULO                                                       HYMN1920
000192          C                              HI-ORDER TABLES                           HYMN1930
000193                DO 260 IZ = 2, IDZP                                                HYMN1940
000194                   A2 = HDZ/UL(IZ)                                                 HYMN1950
000195                   V1(IZ) = V1(IZ-1) + A1 + A2                                     HYMN1960
000196                   V2(IZ) = EXP( XK*V1(IZ) )                                       HYMN1970
000197                   A1 = A2                                                         HYMN1980
000198                   DUL (IZ) = ( UL  (IZ+1) - UL  (IZ-1) )*HDZR                     HYMN1990
000199                   DRHO(IZ) = ( RHO (IZ+1) - RHO (IZ-1) )*HDZR                     HYMN2000
000200                   DROL(IZ) = ( RHOL(IZ+1) - RHOL(IZ-1) )*HDZR                     HYMN2010
000201                   DQ  (IZ) = ( QBAR(IZ+1) - QBAR(IZ-1) )*HDZR                     HYMN2020
000202                   D2U (IZ) = ( DU  (IZ+1) - DU  (IZ-1) )*HDZR                     HYMN2030
000203             260   CONTINUE                                                        HYMN2040
000204          C                    FINAL VALUES                                        HYMN2050
000205                DUL (IDZP) = XK*(UE-UL(IDZP))/UL(IDZP)                             HYMN2060
000206                DROL(IDZP) = 0.0                                                   HYMN2070
000207                DRHO(IDZP) = 0.0                                                   HYMN2080
000208                DQ  (IDZP) = 0.0                                                   HYMN2090
000209                D2U (IDZP) = 0.0                                                   HYMN2100
000210                D2U(2) = 0.5*D2U(3)                                                HYMN2110
000211                DQ (2) = 0.5*DQ (3)                                                HYMN2120
000212                D2U(IDZ) = 0.5*D2U(IDZ-1)                                          HYMN2130
000213                DQ (IDZ) = 0.5*DQ (IDZ-1)                                          HYMN2140
000214          C                                                                        HYMN2150
000215                KNOT = XK .EQ. 0.0                                                 HYMN2160
000216                XI2R = 0.0                                                         HYMN2170
000217                XI3R = 0.0                                                         HYMN2180
000218                XI4R = 0.0                                                         HYMN2190
000219                VK1 = 0.0                                                          HYMN2200
000220                VK2 = 0.0                                                          HYMN2210
000221                IF ( TABLR )              GO TO 270                                HYMN2220
000222                ANH  = AVN(1)                                                      HYMN2230
000223                BNH  = BVN (1) * RLON                                              HYMN2240
000224                CNHR = CVNR(1) * TLON                                              HYMN2250
000225                CNHI = CVNI(1) * TLON                                              HYMN2260
000226          C                                                                        HYMN2270
000227            270 CONTINUE                                                           HYMN2280
000228                NW  = XNW                                                          HYMN2290
000229          C                                                                        HYMN2300
000230          C*************************************************************************HYMN2310
000231          C                                                                        HYMN2320
000232          C     CALCULATIONS FOR EACH FREQUENCY, W                                 HYMN2330
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C                                                                       HYMN2340
C***********************************************************************HYMN2350
C                                                                       HYMN2360
      DO 820 IW = 1, NW                                                 HYMN2370
         W = WC(IW)                                                     HYMN2380
         OMEG2 = SNH*SNH - W*W                                          HYMN2390
         OMEG = SQRT(ABS(OMEG2))                                        HYMN2400
         LIMIT = .FALSE.                                                HYMN2410
C                                                                       HYMN2420
         CALL  INT4  ( WET, ERT, W, ER )                                HYMN2430
         CALL  INT4  ( WET, EIT, W, EI )                                HYMN2440
         IF ( OMEG2 )          280,290,300                              HYMN2450
  280    IM = 1                                                         HYMN2460
         GO TO 310                                                      HYMN2470
C                                                                       HYMN2480
  290    IM = 2                                                         HYMN2490
        OMEG = 0.5E-10                                                  HYMN2500
        OMEG2 = 0.25E-20                                                HYMN2510
C                                                                       HYMN2520
  300    IM = 3                                                         HYMN2530
C                                                                       HYMN2540
C    EVALUATION OF SIX INTEGRALS  BY  BOOLE  FORMULA  ( OR SIMPSON )    HYMN2550
C     BOOLE INTEGRATION IF  ZINC INPUT POSITIVE,  ELSE SIMPSON RULE     HYMN2560
C        ( BOOLE IS SIMPSON RULE WITH ERROR FORMULA )                   HYMN2570
C                                                                       HYMN2580
C        IM  IS  ( 1, 2, 3 )  AS  OMEG2  IS  ( -, 0, + ),               HYMN2590
C        THEN USE  ( CIRCULAR, LIMIT, HYPERBOLIC )  FUNCTIONS           HYMN2600
C                                                                       HYMN2610
  310    DO 320 I = 1, 6                                                HYMN2620
  320       ZING(I) = 0.0                                               HYMN2630
         NOD = 3                                                        HYMN2640
         DO 430 IZ = 1, IDZP, INT                                       HYMN2650
            Z = ZZ(IZ)                                                  HYMN2660
            GO TO (350,340,330),  NOD                                   HYMN2670
C                                                                       HYMN2680
  330       WT = 1.0                                                    HYMN2690
            NOD = 1                                                     HYMN2700
            GO  TO 360                                                  HYMN2710
C                                                                       HYMN2720
  340       WT = 2.0                                                    HYMN2730
            IF ( IZ .EQ. IDZP )   GO TO 330                             HYMN2740
            NOD = 1                                                     HYMN2750
            GO TO 360                                                   HYMN2760
C                                                                       HYMN2770
  350       WT = 4.0                                                    HYMN2780
            NOD = 2                                                     HYMN2790
C                                                                       HYMN2800
  360       PSI = OMEG * (ZE-Z)                                         HYMN2810
            GO TO (390,370,380),  IM                                    HYMN2820
C                                                                       HYMN2830
  370       ZEZ = ZE - Z                                                HYMN2840
            ZF(1) = QBAR(IZ) * ZEZ                                      HYMN2850
            ZF(2) = QBAR(IZ)                                            HYMN2860
            ZF(3) = ZIP3(IZ) * ZEZ                                      HYMN2870
            ZF(4) = ZIP3(IZ)                                            HYMN2880
            ZF(5) = ZIP5(IZ) * ZEZ                                      HYMN2890
            ZF(6) = ZIP5(IZ)                                            HYMN2900
            GO TO 410                                                   HYMN2910
C                                                                       HYMN2920
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  380       CF = COSH(PSI)                                                HYMN2930
            SF = SINH(PSI)                                                HYMN2940
            GO TO 400                                                     HYMN2950
C                                                                         HYMN2960
  390       CF = COS (PSI)                                                HYMN2970
            SF = SIN (PSI)                                                HYMN2980
C                                                                         HYMN2990
  400       ZF(1) = QBAR(IZ) * SF                                         HYMN3000
            ZF(2) = QBAR(IZ) * CF                                         HYMN3010
            ZF(3) = ZIP3(IZ) * SF                                         HYMN3020
            ZF(4) = ZIP3(IZ) * CF                                         HYMN3030
            ZF(5) = ZIP5(IZ) * SF                                         HYMN3040
            ZF(6) = ZIP5(IZ) * CF                                         HYMN3050
C       ZF ARE COMPLETE INTEGRANDS                                        HYMN3060
C                                                                         HYMN3070
  410       DO 420 I = 1, 6                                               HYMN3080
               ZING(I) = ZING(I) + WT*ZF(I)                               HYMN3090
  420          CONTINUE                                                   HYMN3100
  430     .  CONTINUE                                                     HYMN3110
C                                                                         HYMN3120
          GO TO (460,440),  INT                                           HYMN3130
C                                                                         HYMN3140
  440     INT = 1                                                         HYMN3150
          DO 450 I = 1, 6                                                 HYMN3160
  450       SIMP(I) = ZING(I)*DZ/1.5                                      HYMN3170
C                SIMP IS SIMPSON INTEGRAL FOR IDZ/2 INCREMENTS            HYMN3180
          GO TO 310                                                       HYMN3190
C                                                                         HYMN3200
  460     DO 470 I = 1, 6                                                 HYMN3210
  470       ZING(I) = ZING(I)*DZ/3.0                                      HYMN3220
C                ZING IS SIMPSON INTEGRAL FOR  IDZ  INCREMENTS            HYMN3230
C                                                                         HYMN3240
          IF ( SIMPL )          GO TO 490                                 HYMN3250
      INT = 2                                                             HYMN3260
          DO 480 I = 1, 6                                                 HYMN3270
            ERRZ(I) = ( ZING(I)-SIMP(I) ) / 15.0                          HYMN3280
            IF ( ABS(ERRZ(I)/ZING(I) ) .GT. 0.05 )  CKOUT = .TRUE.        HYMN3290
C     ZING, SIMP ARE SIMPSON INTEGRALS WITH  IDZ, IDZ/2  INCREMENTS       HYMN3300
            ZING(I) = ZING(I) + ERRZ(I)                                   HYMN3310
C     CORRECTED  ZING  IS NOW  BOOLE INTEGRAL                             HYMN3320
  480       CONTINUE                                                      HYMN3330
C                                                                         HYMN3340
C         ABOVE  ZING(I)  ARE THE REQUIRED INTEGRALS                      HYMN3350
C                                                                         HYMN3360
  490     IF ( .NOT. CKOUT )    GO TO 500                                 HYMN3370
          WRITE (6,100)  ZING                                             HYMN3380
          IF ( .NOT. SIMPL )    WRITE (6,110)  ERRZ                       HYMN3390
C                                                                         HYMN3400
  500     OZE = OMEG * ZE                                                 HYMN3410
          WKSQ = XK*XK + W*W                                              HYMN3420
          T1 = XK*W / WKSQ                                                HYMN3430
          T2 = W*W / WKSQ                                                 HYMN3440
C                                                                         HYMN3450
          Y1R = GAM*ZING(2)-ZING(2) + ZING(4) + W*T1*ZING(6)              HYMN3460
          Y1I = XK*T1*ZING(6)                                             HYMN3470
C                                                                         HYMN3480
          GO TO (530,510,520),  IM                                        HYMN3490
C                                                                         HYMN3500
  510     Y2R = -SNH*ER/W                                                 HYMN3510
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000351                Y2I = -SNH*EI/W                                          HYMN3520
000352                ERCON = SNH*ER                                           HYMN3530
000353                EICON = SNH*EI                                           HYMN3540
000354                GO TO 550                                                HYMN3550
000355          C                                                              HYMN3560
000356            520 COZE = COSH(OZE)                                         HYMN3570
000357                SOZE = SINH(OZE)                                         HYMN3580
000358                GO TO 540                                                HYMN3590
000359          C                                                              HYMN3600
000360            530 COZE =  COS(OZE)                                         HYMN3610
000361                SOZE = -SIN(OZE)                                         HYMN3620
000362          C                                                              HYMN3630
000363            540 ERCON = SNH*ER/OMEG                                      HYMN3640
000364                EICON = SNH*EI/OMEG                                      HYMN3650
000365                Y2R = -SNH*ER/W*COZE                                     HYMN3660
000366                Y2I = -SNH*EI/W*COZE - OMEG/W*SOZE                       HYMN3670
000367          C                                                              HYMN3680
000368            550 TEMP = GAM*ZING(1)-ZING(1) + ZING(3) + W*T1*ZING(5)      HYMN3690
000369                Y3R = ERCON*XK*T1*ZING(5) + EICON*TEMP                   HYMN3700
000370                Y3I = EICON*XK*T1*ZING(5) - ERCON*TEMP                   HYMN3710
000371                Y6R =  EICON*ZING(1) + ZING(2)                           HYMN3720
000372                Y6I = -ERCON*ZING(1)                                     HYMN3730
000373          C                                                              HYMN3740
000374          C                                                              HYMN3750
000375          C*********************************************************** HYMN3760
000376          C                                                              HYMN3770
000377          C****   CALCULATION OF FIRST-ORDER SOLUTION...                 HYMN3780
000378          C                                                              HYMN3790
000379          C                                                              HYMN3800
000380          C                                                              HYMN3810
000381            560 H1R = ( Y1R+Y2R+Y3R )/GAM                                HYMN3820
000382                H1I = ( Y1I+Y2I+Y3I )/GAM                                HYMN3830
000383                HD = Y6R*Y6R + Y6I*Y6I                                   HYMN3840
000384          C                                                              HYMN3850
000385                HR = ( H1R*Y6R + H1I*Y6I ) / HD                          HYMN3860
000386                HI = ( H1I*Y6R - H1R*Y6I ) / HD                          HYMN3870
000387          C                                                              HYMN3880
000388                THR(IW) = HR                                             HYMN3890
000389                THI(IW) = HI                                             HYMN3900
000390          C                                                              HYMN3910
000391                IF ( .NOT. HRUN )     GO TO 820                          HYMN3920
000392          C                                                              HYMN3930
000393          C*********************************************************** HYMN3940
000394          C                                                              HYMN3950
000395          C     TERMS FROM HIGH-ORDER ANALYSIS   ( STILL IN  W-LOOP )    HYMN3960
000396          C        INITIALIZE  INTEGRALS, INTEGRANDS FOR  Z=0.0          HYMN3970
000397          C                                                              HYMN3980
000398                DO 570 I = 1, 6                                          HYMN3990
000399                   AL(I) = 0.0                                           HYMN4000
000400                   DO 570 IZ = 1, IDZP                                   HYMN4010
000401            570       GS(I,IZ) = 0.0                                     HYMN4020
000402                DO 580 I = 1, 12                                         HYMN4030
000403                   OLD(I) = 0.0                                          HYMN4040
000404                   ZAP(I) = 0.0                                          HYMN4050
000405                   GL(I,1) = 0.0                                         HYMN4060
000406            580    SLAM(I) = 0.0                                         HYMN4070
000407                OLD(3) = -XK*OMEG2                                       HYMN4080
000408                IF ( IM .EQ. 1 )     SOZE = -SOZE                        HYMN4090
000409                NOD = 1                                                  HYMN4100
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      TEMP = -T1*RHOLO                                                  HYMN4110
      GL( 9,1) = TEMP*XK*W*SOZE                                         HYMN4120
      GL(10,1) = TEMP*XK*W*COZE                                         HYMN4130
      GL(11,1) = TEMP*OMEG2*SOZE                                        HYMN4140
      GL(12,1) = TEMP*OMEG2*COZE                                        HYMN4150
C                                                                       HYMN4160
      IF ( .NOT. TABLR )   GO TO 585                                    HYMN4161
      CALL  INT4  ( WIT, AVN , W, ANH  )                                HYMN4162
      CALL  INT4  ( WIT, BVN , W, BNH  )                                HYMN4163
      CALL  INT4  ( WIT, CVNR, W, CNHR )                                HYMN4164
      CALL  INT4  ( WIT, CVNI, W, CNHI )                                HYMN4165
C                                                                       HYMN4166
      BNH  = RLON * BNH                                                 HYMN4167
      CNHR = TLON * CNHR                                                HYMN4168
      CNHI = TLON * CNHI                                                HYMN4169
C                                                                       HYMN4170
  585 YE = ANH - CNHI/(W*GAM)                                           HYMN4171
      YF = ( BNH + CNHR ) / (W*GAM)                                     HYMN4180
      H2R = Y6R*YE - Y6I*YF                                             HYMN4190
      H2I = Y6R*YF + Y6I*YE                                             HYMN4200
      HSSQ = H2R*H2R + H2I*H2I                                          HYMN4210
      HA = ( H1R*H2R + H1I*H2I ) / HSSQ                                 HYMN4220
      HB = ( H1I*H2R - H1R*H2I ) / HSSQ                                 HYMN4230
C                                                                       HYMN4240
      CALL  INT4  ( WET, CRT, W, CR )                                   HYMN4250
      CALL  INT4  ( WET, CIT, W, CI )                                   HYMN4260
C                                                                       HYMN4270
      GO TO (590,610,630),  IM                                          HYMN4280
  590 DO 600 IZ = 1, IDZP                                               HYMN4290
         ARG = OMEG*ZZ(IZ)                                              HYMN4300
         STAB(IZ) = SIN (ARG)                                           HYMN4310
  600    CTAB(IZ) = COS (ARG)                                           HYMN4320
      SIGN = -1.0                                                       HYMN4330
      GO TO 650                                                         HYMN4340
C                                                                       HYMN4350
  610 DO 620 IZ = 1, IDZP                                               HYMN4360
         STAB(IZ) = ZZ(IZ)                                              HYMN4370
  620    CTAB(IZ) = 1.0                                                 HYMN4380
      GL(11,1) = TEMP * ZE                                              HYMN4390
      GL(12,1) = TEMP                                                   HYMN4400
      GO TO 650                                                         HYMN4410
C                                                                       HYMN4420
  630 DO 640 IZ = 1, IDZP                                               HYMN4430
         ARG = OMEG*ZZ(IZ)                                              HYMN4440
         STAB(IZ) = SINH(ARG)                                           HYMN4450
  640    CTAB(IZ) = COSH(ARG)                                           HYMN4460
      SIGN = 1.0                                                        HYMN4470
C                                                                       HYMN4480
C                                                                       HYMN4490
  650 DO 780 IZ = 2, IDZP                                               HYMN4500
         NOD = NOD + 1                                                  HYMN4510
         V3 = XK*RHOL(IZ)/RHO(IZ)                                       HYMN4520
         V4 = DU(IZ) + V3                                               HYMN4530
         V5 = QBAR(IZ)*V4 + RHO(IZ)*U(IZ)*DQ(IZ)                        HYMN4540
         V6 = ( RHOL(IZ)/UL(IZ)*DUL(IZ) - DROL(IZ) ) / RHO(IZ)          HYMN4550
         V7 = ( 2.0*(D2U(IZ)-DU(IZ)) + V3 - XK*V6 )                     HYMN4560
         V8  = XK*ZIP5(IZ) - U(IZ) - 3.0*DU(IZ)                         HYMN4570
     0   V9  = V3*( DU(IZ) - DUL(IZ) - UL(IZ)/RHOL(IZ)*DROL(IZ) )       HYMN4580
     1          + DU(IZ)*DU(IZ)                                         HYMN4590
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000469          0      V10 = ( GAM*DQ(IZ) - DQ(IZ) + RHO(IZ)*D2U(IZ) + D2U(IZ) )   HYMN4600
000470          1            * U(IZ)/RHO(IZ)                                       HYMN4610
000471                 V11 = U(IZ)/RHO(IZ)*DROL(IZ)/RHO(IZ)                         HYMN4620
000472                 V12 = ( GAM*QBAR(IZ) - QBAR(IZ) )*DU(IZ)                     HYMN4630
000473                 V13 = ( V12 + D2U(IZ) )/RHO(IZ)                              HYMN4640
000474                 V16 = QBAR(IZ)/RHO(IZ)                                       HYMN4650
000475                 V17 = (GAM-1.0) * ( V16*V16 + U(IZ)/RHO(IZ)*DQ(IZ) )         HYMN4660
000476          0      V18 = ((U(IZ)-UL(IZ))*DQ(IZ) + QBAR(IZ)*(DU(IZ)-DUL(IZ)))   HYMN4670
000477          1             * RHO(IZ)                                             HYMN4680
000478                 V19 = ( UL(IZ)-XK-DUL(IZ) ) / ( UL(IZ)*UL(IZ) ) * RHOL(IZ)  HYMN4690
000479                 V20 = V19 + DROL(IZ)/UL(IZ)                                  HYMN4700
000480                 V21 = V16 - GAM*V16 - DU(IZ) - DU(IZ)/RHO(IZ)                HYMN4710
000481                    V22 = GAM - 1.0                                           HYMN4720
000482                    V23 = RHO(IZ) + 1.0                                       HYMN4730
000483                    V24 = RHO(IZ) - 1.0                                       HYMN4740
000484                    V25 = V22 * (QBAR(IZ)*DU(IZ) + U(IZ)*DQ(IZ))              HYMN4750
000485                    V26 = DU(IZ) * (V22*QBAR(IZ) + (GAM + V23)*DU(IZ))        HYMN4760
000486                    V27 = RHO(IZ)*V10/T2                                      HYMN4770
000487          0         V28 = V22 * (QBAR(IZ)*(QBAR(IZ)/RHO(IZ) + DU(IZ))         HYMN4780
000488          1                 + 2.0*U(IZ)*DQ(IZ))                               HYMN4790
000489          0         V29 = RHO(IZ) * (D2U(IZ)*(U(IZ) - UL(IZ))                 HYMN4800
000490          1                     + DU(IZ)*(DU(IZ) - DUL(IZ)))                  HYMN4810
000491                    V30 = U(IZ)*D2U(IZ)                                       HYMN4820
000492      C                                                                       HYMN4830
000493      C     THE FUNCTIONS  V1 ... V20  ARE INDEPENDENT OF W.  HENCE WE COULD  HYMN4840
000494      C        TRADE CORE FOR TIME BY TAKING ALL OR SOME OUT OF W-LOOP AS     HYMN4850
000495      C        SUBSCRIPTED VARIABLES.  LET S SEE FIRST WHAT CORE WE HAVE.     HYMN4860
000496      C                                                                       HYMN4870
000497                 ARG = W * V1(IZ)                                             HYMN4880
000498                 CWV = COS(ARG)                                               HYMN4890
000499                 SWV = SIN(ARG)                                               HYMN4900
000500                 XI10R = CWV*V2(IZ)/RHO(IZ)                                   HYMN4910
000501                 XI10I = SWV*V2(IZ)/RHO(IZ)                                   HYMN4920
000502                 ZETAR = CWV/V2(IZ)                                           HYMN4930
000503                 ZETAI = SWV/V2(IZ)                                           HYMN4940
000504                 XI14R = XI10R*DUL(IZ)                                        HYMN4950
000505                 XI14I = XI10I*DUL(IZ)                                        HYMN4960
000506                 OZEZ = OMEG * ( ZE-ZZ(IZ) )                                  HYMN4970
000507                 GO TO (660,670,680),  IM                                     HYMN4980
000508      C                                                                       HYMN4990
000509        660      P0  = CTAB(IZ)                                               HYMN5000
000510                 PP0 = -OMEG*STAB(IZ)                                         HYMN5010
000511                 ST = SIN ( OZEZ )                                            HYMN5020
000512                 CT = COS ( OZEZ )                                            HYMN5030
000513                 GO TO 690                                                    HYMN5040
000514      C                                                                       HYMN5050
000515        670      P0  = 1.0                                                    HYMN5060
000516                 PP0 = 0.0                                                    HYMN5070
000517                 ST = ZE-ZZ(IZ)                                               HYMN5080
000518                 CT = 1.0                                                     HYMN5090
000519                 GO TO 690                                                    HYMN5100
000520      C                                                                       HYMN5110
000521        680      P0  = CTAB(IZ)                                               HYMN5120
000522                 PP0 = OMEG*STAB(IZ)                                          HYMN5130
000523                 ST = SINH( OZEZ )                                            HYMN5140
000524                 CT = COSH( OZEZ )                                            HYMN5150
000525      C                                                                       HYMN5160
000526        690       IJK = 0                                                     HYMN5170
000527                  DO 700 JZ = IZ, IDZP                                        HYMN5180
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                IJK = IJK + 1                                                HYMN5190
     0          GS(1,JZ) = (QBAR(IZ)*STAB(IJK)+QBAR(IZ-1)*STAB(IJK+1))      HYMN5200
     1                     * HDZ + GS(1,JZ)                                  HYMN5210
     0          GS(2,JZ) = (QBAR(IZ)*CTAB(IJK)+QBAR(IZ-1)*CTAB(IJK+1))      HYMN5220
     1                     * HDZ + GS(2,JZ)                                  HYMN5230
     0          GS(3,JZ) = (ZIP3(IZ)*STAB(IJK)+ZIP3(IZ-1)*STAB(IJK+1))      HYMN5240
     1                     * HDZ + GS(3,JZ)                                  HYMN5250
     0          GS(4,JZ) = (ZIP3(IZ)*CTAB(IJK)+ZIP3(IZ-1)*CTAB(IJK+1))      HYMN5260
     1                     * HDZ + GS(4,JZ)                                  HYMN5270
     0          GS(5,JZ) = (ZIP5(IZ)*STAB(IJK)+ZIP5(IZ-1)*STAB(IJK+1))      HYMN5280
     1                     * HDZ + GS(5,JZ)                                  HYMN5290
     0          GS(6,JZ) = (ZIP5(IZ)*CTAB(IJK)+ZIP5(IZ-1)*CTAB(IJK+1))      HYMN5300
     1                     * HDZ + GS(6,JZ)                                  HYMN5310
C                                                                            HYMN5320
  700           CONTINUE                                                     HYMN5330
C                                                                            HYMN5340
              P10R = -XK*W*GS(5,IZ) * T1                                     HYMN5350
              P10I = ( GAM*GS(1,IZ)-GS(1,IZ)+GS(3,IZ)+W*T1*GS(5,IZ) ) * W    HYMN5360
C           ( P11R = 0.0 )                                                   HYMN5370
              P11I = -W*GS(1,IZ)                                             HYMN5380
              IF ( LIMIT )       GO TO 710                                   HYMN5390
              P10R = P10R/OMEG                                               HYMN5400
              P10I = P10I/OMEG                                               HYMN5410
              P11I = P11I/OMEG                                               HYMN5420
  710         PP10R = -W*XK*T1 * GS(6,IZ)                                    HYMN5430
     0        PP10I = (GAM*GS(2,IZ) - GS(2,IZ) + GS(4,IZ)                    HYMN5440
     1                                         + W*T1*GS(6,IZ) ) * W         HYMN5450
C           ( PP11R = 0.0 )                                                  HYMN5460
              PP11I = -W*GS(2,IZ)                                            HYMN5470
C                                                                            HYMN5480
              IF ( KNOT )        GO TO 730                                   HYMN5490
C               EVALUATE INTEGRALS IN EXPRESSIONS FOR LAMDAS  ( AL(I) )      HYMN5500
              XI16R = ( W*RHOL(IZ)*ZETAR - V19*ZETAI ) * T1                  HYMN5510
              XI16I = ( W*RHOL(IZ)*ZETAI - V19*ZETAR ) * T1                  HYMN5520
              T3 = ( W*T1*DROL(IZ)/RHO(IZ) + D2U(IZ) ) * P0                  HYMN5530
              G(1) = T3 * XI10R                                              HYMN5540
              G(2) = T3 * XI10I                                              HYMN5550
              T4 = OMEG2*P0 + PP0                                            HYMN5560
              G(3) = XI14R * T4                                              HYMN5570
              G(4) = XI14I * T4                                              HYMN5580
              G(5) = PP0 * XI10R                                             HYMN5590
              G(6) = PP0 * XI10I                                             HYMN5600
              G( 7) = XI14R * PP11I                                          HYMN5610
              G( 8) = XI14I * PP11I                                          HYMN5620
              G( 9) = XI14R * PP10R                                          HYMN5630
              G(10) = XI14I * PP10R                                          HYMN5640
              G(11) = XI14R * PP10I                                          HYMN5650
              G(12) = XI14I * PP10I                                          HYMN5660
C                                                                            HYMN5670
              DO 720 I = 1, 12                                               HYMN5680
                 ZAP(I) = ( G(I) + OLD(I) )*HDZ + ZAP(I)                     HYMN5690
  720            OLD(I) = G(I)                                               HYMN5700
C                       ( TRAPEZOIDAL RULE )                                 HYMN5710
     0           VK1 = XK * (  T2*RHOL(IZ)/RHO(IZ)*(V24*DU(IZ) - V3)         HYMN5720
     1                      + RHOL(IZ) * (W*T1*RHOL(IZ)/RHO(IZ)+DU(IZ)      HYMN5730
     2                                  - DUL(IZ) - XK*ZETAR)                HYMN5740
     3                      - UL(IZ)*DROL(IZ) - U(IZ)/RHO(IZ)*DROL(IZ)      HYMN5750
     4                  - RHOL(IZ)/RHO(IZ)*(V22*QBAR(IZ) + V23*DU(IZ)))     HYMN5760
     0           VK2 = XK * (  T2*U(IZ)/RHO(IZ)*DROL(IZ)                     HYMN5770
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     1                    + XK*GAM*RHOL(IZ)*ZETAI/W)                    HYMN5780
C                                                                       HYMN5790
  730       XI1R = T2/RHO(IZ) * (V25 - V26 - V27 - V28 + V29 + VK1)     HYMN5800
            XI1I = T2 * (VK2 + V30)                                     HYMN5810
            XI2I = ( GAM*V16 - V16 + DU(IZ) + T2*V4 )*W                 HYMN5820
            XI3I = W*U(IZ) - T2/W*V7                                    HYMN5830
            XI4I = T1*V6 + 2.0*W*U(IZ)                                  HYMN5840
            XI5I = ( T2*V8 + DU(IZ)/RHO(IZ) )/W                         HYMN5850
C           XI2R = XI3R = XI4R = XI5R = 0                               HYMN5860
C                                                                       HYMN5870
C                                                                       HYMN5880
C                                                                       HYMN5890
            IF ( KNOT )       GO TO 740                                 HYMN5900
            A1R = -XI16R*ZAP(8) - XI16I*ZAP(7)                          HYMN5910
            A1I =  XI16R*ZAP(7) - XI16I*ZAP(8) + GAM*P0*V5*T1           HYMN5920
            A2R = T1/W*(V16*V3-V5/RHO(IZ))*P0                           HYMN5930
            T5 = W/UL(IZ) * RHOL(IZ)/UL(IZ)                             HYMN5940
            T6 = V20*ZETAI - T5*ZETAR                                   HYMN5950
            T7 = V20*ZETAR - T5*ZETAI                                   HYMN5960
            T8 = W/RHO(IZ) * ( RHOL(IZ) - RHO(IZ)*RHOL(IZ) )            HYMN5970
C                                                                       HYMN5980
     0      A4R = T1 * ( T8*( ZETAI*ZAP(5) + ZETAR*ZAP(6) )             HYMN5990
     1                  - RHOL(IZ)*( ZETAR*ZAP(1) + ZETAI*ZAP(2) )      HYMN6000
     2                  - T6*ZAP(3) + T7*ZAP(4) )                       HYMN6010
     3              + XI16R*(ZAP( 9)-ZAP(12)) - XI16I*(ZAP(11)+ZAP(10)) HYMN6020
C                                                                       HYMN6030
     0      A4I = T1 * ( T8*( ZETAI*ZAP(6) - ZETAR*ZAP(5) )             HYMN6040
     1                  - RHOL(IZ)*( ZETAR*ZAP(2) - ZETAI*ZAP(1) )      HYMN6050
     2                  - T7*ZAP(3) - T6*ZAP(4) )                       HYMN6060
     3              + XI16R*(ZAP(11)+ZAP(10)) + XI16I*(ZAP( 9)-ZAP(12)) HYMN6070
C                                                                       HYMN6080
  740       T9  = HA * P11I                                             HYMN6090
            T10 = HB * P11I                                             HYMN6100
            TEMP = -GAM*W*QBAR(IZ)                                      HYMN6110
     0      A1R = A1R + TEMP*(T9+P10I) + GAM*P0*(V18+T2*V5)             HYMN6120
     1              + XI2I*P11I + XI4I*PP11I                            HYMN6130
            A1I = A1I + TEMP*(T10-P10R)                                 HYMN6140
            A2R = A2R + V16*(T10-P10R)                                  HYMN6150
     0      A2I = ( (V18+T2*V5)/RHO(IZ) - V16*(V3*T2-DU(IZ)) )/W*P0     HYMN6160
     1            -V16*(T9+P10I)                                        HYMN6170
     0      A4R = A4R + XI1R*P0    + XI4I*PP10I        + XI2I*P10I      HYMN6180
     0      A4I = A4I + ( XI1I-OMEG2*XI5I )*P0 - XI3I*PP0  - XI4I*PP10R HYMN6190
     1                - XI2I*P10R                                      HYMN6200
C                                                                       HYMN6210
C*********************************************************************** HYMN6220
C                                                                       HYMN6230
C     SET UP INTEGRANDS  (  SIMPSON RULE HERE  )                        HYMN6240
            DO 750 I = 1, 6                                             HYMN6250
               GL(2*I-1,NOD) = AL(I)*ST                                 HYMN6260
               GL(2*I  ,NOD) = AL(I)*CT                                 HYMN6270
               AL(I) = 0.0                                              HYMN6280
  750          CONTINUE                                                 HYMN6290
C                                                                       HYMN6300
            GO TO (780,780,760),  NOD                                   HYMN6310
C                                                                       HYMN6320
  760       DO 770 I = 1, 12                                            HYMN6330
               SLAM(I) = SLAM(I) + GL(I,1) + 4.0*GL(I,2) + GL(I,3)      HYMN6340
C                                  WEIGHTED SUM FOR THREE ORDINATES     HYMN6350
               GL(I,1) = GL(I,3)                                        HYMN6360
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  770          CONTINUE                                                  HYMN6370
            NOD = 1                                                      HYMN6380
C                                                                        HYMN6390
  780       CONTINUE                                                     HYMN6400
C                                                                        HYMN6410
C*******************   ENDS  PRINCIPAL  Z-LOOP   ******************       HYMN6420
C                          STILL DOING FOR  IW                           HYMN6430
C                                                                        HYMN6440
C*********************************************************************** HYMN6450
C                                                                        HYMN6460
C         COMPLETE INTEGRATION                                           HYMN6470
          DO 790 I = 1, 12                                               HYMN6480
             SLAM(I) = SLAM(I) * DZ/3.0                                  HYMN6490
  790        CONTINUE                                                    HYMN6500
      IF ( LIMIT )            GO TO 800                                  HYMN6510
C     CALCULATE DEFECT  ( CONTRIBUTION OF INTEGRALS FROM  Z=ZC TO Z=ZE )HYMN6520
          TEMP = 2.0*W*UE                                                HYMN6530
          SLAM( 1) = SLAM( 1) + TEMP*PP11I*(CF-1.0)/OMEG2                HYMN6540
          SLAM( 2) = SLAM( 2) + TEMP*PP11I*SF/OMEG                       HYMN6550
          SLAM( 9) = SLAM( 9) + TEMP*PP10I*(CF-1.0)/OMEG2                HYMN6560
          SLAM(10) = SLAM(10) + TEMP*PP10I*SF/OMEG                       HYMN6570
          SLAM(11) = SLAM(11) - TEMP*PP10R*(CF-1.0)/OMEG2                HYMN6580
     1              -0.5*W*UE*( PSI*COZE-CTAB(IDZP)*SF )/OMEG            HYMN6590
     2              + 0.5*T2/W*UE*( PSI*SOZE-STAB(IDZP)*SF )*SIGN        HYMN6600
          SLAM(12) = SLAM(12) - TEMP*PP10R*SF/OMEG                       HYMN6610
     1              - 0.5*W*UE*( PSI*SOZE-STAB(IDZP)*SF )*SIGN           HYMN6620
     2              + 0.5*T2/W*UE*( PSI*COZE+CTAB(IDZP)*SF )*OMEG*SIGN   HYMN6630
C                                                                        HYMN6640
  800     G21R  = ANH*SLAM(1) + BNH*SLAM(5) + CNHR*SLAM(5) - CNHI*SLAM(7)HYMN6750
          G21I  = ANH*SLAM(3) + BNH*SLAM(7) + CNHR*SLAM(7) + CNHI*SLAM(5)HYMN6760
          DG21R = ANH*SLAM(2) + BNH*SLAM(6) + CNHR*SLAM(6) - CNHI*SLAM(8)HYMN6770
          DG21I = ANH*SLAM(4) + BNH*SLAM(8) + CNHR*SLAM(8) + CNHI*SLAM(6)HYMN6780
C                                                                        HYMN6790
C          THE FOLLOWING AVAILABLE BY EQUIVALENCE...                     HYMN6800
C         G20R    IS  SLAM ( 9)                                          HYMN6810
C         G20I    IS  SLAM (11)                                          HYMN6820
C         DG20R   IS  SLAM (10)                                          HYMN6830
C         DG20I   IS  SLAM (12)                                          HYMN6840
C                                                                        HYMN6850
C     FOR NONZERO OMEG, DIVISION BY OMEG IS IMPLICIT IN ERCON, EICON.    HYMN6860
C     IAR, IAI, IBR, IBI  ARE TYPE REAL.                                 HYMN6870
          TEMP = UE * W * ZING(2)                                        HYMN6880
     0    IAR = H1R - DG20R - ERCON*G20I - EICON*G20R                    HYMN6890
     1              + ( ( CI*Y1I - CR*Y1R )*W + CR*Y1I + CI*Y1R )*W*UE   HYMN6900
     0    IAI = H1I - DG20I + ERCON*G20R - EICON*G20I                    HYMN6910
     1              - ( ( CR*Y1I + CI*Y1R )*W + CR*Y1R - CI*Y1I )*W*UE   HYMN6920
          IBR = H2R + DG21R + ERCON*G21I + EICON*G21R + TEMP*( CI-W*CR ) HYMN6930
          IBI = H2I + DG21I - ERCON*G21R + EICON*G21I - TEMP*( CR+W*CI ) HYMN6940
C                                                                        HYMN6950
          HTD = IBR*IBR + IBI*IBI                                        HYMN6960
          HTR = ( IAR*IBR + IAI*IBI ) / HTD                              HYMN6970
          HTI = ( IAI*IBR - IAR*IBI ) / HTD                              HYMN6980
C                                                                        HYMN6990
          THTR(IW) = HTR                                                 HYMN7000
          THTI(IW) = HTI                                                 HYMN7010
C                                                                        HYMN7020
      IF ( .NOT. CKOUT )     GO TO 820                                   HYMN7030
      WRITE (6,150)                                                      HYMN7040
      WRITE (6,160)  U  ,  IAR,  IAI ,  IBR ,  IBI , ERCON, EICON,       HYMN7050
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     1              G20R, G21R, DG20R, DG21R,  H1R ,  H2R ,  CR  ,      HYMN7060
     2              G20I, G21I, DG20I, DG21I,  H1I ,  H2I ,  CI         HYMN7070
C                                                                       HYMN7080
  820    CONTINUE                                                       HYMN7090
C                          END  OF  W-LOOP                              HYMN7100
C***********************************************************************HYMN7110
C                                                                       HYMN7120
      KER = NW                                                          HYMN7130
      XOUT(9) = XNW                                                     HYMN7140
C                                                                       HYMN7150
      IF ( HRUN )     GO TO 850                                         HYMN7160
C                                                                       HYMN7170
      DO 830 IW = 1, NW                                                 HYMN7180
         XOUT(IW+ 9) = WC (IW)                                          HYMN7190
         XOUT(IW+39) = THR(IW)                                          HYMN7200
         XOUT(IW+69) = THI(IW)                                          HYMN7210
  830    CONTINUE                                                       HYMN7220
      GO TO (880,840),  KOUT                                            HYMN7230
  840 IF ( CKOUT )     CALL PAGE  ( 70 )                                HYMN7240
      WRITE (6,40)                                                      HYMN7250
      WRITE (6,50)  ( WC(I), THR(I), THI(I),  I = 1, NW  )              HYMN7260
      GO TO 880                                                         HYMN7270
C                                                                       HYMN7280
  850 DO 860 IW = 1, NW                                                 HYMN7290
         XOUT(IW+ 9) = WC (IW)                                          HYMN7300
         XOUT(IW+39) = THTR(IW)                                         HYMN7310
         XOUT(IW+69) = THTI(IW)                                         HYMN7320
  860    CONTINUE                                                       HYMN7330
      GO TO (880,870),  KOUT                                            HYMN7340
  870 IF ( CKOUT )     CALL PAGE  ( 70 )                                HYMN7350
      WRITE (6,40)                                                      HYMN7360
      WRITE (6,60)  ( WC(I), THR(I), THI(I), THTR(I), THTI(I),          HYMN7370
     1                I = 1, NW  )                                      HYMN7380
C                                                                       HYMN7390
  880 IF ( .NOT. CKOUT )      GO TO 890                                 HYMN7400
      CALL  PAGE ( 70 )                                                 HYMN7410
      WRITE (6,120)  ( ZZ(I), U(I), DU(I), UL(I), RHO(I), RHOL(I),      HYMN7420
     1  QBAR(I), ZIP3(I), ZIP5(I),  I = 1, IDZP )                       HYMN7430
      IF  ( .NOT. HRUN )     GO TO 890                                  HYMN7440
      CALL  PAGE ( 70 )                                                 HYMN7450
      WRITE (6,130)                                                     HYMN7460
      WRITE (6,140)  ( ZZ(I),D2U(I),DUL(I),DRHO(I),DROL(I),DQ(I),V1(I), HYMN7470
     1    V2(I),  I = 1, IDZP )                                         HYMN7480
C                                                                       HYMN7490
C                                                                       HYMN7500
C                                                                       HYMN7510
C     N.B.  HTR, HTI  ARE FINAL RESULTS OF THIS SUBROUTINE WHEN PLACED  HYMN7520
C           IN XOUT.   HTR, HTI INCLUDE INJECTOR EFFECTS, WHILE  HR, HI HYMN7530
C           DO NOT.  HENCE IF SUBROUTINE  DDD  IS ENTERED WITH HTR, HTI,HYMN7540
C           DDD  WILL EXPAND TABLE (BY INTERPOLATION), PRINT,           HYMN7550
C           AND RETURN.                                                 HYMN7560
C                                                                       HYMN7570
C                                                                       HYMN7580
C                                                                       HYMN7590
  890 RETURN                                                            HYMN7600
            END                                                         HYMN7610
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@ ELT SUB10,1,690702, 36302

      SUBROUTINE DDD(DIN,DOUT,CD,NER,ERR)                               HTNT  10
C                                                                       HTNT  20
C     PROGRAM  D  COMPUTE HTR,HTI + INTERPOLATE 40 POINTS               HTNT  30
C           20 SEP 67  MODIFIED FOR TABULAR INJECTOR COEFFICIENTS       HTNT  40
C                                                                       HTNT  50
      LOGICAL LOGIK,HRUN,TABLR                                          HTNT  60
      COMMON /PROLOG/ LOGIK(50)                                         HTNT  70
      COMMON  /ABCDF /  EXTRA(100),  ABLOK(600), A    , B , SPACE(3556), HTNT  80
     1          WIT(17), AVN(17), BVN(17),CVNR(17), CVNI(17)            HTNT  90
      DIMENSION DIN(1),DOUT(1),A(133),B(133),OMEGA(1),HR(1),HI(1)       HTNT 100
     1,HTR(30),HTI(30),HTRINT(1),HTIINT(1), OMGA(1)                     HTNT 110
     2,DOM(30)                                                          HTNT 120
      EQUIVALENCE (LOGIK(8),HRUN),(LOGIK(17),TABLR)                     HTNT 130
      EQUIVALENCE (A(1),ANH),(A(2),BNH),(A(3),CNHRE),(A(4),CNHIM),      HTNT 140
     1(A(5),GAMMA),(A(6),XLRN),(A(7),XLON),(A(9),XNW),(A(10),OMEGA),    HTNT 150
     2(A(40),HR),(A(70),HI),(B(9),ONW),(B(10),OMGA),(B(51),HTRINT),     HTNT 160
     3(B(92),HTIINT) ,  ( OMEGA, DOM )                                  HTNT 170
C                                                                       HTNT 180
   10 FORMAT ( 21H0 INPUT TO PROGRAM  D // 10X8H GAMMA = F8.4,5X6HLR/N =HTNT 190
     1  F12.8, 5X6HLT/N = F12.8 )                                       HTNT 200
   20 FORMAT ( 18X3HANH12X3HBNH11X6HCNH RE 9X6HCNH IM // 9X 4F15.7 // ) HTNT 210
   30 FORMAT ( // 38H INJECTOR DISTRIBUTION COEFFICIENTS... //          HTNT 220
     117X5HOMEGA 11X3HANH 12X3HBNH 11X6HCNH RE 9X6HCNH IM // (9X5F15.7))HTNT 230
   40 FORMAT (1H0, 19X,8HOMEGA(C),9X3H HR,13X3H HI  )                   HTNT 240
   50 FORMAT (1H0,19X, 8HOMEGA(C),9X3HHTR 13X3HHTI )                    HTNT 250
   60 FORMAT(1H ,10X,3F16.6)                                            HTNT 260
   70 FORMAT (1H0 ,20H PROGRAM  D  OUTPUT  // 19X,8HOMEGA(C) 9X         HTNT 270
     16H   HTR ,10X,6H   HTI  // )                                      HTNT 280
   80 FORMAT (91H0ALL VALUES OF HTR ARE NEGATIVE- ( I.E. OUT OF RANGE OFHTNT 290
     1INTEREST- WILL PROCEED TO NEXT CASE))                             HTNT 300
   90 FORMAT(//,30X,69H   FOLLOWING WILL BE INTERPOLATION WITHIN HTR HTIHTNT 310
     1 TABLE GIVEN ABOVE   )                                            HTNT 320
  100 FORMAT (19X,8H OMEGA  ,9X6HHTRINT,10X,6HHTIINT  )                 HTNT 330
  110 FORMAT (11X,F10.5,10X,F10.5,10X,F10.5)                            HTNT 340
C                                                                       HTNT 350
      ERR=0.0                                                           HTNT 360
      C=0.0                                                             HTNT 370
      CALL DVCHK (K000FX)                                               HTNT 380
  120 DO 130 I=1,133                                                    HTNT 390
      A(I)= DIN(I)                                                      HTNT 400
  130 B(I)=0.0                                                          HTNT 410
      NER=IFIX(XNW)                                                     HTNT 420
      IF(NER)140,140,160                                                HTNT 430
  140 WRITE (6,150)NER                                                  HTNT 440
  150 FORMAT (1H0,10X,31H NUMBER OF OMEGAS IN ERROR  =  ,3X,I4   )      HTNT 450
      GO TO 510                                                         HTNT 460
  160 IF(NER-29)170,170,140                                             HTNT 470
  170 ONW = 40.0                                                        HTNT 480
      IF ( HRUN )            GO TO 190                                  HTNT 490
      NWI = A(8) + 0.01                                                 HTNT 500
      IF ( NWI .GT. 2 )      GO TO 180                                  HTNT 510
      ASSIGN 280 TO  NT                                                 HTNT 520
      TABLR = .FALSE.                                                   HTNT 530
      ANH = AVN (1)                                                     HTNT 540
      BNH = BVN (1)                                                     HTNT 550
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000056          CNHRE = CVNR(1)                                          HTNT 560
000057          CNHIM = CVNI(1)                                          HTNT 570
000058          GO TO 190                                                HTNT 580
000059      180 ASSIGN 270 TO  NT                                        HTNT 590
000060          TABLR = .TRUE.                                           HTNT 600
000061      190 IF(CD-99.0)260,260,200                                   HTNT 610
000062      200 CALL  PAGE  ( 60 )                                       HTNT 620
000063          WRITE (6,10)  GAMMA, XLRN, XLON                          HTNT 630
000064          IF ( HRUN  )            GO TO 230                        HTNT 640
000065          IF ( TABLR )            GO TO 210                        HTNT 650
000066          WRITE (6,20)  ANH, BNH, CNHRE, CNHIM                     HTNT 660
000067          GO TO 220                                                HTNT 670
000068      210 WRITE (6,30)  ( WIT(I), AVN(I), BVN(I), CVNR(I), CVNI(I), HTNT 680
000069         1                I = 1, NWI )                             HTNT 690
000070      220 WRITE (6,40)                                             HTNT 700
000071          GO TO 240                                                HTNT 710
000072      230 WRITE (6,50)                                             HTNT 720
000073      240 DO 250 I = 1,NER                                         HTNT 730
000074      250 WRITE (6,60)OMEGA(I),HR(I),HI(I)                         HTNT 740
000075    C                                                              HTNT 750
000076      260 IF ( HRUN )             GO TO 350                        HTNT 760
000077          DO 340 I=1,NER                                           HTNT 770
000078          W = OMEGA(I)                                             HTNT 780
000079          GO TO NT,(270,280)                                       HTNT 790
000080      270 CALL  INT4  ( WIT, AVN , W, ANH   )                      HTNT 800
000081          CALL  INT4  ( WIT, BVN , W, BNH   )                      HTNT 810
000082          CALL  INT4  ( WIT, CVNR, W, CNHRE )                      HTNT 820
000083          CALL  INT4  ( WIT, CVNI, W, CNHIM )                      HTNT 830
000084      280 DEN = GAMMA*W                                            HTNT 840
000085          X = ANH - CNHIM/DEN*XLON                                 HTNT 850
000086          Y = BNH / DEN * XLRN + CNHRE * XLON / DEN                HTNT 860
000087          SQD = X * X + Y * Y                                      HTNT 870
000088          HTR(I) = (X * HR(I) + Y * HI(I) ) /SQD                   HTNT 880
000089          HTI(I) = (X * HI(I) - Y * HR(I) ) / SQD                  HTNT 890
000090          CALL DVCHK (K000FX)                                      HTNT 900
000091           GO TO (310,290),K000FX                                  HTNT 910
000092      290 IF (CD-10.0) 340,300,300                                 HTNT 920
000093      300 IF (I-1) 330,320,330                                     HTNT 930
000094      310 C=10.0                                                   HTNT 940
000095      320 LIN=NER+6                                                HTNT 950
000096          CALL PAGE (LIN)                                          HTNT 960
000097          WRITE (6,70)                                             HTNT 970
000098      330 WRITE (6,60)DOM(I),HTR(I),HTI(I)                         HTNT 980
000099      340 CONTINUE                                                 HTNT 990
000100          GO TO 370                                                HTNT1000
000101    C                                                              HTNT1010
000102      350 DO 360 I = 1,NER                                         HTNT1020
000103          HTI(I) = HI(I)                                           HTNT1030
000104      360 HTR(I) = HR(I)                                           HTNT1040
000105      370 JOMEG1 = 0                                               HTNT1050
000106          JOMEG2=0                                                 HTNT1060
000107          IF ( CD .LE. 99.0 )      CALL  PAGE  (60)                HTNT1065
000108          DO 390 I =1,NER                                          HTNT1070
000109          IF (HTR(I)) 390,390,380                                  HTNT1080
000110      380 JOMEG1 = 1                                               HTNT1090
000111          GO TO 410                                                HTNT1100
000112      390 CONTINUE                                                 HTNT1110
000113          IF (JOMEG1)400,400,410                                   HTNT1120
000114      400 WRITE (6,80)                                             HTNT1130
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000115          ERR= -1.0                                                HTNT1140
000116          GO TO 520                                                HTNT1150
000117      410 DO 430 J =I,NER                                          HTNT1160
000118          IF (HTR(J)) 420,430,430                                  HTNT1170
000119      420 JOMEG2 = J                                               HTNT1180
000120          GO TO 440                                                HTNT1190
000121      430 CONTINUE                                                 HTNT1200
000122          JOMEG2 =NER                                              HTNT1210
000123      440 DLTMEG = (DOM(JOMEG2) -DOM(JOMEG1))/ 39.0                HTNT1220
000124          L=NER+1                                                  HTNT1230
000125          HTI(L)=0.0                                               HTNT1240
000126          HTR(L)=0.0                                               HTNT1250
000127          DOM(L)=0.0                                               HTNT1260
000128          OMGA(1) =DOM(JOMEG1)                                     HTNT1270
000129          DO 490 I=1,40                                            HTNT1280
000130          CALL INT4 (DOM(1),HTR(1),OMGA(I),HTRINT(I) )             HTNT1290
000131          CALL INT4 (DOM(1),HTI(1),OMGA(I),HTIINT(I) )             HTNT1300
000132          IF (CD-10.0)480,450,450                                  HTNT1310
000133      450 IF ( I-1 )   470,460,470                                 HTNT1320
000134      460 IF ( .NOT. HRUN )    CALL  PAGE  ( 60 )                  HTNT1330
000135          WRITE (6,90)                                             HTNT1340
000136          WRITE (6,100)                                            HTNT1350
000137      470 WRITE (6,60) OMGA(I),HTRINT(I),HTIINT(I)                 HTNT1360
000138      480 OMGA(I+1) = OMGA(I) + DLTMEG                             HTNT1370
000139      490 CONTINUE                                                 HTNT1380
000140          DO 500 I=1,133                                           HTNT1390
000141      500 DOUT (I) = B(I)                                          HTNT1400
000142          IF(C) 510,520,510                                        HTNT1410
000143      510 NER=0                                                    HTNT1420
000144      520 RETURN                                                   HTNT1430
000145          END
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@ ELT SUB11,1,691029, 50059

      SUBROUTINE CCC(DIN,DOUT,WC,CODE,NER)                              NOZM  10
C*****************************************************************NOZM  20
C***** THIS PROGRAM WAS WRITTEN FROM A REPORT ON NOZZLE ADMITTANCE******NOZM  30
C***** THEORY FROM PRINCETON UNIVERSITY.  THE ANALYSIS WAS DONE BY******NOZM  40
C***** CARL LUNDELIUS AND THE PROGRAMMING BY JERRY HOWARD.JOB 8052******NOZM  50
C*************                                                       NOZM  60
C     NOZMIT MODIFIED 25 JUL 67  TO SUPPLY CR1,CI1 IN PLACE OF BR1,BI1. NOZM  70
C*****************************************************************NOZM  80
C                                                                     NOZM  90
      LOGICAL  LOGIK,  SL1,  SL2,  EORJ                                 NOZM 100
      COMMON  /ABCDF/  EXTRA(100),  ABLOK(600)                          NOZM 110
     1      , XX      , U2TBL   , DESIRE , RAT     , RAC     , RCC     NOZM 120
     2      , RCT     , ALFA    , G      , KN      , Y       , YP      NOZM 130
     3      , YOUT    , TEMP    , E      , XTABLE  , YTABLE  , A       NOZM 140
     4      , R       , AM      , AP     , AMP     , ZZ      , AMM     NOZM 150
     5      , AMP2    , CALFA   , CTALFA , DELAM   , DELTZ   , FKN     NOZM 160
     6      , G1      , G2      , G3     , G4      , JFLAG1  , KNM1    NOZM 170
     7      , K       , NN      , PI     , PROD    , RSTA1   , RSTA2   NOZM 180
     8      , SALFA   , T1      , T2     , T3      , XINT    , XK      NOZM 190
     9      , ZZ1     , ZZ2     , ZZ3    , A1      , ABC     , ABD     NOZM 200
      COMMON  /ABCDF/                                                   NOZM 210
     1        AI1     , ALPHAI  , ALPHAR , AR1     , B101    , B102    NOZM 220
     2      , B10     , B1      , B2     , B3      , B4      , B5      NOZM 230
     3      , B6      , B7      , B8     , B91     , B92     , B9      NOZM 240
     4      , BI1     , BR1     , C2     , C3      , CHII    , CHIR    NOZM 250
     5      , CI1     , CR1     , C      , D10     , D11     , D1      NOZM 260
     6      , D2      , D3      , D4     , D5      , D6      , D7      NOZM 270
     7      , D8      , D9      , DC2    , D       , DU2     , EI      NOZM 280
     8      , ER      , F3I     , F3R    , FI      , FR      , H1      NOZM 290
     9      , H       , I       , IWO    , IW      , IWW     , J       NOZM 300
      COMMON  /ABCDF/                                                   NOZM 310
     1        MDESIR  , NK      , NP     , S2      , S       , TT      NOZM 320
     2      , U2      , U       , W2     , W       , XI0I    , XI0R    NOZM 330
     3      , XI2I    , XI2R    , XI     , XJI     , XJR     , XMNEW   NOZM 340
     4      , XMOLD   , XNEW    , XOLD   , XPT     , X       , ZI      NOZM 350
     5      , ZR                                                      NOZM 360
      COMMON  /PROLOG/  LOGIK(50), SL1, SL2, EORJ                       NOZM 370
C                                                                     NOZM 380
      DIMENSION XX(200),U2TBL(200),XTABLE(200),YTABLE(200),ZZ(200)      NOZM 390
      DIMENSION  Y(8),YP(8),YOUT(8),TEMP(72),E(8)                       NOZM 400
      DIMENSION A(200),R(200),AM(200),AP(200),AMP(200)                  NOZM 410
      DIMENSION   DIN(1), DOUT(1),WC(1)                                 NOZM 420
C                                                                     NOZM 430
C******************************************************************* NOZM 440
C                                                                     NOZM 450
C                                                                     NOZM 460
      NER  =  0                                                         NOZM 470
C **********                                                          NOZM 480
C READ INPUT*                                                         NOZM 490
C **********                                                          NOZM 500
      G  =  DIN(1)                                                      NOZM 510
      NOMEG=WC(2)+2.0001                                                NOZM 520
      MDESIR  =  DIN(2)  +  .0001                                       NOZM 530
      GEO=DOUT(4)                                                          *NEW
      IF  (CODE)   10,20,30                                             NOZM 550**-1
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   10 NER =  1                                                          NOZM 560
   20 RETURN                                                            NOZM 570
   30 IF(WC(1))40,50,40                                                 NOZM 580
   40 WCONST=DOUT(3)/(6.2831853*DOUT(1))                                NOZM 590
      GEO=GEO/DOUT(1)                                                   NOZM 600
      GO TO 60                                                          NOZM 610
   50 WCONST=DOUT(3)/(6.2831853*DOUT(2))                                NOZM 620
      GEO=GEO/DOUT(2)                                                   NOZM 630
   60 IF(CODE-99.0)100,100,70                                           NOZM 640
C ****************                                                      NOZM 650
C PRINT OUT INPUT*                                                      NOZM 660
C ****************                                                      NOZM 670
   70 CALL PAGE(5)                                                      NOZM 680
      WRITE (6,80)                                                      NOZM 690
   80 FORMAT (1H0,75H PROGRAM  C  INPUT - CALCULATES NOZZLE ADMITTANCE  NOZM 700
     1COEFFICIENTS USING 8052   )                                       NOZM 710
      WRITE (6,90)G,  MDESIR                                            NOZM 720
   90 FORMAT (1H0,5X,3HG =,F9.3,11H , MDESIR =,I2  )                    NOZM 730
  100 CONTINUE                                                          NOZM 740
C ******************************************************************    NOZM 750
C MDESIR=1,INPUT TABLE,INPUT DESIRE  MDESIR=2,CALCULATE TABLE,INPUT*    NOZM 760
C DESIRE  MDESIR=3,CALCULATE TABLE,CALCULATE DESIRE (AT LAST POINT)*    NOZM 770
C ******************************************************************    NOZM 780
      GO TO (150,110,110),MDESIR                                        NOZM 790
  110 RAT   =  DIN(4)                                                   NOZM 800
      RAC   =  DIN(5)                                                   NOZM 810
      RCC   =  DIN(6)                                                   NOZM 820
      RCT   =  DIN(7)                                                   NOZM 830
      ALFA  =  DIN(8)                                                   NOZM 840
      KN    =  DIN(9)  +  .0001                                         NOZM 850
      IF   (CODE  -  99.0)   140,140,120                                NOZM 860
  120 CALL  PAGE (1)                                                    NOZM 870
      WRITE (6,130)RAT, RAC, RCC, RCT, ALFA, KN                         NOZM 880
  130 FORMAT  (1H ,5X5HRAT =,F7.3,6H,RAC =,F7.3,6H,RCC =,F7.3,6H,RCT =, NOZM 890
     1   F7.3, 7H,ALFA = F7.3,5H,KN = I4   )                            NOZM 900
  140 CONTINUE                                                          NOZM 910
      CALL TBLCAL                                                       NOZM 920
      KN = KN/2 + 1                                                     NOZM 930
      GO TO 190                                                         NOZM 940
C ***************************************************                    NOZM 950
C READ VELOCITY POTENTIAL TABLE. FIRST POINT IS (0,1)*                  NOZM 960
C ***************************************************                    NOZM 970
  150 J = 10                                                            NOZM 980
      DO 170 I = 1,200                                                  NOZM 990
      XX(I) =  DIN(J)                                                   NOZM1010
      U2TBL(I)  =  DIN(J+1)                                             NOZM1020
      J = J+2                                                           NOZM1030
      IF (I)  170,170,160                                               NOZM1040
  160 IF ( XX(I) )   170,180,180                                        NOZM1050
  170 CONTINUE                                                          NOZM1060
C ***********************************************                        NOZM1070
C KN = COUNT OF TOTAL NO. OF POINTS IN THE TABLE.*                      NOZM1080
C ***********************************************                        NOZM1090
  180 KN = I - 1                                                        NOZM1100
  190 IF(CODE-199.0)240,240,200                                         NOZM1110
  200 CALL PAGE(70)                                                     NOZM1120
      WRITE (6,220)                                                     NOZM1130
      KKKN=KN/2+1                                                       NOZM1140
      DO 210 I=1,KKKN                                                   NOZM1150
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      KKK=KKKN+I                                                        NOZM1160
      VOL1=SQRT(U2TBL(I))                                               NOZM1170
      VOL2=SQRT(U2TBL(KKK))                                             NOZM1180
      WRITE (6,230)I,ZZ(2*I-1),XX(I),VOL1,KKK,ZZ(2*KKK-1),XX(KKK),VOL2  NOZM1190
  210 CONTINUE                                                          NOZM1200
  220 FORMAT(//,40X, 25HVELOCITY POTENTIAL TABLE ,//,35X, 46HZ = AXIAL PNOZM1210
     1OSITION IN NOZZLE (INCHES)            ,/,35X,39HX = VELOCITY POTENNOZM1220
     2TIAL (NONDIMENSIONAL) ,/,35X, 69HV = AXIAL VELOCITY (UNDIMENSIONALNOZM1230
     3IZED BY SPEED OF SOUND AT THROAT)                                 NOZM1240
     4 ,//,5X,5HPOINT.11X,1HZ,16X,1HX,15X,1HV,16X,5HPOINT,11X,1HZ,16X,1HNOZM1250
     5X,16X,1HV,//,)                                                    NOZM1260
  230 FORMAT(6X,I3,6X,3(E12.5,5X),6X,I3,6X,2(E12.5,5X),E12.5,)          NOZM1270
  240 CONTINUE                                                          NOZM1280
C ***************************************************                   NOZM1290
C REVERSE ORDER OF TABLE VALUES AND SET UP FOR INT4D*                   NOZM1300
  250 NK = KN+1                                                         NOZM1310
      XTABLE(NK) = 0.0                                                  NOZM1320
      YTABLE(NK) = 0.0                                                  NOZM1330
      DO 260 I = 1,KN                                                   NOZM1340
      NK = NK - 1                                                       NOZM1350
      XTABLE(I) = XX(NK)                                                NOZM1360
      YTABLE(I) = U2TBL(NK)                                             NOZM1370
  260 CONTINUE                                                          NOZM1380
C                                                                       NOZM1390
C ************************                                              NOZM1400
C READ ONE CASE AT A TIME*                                              NOZM1410
C ************************                                              NOZM1420
      IWW  = 410                                                        NOZM1430
      IWO  =  2                                                         NOZM1440
      NP   = DIN(3) + .0001                                             NOZM1450
      IF   (CODE   -  99.0)  290,290,270                                NOZM1460
  270 NPR  =  NP + 3                                                    NOZM1470
      NPT  =  3 * NP  + 409                                             NOZM1480
      CALL  PAGE (NPR)                                                  NOZM1490
      WRITE (6,280)( DIN(I), I =  410, NPT  )                           NOZM1500
  280 FORMAT(1H0,39X, 6X,4H  WN,12X,6H(SNH)N,10X,4H DES //              NOZM1510
     1        (40X,3E16.6 ))                                            NOZM1520
  290 CONTINUE                                                          NOZM1530
  300 IF  (CODE -  9.0)   340,340,310                                   NOZM1540
C ******************************                                        NOZM1550
C PRINT HEADER AND OUTPUT SYMBOLS*                                      NOZM1560
C ******************************                                        NOZM1570
  310 CALL PAGE(70)                                                     NOZM1580
      KPAGE=48                                                          NOZM1590
      KCOUNT=0                                                          NOZM1600
      WRITE (6,320)                                                     NOZM1610
  320 FORMAT (1H0, 20H PROGRAM  C  OUTPUT   )                           NOZM1620
      WRITE (6,330)                                                     NOZM1630
  330 FORMAT(//4X,6H(SNH)C,5X2HWC,6X,7HMACH NO,9X,2HAR,14X,2HAI,14X,2HBRNOZM1640
     1,14X,2HBI,14X,2HCR,14X,2HCI/4X,6H(SNH)N,5X2HWN,9X,1HG,6X,13H-AR/(MNOZM1650
     2ACH NO),3X,13H-AI/(MACH NO),9X,2HT1,14X,2HT2,8X,13H-CR/(MACH NO),3NOZM1660
     3X,13H-CI/(MACH NO)//)                                             NOZM1670
  340 CONTINUE                                                          NOZM1680
      DO 660 IW =  1,NP                                                 NOZM1690
      W  =   DIN(IWW)                                                   NOZM1700
      S  =   DIN(IWW+1)                                                 NOZM1710
      GO  TO (350,350,360), MDESIR                                      NOZM1720
  350 DESIRE   =  DIN(IWW+2)                                            NOZM1730
  360 IWW =  IWW + 3                                                    NOZM1740
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C                                                                       NOZM1750
      XMOLD=0.0                                                         NOZM1760
      XMNEW=0.0                                                         NOZM1770
      XOLD=0.0                                                          NOZM1780
      XPT = 0.0                                                         NOZM1790
      X = 0.0                                                           NOZM1800
      XNEW=0.0                                                          NOZM1810
      XI = -.001                                                        NOZM1820
      H=XI                                                              NOZM1830
      W2=W*W                                                            NOZM1840
      S2=S*S                                                            NOZM1850
      G2=G*G                                                            NOZM1860
C ***********************************                                   NOZM1870
C     INITIALIZE 8 EQUATIONS AT X=0.*                                   NOZM1880
C ***********************************                                   NOZM1890
      DO 370 I = 1,8                                                    NOZM1900
  370 E(I) = 1.E-05                                                     NOZM1910
      I = 0                                                             NOZM1920
      CALL ADSET(8,Y,YP,YOUT,TEMP,X,H,E)
      A1=.5*(G+1.0)                                                     NOZM1940
      C2=1.0                                                            NOZM1950
      C3=(G+1.0)*(G+1.0)+4.0*W2                                         NOZM1960
      B6=A1*A1+W2                                                       NOZM1970
      B7=.25*(A1*(W2-S2)-W2*(G-1.0))/B6                                 NOZM1980
      B8=-.125*W*(G2-1.0+2.0*(W2-S2))/B6                                NOZM1990
      B91=B7*(A1*A1*A1+W2)-A1*B8*(1.0-A1*W)+.125*(G2-1.0)*(W2-S2)       NOZM2000
      B92=A1*A1*(B7*B7-B8*B6)+2.0*A1*W*B7*B6                            NOZM2010
      B9=(B91+B92)/B6                                                   NOZM2020
      B101=.5*A1*(3.0-G)*W*B7+B8*(A1*A1*A1+W2)+.125*(G-1.0)*W*(A1*A1-S2)NOZM2030
      B102=-A1*W*(B7*B7-B8*B8)+2.0*A1*A1*B7*B8                          NOZM2040
      B10=(B101+B102)/B6                                                NOZM2050
C                                                                       NOZM2060
      Y(1)=0.0                                                          NOZM2070
      Y(2)=0.0                                                          NOZM2080
      Y(3)=0.0                                                          NOZM2090
      Y(4)=0.0                                                          NOZM2100
      Y(5)=0.0                                                          NOZM2110
      Y(6)=0.0                                                          NOZM2120
      Y(7)=B7                                                           NOZM2130
      Y(8)=B8                                                           NOZM2140
C                                                                       NOZM2150
      U2=1.0                                                            NOZM2160
      U11=ATAN((B8+W)/B7)                                               NOZM2170
C                                                                       NOZM2180
      YP(1)=.5*C2                                                       NOZM2190
      YP(2)=0.0                                                         NOZM2200
      YP(3)=.5*(G+1.0)*(G+1.0)/(C2*C3)                                  NOZM2210
      YP(4)=-W*(G+1.0)/(C2*C3)                                          NOZM2220
      YP(5)=(G+1.0)*(G+1.0)*S2*C2**(1.0/(G-1.0))/(4.0*C3)               NOZM2230
      YP(6)=-.5*W*(G+1.0)*S2*C2**(1.0/(G-1.0))/C3                       NOZM2240
      YP(7)=-B9                                                         NOZM2250
      YP(8)=-B10                                                        NOZM2260
380   CALL ADINT
C ****************************************                              NOZM2280
C INTERPOLATING ON VELOCITY POTENTIAL TABLE*                            NOZM2290
C ****************************************                              NOZM2300
  390 CALL INT4D(XTABLE(1),YTABLE(1),X,U2,DU2)                          NOZM2310
      C2=.5*(G+1.0-U2*(G-1.0))                                          NOZM2320
      C=SQRT(C2)                                                        NOZM2330
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      U=SQRT(U2)                                                        NOZM2340
      DC2=-.5*(G-1.0)*DU2                                               NOZM2350
C ***************************************************************       NOZM2360
C SINGULARITY AT THROAT-FAKE EQUATIONS 7 AND 8 UNTIL PAST*              NOZM2370
C ***************************************************************       NOZM2380
      IF(X-XI)400,400,410                                               NOZM2390
  400 B1=U2*(C2-U2)                                                     NOZM2400
      B2=A1*U2*DU2/C2                                                   NOZM2410
      B3=W*U2                                                           NOZM2420
      B4=.25*(W2-U*C2**(G/(G-1.0))*S2)                                  NOZM2430
      B5=.25*((G-1.0)*U2*DU2*W)/C2                                      NOZM2440
C                                                                       NOZM2450
      ABD=Y(7)*Y(7)-Y( 8)*Y( 8)                                         NOZM2460
      YP(7)=(B2*Y(7)-B3*Y( 8)-B4)/B1-ABD                                NOZM2470
      YP( 8)=(B3*Y(7)+B2*Y( 8)+B5)/B1-2.0*Y(7)*Y( 8)                    NOZM2480
C                                                                       NOZM2490
  410 YP(1)=.5*(DU2-W*Y(2)/U2)                                          NOZM2500
      YP(2)=.5*W*Y(1)/U2                                                NOZM2510
      D1=-Y(3)*Y(7)+Y(4)*(Y( 8)-W*(.5/U2+2.0/((G+1.0)*(1.0-U2))))       NOZM2520
      D2=S2*C2**(1.0/(G-1.0))*Y(2)/(2.0*W*U)                            NOZM2530
      D3=(-W*Y(2)/U2+DU2*(1.0+(G-1.0)*Y(1)/C2))/(2.0*C2)                NOZM2540
      YP(3)=D1+D2+D3                                                    NOZM2550
C                                                                       NOZM2560
      D4=-Y(4)*Y(7)-Y(3)*(Y( 8)-W*(.5/U2+2.0/((G+1.0)*(1.0-U2))))       NOZM2570
      D5=-S2*C2**(1.0/(G-1.0))*U*((1.0-U2)/(2.0*U2)+Y(1)/U2)/(2.0*W)    NOZM2580
      D6=(W*Y(1)/U2+DU2*(G-1.0)*Y(2)/C2)/(2.0*C2)                       NOZM2590
      YP(4)=D4+D5+D6                                                    NOZM2600
C                                                                       NOZM2610
      D7=S2*C2**(1.0/(G-1.0))/(4.0*U)-Y(5)*Y(7)                         NOZM2620
      D8=Y(6)*(Y( 8)-W*(.5/U2+2.0/((G+1.0)*(1.0-U2))))                  NOZM2630
      YP(5)=D7+D8                                                       NOZM2640
C                                                                       NOZM2650
      ABC=-Y(6)*Y(7)                                                    NOZM2660
      YP(6)=ABC-Y(5)*(Y( 8)-W*(.5/U2+2.0/((G+1.0)*(1.0-U2))))           NOZM2670
C                                                                       NOZM2680
      CALL ADCOR($390)
C                                                                       NOZM2700
  420 XMNEW=U/C                                                         NOZM2710
      XNEW=X                                                            NOZM2720
C                                                                       NOZM2730
      IF(XMNEW-DESIRE)430,500,440                                       NOZM2740
C ***************************************************************       NOZM2750
C IF OUR CALCULATED MACH NUMBER IS CLOSE ENOUGH TO DESIRE WE WILL STOP* NOZM2760
C ***************************************************************       NOZM2770
  430 IF(ABS(XMNEW-DESIRE)-1.E-5)500,500,470                            NOZM2780
  440 IF(X+H-XX(KN))450,460,460                                         NOZM2790
  450 XNEW = XX(KN)                                                     NOZM2800
      GO TO 500                                                         NOZM2810
  460 XMOLD = XMNEW                                                     NOZM2820
      XOLD=XNEW                                                         NOZM2830
      GO TO 380                                                         NOZM2840
C ***************************************************************       NOZM2850
C PASSED DESIRED MACH NUMBER                                    *       NOZM2860
C LINEAR INTERPOLATION TO GET X CORRESPONDING TO DESIRED MACH*          NOZM2870
C ***************************************************************       NOZM2880
  470 XPT=XOLD+(XNEW-XOLD)/(XMNEW-XMOLD)*(DESIRE-XMOLD)                 NOZM2890
      XOLD = XNEW                                                       NOZM2900
      XMOLD = XMNEW                                                     NOZM2910
      XNEW = XPT                                                        NOZM2920
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      CALL INT4(XTABLE(1),YTABLE(1),XNEW,U2)                            NOZM2930
      C2 = .5*(G+1.0-U2*(G-1.0))                                        NOZM2940
      C = SQRT(C2)                                                      NOZM2950
      U = SQRT(U2)                                                      NOZM2960
      XMNEW = U/C                                                       NOZM2970
      I = I+1                                                           NOZM2980
      IF(I-15)430,460,480                                               NOZM2990
  480 WRITE (6,490)                                                     NOZM3000
  490 FORMAT(72H0 ITERATION SCHEME DOES NOT CONVERGE AFTER 10 ITERATIONSNOZM3010
     1, SEE PROGRAMMER)                                                 NOZM3020
      GO TO 10                                                          NOZM3030
500   CALL ADPAR(XNEW)
C                                                                       NOZM3050
C                                                                       NOZM3060
C ***************************************************                   NOZM3070
C COMPUTE ADMITTANCE COEFFICIENTS AND PRINT FINAL RESULTS*              NOZM3080
C ***************************************************                   NOZM3090
  510 CALL INT4D (XTABLE(1),YTABLE(1),XNEW,U2,DU2)                      NOZM3100
  520 C2=.5*(G+1.0-U2*(G-1.0))                                          NOZM3110
      C=SQRT(C2)                                                        NOZM3120
      U=SQRT(U2)                                                        NOZM3130
C                                                                       NOZM3140
      DC2=-.5*(G-1.0)*DU2                                               NOZM3150
      D=SQRT(2.0/(G+1.0))*U*C2/((C2/(.5*(G+1.0)))**(1.0*G/(G-1.0)))     NOZM3160
      D9=(1.0-U2)*(G+1.0)                                               NOZM3170
      F3R=YOUT(1)/C2                                                    NOZM3180
      F3I=YOUT(2)/C2                                                    NOZM3190
      XI2R=2.0*YOUT(3)/D9                                               NOZM3200
      XI2I=2.0*YOUT(4)/D9                                               NOZM3210
      XI0R=2.0*YOUT(5)/D9                                               NOZM3220
      XI0I=2.0*YOUT(6)/D9                                               NOZM3230
      ZR=YOUT(7)                                                        NOZM3240
      ZI=YOUT( 8)                                                       NOZM3250
      ER=C2*XI0R-ZR                                                     NOZM3260
      EI=C2*XI0I-ZI                                                     NOZM3270
      FR=U2*C2*XI0R-ZR*U2                                               NOZM3280
      FI=U2*C2*XI0I-ZI*U2-.5*W                                          NOZM3290
      D10=FR*FR+FI*FI                                                   NOZM3300
      AR1= D*(ER*FR+EI*FI)/D10                                          NOZM3310
      AI1= D*(EI*FR-ER*FI)/D10                                          NOZM3320
      IF(S)540,530,540                                                  NOZM3330
  530 G1=W*C2*SQRT(U/(C2**(1.0/(G-1.0))))                               NOZM3340
      GO TO 550                                                         NOZM3350
  540 G1=W*C2*SQRT(U/(C2**(1.0/(G-1.0))))/S                             NOZM3360
  550 BR1= G1*(-FR*XI0I+FI*XI0R)/D10                                    NOZM3370
      BI1= G1*(FR*XI0R+FI*XI0I)/D10                                     NOZM3380
      H1=U*C2*SQRT(2.0/(G+1.0))                                         NOZM3390
      XJR=F3R*ZR-F3I*ZI+.5*(1.0-U2)*XI0R+.5*W*XI2I                      NOZM3400
      XJI=F3I*ZR+F3R*ZI+.5*(1.0-U2)*XI0I-.5*W*XI2R                      NOZM3410
      CR1 = H1*(XJR*FR+XJI*FI)/D10                                      NOZM3420
      CI1 = H1*(XJI*FR-XJR*FI)/D10                                      NOZM3430
C                                                                       NOZM3440
  560 ALPHAR = -AR1/DESIRE                                              NOZM3450
      ALPHAI = -AI1/DESIRE                                              NOZM3460
      CHIR = -CR1/DESIRE                                                NOZM3470
      CHII = -CI1/DESIRE                                                NOZM3480
      TT = (W/(S*SQRT(.5*(G+1.0))))/SQRT(U*(.5*(G+1.0)-U2*(G-1.0)/2.0)**NOZM3490
     1( 1.0/(G-1.0)))                                                   NOZM3500
      T1 = AR1*TT - BI1                                                 NOZM3510
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      T2 = AI1*TT + BR1                                                 NOZM3520
C                                                                       NOZM3530
C ***************************                                           NOZM3540
C  CASE IS COMPLETED                                                    NOZM3550
C ***************************                                           NOZM3560
C                                                                       NOZM3570
C  FOR S=0  ADM COEF ARE ALPHA FOR 8005  LONGITUDINAL                   NOZM3580
C                                                                       NOZM3590
C  FOR S=N  ADM COEF ARE  T    FOR  993  TRANSVERSE                     NOZM3600
C                                                                       NOZM3610
      IF(S)580,570,580                                                  NOZM3620
  570 DOUT(IWO+1)=ALPHAR                                                NOZM3630
      DOUT(IWO+101)=ALPHAI                                              NOZM3640
      DOUT(IWO)=W/GEO                                                   NOZM3650
      DOUT(IWO+100)=W/GEO                                               NOZM3660
      GO TO 590                                                         NOZM3670
  580 CONTINUE                                                          NOZM3680
      DOUT(IW+19)=W/GEO                                                 NOZM3690
      DOUT(IW+49)=T1                                                    NOZM3700
      DOUT(IW+79)=T2                                                    NOZM3710
      DOUT(IW+109) = CR1                                                NOZM3720
      DOUT(IW+139) = CI1                                                NOZM3730
  590 IWO =IWO+2                                                        NOZM3740
      IF  ( CODE  -  9.0)    660,660,600                                NOZM3750
  600 CONTINUE                                                          NOZM3760
      KKKN=(2*IW)+1                                                     NOZM3770
      IF(NOMEG-KKKN)610,620,620                                         NOZM3780
  610 KKKN=KKKN-1                                                       NOZM3790
  620 KCOUNT=KCOUNT+4                                                   NOZM3800
      IF(KCOUNT-KPAGE)640,640,630                                       NOZM3810
  630 CALL PAGE(70)                                                     NOZM3820
      WRITE (6,330)                                                     NOZM3830
      KCOUNT=0                                                          NOZM3840
      KPAGE=48                                                          NOZM3850
C ********************                                                  NOZM3860
C PRINT FINAL RESULTS*                                                  NOZM3870
C ********************                                                  NOZM3880
  640 WRITE (6,650)WC(1),WC(KKKN),DESIRE,AR1,AI1,BR1,BI1,CR1,CI1,S,W,G,ANOZM3890
     1LPHAR,ALPHAI,T1,T2,CHIR,CHII                                      NOZM3900
  650 FORMAT(2(3X,F7.4,2X,F7.4,3X,F7.4,6E16.5/))                        NOZM3910
      FCCPS=(WCONST*WC(KKKN))*12.0                                      NOZM3920
      WRITE (6,670)FCCPS                                                NOZM3930
  660 CONTINUE                                                          NOZM3940
  670 FORMAT(4X,8HFC(CPS)=F10.4//)                                      NOZM3950
      DOUT(205)=DESIRE                                                  NOZM3960
      IF(S) 690,680,690                                                 NOZM3970
  680 DOUT(1)=NP                                                        NOZM3980
      DOUT(101)=NP                                                      NOZM3990
      RETURN                                                            NOZM4000
  690 DOUT(18)=NP                                                       NOZM4010
      DOUT(NP+21)=0.0                                                   NOZM4020
      DOUT(NP+51)=0.0                                                   NOZM4030
      DOUT(NP+81)=0.0                                                   NOZM4040
      DOUT(NP+111)=0.0                                                  NOZM4050
      DOUT(NP+141)=0.0                                                  NOZM4060
      RETURN                                                            NOZM4070
      END                                                               NOZM4080
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@ ELT SUB12,1,690702, 36309

      SUBROUTINE TBLCAL                                                 VELP  10
C TBLCAL SUBROUTINE CALCULATES XX VS U2TBL FROM NOZZLE GEOMETRY        *VELP  20
C SIMPSONS RULE IS USED WITH KN INPUT ODD AND CHANGED TO KN/2+1 IN MAIN*VELP  30
C                                                                       VELP  40
      LOGICAL  LOGIK,  SL1,  SL2,  EORJ                                 VELP  50
      COMMON  /PROLOG/  LOGIK(50), SL1, SL2, EORJ                       VELP  60
C                                                                       VELP  70
      COMMON  /ABCDF/  EXTRA(100),  ABLOK(600)                          VELP  80
     1      ,  XX      , U2TBL   , DESIRE , RAT     , RAC     , RCC     VELP  90
     2      ,  RCT     , ALFA    , G      , KN      , Y       , YP      VELP 100
     3      ,  YOUT    , TEMP    , E      , XTABLE  , YTABLE  , A       VELP 110
     4      ,  R       , AM      , AP     , AMP     , ZZ      , AMM     VELP 120
     5      ,  AMP2    , CALFA   , CTALFA , DELAM   , DELTZ   , FKN     VELP 130
     6      ,  G1      , G2      , G3     , G4      , JFLAG1  , KNM1    VELP 140
     7      ,  K       . NN      , PI     . PROD    , RSTA1   , RSTA2   VELP 150
     8      ,  SALFA   , T1      , T2     , T3      , XINT    , XK      VELP 160
     9      ,  ZZ1     , ZZ2     , ZZ3    , A1      , ABC     , ABD     VELP 170
      COMMON  /ARCDF/                                                   VELP 180
     1         AI1     . ALPHAI  , ALPHAR , AR1     , B101    , B102    VELP 190
     2      ,  B10     , B1      , B2     , B3      , B4      , B5      VELP 200
     3      ,  B6      . B7      , B8     , B91     , B92     , B9      VELP 210
     4      ,  BI1     , BR1     , C2     , C3      , CHII    , CHIR    VELP 220
     5      ,  CI1     , CR1     , C      . D10     , D11     , D1      VELP 230
     6      ,  D2      , D3      , D4     , D5      , D6      , D7      VELP 240
     7      ,  D8      , D9      , DC2    , D       , DU2     , EI      VELP 250
     8      ,  ER      , F3I     , F3R    , FI      , FR      , H1      VELP 260
     9      ,  H       , I       , IWO    , IW      , IWW     , J       VELP 270
      COMMON  /ABCDF/                                                   VELP 280
     1         MDESIR  , NK      , NP     , S2      , S       , TT      VELP 290
     2      ,  U2      , U       , W2     , W       , XIOI    , XIOR    VELP 300
     3      ,  XI2I    , XI2R    , XI     , XJI     , XJR     , XMNEW   VELP 310
     4      ,  XMOLD   , XNEW    , XOLD   , XPT     , X       , ZI      VELP 320
     5      ,  ZR                                                      VELP 330
C                                                                       VELP 340
      DIMENSION XX(200),U2TBL(200),XTABLE(200),YTABLE(200),ZZ(200)      VELP 350
      DIMENSION  Y(8),YP(8),YOUT(8),TEMP(72),E(8)                       VELP 360
      DIMENSION A(200),R(200),AM(200),AP(200),AMP(200)                  VELP 370
C                                                                       VELP 380
C                                                                       VELP 390
      FKN = KN                                                          VELP 400
      KNM1 = KN - 1                                                     VELP 410
      DELAM = 1.0/(FKN+1.0)                                             VELP 420
      PI = 3.1415927                                                    VELP 430
      ZZ(1)= 0.0                                                        VELP 440
C                                                                       VELP 450
      DO 10 J = 1,200                                                   VELP 460
      ZZ(J) = 0.0                                                       VELP 470
      A(J) = 0.0                                                        VELP 480
      R(J) = 0.0                                                        VELP 490
      AMP(J) = 0.0                                                      VELP 500
      AM(J) = 0.0                                                       VELP 510
      XX(J) = 0.0                                                       VELP 520
      U2TBL(J) = 0.0                                                    VELP 530
   10 AP(J) = 0.0                                                       VELP 540
C                                                                       VELP 550
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```
      R(1)= RAT                                                         VELP 560
      A(1)=PI*R(1)**2                                                   VELP 570
      U2TBL(1)=1.0                                                      VELP 580
      R(KN) = RAC                                                       VELP 590
      ALFA = ALFA*.01745329                                             VELP 600
      CALFA=COS(ALFA)                                                   VELP 610
      SALFA=SIN(ALFA)                                                   VELP 620
      CTALFA=CALFA/SALFA                                                VELP 630
      RSTA1=RAT+RCT*(1.0-CALFA)                                         VELP 640
      RSTA2=RAC-RCC*(1.0-CALFA)                                         VELP 650
      ZZ1=RCT*SALFA                                                     VELP 660
      ZZ2=ZZ1+CTALFA*(RSTA2-RSTA1)                                      VELP 670
      ZZ3=ZZ2+RCC*SALFA                                                 VELP 680
      DELTZ = ZZ3/(FKN-1.0)                                             VELP 690
C                                                                       VELP 700
      JFLAG1=1                                                          VELP 710
C                                                                       VELP 720
      DO 80 I = 2,KNM1                                                  VELP 730
      ZZ(I) = ZZ(I-1) + DELTZ                                           VELP 740
      GO TO (20,40,60),JFLAG1                                           VELP 750
   20 R(I)=RAT+RCT-SQRT(RCT**2-ZZ(I)**2)                                VELP 760
      IF(R(I)-RSTA1)70,70,30                                            VELP 770
   30 JFLAG1=2                                                          VELP 780
   40 R(I)=RSTA1+(RSTA2-RSTA1)*(ZZ(I)-ZZ1)/(ZZ2-ZZ1)                    VELP 790
      IF(R(I) - RSTA2)70,70,50                                          VELP 800
   50 JFLAG1=3                                                          VELP 810
   60 R(I)=RAC-RCC+SQRT(RCC**2-(ZZ3-ZZ(I))**2)                          VELP 820
   70 A(I)=PI*R(I)**2                                                   VELP 830
   80 CONTINUE                                                          VELP 840
C                                                                       VELP 850
      ZZ(KN) = ZZ(KNM1) + DELTZ                                         VELP 860
      A(KN) = PI*RAC**2                                                 VELP 870
      AMM = 1.0+ DELAM                                                  VELP 880
      G1=2.0/(G +1.0)                                                   VELP 890
      G2 =(G - 1.0)/2.0                                                 VELP 900
      G3 = (G + 1.0)/(2.0*G - 2.0)                                      VELP 910
      G4=1.0/G1                                                         VELP 920
C                                                                       VELP 930
      DO 90 J = 1,KN                                                    VELP 940
      AMM = AMM - DELAM                                                 VELP 950
      AM(J) = AMM                                                       VELP 960
      AP(J)=(A(1)/AMM)*(G1*(1.0+G2*AMM**2))**G3                         VELP 970
   90 CONTINUE                                                          VELP 980
C                                                                       VELP 990
      DO 100 K = 2,KN                                                   VELP1000
      CALL INT4(AP(1),AM(1),A(K),AMP(K))                                VELP1010
      AMP2=AMP(K)**2                                                    VELP1020
      U2TBL(K)=(G4*AMP2)/(1.0+G2*AMP2)                                  VELP1030
  100 CONTINUE                                                          VELP1040
C                                                                       VELP1050
      DESIRE = AMP(KN)                                                  VELP1060
      XINT = 0.0                                                        VELP1070
      NN = KN - 2                                                       VELP1080
      K = 1                                                             VELP1090
      XK = SQRT(G1*RAT/RCT)                                             VELP1100
      PROD = 2.0*XK*DELTZ/3.0                                           VELP1110
      DO 110 J = 1,NN,2                                                 VELP1120
      T1 = SQRT(U2TBL(J))                                               VELP1130
      T2 = SQRT(U2TBL(J+1))                                             VELP1140
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      T3 = SQRT(U2TBL(J+2))                                    VELP1150
      XINT = XINT + PROD*(T1+4.0*T2+T3)                        VELP1160
      K = K + 1                                                VELP1170
      XX(K) = -XINT/RAT                                        VELP1180
      U2TBL(K-1) = U2TBL(J)                                    VELP1190
  110 CONTINUE                                                 VELP1200
      U2TBL(K) = U2TBL(KN)                                     VELP1210
C*********                                                     VELP1220
      RETURN                                                   VELP1230
      END                                                      VELP1240
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@ ELT SUB13,1,690708, 48736

      SUBROUTINE  LONGL                                                 LONG  10
C                                                                       LONG  20
      COMMON  /ABCDF /  DINP(4300)                                      LONG  30
      DIMENSION                                                         LONG  40
     1   EXTRA(100),DISTL(20),DISTM(20),AMIT(90),                       LONG  50
     2   TAB(150,3), OMG(150), ALFR(150), ALFI(150), W(27)              LONG  60
      EQUIVALENCE                                                       LONG  70
     1   (EXTRA(11),GAMMA),   (DINP(107), U1BAR ) , (EXTRA(23), W ),    LONG  80
     2   (EXTRA(14),RAC),(EXTRA(15), ELCH),(EXTRA(16),SOUND,CO),        LONG  90
     3   ( DINP(17),ULM ),( DINP(18),ZK ),                              LONG 100
     4   (EXTRA(20),ELNOZ),(EXTRA(51),DISTL),(EXTRA(71),DISTM),         LONG 110
     5   (DINP(1), EXTRA),                                              LONG 120
     6   (DINP(151),TAB,OMG),(DINP(301),ALFR),(DINP(451),ALFI),         LONG 130
     7   (DINP(601),AMIT)                                               LONG 140
C                                                                       LONG 150
C                                                                       LONG 160
   10 FORMAT (21X F7.1, 11X F10.5, 10X F10.5, 10X F10.5)                LONG 170
   20 FORMAT ( /  11X 30H RESULTS FOR LONGITUDINAL MODE //21X7HFC(CPS)  LONG 180
     1 15X5HOMEGA14X7HTAU(MS)16X1HN )                                   LONG 190
   30 FORMAT     (//8H U1BAR =,E15.8,3X,7HGAMMA =,E15.8,3X,3HK =,E15.8,3LONG 200
     1X,3HX =,E15.8,3X5HULM =E15.8 )                                    LONG 210
C                                                                       LONG 220
      CALL  PAGE  (60)                                                  LONG 230
      NINC = 10                                                         LONG 240
      EIN = 1.0E-4                                                      LONG 241
      CALL  INT4  ( DISTL(1), DISTM(1), ELCH, EDIST )                   LONG 250
      CALL  INTGR  ( 0.0, ELCH, X, NINC )                               LONG 260
31    CONTINUE                                                                *NEW
         CALL  INT4  ( DISTL(1), DISTM(1), X    , UOFX )                LONG 270
      CALL  INTGS($31,UOFX,SUMM,EIN,MINC)                                     *NEW
      XX = 1.0 - SUMM/(EDIST*ELCH)                                      LONG 290**-1
      ULO = ULM / SOUND                                                 LONG 300
      WRITE (6,30)U1BAR, GAMMA, ZK, XX, ULM                             LONG 320
      WRITE (6,20)                                                      LONG 350
      U1BAR2=U1BAR*U1BAR                                                LONG 360
      T1BAR=1.0-.5*(GAMMA-1.0)*U1BAR2                                   LONG 370
      C1BAR=SQRT(T1BAR)                                                 LONG 380
      ZETA1B=1.0/(T1BAR-GAMMA*U1BAR2*(ZK-1.0))                          LONG 390
      ASTAR=2.0*C1BAR/(C1BAR**2-U1BAR2)                                 LONG 400
C                                                                       LONG 410
   50 NOMEG = EXTRA(22) + .001                                          LONG 420
      IJ = NOMEG-1                                                      LONG 430
      KK = 1                                                            LONG 440
      IK = 5*IJ + 1                                                     LONG 450
      DO 60 J = 1, IJ                                                   LONG 460
         OMG(KK) = W(J)                                                 LONG 470
         DELT = 0.2*(W(J+1)-W(J))                                       LONG 480
         KK = KK+1                                                      LONG 490
         DO 60 I = 1, 4                                                 LONG 500
            OMG(KK) = OMG(KK-1) + DELT                                  LONG 510
            KK = KK + 1                                                 LONG 520
   60 CONTINUE                                                          LONG 530
      OMG(KK) = W(NOMEG)                                                LONG 540
      DO 70 KK = 1, IK                                                  LONG 550
         CALL  INT4  ( AMIT(1), AMIT(31), OMG(KK), ALFR(KK) )           LONG 560
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000056          CALL  INT4  ( AMIT(1), AMIT(61), OMG(KK), ALPT(KK) )          LONG 570
000057       70 CONTINUE                                                      LONG 580
000058          DO 130 I = 1, IK                                              LONG 590
000059          IF ( I .EQ. 51 .OR. I .EQ. 101 )      CALL  PAGE ( 60 )       LONG 600
000060          OMEGA=TAB(I,1)                                                LONG 610
000061          ALPRE=TAB(I,2)                                                LONG 620
000062          ALPIM=TAB(I,3)                                                LONG 630
000063          DENB=(C1BAR-U1BAR*ALPRE)**2+U1BAR2*ALPIM*ALPIM                LONG 640
000064          BRE=(C1BAR*C1BAR-U1BAR2*(ALPRE*ALPRE+ALPIM*ALPIM))/DENB       LONG 650
000065          BIM=2.0*C1BAR*U1BAR*ALPIM/DENB                                LONG 660
000066          UL=ULO-ZK*XX                                                  LONG 670
000067          ZETAL=ZETA1B*U1BAR/UL                                         LONG 680
000068          A=2.0*ZETA1B*U1BAR*GAMMA*ZK/OMEGA                             LONG 690
000069          B=T1BAR/GAMMA+U1BAR2/GAMMA                                    LONG 700
000070          C=2.0*U1BAR*C1BAR/GAMMA                                       LONG 710
000071          D=1.0+ZETAL*ZK/OMEGA                                          LONG 720
000072          PHI=OMEGA*ASTAR*(1.0-XX)                                      LONG 730
000073          THETA=2.0*OMEGA*XX                                            LONG 740
000074          SINPHI=SIN(PHI)                                               LONG 750
000075          COSPHI=COS(PHI)                                               LONG 760
000076          SINTH=SIN(THETA)                                              LONG 770
000077          COSTH=COS(THETA)                                              LONG 780
000078          CR=1.0+BRE*COSPHI-BIM*SINPHI                                  LONG 790
000079          CI=BIM*COSPHI+BRE*SINPHI                                      LONG 800
000080          DR=1.0-BRE*COSPHI+BIM*SINPHI                                  LONG 810
000081          DI= -BIM*COSPHI-BRE*SINPHI                                    LONG 820
000082          ER=1.0-COSTH                                                  LONG 830
000083          EI=  SINTH                                                    LONG 840
000084          FR=1.0+COSTH                                                  LONG 850
000085          FI=-SINTH                                                     LONG 860
000086          CAPI=(FR/GAMMA)*(U1BAR*CR-C1BAR*DR)-(FI/GAMMA)*(U1BAR*CI-C1BAR*DI)LONG 870
000087         1+(D*B-U1BAR*A)*(ER*CR-EI*CI)+(C1BAR*A-C*D)*(ER*DR-EI*DI)      LONG 880
000088          CAPJ=(FI/GAMMA)*(U1BAR*CR-C1BAR*DR)+(FR/GAMMA)*(U1BAR*CI-C1BAR*DI)LONG 890
000089         1+(D*B-U1BAR*A)*(ER*CI+EI*CR)+(C1BAR*A-C*D)*(ER*DI+EI*DR)      LONG 900
000090          CAPK=FR*(B*CR-C*DR)-FI*(B*CI-C*DI)                            LONG 910
000091          CAPL=FI*(B*CR-C*DR) +FR*(B*CI-C*DI)                           LONG 920
000092          DENMN=CAPK*CAPK+CAPL*CAPL                                     LONG 930
000093          CAPM=(CAPK*CAPI+CAPL*CAPJ)/DENMN                              LONG 940
000094          CAPN=(CAPK*CAPJ-CAPL*CAPI)/DENMN                              LONG 950
000095          SE=UL*GAMMA*(1.0+ZETAL-ZETA1B)                                LONG 960
000096          T=.5*(CAPM*CAPM+CAPN*CAPN)/CAPM                               LONG 970
000097          ZN=T/SE                                                       LONG 980
000098          COSOD=1.0-CAPM/T                                              LONG 990
000099          SINOD = CAPN /T                                               LONG1000
000100          OMDEL  = ATAN(SINOD/COSOD)                                    LONG1010
000101          IF (SINOD) 80,110,110                                         LONG1020
000102       80 IF (COSOD) 100,100,90                                         LONG1030
000103       90 OMDEL=6.2831853+OMDEL                                         LONG1040
000104          GO TO 120                                                     LONG1050
000105      100 OMDEL=3.1415927+OMDEL                                         LONG1060
000106          GO TO 120                                                     LONG1070
000107      110 IF (COSOD) 100,120,120                                        LONG1080
000108      120 DELTA=OMDEL/OMEGA                                             LONG1090
000109    C     NON-DIMENSIONALIZED RESULTS                                   LONG1100
000110          TAUMS = DELTA*ELCH/SOUND*83.333333                            LONG1110
000111          FREQ = OMEGA*SOUND/ELCH*12.0/6.2831853                        LONG1120
000112          WRITE (6,10)  FREQ, OMEGA, TAUMS, ZN                          LONG1130
000113      130 CONTINUE                                                      LONG1140
000114          RETURN                                                        LONG1150
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LONG1160

EVD

000115

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@ ELT SUB14,1,690702, 39148

      SUBROUTINE  FFF ( FIN, FOUT, CF, NER, W )                         NTAU  10
C*********************************************************************** NTAU  20
      DIMENSION FIN(1),FOUT(1),A(133),B(133),OMGA(1),XN(1),TAU(1),OMX(1)NTAU  30
     1,HTRINT(1),HTIINT(1)                                              NTAU  40
      DIMENSION XNNEW(41),FCCPS(41),W (1)                               NTAU  50
      COMMON  /ABCDF /  EXTRA(100),  ABLOK(600), A    , B,  XNNEW, FCCPS NTAU  60
      EQUIVALENCE (A(9),ONW),(A(10),OMGA),(A(51),HTRINT),(A(92),HTIINT),NTAU  70
     1(B(9),XNW),(B(10),OMX),(B(51),TAU),(B(92),XN)                     NTAU  80
C                                                                       NTAU  90
C                                                                       NTAU 100
      CONST=FOUT(101)                                                   NTAU 110
      XNMIN=1000.0                                                      NTAU 120
      CALL PAGE(70)                                                     NTAU 130
      CALL DVCHK (K000FX)                                               NTAU 140
   10 DO 20 I=1,133                                                     NTAU 150
      A(I) =FIN(I)                                                      NTAU 160
   20 B(I)=0.0                                                          NTAU 170
      NER=IFIX(ONW)                                                     NTAU 180
      XNW=ONW                                                           NTAU 190
      IF(CF-99.0)70,70,30                                               NTAU 200
   30 CALL PAGE (44)                                                    NTAU 210
      WRITE (6,40)                                                      NTAU 220
   40 FORMAT (1H0,50H PROGRAM  F  INPUT  SOLVE FOR N(W) AND TAU(W)      NTAU 230
     1//19X,8H(OMEGA)D,9X,6HHTRINT,10X,6HHTIINT)                        NTAU 240
      DO 50 I =1,40                                                     NTAU 250
   50 WRITE (6,60)OMGA(I),HTRINT(I), HTIINT(I)                          NTAU 260
   60 FORMAT(1H ,10X,3F16.6)                                            NTAU 270
   70 CONTINUE                                                          NTAU 280
      DO 120 I =1,40                                                    NTAU 290
      XN(I)=(HTRINT(I)*HTRINT(I) + HTIINT(I)*HTIINT(I))/(2.0*HTRINT(I)) NTAU 300
      DNOM = XN(I) - HTRINT(I)                                          NTAU 310
      CALL QUAD (DNOM,HTIINT(I),TAU(I))                                 NTAU 320
      TAU(I)=(TAU(I)*A(1)*83.333333)/(A(2)*OMGA(I))                     NTAU 330
C A(1)=L,A(2)=CO                                                        NTAU 340
      OMX(I)=OMGA(I)                                                    NTAU 350
      CALL DVCHK (K000FX)                                               NTAU 360
       GO TO (80,90),K000FX                                             NTAU 370
   80 NER=0                                                             NTAU 380
      GO TO 220                                                         NTAU 390
   90 IF(XN(I))120,120,100                                              NTAU 400
  100 IF(XN(I)-XNMIN) 110,120,120                                       NTAU 410
  110 XNMIN=XN(I)                                                       NTAU 420
      IMIN=I                                                            NTAU 430
  120 CONTINUE                                                          NTAU 440
      DO 130 I=1,100                                                    NTAU 450
  130 FOUT(I) = B(I)                                                    NTAU 460
      IF ( CF-9.0 )          180,180,140                                NTAU 470
  140 CALL PAGE (45)                                                    NTAU 480
      WRITE (6,150)                                                     NTAU 490
  150 FORMAT(1H0,20H PROGRAM  F  OUTPUT  //21X,7HFC(CPS),13X,8H(OMGA)D, NTAU 500
     113X,7HTAU(MS),16X,1HN  )                                          NTAU 510
      DO 160 I=1,40                                                     NTAU 520
      FCCPS(I)=CONST*OMX(I)                                             NTAU 530
  160 WRITE (6,170)FCCPS(I),OMX(I),TAU(I),XN(I)                         NTAU 540
  170 FORMAT(21X,F7.1 ,11X,F10.5,10X,F10.5,10X,F10.5)                   NTAU 550
```

```
000056          180 HTIINT(41) = 0.0                                          NTAU 560
000057              HTRINT(41)=0.0                                            NTAU 570
000058              XN(41)=0.0                                                NTAU 580
000059              OMX(41)=0.0                                               NTAU 590
000060              FCCPS(41)=0.0                                             NTAU 600
000061          190 FORMAT(36X,5HNMIN=,F10.5,/36X,8HTAU(MS)=,F10.5,/36X,9H(OMEGA)D=,F1NTAU 610
000062             10.5,/36X,8HFC(CPS)=,F10.1,)                               NTAU 620
000063              DO 200 I =1,40                                            NTAU 630
000064          200  CALL INT4D(OMX(1),XN(1),OMX(I),SAVNOT,XNNEW(I))          NTAU 640
000065              XNNEW(41)=0.0                                             NTAU 650
000066               CALL INT4(XNNEW(1),OMX(1),0.0,DOMMIN)                    NTAU 660
000067              FCMIN=CONST*DOMMIN                                        NTAU 670
000068              CALL INT4(FCCPS(1),HTRINT(1),FCMIN,HTR1)                  NTAU 680
000069              CALL INT4(FCCPS(1),HTIINT(1),FCMIN,HTI1)                  NTAU 690
000070              HTRMIN=(HTR1*HTR1+HTI1*HTI1)/(2.0*HTR1)                   NTAU 700
000071              DNOM=HTRMIN-HTR1                                          NTAU 710
000072              CALL QUAD(DNOM,HTI1,TAUMIN)                               NTAU 720
000073              TAUMIN=(TAUMIN*A(1)*83.333333)/(A(2)*DOMMIN)              NTAU 730
000074              CALL PAGE (8)                                             NTAU 740
000075              WRITE (6,210)                                             NTAU 750
000076          210 FORMAT(//21X,58H THE FOLLOWING ARE VALUES INTERPOLATED AT SLOPE OFNTAU 760
000077             1 N=0.0                    ,/)                             NTAU 770
000078              WRITE (6,190)HTRMIN,TAUMIN,DOMMIN,FCMIN                   NTAU 780
000079          220 RETURN                                                    NTAU 790
000080              END                                                       NTAU 800
```

```
@ ELT SUB15,1,690702, 39149

      SUBROUTINE QUAD (A,B,ANGLE)                                       QUAD  10
      IF(B) 10,50,80                                                    QUAD  20
   10 IF(A) 20,30,40                                                    QUAD  30
   20 ROTATE = 3.1415927                                                QUAD  40
      GO TO 110                                                         QUAD  50
   30 ANGLE = 4.7123890                                                 QUAD  60
      GO TO 120                                                         QUAD  70
   40 ROTATE = 6.2831853                                                QUAD  80
      GO TO 110                                                         QUAD  90
   50 IF (A) 60,70,70                                                   QUAD 100
   60 ANGLE = 3.1415927                                                 QUAD 110
      GO TO 120                                                         QUAD 120
   70 ANGLE = 0.0                                                       QUAD 130
      GO TO 120                                                         QUAD 140
   80 IF(A) 20,90,100                                                   QUAD 150
   90 ANGLE = 1.5707963                                                 QUAD 160
      GO TO 120                                                         QUAD 170
  100 ROTATE = 0.0                                                      QUAD 180
  110 ANGLE = ATAN(B/A) + ROTATE                                        QUAD 190
  120 RETURN                                                            QUAD 200
      END                                                               QUAD 210
```

```
@ ELT SUB16,1,690702, 39150

      SUBROUTINE CORE(X,N,CODE)                                          KORE  10
      DIMENSION X(1)                                                     KORE  20
      IF(CODE-500.0)40,10,10                                             KORE  30
   10 CODE=100.0                                                         KORE  40
      CALL PAGE(70)                                                      KORE  50
      WRITE (6,20)                                                       KORE  60
   20 FORMAT(10X,37HINPUT DATA DUMP FOR PROGRAM FAILIER       //)        KORE  70
      WRITE (6,30)(X(I),I=1,N)                                           KORE  80
   30 FORMAT(5X,10(F10.4,2X))                                            KORE  90
   40 RETURN                                                             KORE 100
      END                                                                KORE 110
```

```
@ ELT SUB17,1,690702, 39151

      SUBROUTINE  INJCTR                                                INJ   10
C                                                                       INJ   20
      COMMON  /PROLOG/  LOGIK(38), HEAD(12), SL1, SL2, EORJ             INJ   30
      COMMON  /JECTOR/  EJDATA( 9600)                                   INJ   40
C                                                                       INJ   50
      EQUIVALENCE  (LOGIK(5),ERUN) , (LOGIK(10),JRUN ) , (LOGIK(9),IRUN)INJ   60
      LOGICAL  LOGIK, ERUN, JRUN, SL1, SL2, EORJ, IRUN                  INJ   70
      DIMENSION  HEAD1(12)                                              INJ   80
C                                                                       INJ   90
      IF ( SL1 )              GO TO 20                                  INJ  100
      DO 10 I = 1, 9600                                                 INJ  110
   10    EJDATA(I) = 0.0                                                INJ  120
      SL1 = .TRUE.                                                      INJ  130
      GO TO 30                                                          INJ  140
C                                                                       INJ  150
   20 READ (13)  EJDATA                                                 INJ  160
      BACKSPACE  13                                                     INJ  170
   30 CALL  AS138  ( EJDATA, HEAD1, NE )                                INJ  180
      IF ( NE .NE. 1 )         CALL  EXIT                               INJ  190
      WRITE (13)  EJDATA                                                INJ  195
      BACKSPACE  13                                                     INJ  196
      IF ( .NOT. JRUN )       GO TO 40                                  INJ  200
      CALL  JJJ                                                         INJ  210
   40 IF ( ERUN .OR. IRUN )   CALL  INJDIS                              INJ  220
C                                                                       INJ  230
   50 RETURN                                                            INJ  240
            END                                                         INJ  250
```

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@ ELT SUB18,1,690708, 48741

      SUBROUTINE JJJ                                                    JECT  10
C                                                                       JECT  20
C  ************  DECK MODIFIED 20 AUG 67     ********************       JECT  30
C                                                                       JECT  40
      DIMENSION  THET1(1450), R1(1450), TMU(1000)                       JECT  50
      DIMENSION            NELE(1000),X(1000),Y(1000),NTYPEE(1000),R(22)JECT  60
     1,THETA(182),AS(20),WTE(1000),AAX(1000),AAF(1000),NBAND(1000),XMRE(JECT  70
     21000),XMUTOT(20).AXTY(200),AFTY(200),XX(1000),YY(1000)            JECT  80
      COMMON  /JECTOR/  DATA ( 9600)                                    JECT  90
C                                                                       JECT 130
      EQUIVALENCE (DATA(3),XM), (DATA(4),XN)                            JECT 140
      EQUIVALENCE (DATA(1021),THET1),(DATA(2471),R1),(DATA(3921),TMU)   JECT 150
      EQUIVALENCE (NTYPEE,DATA(2001)),(AXTY,DATA(1001)),(AFTY,DATA(1201)JECT 160
     1), (DATA(1921),XX),(DATA(2921),YY),(DATA(4921),XMUTOT)            JECT 170
C                                                                       JECT 180
      NERROR=0                                                          JECT 200
      SECT=DATA(5)                                                      JECT 210
      WT=DATA(9573)                                                     JECT 220
      RINJ=DATA(9574)                                                   JECT 230
      XMR=DATA(9575)                                                    JECT 240
      FFC=DATA(9576)                                                    JECT 250
      DFFC=DATA(9577)                                                   JECT 260
      NT=DATA(9570)+.0001                                               JECT 270
      POLAR=DATA(9572)                                                  JECT 280
      NE=DATA(9571)+.0001                                               JECT 290
      ROX=DATA(9579)                                                    JECT 300
      ROF=DATA(9580)                                                    JECT 310
      EMUMAX=5.0                                                        JECT 320
      PXADJ=1.0                                                         JECT 330
      PFADJ=1.0                                                         JECT 340
      CDX=DATA(9585)                                                    JECT 350
      CDF=DATA(9586)                                                    JECT 360
      XFC=DATA(9591)                                                    JECT 370
      DXFC=DATA(9592)                                                   JECT 380
      PFFC = DATA(9589)/100.0                                           JECT 390
      PXFC = DATA(9590)/100.0                                           JECT 400
      IF (XM .EQ. 0.0 ) XM = 20.0                                       JECT 410
      IF ( XN .EQ. 0.0 ) XN = 180.0                                     JECT 420
   10 K=319                                                             JECT 430
      THFNL=6.2831853/SECT                                              JECT 440
      IF(DATA(322))20,30,30                                             JECT 450
   20 ROTATE=3.1415926/SECT                                             JECT 460
      GO TO 40                                                          JECT 470
   30 ROTATE=0.0                                                        JECT 480
   40 IF(POLAR)50,180,50                                                JECT 490
   50 IF(SECT-1.0)80,80,60                                              JECT 500
   60 DO 70 I=1,NE                                                      JECT 510
      KK=K+1                                                            JECT 520
      NELE(I)=DATA(KK)+.0001                                            JECT 530
      X(I)=DATA(KK+1)                                                   JECT 540
      Y(I)=DATA(KK+2)                                                   JECT 550
      NTYPEE(I)=DATA(KK+3)+.0001                                        JECT 560
      SAVE=SQRT(X(I)*X(I)+Y(I)*Y(I))                                    JECT 570
      Y(I)=(ATAN(Y(I)/X(I)))+ROTATE                                     JECT 580
      X(I)=SAVE                                                         JECT 590
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          K=K+4                                                         JECT 600
   70 CONTINUE                                                          JECT 610
          GO TO 220                                                     JECT 620
   80 DO 170 I=1,NE                                                     JECT 630
          KK=K+1                                                        JECT 640
          NELE(I)=DATA(KK)+.0001                                        JECT 650
          X(I)=DATA(KK+1)                                               JECT 660
          Y(I)=DATA(KK+2)                                               JECT 670
          NTYPEE(I)=DATA(KK+3)+.0001                                    JECT 680
C         THE FOLLOWING SEGMENT OF CODING REPLACES SUBROUTINE MOVXY...  JECT 690
             IF ( Y(I) )          90,130,140                            JECT 700
   90        IF ( X(I) )        100,110,120                             JECT 710
  100        ROTATE = 3.1415927                                         JECT 720
             GO TO 160                                                  JECT 730
  110        X(I) = 1.0E-15                                             JECT 740
  120        ROTATE = 6.2831853                                         JECT 750
             GO TO 160                                                  JECT 760
  130        ROTATE = 0.0                                               JECT 770
             GO TO 160                                                  JECT 780
  140        IF ( X(I) )        100,150,130                             JECT 790
  150        X(I) = 1.0E-15                                             JECT 800
             ROTATE = 0.0                                               JECT 810
  160 SAVE = SQRT ( X(I)*X(I)+Y(I)*Y(I) )                               JECT 820
          SAVE=SQRT(X(I)*X(I)+Y(I)*Y(I))                                JECT 830
          Y(I)=(ATAN(Y(I)/X(I)))+ROTATE                                 JECT 840
          X(I)=SAVE                                                     JECT 850
          K=K+4                                                         JECT 860
  170 CONTINUE                                                          JECT 870
          GO TO 220                                                     JECT 880
  180 IF(SECT-1.0)190,190,200                                           JECT 890
  190 ROTATE=0.0                                                        JECT 900
  200 DO 210 I=1,NE                                                     JECT 910
          KK=K+1                                                        JECT 920
          NELE(I)=DATA(KK)+.0001                                        JECT 930
          X(I)=DATA(KK+1)                                               JECT 940
          Y(I)=(DATA(KK+2)*.0174532)+ROTATE                             JECT 950
          NTYPEE(I)=DATA(KK+3)+.0001                                    JECT 960
          K=K+4                                                         JECT 970
  210 CONTINUE                                                          JECT 980
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCJECT 990
C         CALCULATING AREAS OF ELEMENTS                                 JECT1000
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCJECT1010
  220 NN=4944                                                           JECT1020
          DO 280 I=1,NT                                                 JECT1030
          KK=NN+1                                                       JECT1040
          NST=DATA(KK)+.0001                                            JECT1050
          KK1=KK+1                                                      JECT1060
          JJ=KK1                                                        JECT1070
          NX=DATA(KK1)+.0001                                            JECT1080
          AXTY(NST)=0.0                                                 JECT1090
          IF(NX)230,250,230                                             JECT1100
  230 DO 240 JX=1,NX                                                    JECT1110
          JJ=KK1+JX                                                     JECT1120
          AXTY(NST)=AXTY(NST)+(.7853891*(DATA(JJ)*DATA(JJ)))            JECT1130
  240 CONTINUE                                                          JECT1140
  250 NN1=JJ+1                                                          JECT1150
          NN=NN1                                                        JECT1160
          NF=DATA(NN1)+.0001                                            JECT1170
          AFTY(NST)=0.0                                                 JECT1180
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000115          IF(NF)260,280,260                                       JECT1190
000116      260 DO 270 JF=1,NF                                          JECT1200
000117          NN=NN1+JF                                               JECT1210
000118          AFTY(NST)=AFTY(NST)+(.7853981*(DATA(NN)*DATA(NN)))      JECT1220
000119      270 CONTINUE                                                JECT1230
000120      280 CONTINUE                                                JECT1240
000121          AXTOT=0.0                                               JECT1250
000122          AFTOT=0.0                                               JECT1260
000123          DO 290 I=1,NE                                           JECT1270
000124          NN=NTYPEE(I)                                            JECT1280
000125          AAX(I)=AXTY(NN)                                         JECT1290
000126          AAF(I)=AFTY(NN)                                         JECT1300
000127          AXTOT=AXTOT+AAX(I)                                      JECT1310
000128          AFTOT=AFTOT+AAF(I)                                      JECT1320
000129      290 CONTINUE                                                JECT1330
000130          AXTOT=AXTOT*SECT                                        JECT1340
000131          AFTOT=AFTOT*SECT                                        JECT1350
000132  CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCJECT1360
000133  C       CALCULATING RADII AND ANGLE BOUNDRIES                   JECT1370
000134  CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCJECT1380
000135      300 NPTS=180.0/SECT                                         JECT1390
000136          TPS=NPTS                                                JECT1400
000137          DELTH=THFNL/TPS                                         JECT1410
000138          AREA = 3.141592 * RINJ**2                               JECT1420
000139          ASECT = AREA/(XM*XN)                                    JECT1430
000140          R(1) = 0.0                                              JECT1440
000141          ANP = ASECT * 180.0 / 3.141592                          JECT1450
000142          DO 310 I = 2,21                                         JECT1460
000143          R(I) = SQRT ( ANP + R(I-1)**2)                          JECT1470
000144      310 CONTINUE                                                JECT1480
000145          R(22) = 0.0                                             JECT1490
000146          XNUM=0.0                                                JECT1500
000147          NPTS1=NPTS+1                                            JECT1510
000148          DO 320 J=2,NPTS1                                        JECT1520
000149          XNUM=XNUM+1.0                                           JECT1530
000150          THETA(J)=DELTH*XNUM                                     JECT1540
000151      320 CONTINUE                                                JECT1550
000152  CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCJECT1560
000153  C       CALCULATING WEIGHT FLOW                                 JECT1570
000154  CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCJECT1580
000155          WFT1=WT/(XMR+1.0)                                       JECT1590
000156          WXT1=WT-WFT1                                            JECT1600
000157          WFT2=WFT1                                               JECT1610
000158          WXT2=WXT1                                               JECT1620
000159          IF(PFFC)340,340,330                                     JECT1630
000160      330 WFT2=WFT1*(1.0-PFFC)                                    JECT1640
000161      340 IF(PXFC)360,360,350                                     JECT1650
000162      350 WXT2=WXT1*(1.0-PXFC)                                    JECT1660
000163      360 SIGMEN=WT/(3.141592*RINJ*RINJ)                          JECT1670
000164      370 AXTMAX=AXTOT                                            JECT1680
000165          AXTMIN=AXTOT                                            JECT1690
000166          AFTMAX=AFTOT                                            JECT1700
000167          AFTMIN=AFTOT                                            JECT1710
000168      380 AFFC=0.0                                                JECT1720
000169          AXFC=0.0                                                JECT1730
000170          IF(DFFC)400,400,390                                     JECT1740
000171      390 AFFC=FFC*.785398*DFFC*DFFC                              JECT1750
000172          AFTMIN=AFTMIN-AFFC                                      JECT1760
000173          AFTMAX=AFTMAX-AFFC                                      JECT1770
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000174          400 IF(DXFC)420,420,410                                    JECT1780
000175          410 AXFC=XFC*.785398*DXFC*DXFC                             JECT1790
000176              AXTMIN=AXTMIN-AXFC                                     JECT1800
000177              AXTMAX=AXTMAX-AXFC                                     JECT1810
000178          420 AXNOM=(AXTMAX+AXTMIN)/2.0                              JECT1820
000179              AFNOM=(AFTMAX+AFTMIN)/2.0                              JECT1830
000180              IF(DFFC+DXFC)440,440,430                               JECT1840
000181          430 WXT2=(WXT2*AXNOM)/(AXNOM+AXFC)                         JECT1850
000182              WFT2=(WFT2*AFNOM)/(AFNOM+AFFC)                         JECT1860
000183          440 XMR1=WXT2/WFT2                                         JECT1870
000184          450 ETOF=0.0                                               JECT1880
000185              ETFF=0.0                                               JECT1890
000186              QX=WXT2/AXTOT                                          JECT1900
000187              QF=WFT2/AFTOT                                          JECT1910
000188              CALL DVCHK (K000FX)                                    JECT1920
000189          460 DO 480 I=1,NE                                          JECT1940
000190              NBAND(I)=0                                             JECT1950
000191              WFE1=AAF(I)*QF                                         JECT1960
000192              WXE1=AAX(I)*QX                                         JECT1970
000193              WTE(I)=WFE1+WXE1                                       JECT1980
000194              XMRE(I)=WXE1/WFE1                                      JECT1990
000195              ETOF=ETOF+WXE1                                         JECT2000
000196              ETFF=ETFF+WFE1                                         JECT2010
000197              CALL DVCHK (K000FX)                                    JECT2020
000198               GO TO (470,480),K000FX                                JECT2030
000199          470 NBAND(I)=-1                                            JECT2040
000200          480 CONTINUE                                               JECT2050
000201              ETOF=SECT*ETOF                                         JECT2060
000202              ETFF=SECT*ETFF                                         JECT2070
000203              WMRELM=ETOF/ETFF                                       JECT2080
000204              AXXTT=AXTOT+AXFC                                       JECT2090
000205              AFFTT=AFTOT+AFFC                                       JECT2100
000206               WFT2 = ETFF                                           JECT2110
000207               WXT2 = ETOF                                           JECT2120
000208              WFT1=WFT2/(1.0-PFFC)                                   JECT2130
000209              WXT1=WXT2/(1.0-PXFC)                                   JECT2140
000210               WFT1 = WFT1*AFFTT/AFTOT                               JECT2150
000211               WXT1 = WXT1*AXXTT/AXTOT                               JECT2160
000212              XMRINJ=WXT1/WFT1                                       JECT2170
000213              D= ((WXT1/(CDX*AXXTT))**2)*2.2360248                   JECT2180
000214              WTOT=WXT1+WFT1                                         JECT2190
000215              DPX1=D/ROX                                             JECT2200
000216              D= ((WFT1/(CDF*AFFTT))**2)*2.2360248                   JECT2210
000217              DPF1=D/ROF                                             JECT2220
000218               TOFCF = WXT1*(1.0 - PXFC)                             JECT2230
000219               TOFCF = (TOFCF*(AXXTT - AXFC))/AXXTT                  JECT2240
000220               TOFCF = WXT1 - TOFCF                                  JECT2250
000221               TFFC = WFT1*(1.0 - PFFC)                              JECT2260
000222               TFFC = (TFFC*(AFFTT - AFFC))/AFFTT                    JECT2270
000223               TFFC = WFT1 - TFFC                                    JECT2280
000224              VINJX=SQRT((9273.6*DPX1 /ROX))                         JECT2290
000225              VINJF=SQRT((9273.6*DPF1 /ROF))                         JECT2300
000226              XXY=TPS*SIGMEN*SECT                                    JECT2310
000227          490 WRITE (6,820)                                          JECT2320
000228              GO TO 500                                              JECT2330
000229          500 WRITE (6,760)AXTOT,AFTOT,AXFC,AFFC,AXXTT,AFFTT,DPX1,DPF1  JECT2340
000230              WRITE (6,770)WTOT,WMRELM,XMRINJ,ETOF,ETFF,TOFCF,TFFC, WXT1, WFT1 ,JECT2350
000231             1VINJX,VINJF                                            JECT2360
000232              PFFC=PFFC*100.0                                        JECT2370
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000233          PXFC=PXFC*100.0                                          JECT2380
000234      510 WRITE (6,830)WT,NT,NE,CDX                                JECT2390
000235          WRITE (6,780)CDF,PFFC,PXFC,DFFC,DXFC,FFC,XFC,ROX,ROF     JECT2400
000236          CALL PAGE(70)                                            JECT2410
000237          WRITE (6,810)                                            JECT2420
000238          NPGE=49                                                  JECT2430
000239          DO 540 I=1,NE                                            JECT2440
000240          IF(NPGE-I)520,520,530                                    JECT2450
000241      520 CALL PAGE(70)                                            JECT2460
000242          NPGE=NPGE+48                                             JECT2470
000243          WRITE (6,810)                                            JECT2480
000244      530 DEGREE=Y(I)/.0174532                                     JECT2490
000245          B=X(I)*SIN(Y(I))                                         JECT2500
000246          A=X(I)*COS(Y(I))                                         JECT2510
000247          WRITE (6,800)NELE(I),NTYPEE(I),X(I),DEGREE,A,B           JECT2520
000248      540 CONTINUE                                                 JECT2530
000249          CALL PAGE(70)                                            JECT2540
000250          NPGE=46                                                  JECT2550
000251          JCONT=0                                                  JECT2560
000252          WRITE (6,840)                                            JECT2570
000253          NN=4944                                                  JECT2580
000254          DO 670 I=1,NT                                            JECT2590
000255          KK=NN+1                                                  JECT2600
000256          NST=DATA(KK)+.0001                                       JECT2610
000257          KK1=KK+1                                                 JECT2620
000258          JJ=KK1                                                   JECT2630
000259          NX=DATA(KK1)+.0001                                       JECT2640
000260          JCONT=JCONT+NX+1                                         JECT2650
000261          IF(NPGE-JCONT)550,550,560                                JECT2660
000262      550 CALL PAGE(70)                                            JECT2670
000263          WRITE (6,840)                                            JECT2680
000264          JCONT=0                                                  JECT2690
000265      560 AXMAX=0.0                                                JECT2700
000266          AFMAX=0.0                                                JECT2710
000267          WFE1=0.0                                                 JECT2720
000268          WXE1=0.0                                                 JECT2730
000269          WRITE (6,850)NST,NX                                      JECT2740
000270          IF(NX)570,590,570                                        JECT2750
000271      570 DO 580 JX=1,NX                                           JECT2760
000272          JJ=KK1+JX                                                JECT2770
000273          A=.7853891*DATA(JJ)*DATA(JJ)                             JECT2780
000274          B=A*QX                                                   JECT2790
000275          WRITE (6,860)DATA(JJ),A,B                                JECT2800
000276          AXMAX=AXMAX+A                                            JECT2810
000277          WXE1=WXE1+B                                              JECT2820
000278      580 CONTINUE                                                 JECT2830
000279      590 NN1=JJ+1                                                 JECT2840
000280          NN=NN1                                                   JECT2850
000281          NF=DATA(NN1)+.0001                                       JECT2860
000282          JCONT=JCONT+NF+2                                         JECT2870
000283          IF(NPGE-JCONT)600,600,610                                JECT2880
000284      600 CALL PAGE (70)                                           JECT2890
000285          WRITE (6,840)                                            JECT2900
000286          JCONT=0                                                  JECT2910
000287      610 WRITE (6,870)NF                                          JECT2920
000288          IF(NF)620,640,620                                        JECT2930
000289      620 DO 630 JF=1,NF                                           JECT2940
000290          NN=NN1+JF                                                JECT2950
000291          A=.7853891*DATA(NN)*DATA(NN)                             JECT2960
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      B=A*QF                                                            JECT2970
      WRITE (6,880)DATA(NN),A,B                                         JECT2980
      AFMAX=AFMAX+A                                                     JECT2990
      WFE1=WFE1+B                                                       JECT3000
  630 CONTINUE                                                          JECT3010
  640 WTOT1=WXE1+WFE1                                                   JECT3020
      IF(WFE1)660,650,660                                               JECT3030
  650 WRITE (6,900)AXMAX,AFMAX,WTOT1                                    JECT3040
      GO TO 670                                                         JECT3050
  660 XMR1=WXE1/WFE1                                                    JECT3060
      WRITE (6,890)AXMAX,AFMAX,WTOT1,XMR1                               JECT3070
  670 CONTINUE                                                          JECT3080
  680 READ  (13)  DATA                                                  JECT3090
      BACKSPACE  13                                                     JECT3100
      LINKNT = 0                                                        JECT3110
      AJS = XM*XN/WT                                                    JECT3120
      DO 700 J = 1,NE                                                   JECT3130
      TMU(J) = WTE(J)*AJS                                               JECT3140
      IF (LINKNT .GT. 0) GO TO 690                                      JECT3150
      CALL PAGE(70)                                                     JECT3160
      WRITE (6,910)                                                     JECT3170
      WRITE (6,930)                                                     JECT3180
      LINKNT = 50                                                       JECT3190
  690 WRITE(6,920) J, X(J), Y(J), TMU(J)                                JECT3200
      LINKNT = LINKNT - 1                                               JECT3210
  700 CONTINUE                                                          JECT3220
      DO  705  I = 1, NE                                                JECT3222
         XX(I) = X(I)                                                   JECT3224
  705    YY(I) = Y(I)                                                   JECT3225
      WRITE  (13)       DATA                                            JECT3230
      BACKSPACE  13                                                     JECT3240
      XMUMAX=0.0                                                        JECT3250
      AJS = AJS*SECT/XN                                                 JECT3260
      DO 730 J=1,20                                                     JECT3270
      TOTW=0.0                                                          JECT3280
      XXX = XXY * ASECT                                                 JECT3290
      DO 710 I=1,NE                                                     JECT3310**-1
      IF (X(I) .LE. R(J+1) .AND. X(I) .GT. R(J)) TOTW = TOTW + WTE(I)   JECT3320
  710 CONTINUE                                                          JECT3330
      XMUTOT(J) = TOTW*AJS                                              JECT3340
      IF(XMUTOT(J)-XMUMAX)730,730,720                                   JECT3350
  720 XMUMAX=XMUTOT(J)                                                  JECT3360
  730 CONTINUE                                                          JECT3370
      CALL PAGE(70)                                                     JECT3380
      WRITE (6,790)                                                     JECT3390
      DO 740 J=1,20                                                     JECT3400
      XXMAX=XMUTOT(J)/XMUMAX                                            JECT3410
      WRITE (6,750)R(J+1),XMUTOT(J),XXMAX                               JECT3420
  740 CONTINUE                                                          JECT3430
      RETURN                                                            JECT3440
  750 FORMAT(32X,F6.3,14X,F7.3,13X,F6.4)                                JECT3450
  760 FORMAT(//,5X,28HA....PROPELLENT ORFICE AREAS,//,9X,34HELEMENT TOTAJECT3460
     1L OXIDIZER AREA       =,F11.8,8H SQ. IN.,15X,30HELEMENT TOTAL FUEL JECT3470
     2AREA       =,F11.8,8H SQ. IN.,/,9X,34HTOTAL OXIDIZER FILM COOLING AJECT3480
     3REA =,F11.8,8H SQ. IN.,15X,30HTOTAL FUEL FILM COOLING AREA =,F11.8JECT3490
     4,8H SQ. IN.,/,9X,34HINJECTOR TOTAL OXIDIZER AREA      =,F11.8,8H SQJECT3500
     5. IN.,15X,30HINJECTOR TOTAL FUEL AREA      =,F11.8,8H SQ. IN.,//,5XJECT3510
     6,54HB....INJECTOR PRESSURE DROPS FOR ABOVE INJECTOR DESIGN,//,9X, JECT3520
     724HOXIDIZER PRESSURE DROP =,F6.1,3HPSI,35X,20HFUEL PRESSURE DROP =JECT3530
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      8,F6.1,4H PSI,///,5X,71HC....PROPELLANT FLOWS AND INJECTOR VELOCITIJECT3540
      9ES FOR ABOVE INJECTOR DESIGN,/)                                  JECT3550
  770 FORMAT(/,48X,19HTOTAL WEIGHT FLOW =,F6.1,7H LB/SEC,/,42X,39HAVERAGJECT3560
      1E MIXTURE RATIO OF THE ELEMENTS =,F7.3,/,41X,40HOVERALL MIXTURE RAJECT3570
      2TIO FOR THE INJECTOR =,F7.3,//,9X,34HELEMENT TOTAL OXIDIZER FLOW  JECT3580
      3    =,F6.1,7H LB/SEC,21X,26HELEMENT TOTAL FUEL FLOW  =,F6.1,7H LB/JECT3590
      4SEC,/,9X,34HTOTAL OXIDIZER FILM COOLING FLOW =,F6.1,7H LB/SEC,21X,JECT3600
      526HTOTAL FUEL FILM COOLING  =,F6.1,7H LB/SEC,/,9X,34HINJECTOR TOTAJECT3610
      6L OXIDIZER FLOW     =,F6.1,7H LB/SEC,21X,25HINJECTOR TOTAL FUEL FLJECT3620
      7OW=,F7.1,7H LB/SEC,/,9X,37HOXIDIZER OVERALL INJECTION VELOCITY =,FJECT3630
      86.1,7H FT/SEC,18X,33HFUEL OVERALL INJECTION VELOCITY =,F6.1,7H FT/JECT3640
      9SEC,//)                                                          JECT3650
  780 FORMAT(9X,23HFUEL LOSS COEFFICIENT =,F5.3,/,9X,27HPERCENT FUEL FILJECT3660
      1M COOLING =,F5.1,/,9X,31HPERCENT OXIDIZER FILM COOLING =,F5.1,/,9XJECT3670
      2,38HDIAMETER OF FUEL FILM COOLING ORFICE =,F7.5,75H IN. (NOTE..THIJECT3680
      3S MIGHT BE AN EQUIVALENT  DIAMETER FOR MULTIPLE-ROW COOLING),/,9X,JECT3690
      442HDIAMETER OF OXIDIZER FILM COOLING ORFICE =,F7.5,21H IN. (SEE ABJECT3700
      5OVE NOTE),/,9X,51HNUMBER OF FUEL FILM COOLING ORIFICES PER INJECTOJECT3710
      6R =,F5.0,/,9X,54HNUMBER OF OXIDIZER FILM COOLING ORFICES PER INJECJECT3720
      7TOR =,F5.0,/,9X,18HOXIDIZER DENSITY =,F7.2,4H PCF,/,9X,14HFUEL DENJECT3730
      8SITY =,F6.1,4H PCF,///)                                          JECT3740
  790 FORMAT(////,3X,114HSECTION 4..RESULTANT FLOW DISTRIBUTION (MU) AS JECT3750
      1A FUNCTION OF ONLY THE RADIUS, I.E.. AVERAGE OF MU IN A RADIAL BANJECT3760
      2D,    ///,32X,6HRADIUS,15X,5HMU(R),11X,13HMU(R)/MU(MAX),/,34X,3HINJECT3770
      3.,//)                                                            JECT3780
  800 FORMAT(13X,I3,18X,I2,4X,4(10X,F10.5))                             JECT3790
  810 FORMAT(//,2X, 49HSECTION 2.... ELEMENT LOCATION AND INJECTION TYPEJECT3800
      1,///,11X, 7HELEMENT,15X, 4HTYPE,17X,1HR,17X, 5HTHETA,17X,1HX,19X,1JECT3810
      2HY,/,13X, 3HNO.,18X, 3HNO.,14X, 8H(INCHES),12X, 8H(DEGREE),12X, 8HJECT3820
      3(INCHES),12X,8H(INCHES),//)                                      JECT3830
  820 FORMAT(///,3X, 74HSECTION 1....MISCELLANEOUS INFORMATION FOR INJECJECT3840
      1TOR DESIGNED BY PROJECTS         ,/)                             JECT3850
  830 FORMAT(//,5X, 46HD......INPUT INFORMATION USED IN COMPUTATIONS  ,/JECT3860
      1/,9X, 23HTOTAL PROPELLENT FLOW =,F6.1,7H LB/SEC,/,9X, 59HTOTAL NUMJECT3870
      2BER OF ELEMENT TYPES (SYMMETRICAL SECTION ONLY) = ,I3,/,9X, 54HTOTJECT3880
      3AL NUMBER OF ELEMENTS (SYMMETRICAL SECTION ONLY) = ,I4,/,9X, 27HOXJECT3890
      4IDIZER LOSS COEFFICIENT =,F5.3,)                                 JECT3900
  840 FORMAT(//,2X, 78HSECTION 3....TYPE DESCRIPTION,ORIFICE AREA, PROPEJECT3910
      1LLANT FLOW, AND MIXTURE RATIO,//,3X, 84HTYPE   *-------- OXIDIZER JECT3920
      2ORIFICE DATA -----*-*---------- FUEL ORIFICE DATA --------*,//,93X,JECT3930
      3 5HTOTAL,5X, 5HTOTAL,5X, 5HTOTAL,4X, 7HMIXTURE,/,12X, 6HNUMBER,34XJECT3940
      4, 6HNUMBER,33X, 8HOXIDIZER.4X, 4HFUEL,3X,10HPROPELLENT,3X, 5HRATIOJECT3950
      5,/,14X,2HOF,5X, 8HDIAMETER,4X, 4HAREA,6X, 4HFLOW,7X,2HOF,5X, 8HDIAJECT3960
      6METER,4X, 4HAREA,6X, 4HFLOW,6X, 4HAREA,6X, 4HAREA,4X, 9HFLOW RATE,JECT3970
      7/,11X, 7HORIFICE,6X,3HIN.,5X, 7HSQ. IN.,4X, 6HLB/SEC,3X, 8HORIFICEJECT3980
      8S,5X, 3HIN.,4X, 7HSQ. IN.,4X, 6HLB/SEC,3X, 7HSQ. IN.,3X, 7HSQ. IN.JECT3990
      9,4X, 6HLB/SEC,//,)                                               JECT4000
  850 FORMAT(3X,I3,7X,I2)                                               JECT4010
  860 FORMAT(22X,F6.4,3X,F8.6,2X,F8.6)                                  JECT4020
  870 FORMAT(54X,I2)                                                    JECT4030
  880 FORMAT(62X,F6.4,3X,F8.6,2X,F8.6)                                  JECT4040
  890 FORMAT(91X,F8.5,2X,F8.5,2X,F8.4,3X,F7.4)                          JECT4050
  900 FORMAT(91X,F8.5,2X,F8.5,2X,F8.3,2X,8HINFINITY)                    JECT4060
  910 FORMAT (///10X15HELEMENT RESULTS )                                JECT4070
  920 FORMAT (32XI5,11XF10.3,10XF10.4,11XF10.4 )                        JECT4080
  930 FORMAT (//31X7HELEMENT14X6HRADIUS15X5HANGLE11X12HDISTRIBUTION/90X JECT4090
      111HCOEFFICIENT/34X3HNO.35X7HRADIANS15X2HMU// )                   JECT4100
                    END                                                 JECT4110
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@ ELT SUB19,1,691029, 58811

      SUBROUTINE  INJDIS                                                INJD  10
C                                                                       INJD  20
C  ************  DECK MODIFIED 20 AUG 67     ********************       INJD  30
C                                                                       INJD  40
      REAL IPP,IPR,IPT,INTEG,IPX                                        INJD  50
      INTEGER DSCRB, TIME                                               INJD  60
      LOGICAL  LOGIK,  SL1,  SL2,  EORJ, IRUN                           INJD  70
      COMMON  /PROLOG/  LOGIK(50), SL1, SL2, EORJ                       INJD  80
      COMMON  /JECTOR/  DATA ( 9600)                                    INJD  90
      COMMON    GAMMA, NW,  WC,  AVN,  BVN,  CVNR,  CVNI,  CE,  CI      INJD 110
      DIMENSION                                                         INJD 120
     1    U     (1000),  AVN   (  30),  BVN   (  30),  CVNR  (  30),    INJD 130
     2    CVNI  (  30),  RR    (1000),  THATA (1000),  FIRST (  30),    INJD 140
     3    SECOND(  30),  Z     (   2),                WC    (  30),    INJD 150
     4     IPP(50), OPP(50), IPR(50), OPR(50), IPT(50), OPT(50),        INJD 160
     5    X     (1000),  Y     (1000)                                   INJD 170
      EQUIVALENCE  ( IRUN, LOGIK(9) ),                                  INJD 180
     1   (E1    ,DATA(1)),                    (XM    ,DATA(3)),          INJD 190
     2   (XN    ,DATA(4)),(V      ,DATA(6)),(SVN   ,DATA(8)),           INJD 200
     3   (POO  ,DATA(13)),                     (Z1 ,DATA(15)),          INJD 210
     4   (RR, X, DATA(1921) ),(THATA, Y, DATA(2921)),                   INJD 220
     5   (U  ,DATA(3921)),                                              INJD 230
     6                                   (IPP  ,DATA(20)),              INJD 240
     7   (OPP  ,DATA(70)),(IPR ,DATA(120)), (OPR ,DATA(170)),           INJD 250
     8   (IPT ,DATA(220)),(OPT ,DATA(270)),(TFLP,DATA(9596)),           INJD 260
     9   (TFLR,DATA(9597)),(TFLT,DATA(9598))                            INJD 270
C                                                                       INJD 280
   10 FORMAT (//12X30HRESULTS OF DESCRIBING FUNCTION // 23X10HELEMENT   INJD 290
     1 6HRADIUS4X5HANGLE3X10HFRACTIONAL /13X5HOMEGA7X3HNO.7X3H   7X3HRADINJD 300
     2 4X9HFLOW-RATE10X2HFP12X2HFR12X2HFT // )                         INJD 310
   20 FORMAT (10XF9.4,I9,F11.3,F10.4,F11.5,2X3F14.6 )                   INJD 320
   30 FORMAT (//  12X41HRESULTS OF INJECTION DISTRIBUTION EFFECTS //    INJD 330
     143X5HOMEGA6X3HAVN8X3HBVN7X3HCVN7X3HCVN / 48X3(6X4HREAL),6X4HIMAG/ INJD 340
     2/ )                                                               INJD 350
   40 FORMAT (39X5F10.4 )                                               INJD 360
   50 FORMAT ( 44X5HALL  4F10.4 )                                       INJD 370
   60 FORMAT ( // 5X39HINPUT TO INJECTION DISTRIBUTION PROGRAM//10X9HCONINJD 380
     1STANTS//14X18HNUMBER OF OMEGAS = I3//14X20HNUMBER OF ELEMENTS =I5,INJD 390
     1 13H FOR EACH OF I4, 20H SYMMETRIC SECTIONS.                      INJD 391
     2//14X22HRADIAL DIVISIONS(XM) = F5.0//14X24HANGULAR DIVISIONS (XN) INJD 400
     3=F5.0//14X27HACOUSTIC MODE NUMBER(SVN) =F7.4//14X30HORDER OF BESSEINJD 410
     4L FUNCTIONS(V) = F3.0//14X17HINJECTOR RADIUS =F8.3,5H, IN.//14X32HINJD 420
     5RATIO OF SPECIFIC HEATS(GAMMA) =F7.4//14X39HMAXIMUM PRESSURE AMPLIINJD 430
     6TUDE RATIO(POO) =F7.3///14X39HTRANSFER FUNCTIONS FOR LINEAR OPERATINJD 440
     7ION//20X16HPRESSURE(TFLP) =F7.3//20X23HRADIAL VELOCITY(TFLR) =F7.3INJD 450
     8//20X27HTANGENTIAL VELOCITY(TFLT) =F7.3 )                         INJD 460
   70 FORMAT (// 10X17HINPUT FREQUENCIES )                              INJD 470
   80 FORMAT (/ 7X 5F20.4 )                                             INJD 480
   90 FORMAT (///10X19HELEMENT INFORMATION )                            INJD 490
  100 FORMAT (//31X7HELEMENT14X6HRADIUS15X5HANGLE11X12HDISTRIBUTION/90X INJD 500
     111HCOEFFICIENT/34X3HNO.17X3HIN.15X7HRADIANS15X2HMU// )            INJD 510
  110 FORMAT (32XI5,11XF10.3,10XF10.4,11XF10.4 )                        INJD 520
  120 FORMAT (1H1//26H TABULAR NONLINEAR EFFECTS//11X8HPRESSURE11X10HCOMINJD 530
     1BUSTION12X6HRADIAL12X10HCOMBUSTION10X10HTANGENTIAL10X10HCOMBUSTIONINJD 540
     2/51X8HVELOCITY32X8HVELOCITY/ 9X 3(12HPERTURBATION13X4HGAIN12X) )  INJD 550
```

```
  130 FORMAT ( 6(F18.3,2X) )
  140 FORMAT (//33X65H***********  THESE VALUES PERTAIN TO A STANDING MO
     1DE  ********** )
  150 FORMAT (//33X65H***********  THESE VALUES PERTAIN TO A SPINNING MO
     1DE  ********** )
  160 FORMAT (23X42HTHE VALUE OF IZZIT IS ZERO AND NOT ALLOWED)
  170 FORMAT(23X45HVALUE OF BESSEL ARGUMENT TOO HIGH OR LOW Z = F10.4)
C
  180 DSCRB = 1
      IF ( .NOT. IRUN )      GO TO 190
      CE = 100.0
      DSCRB = 2
      GO TO 200
  190 NW = 1
      WC(1) = 1.0
  200 TIME = 1
      RINJ = DATA(9574)
      NE = DATA(9571)  +0.0001
      NS = DATA(5) + 0.0001
      NUMBR = DATA(9599)  + 0.0001
      IZZIT = DATA(2)
      K = V +0.0001
      KK = K + 1
      L=K
      M=L+1
      N=L+2
C     ONLY THE REAL PART IS USED.
      IF ( E1 .LE. 0.0 )     E1 = 0.0001
      IF ( NUMBR .LE. 0 )     NUMBR = 10
      IF ( CE .LE. 99.0 )     GO TO 260
      CALL  PAGE  ( 70 )
      WRITE (6,60) NW,NE,NS,XM,XN,SVN,V,RINJ,GAMMA,POO,TFLP,TFLR,TFLT
      GO TO (220,210), DSCRB
  210 WRITE (6,70)
      WRITE (6,80) (WC(IW), IW = 1,NW)
  220 LINKNT = 0
      DO 240 J = 1,NE
      IF (LINKNT .GT. 0) GO TO 230
      CALL  PAGE  ( 70 )
      WRITE (6,90)
      WRITE (6,100)
      LINKNT = 50
  230 WRITE (6,110) J, RR(J), THATA(J), U(J)
      LINKNT = LINKNT - 1
  240 CONTINUE
      GO TO (260,250), DSCRB
  250 WRITE (6,120)
      WRITE (6,130) (IPP(I),OPP(I),IPR(I),OPR(I),IPT(I),OPT(I),I=1,50)
CXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
C         RUNNING DESCRIBING FUNCTION IMPLIES THAT THE EXPANSION
C   COEFFICIENTS AVN, BVN, AND CVN ARE FUNCTIONS OF THE FREQUENCY,OMEGA.
C   THEREFORE, AN OMEGA LOOP MUST BE ESTABLISHED. OTHERWISE, THIS LOOP
C  IS GONE THROUGH ONLY ONCE.
CXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  260 DO 470 IW = 1, NW
      WCR = WC(IW)
      VOO = POO/(GAMMA*WCR)
      SUMP = 0.0
      SUMR = 0.0
```

```
000115          SUMT = 0.0                                                      INJD1130
000116          LINKNT = 0                                                      INJD1140
000117          DO 450 J = 1, NE                                                INJD1150
000118          R = RR(J)/RINJ                                                  INJD1160
000119          ETA = U(J)/(XM*XN)                                              INJD1170
000120    C*****************************************************************
000121    C     THE ANSWERS WILL BE
000122    C  STORED  IN THE FOLLOWING FASHION,  J(V-1) = FIRST(L),  J(V) =      INJD1230
000123    C  FIRST(M),  AND J(V+1) = FIRST(N).                                  INJD1240
000124    C*****************************************************************INJD1250
000125          KERR = 0                                                        INJD1260
000126          Z(1) = SVN*R                                                    INJD1270
000127          Z(2) = 0.0                                                      INJD1280
000128          CALL  BESSEL  ( FIRST(1), SECOND(1), KK, Z(1), KERR )           INJD1290
000129          IF ( KERR )     270,270,550                                     INJD1300
000130      270 SIVN = FIRST(M)                                                 INJD1310
000131          DSIVN = ( V*FIRST(M) - Z(1)*FIRST(N) )/R                        INJD1320
000132          Z(1) = SVN                                                      INJD1330
000133          Z(2) = 0.0                                                      INJD1340
000134          CALL  BESSEL  ( FIRST(1), SECOND(1), KK, Z(1), KERR )           INJD1350
000135          IF  ( KERR )     280,280,550                                    INJD1360
000136      280 GO TO (290,320),  TIME                                          INJD1370
000137      290 IF ( K )    300,300,310                                         INJD1380
000138      300 D = ( FIRST(M)*FIRST(M) + FIRST(L)*FIRST(L) ) / 2.0             INJD1390
000139          GO TO 320                                                       INJD1400
000140      310 D = ( FIRST(M)*FIRST(M) - FIRST(L)*FIRST(N))*3.14159/(2.0*DATA(5))INJD1410
000141      320 IF ( IZZIT )    330,560,340                                     INJD1420
000142    CXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXINJD1430
000143    C  IZZIT IS NEGATIVE FOR STANDING MODES AND POSITIVE FOR SPINNING MODES INJD1440
000144    CXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXINJD1450
000145      330 VT = V*THATA(J)                                                 INJD1460
000146          CVT = COS(VT)                                                   INJD1470
000147          SVT = SIN(VT)                                                   INJD1480
000148          GO TO 350                                                       INJD1490
000149      340 CVT = 1.0                                                       INJD1500
000150          SVT = 1.0                                                       INJD1510
000151      350 FP = 1.0                                                        INJD1520
000152          FR = 1.0                                                        INJD1530
000153          FT = 1.0                                                        INJD1540
000154          GO TO (420,360), DSCRB                                          INJD1550
000155      360 PO = ABS(POO*SIVN*CVT)                                          INJD1560
000156          VO = ABS(VOO*DSIVN*CVT)                                         INJD1570
000157          WO = ABS(VOO*SIVN*V*SVT/R)                                      INJD1580
000158           A = -3.14159                                                   INJD1590
000159          B = -A                                                          INJD1600
000160          IF ( TFLP )     370,380,370                                     INJD1610
000161      370 SAVEP = 1.0/(3.14159*PO*TFLP)                                   INJD1620
000162          CALL INTGR(A,B,PSI,NUMBR)                                       INJD1630
000163    371   CONTINUE
000164          CPSI = COS(PSI)                                                 INJD1640
000165          IPX = PO*CPSI                                                   INJD1650
000166          CALL INT4(IPP(1), OPP(1), IPX, OPX)                             INJD1660
000167          F = OPX*CPSI                                                    INJD1670
000168          CALL INTGS($371,F,INTEG,E1,MM)
000169          FP = SAVEP*INTEG                                                INJD1690
000170      380 IF ( TFLR )     390,400,390                                     INJD1700
000171      390 SAVER = 1.0/(3.14159*VO*TFLR)                                   INJD1710
000172          CALL INTGR(A,B,PSI,NUMBR)                                       INJD1720
000173    391   CONTINUE
```

```
000174          CPSI = COS(PSI)                                          INJD1730
000175          IPX = VO*CPSI                                            INJD1740
000176          CALL INT4 (IPR(1), OPR(1), IPX, OPX)                     INJD1750
000177          F = OPX*CPSI                                             INJD1760
000178          CALL INTGS($391,F,INTEG,E1,MM)
000179          FR = SAVER*INTEG                                         INJD1780
000180      400 IF ( TFLT )     410,420,410                              INJD1790
000181      410 SAVET = 1.0/(3.14159*WO*TFLT)                                   *NEW
000182           CALL INTGR(A,B,PSI,NUMBR)                               INJD1810**-1
000183      411 CONTINUE
000184          CPSI = COS(PSI)                                          INJD1820
000185          IPX = WO*CPSI                                            INJD1830
000186          CALL INT4 (IPT(1), OPT(1), IPX, OPX)                     INJD1840
000187          F = OPX*CPSI                                             INJD1850
000188          CALL INTGS($411,F,INTEG,E1,MM)
000189          FT = SAVET*INTEG                                         INJD1870
000190      420 TERMP = ETA*FP*SIVN**2*CVT**2                            INJD1880
000191          SUMP = SUMP + TERMP                                      INJD1890
000192          TERMR = ETA*FR*SIVN*DSIVN*CVT**2                         INJD1900
000193          SUMR = SUMR + TERMR                                      INJD1910
000194          TERMT = -ETA*FT*SIVN**2*CVT*V*SVT/R                      INJD1920
000195          SUMT = SUMT + TERMT                                      INJD1930
000196          TIME = 2                                                 INJD1940
000197          GO TO (450,430),  DSCRB                                  INJD1950
000198      430 IF ( LINKNT .GT. 0 )     GO TO 440                       INJD1960
000199          CALL  PAGE  ( 70 )                                       INJD1970
000200          WRITE (6,10)                                             INJD1980
000201          LINKNT = 50                                              INJD1990
000202      440 WRITE (6,20)  WCR, J, R, THATA(J), ETA, FP, FR, FT       INJD2000
000203          LINKNT = LINKNT - 1                                      INJD2010
000204      450 CONTINUE                                                 INJD2020
000205          DD = D                                                   INJD2030
000206          IF (IZZIT .GT. 0) DD = D/2.0                             INJD2040
000207          AVN(IW) = SUMP/DD                                        INJD2050
000208          BVN(IW) = SUMR/DD                                        INJD2060
000209          IF (IZZIT .GT. 0)  GO TO 460                             INJD2070
000210          CVNR(IW) = SUMT/DD                                       INJD2080
000211          CVNI(IW) = 0.0                                           INJD2090
000212          GO TO 470                                                INJD2100
000213      460 CVNR(IW) = 0.0                                           INJD2110
000214          CVNI(IW) = SUMT/DD                                       INJD2120
000215      470 CONTINUE                                                 INJD2130
000216          IF (CE .LT. 10.0 ) GO TO 530                             INJD2140
000217          CALL  PAGE  ( 70 )                                       INJD2150
000218          WRITE (6,30)                                             INJD2160
000219          GO TO (480,490),  DSCRB                                  INJD2170
000220      480 WRITE (6,50)  AVN(1 ), BVN(1 ), CVNR(1 ), CVNI(1 )       INJD2180
000221          GO TO 500                                                INJD2190
000222      490 WRITE (6,40)  ( WC(I), AVN(I), BVN(I), CVNR(I), CVNI(I),  I=1,NW )INJD2200
000223      500 IF ( IZZIT ) 510,560,520                                 INJD2210
000224      510 WRITE(6,140)                                             INJD2220
000225          GO TO 530                                                INJD2230
000226      520 WRITE (6,150)                                            INJD2240
000227      530 CONTINUE                                                 INJD2250
000228      540 RETURN                                                   INJD2260
000229      550 WRITE (6,170) Z(1)                                       INJD2270
000230          GO TO 540                                                INJD2280
000231      560 WRITE (6,160)                                            INJD2290
000232          GO TO 540                                                INJD2300
```

INJD2310

END

000233

```
@ ELT SUB20,1,691029, 50052

      SUBROUTINE TBLCAL                                                 *NEW
C TBLCAL SUBROUTINE CALCULATES XX VS U2TBL FROM NOZZLE GEOMETRY        *ANNU0030**-1
C SIMPSONS RULE IS USED WITH KN INPUT ODD AND CHANGED TO KN/2+1 IN MAIN*ANNU0040
C  DECK ANNULR DERIVED FROM DECK VELPOT... TREATS ANNULAR NOZZLES       ANNU0050
C                                                                       ANNU0060
      LOGICAL  LOGIK,  SL1,  SL2,  EORJ                                 ANNU0070
      COMMON  /PROLOG/  LOGIK(50), SL1, SL2, EORJ                       ANNU0080
C                                                                       ANNU0090
      COMMON  /ABCDF/  EXTRA(100),  ABLOK(600)                          ANNU0100
     1      ,  XX      , U2TBL   , DESIRE , RAT     , RAC     , RCC     ANNU0110
     2      ,  RCT     , HANG    , G      , KN      , Y       , YP      ANNU0120
     3      ,  YOUT    , TEMP    , E      , XTABLE  , YTABLE  , A       ANNU0130
     4      ,  R       , AM      , AP     , AMP     , ZZ      , AMM     ANNU0140
     5      ,  AMP2    , CALFA   , CTALFA , DELAM   , DELTZ   , FKN     ANNU0150
     6      ,  G1      , G2      , G3     , G4      , JFLAG1  , KNM1    ANNU0160
     7      ,  K       , NN      , PI     , PROD    , RSTA1   , RSTA2   ANNU0170
     8      ,  SALFA   , T1      , T2     , T3      , XINT    , XK      ANNU0180
     9      ,  ZZ1     , ZZ2     , ZZ3    , A1      , ABC     , ABD     ANNU0190
      COMMON  /ABCDF/                                                   ANNU0200
     1         AI1     , ALPHAI  , ALPHAR , AR1     , B101    , B102    ANNU0210
     2      ,  B10     , B1      , B2     , B3      , B4      , B5      ANNU0220
     3      ,  B6      , B7      , B8     , B91     , B92     , B9      ANNU0230
     4      ,  BI1     , BR1     , C2     , C3      , CHII    , CHIR    ANNU0240
     5      ,  CI1     , CR1     , C      , D10     , D11     , D1      ANNU0250
     6      ,  D2      , D3      , D4     , D5      , D6      , D7      ANNU0260
     7      ,  D8      , D9      , DC2    , D       , DU2     , EI      ANNU0270
     8      ,  ER      , F3I     , F3R    , FI      , FR      , H1      ANNU0280
     9      ,  H       , I       , IWO    , IW      , IWW     , J       ANNU0290
      COMMON  /ABCDF/                                                   ANNU0300
     1         MDESIR  , NK      , NP     , S2      , S       , TT      ANNU0310
     2      ,  U2      , U       , W2     , W       , XIOI    , XIOR    ANNU0320
     3      ,  XI2I    , XI2R    , XI     , XJI     , XJR     , XMNEW   ANNU0330
     4      ,  XMOLD   , XNEW    , XOLD   , XPT     , X       , ZI      ANNU0340
     5      ,  ZR                                                      ANNU0350
C                                                                       ANNU0360
      DIMENSION XX(200),U2TBL(200),XTABLE(200),YTABLE(200),ZZ(200)      ANNU0370
      DIMENSION  Y(8).YP(8),YOUT(8),TEMP(72),E(8)                       ANNU0380
      DIMENSION A(200),R(200),AM(200),AP(200),AMP(200)                  ANNU0390
C                                                                       ANNU0400
      EQUIVALENCE (XK,GRAD),(EXTRA(91),RATI),                           ANNU0410
     1   ( EXTRA(93),RACI),(EXTRA(94),RCCI),(EXTRA(95),HANGI)           ANNU0420
C                                                                       ANNU0430
      FKN = KN                                                          ANNU0440
      KNM1 = KN - 1                                                     ANNU0450
      DELAM = 1.0/(FKN+1.0)                                             ANNU0460
      PI = 3.1415927                                                    ANNU0470
C                                                                       ANNU0480
      DO 10 J = 1,200                                                   ANNU0490
      ZZ(J) = 0.0                                                       ANNU0500
      A(J) = 0.0                                                        ANNU0510
      R(J) = 0.0                                                        ANNU0520
      AMP(J) = 0.0                                                      ANNU0530
      AM(J) = 0.0                                                       ANNU0540
      XX(J) = 0.0                                                       ANNU0550
      U2TBL(J) = 0.0                                                    ANNU0560
```

```
000056          10 AP(J) = 0.0                                          ANNU0570
000057       C                                                          ANNU0580
000058             R(1)= RAT                                            ANNU0590
000059             RI = RATI                                            ANNU0600
000060             RCTI = EXTRA(92)                                     ANNU0610
000061             A(1) = PI*(R(1)*R(1)-RI*RI)                          ANNU0620
000062             U2TBL(1)=1.0                                         ANNU0630
000063             R(KN) = RAC                                          ANNU0640
000064             ALFA = HANG*.01745329                                ANNU0650
000065             CALFA=COS(ALFA)                                      ANNU0660
000066             SALFA=SIN(ALFA)                                      ANNU0670
000067             CTALFA=CALFA/SALFA                                   ANNU0680
000068             RSTA1=RAT+RCT*(1.0-CALFA)                            ANNU0690
000069             RSTA2=RAC-RCC*(1.0-CALFA)                            ANNU0700
000070             ZZ1=RCT*SALFA                                        ANNU0710
000071             ZZ2=ZZ1+CTALFA*(RSTA2-RSTA1)                         ANNU0720
000072             ZZ3=ZZ2+RCC*SALFA                                    ANNU0730
000073       C                                                          ANNU0740
000074             JFLAG1=1                                             ANNU0750
000075             JFLAG2 = 1                                           ANNU0760
000076             IF ( RACI .EQ. 0.0 .AND. RATI .EQ. 0.0 )  JFLAG2 = 4 ANNU0770
000077             ALFI = HANGI*.01745329                               ANNU0780
000078             CALFI = COS(ALFI)                                    ANNU0790
000079             SALFI = SIN(ALFI)                                    ANNU0800
000080             CTALFI = CALFI/SALFI                                 ANNU0810
000081             RI1 = RATI + RCTI*(1.0-CALFI)                        ANNU0820
000082             RI2 = RACI - RCCI*(1.0-CALFI)                        ANNU0830
000083             ZI1 = RCTI*SALFI                                     ANNU0840
000084             ZI2 = ZI1 + CTALFI*(RI2-RI1)                         ANNU0850
000085             ZI3 = ZI2 + RCCI*SALFI                               ANNU0860
000086             Z4 = ZZ3                                             ANNU0870
000087             IF ( ZI3 .GT. ZZ3 )     Z4 = ZI3                     ANNU0880
000088             DELTZ = Z4 / (FKN-1.0)                               ANNU0890
000089       C                                                          ANNU0900
000090             DO 80 I = 2,KNM1                                     ANNU0910
000091             ZZ(I) = ZZ(I-1) + DELTZ                              ANNU0920
000092             Z = ZZ(I)                                            ANNU0930
000093             GO TO  ( 20, 40, 60, 65 ),  JFLAG1                   ANNU0940
000094          20 R(I)=RAT+RCT-SQRT(RCT**2-ZZ(I)**2)                   ANNU0950
000095             IF(R(I)-RSTA1)70,70,30                               ANNU0960
000096          30 JFLAG1=2                                             ANNU0970
000097          40 R(I)=RSTA1+(RSTA2-RSTA1)*(ZZ(I)-ZZ1)/(ZZ2-ZZ1)      ANNU0980
000098             IF ( Z-ZZ2 )            70,  70,  50                 ANNU0990
000099          50 JFLAG1 = 3                                           ANNU1000
000100          60 IF ( Z-ZZ3 )            62,  65,  65                 ANNU1010
000101          62 R(I) = RAC - RCC + SQRT ( RCC*RCC - (ZZ3-Z)**2 )     ANNU1020
000102             GO TO 70                                                      *NEW
000103          65 R(I) = RAC                                           ANNU1030
000104             JFLAG1 = 4                                           ANNU1040
000105          70 GO TO  ( 72, 74, 76, 77 ),  JFLAG2                   ANNU1050
000106          72 TX = SQRT ( RCTI*RCTI - Z*Z )                        ANNU1060
000107             IF ( RCTI .LT. 0.0 )    TX = -TX                     ANNU1070
000108             RI = RATI + RCTI - TX                                ANNU1080
000109             IF ( Z-ZI1 )            78,  78,  73                 ANNU1090
000110          73 JFLAG2 = 2                                           ANNU1100
000111          74 RI = RI1 + (RI2-RI1)*(ZZ(I)-ZI1)/(ZI2-ZI1)           ANNU1110
000112             IF ( Z-ZI2 )            78,  78,  75                 ANNU1120
000113          75 JFLAG2 = 3                                           ANNU1130
000114          76 TX = SQRT ( RCCI*RCCI - ( ZI3-Z )**2 )               ANNU1140
```

```
      IF ( RCCI .LT. 0.0 )   TX = -TX                                   ANNU1150
      RI = RACI - RCCI + TX                                             ANNU1160
      IF ( Z-ZI3 )           78,  77,  77                               ANNU1170
   77 RI = RACI                                                         ANNU1180
      JFLAG2 = 4                                                        ANNU1190
   78 A(I) = PI*( R(I)*R(I) - RI*RI )                                   ANNU1200
   80 CONTINUE                                                          ANNU1210
C                                                                       ANNU1220
      ZZ(KN) = ZZ(KNM1) + DELTZ                                         ANNU1230
      A(KN) = PI*( RAC*RAC - RACI*RACI )                                ANNU1240
      AMM = 1.0+ DELAM                                                  ANNU1250
      G1=2.0/(G +1.0)                                                   ANNU1260
      G2 =(G - 1.0)/2.0                                                 ANNU1270
      G3 = (G + 1.0)/(2.0*G - 2.0)                                      ANNU1280
      G4=1.0/G1                                                         ANNU1290
C                                                                       ANNU1300
      DO 90 J = 1,KN                                                    ANNU1310
      AMM = AMM - DELAM                                                 ANNU1320
      AM(J) = AMM                                                       ANNU1330
      AP(J)=(A(1)/AMM)*(G1*(1.0+G2*AMM**2))**G3                         ANNU1340
   90 CONTINUE                                                          ANNU1350
C                                                                       ANNU1360
      DO 100 K = 2,KN                                                   ANNU1370
      CALL INT4(AP(1),AM(1),A(K),AMP(K))                                ANNU1380
      AMP2=AMP(K)**2                                                    ANNU1390
      U2TBL(K)=(G4*AMP2)/(1.0+G2*AMP2)                                  ANNU1400
  100 CONTINUE                                                          ANNU1410
C                                                                       ANNU1420
      DESIRE = AMP(KN)                                                  ANNU1430
      XINT = 0.0                                                        ANNU1440
      NN = KN - 2                                                       ANNU1450
      K = 1                                                             ANNU1460
      IF ( RCTI .EQ. 0.0 )   RCTI = 1.0                                 ANNU1470
      GRAD = SQRT ( G1*(RAT/RCT - RATI/RCTI )/( RAT*RAT - RATI*RATI ) ) ANNU1480
     1*RAT                                                                    *NEW
      PROD = 2.0*XK*DELTZ/3.0                                           ANNU1490
      DO 110 J = 1,NN,2                                                 ANNU1500
      T1 = SQRT(U2TBL(J))                                               ANNU1510
      T2 = SQRT(U2TBL(J+1))                                             ANNU1520
      T3 = SQRT(U2TBL(J+2))                                             ANNU1530
      XINT = XINT + PROD*(T1+4.0*T2+T3)                                 ANNU1540
      K = K + 1                                                         ANNU1550
      XX(K) = -XINT/RAT                                                 ANNU1560
      U2TBL(K-1) = U2TBL(J)                                             ANNU1570
  110 CONTINUE                                                          ANNU1580
      U2TBL(K) = U2TBL(KN)                                              ANNU1590
C**********                                                             ANNU1600
      RETURN                                                            ANNU1610
      END                                                               ANNU1620
```

```
@ ELT SUB21,1,690714, 35957

      SUBROUTINE ADSET(N,F,D,FP,T,X,HA,E)
      DIMENSION F(1),D(1),FP(1),T(8,8),HA(1),E(1),AC(6,3),AD(10),AH(10)
     1,ACC(6)
      EQUIVALENCE (ACC(1),AC(13))
      DATA AC /0.,1.,.5,.416666,.375,.348611,.348611,.651389,.151389,
     1  .068056,.026389,0.,0.,0.,0.,0.,0.,0./
      DATA AD /2.,-1.,0.,0.,4.,-4.,1.,8.,-12.,16./
      DATA AH /.5,.125,.0625,.0390625,.25,.125,.078125,.125,.09375,
     1  .0625/
C
C**** THIS SUBROUTINE WILL INTEGRATE N DIFFERINTIAL EQUATIONS.
C**** THE CALLING SEQUENCE IS AS FOLLOWS.
C****    N IS THE NUMBER OF EQUATIONS
C****    F IS THE ARRAY OF FUNCTIONS
C****    D IS THE ARRAY OF DERIVATIVES OF THE FUNCTIONS F
C****    FP IS THE ARRAY OF THE PARTIAL STEP VALUES OF F AT X = TP
C****    T IS AN ARRAY OF 8*N WORDS
C****    HA IS EITHER AN ARRAY OR A SINGLE WORD
C****       IN EITHER CASE HA(1) IS THE INITIAL STEP SIZE GUESS
C****       IF THE ARRAY FEATURE IS USED THE FOLLOWING CONDITIONS HOLD.
C****       IF HA(2) IS EQUAL TO 1111 THEN STEP SIZE IS LIMITED
C****       HA(3) IS THE LOWEST VALE OF THE STEP SIZE ALLOWED
C****       HA(4) IS THE LARGEST VALUE OF THE STEP SIZE ALLOWED
C****       IF HA(2) IS EQUAL TO 2222 BOTH THE LIMIT AND THE CORRECTED
C****          DERIVATIVES ARE USED
C****       IF HA(2) IS EQUAL TO 3333 ONLY THE CORRECTED DERIVATIVES ARE USED
C****       IF HA(2) IS NOT DEFINED THEN NEITHER ARE USED
      KKF=0
C**** SET FOR NO RECAL OF DERIVATIVES
      HMIN=0.
      IF(HA(1).LT.0.) HMIN=-HMAX
      IF(HA(1).LT.0.) HMAX=0.
      HMAX=1.E30
C**** SET MAX-MIN STEP SIZE
      IF(HA(2).EQ.1111.) GO TO 400
      IF(HA(2).EQ.2222.) GO TO 401
      IF(HA(2).EQ.3333.) KKF=1
403   GO TO 4
400   HMIN=HA(3)
      HMAX=HA(4)
      GO TO 403
401   KKF=1
      GO TO 400
C
C
      ENTRY ADINT
      IENT=1
      IDF=0
      IF(INT.EQ.0) GO TO 20
  21  KF=1
      X=X+H
      GO TO  100
20    H=HA(1)
500   DO 504 I=1,N
      IF(E(I).LT.1.E-9) E(I)=1.E-9
```

```
504   CONTINUE
520   IF(IENT.NE.0) RETURN
      RETURN1
C
      ENTRY ADCOR(*)
      IENT=0
2     IF(INT.EQ.0) GO TO 23
22    IF(KKF.EQ.2) GO TO 34
      DO 41 I=1,N
      T(8,I)= F(I)
  41  T(1,I)=D(I)
      KF=2
      GO TO 100
C
  23  INT=1
      DO 40 I=1,N
      T(7,I) =F(I)
  40  T(2,I) =D(I)
      GO TO 21
C
C     TEST ERROR TERM HERE.
  42  CONTINUE
      IDF=2
      DO  16 I=1,N
      BOT=F(I)
      IF(ABS(BOT).LT.1.E-6) BOT=1.E-6
      ERR=ABS((F(I)-T(8,I))/BOT)
      IF(ERR.LT.E(I)) GO TO 18
  19  IDF =1
      GO TO 500
18    IF(64.*ERR.LT.E(I)) GO TO 16
33    IDF=0
16    CONTINUE
      IF(KKF.NE.0) GO TO 404
C     NEW DIFFERENCES
34    IF(NS.GT.5) NS=5
  12  DO 17  I=1,N
      T(7,I) = F(I)
      TE = D(I)
      DO 15 K=2,NS
      TF = TE -T(K,I)
       T(K,I)=TE
  15  TE =TF
17    T(NS+1,I)=TE
      IF(KKF.NE.0) KKF=1
      NS=NS+1
      IF(IDF.EQ.2) GO TO 25
501    RETURN
C
404   KKF=2
700   RETURN1
C
C     HALF
500   IF(H.LE.HMIN) GO TO 34
502   INT =INT +1
      IF(INT.GE.10) GO TO 34
      X=X-H
  24  H=H/2.
      GO TO 28
```

```
C     DOUBLE
25    INT=1
      IF(2.*H.GE.HMAX) RETURN
510   H=H+H
28    NN=NS-2
      DO 26 I=1,N
      KKK=1
      DO 26 L=1,NN
      TE=0.
      DO 27 K=L,NN
      GO TO (44,45),IDF
  44  TF=AH(KKK)
      GO TO 29
  45  TF =AD(KKK)
29    TE = TE +TF*T(K+2,I)
  27  KKK=KKK+1
  26  T(L+2,I) =TE
      IF(IDF-2)21,501,21
C
      ENTRY ADPAR(TP)
  3   KF = 3
      P= (TP-X) / H
      P2 =P*P
      P3 =P*P2
      P4 = P*P3
      P5 = P*P4
      ACC(2)=P
      ACC(3)=P2/2.
      ACC(4) =(2.*P3+3.*P2)/12.
      ACC(5) =(P4+4.*(P3+P2))/24.
      ACC(6) =(6.*P5 +45.*P4+110.*P3 +90.*P2)/720.
       KF=3
      GO TO 100
C
43    DO 46 I=1,N
46    FP(I) = F(I)
      INT=1                                                    *NEW
      RETURN                                                   **-1
C
      ENTRY ADRES
  4   INT=0
       NS=2
      RETURN
C
C
 100  DO 101 I=1,N
      YT=0.
      DO 102 K=1,NS
 102  YT = YT + AC(K,KF)* T(K,I)
 101  F (I) = YT *H  +  T(7,I)
      GO TO (520,42,43),KF
C
C
      END
```

```
@ ELT SUB22,1,690715, 33520

000001                SUBROUTINE AS138 (C,ITITLE,IERR)
000002          C     THIS ROUTINE PROVIDES A HIGHLY SIMPLIFIED INPUT PROCEDURE WHICH ISCTP  20
000003          C     NON-CARD-COLUMN-ORIENTED.  DEVELOPED AT THE AIR FORCE ROCKET      CTP  30
000004          C     PROPULSION LABORATORY BY RPMMD/CAPT V.L.OLIVIER/553-2819          CTP  40
000005          C     LAST REVISED APRIL 1968                                           CTP  50
000006          C     THE CONTROL CHARACTERS ARE DEFINED AS FOLLOWS**                   CTP  60
000007          C          L ....SPECIFIES A LOCATION NUMBER WILL FOLLOW                CTP  70
000008          C          + OR - AND/OR , ARE USED TO SEPARATE DATA ENTRIES            CTP  80
000009          C          E ....SPECIFIES A POWER OF TEN WILL FOLLOW                   CTP  90
000010          C          T ....TERMINATES THE DATA READ IN AND IS FOLLOWED BY BCD     CTP 100
000011          C                INFORMATION THAT CAN BE PRINTED                        CTP 110
000012          C     BLANKS AND ZEROES PRECEDING A NUMBER ARE IGNORED.                 CTP 120
000013          C                                                                       CTP 130
000014          C     EXAMPLES**            1         2         3         4             CTP 140
000015          C          COLUMN 123456789012345678901234567890123456789012345678 9.....CTP 150
000016          C                    L  0002300,24+-1,++E12,E-2  ,10.001   L12   + ++-1CTP 160
000017          C                 L0+     1     ,1,     100.1E20+L50   ,,     ,        CTP 170
000018          C               T  (T IS THE ONLY CONTROL THAT MUST BE IN COLUMN 1)   CTP 180
000019          C                                                                       CTP 190
000020          C     THE RESULTS ARE STORED IN THE C-ARRAY AND ITITLE AS FOLLOWS**     CTP 200
000021          C          C(2301)=24.                                                  CTP 210
000022          C          C(2302)=0.                                                   CTP 220
000023          C          C(2303)=-1.                                                  CTP 230
000024          C          C(2304)=0.                                                   CTP 240
000025          C          C(2305)=1.E+12                                               CTP 250
000026          C          C(2306)=1.E-02                                               CTP 260
000027          C          C(2307)=10.001                                               CTP 270
000028          C          C(13)=0.                                                     CTP 280
000029          C          C(14)=0.                                                     CTP 290
000030          C          C(15)=0.                                                     CTP 300
000031          C          C(16)=-1.                                                    CTP 310
000032          C          C(1)=1.                                                      CTP 320
000033          C          C(2)=1.                                                      CTP 330
000034          C          C(3)=100.1E+20                                               CTP 340
000035          C          C(51)=0.                                                     CTP 350
000036          C          C(52)=0.                                                     CTP 360
000037          C          C(53)=0.                                                     CTP 370
000038          C          ITITLE=T  (T IS THE ONLY CONTROL THAT MUST BE IN COLUMN 1)   CTP 380
000039          C                                                                       CTP 390
000040                DIMENSION C(1),DCARD(72),SYMB(17),XNUM(16)
000041                DIMENSION IDCARD(72), ITITLE(12), MULT1(6), MASK1(6)              CTP1400
000042                EQUIVALENCE (IDCARD(1),DCARD(1))                                  CTP1410
000043                DATA MULT1/01,0100,010000,01000000,0100000000,010000000000/       CTP1420
000044                DATA MASK1/0,04000000000,040000000,0400000,04000,040/             CTP1430
000045                DATA MASK/0770000000000/,BLNK/6H 00000/                           CTP1440
000046                LOGICAL NUMBER,DECMAL,EXPON,LOCATE                                CTP 410
000047                DATA BLANK,TCARD,SYMB/1H ,1HT,1H1,1H2,1H3,1H4,1H5,1H6,1H7,1H8,1H9,CTP 420
000048               11H0,1H+,1H-,1H,,1H.,1HE,1HL,1H&/                                          *NEW
000049                IERR=1                                                            CTP 440
000050                NUMBER=.TRUE.                                                     CTP 450
000051                DECMAL=.FALSE.                                                    CTP 460
000052                EXPON=.FALSE.                                                     CTP 470
000053                LOCATE=.FALSE.                                                    CTP 480
000054                XSIGN=0.0                                                         CTP 490
000055                LOCN=0                                                            CTP 500
```

```
C                                                                       CTP 510
   10 READ (5,240) DCARD                                                CTP 520
      IF (DCARD(1).EQ.TCARD) GO TO 200                                  CTP 530
      DO 190 I=1,73                                                     CTP 540
      IF (I.EQ.73) GO TO 80                                             CTP 550
      IF (DCARD(I).EQ.BLANK) GO TO 190                                  CTP 560
      DO 20 J=1,17
      IF (DCARD(I).EQ.SYMB(J)) GO TO (40,40,40,40,40,40,40,40,40,30,100,CTP 580 **-1
     160,80,50,70,90,100),J
   20 CONTINUE                                                          CTP 600
      GO TO 230                                                         CTP 610
C                                                                       CTP 620
   30 J=0                                                               CTP 630
      IF (IDIG.EQ.0) GO TO 190                                          CTP 640
C                                                                       CTP 650
   40 IDIG=IDIG+1                                                       CTP 660
      IF (.NOT.DECMAL) NDEC=IDIG-1                                      CTP 670
      XNUM(IDIG)=J                                                      CTP 680
      GO TO 190                                                         CTP 690
C                                                                       CTP 700
   50 IF (DECMAL) GO TO 230                                             CTP 710
      DECMAL=.TRUE.                                                     CTP 720
      IF (IDIG.GT.0) GO TO 190                                          CTP 730
      IDIG=1                                                            CTP 740
      XNUM(1)=0.0                                                       CTP 750
      GO TO 190                                                         CTP 760
C                                                                       CTP 770
   60 KSIGN=-1                                                          CTP 780
      GO TO 100                                                         CTP 790
C                                                                       CTP 800
   70 IF (EXPON) GO TO 230                                              CTP 810
      EXPON=.TRUE.                                                      CTP 820
      NUMBER=.FALSE.                                                    CTP 830
C                                                                       CTP 840
   80 KSIGN=0                                                           CTP 850
      GO TO 110                                                         CTP 860
C                                                                       CTP 870
   90 IF (LOCATE) GO TO 230                                             CTP 880
      LOCATE=.TRUE.                                                     CTP 890
      KSIGN=1                                                           CTP 900
      IF (XSIGN.EQ.0.0.AND.IDIG.EQ.0) GO TO 180                         CTP 910
      NUMBER=.FALSE.                                                    CTP 920
      GO TO 110                                                         CTP 930
C                                                                       CTP 940
  100 IF (XSIGN.EQ.0.0.AND.IDIG.EQ.0) GO TO 180                         CTP 950
C                                                                       CTP 960
  110 X=0.0                                                             CTP 970
      IF (IDIG.EQ.0) GO TO 130                                          CTP 980
      DO 120 K=1,IDIG                                                   CTP 990
      X=X+10.**NDEC*XNUM(K)                                             CTP1000
  120 NDEC=NDEC-1                                                       CTP1010
C                                                                       CTP1020
      IDIG=0                                                            CTP1030
      NDEC=0                                                            CTP1040
      DECMAL=.FALSE.                                                    CTP1050
C                                                                       CTP1060
      IF (XSIGN.LT.0.0) X=-X                                            CTP1070
  130 IF (.NOT.NUMBER) GO TO 140                                        CTP1080
      IF (LOCATE) GO TO 160                                             CTP1090
```

```
000115              IF (EXPON) GO TO 170                                    CTP1100
000116              GO TO 150                                               CTP1110
000117          140 NUMBER=.TRUE.                                           CTP1120
000118              ESIGN=XSIGN                                             CTP1130
000119              IF (ESIGN.EQ.0.0) ESIGN=1.0                             CTP1140
000120        C                                                             CTP1150
000121        C                                                             CTP1160
000122          150 LOCN=LOCN+1                                             CTP1170
000123              C(LOCN)=X                                               CTP1180
000124              GO TO 180                                               CTP1190
000125        C                                                             CTP1200
000126          160 LOCN=ABS(X)                                             CTP1210
000127              LOCATE=.FALSE.                                          CTP1220
000128              GO TO 180                                               CTP1230
000129        C                                                             CTP1240
000130          170 EXPON=.FALSE.                                           CTP1250
000131              IF (C(LOCN).EQ.0.0) C(LOCN)=ESIGN                       CTP1260
000132              C(LOCN)=C(LOCN)*10.**IFIX(X)                            CTP1270
000133        C                                                             CTP1280
000134          180 XSIGN=KSIGN                                             CTP1290
000135              KSIGN=1                                                 CTP1300
000136        C                                                             CTP1310
000137          190 CONTINUE                                                CTP1320
000138        C                                                             CTP1330
000139              GO TO 10                                                CTP1340
000140        C                                                             CTP1350
000141        C                                                             CTP1360
000142        C     THE FOLLOWING LOGIC IS TO PACK THE 'DCARD' DATA INTO 'ITITLE'  CTP1370
000143        C     FOR A 'FORMAT(1X,12A6)' PRINTOUT.                       CTP1380
000144        C                                                             CTP1390
000145          200 DCARD(1)=BLNK                                           CTP1450
000146              L=0                                                     CTP1460
000147              DO 220 I=1,72,6                                         CTP1470
000148              L=L+1                                                   CTP1480
000149              KK=I-1                                                  CTP1490
000150              DO 210 J=1,6                                            CTP1500
000151              K=KK+J                                                  CTP1510
000152              DCARD(K)=AND(IDCARD(K),MASK)                            CTP1520
000153              IF (J.EQ.1) GO TO 210                                   CTP1530
000154              IDCARD(K)=IDCARD(K)/MULT1(J)                            CTP1540
000155              IF (ISIGN(1,IDCARD(K)).LT.0) IDCARD(K)=IABS(IDCARD(K))+MASK1(J)  CTP1550
000156          210 CONTINUE                                                CTP1560
000157          220 ITITLE(L)=IDCARD(I)+ISIGN((IDCARD(I+1)+IDCARD(I+2)+IDCARD(I+3)+IDCCTP1570
000158             1ARD(I+4)+IDCARD(I+5)),IDCARD(I))                        CTP1580
000159              RETURN                                                  CTP1590
000160        C                                                             CTP1600
000161          230 IERR=2                                                  CTP1610
000162              WRITE (6,250) DCARD                                     CTP1620
000163              GO TO 10                                                CTP1630
000164        C                                                             CTP1640
000165        C                                                             CTP1650
000166          240 FORMAT (72A1)                                           CTP1660
000167          250 FORMAT (1X,72A1)                                        CTP1670
000168              END                                                     CTP1680-
```

Subroutine 23 was deleted when the program was revised.

```
@ ELT SUB24,1,690708, 37499

000001                SUBROUTINE  INTGR (A,B,X,N)
000002                X=A
000003                I=1
000004                NL=128*N
000005                RETURN
000006                ENTRY INTGS ($,F,Y,E,M)
000007                GO TO (1,2,3),I
000008          C     FIRST TIME
000009           1    X=B
000010                F0 = F
000011                I=2
000012                RETURN1
000013          C
000014           2    FEND = F+F0
000015                N= ((N+3)/4)*4
000016           20   DX = (B-A) / N
000017                F1=0.
000018                F2=0.
000019                F3=0.
000020                F4=0.
000021                K=1
000022                I=3
000023                X=A+ DX
000024                RETURN1
000025          C
000026           3    KF = MOD(K - 1,4)+1
000027                GO TO (10,11,12,13),KF
000028           10   F1=F1 +F
000029                GO TO 14
000030           11   F2=F2 +F
000031                GO TO 14
000032           12   F3=F3 +F
000033                GO TO 14
000034           13   F4=F4 +F
000035           14   X=X+DX
000036                K=K+1
000037                IF(K.NE.N ) RETURN1
000038                SUM1 = DX/3.*(FEND+ 2.*(F2+F4) + 4.*(F1+F3))
000039                SUM2 = 2*DX/3.*(FEND+ 2.*F4+4.*F2)
000040                ER=  (SUM1-SUM2) /15.
000041                IF(ABS(ER/SUM1).LT.E) GO TO 15
000042                IF(N.GT.NL) GO TO 15
000043                N=2*N
000044                GO TO 20
000045           15   Y=SUM1 + ER
000046                M=N
000047                RETURN
000048                END

END CUR
```

```
@ ELT BESJ,1,690714, 35959

      SUBROUTINE BESJ(X,N,BJ,D,IER)                                     BESJ   1
      BJ=.0                                                             BESJ   2
      IF(N)10,20,20                                                     BESJ   3
   10 IER=1                                                             BESJ   4
      RETURN                                                            BESJ   5
   20 IF(X)30,30,31                                                     BESJ   6
   30 IER=2                                                             BESJ   7
      RETURN                                                            BESJ   8
   31 IF(X-15.)32,32,34                                                 BESJ   9
   32 NTEST=20.+10.*X-X** 2/3                                           BESJ  10
      GO TO 36                                                          BESJ  11
   34 NTEST=90.+X/2.                                                    BESJ  12
   36 IF(N-NTEST)40,38,38                                               BESJ  13
   38 IER=4                                                             BESJ  14
      RETURN                                                            BESJ  15
   40 IER=0                                                             BESJ  16
      N1=N+1                                                            BESJ  17
      BPREV=.0                                                          BESJ  18
C        COMPUTE STARTING VALUE OF M                                    BESJ  19
      IF(X-5.)50,60,60                                                  BESJ  20
   50 MA=X+6.                                                           BESJ  21
      GO TO 70                                                          BESJ  22
   60 MA=1.4*X+60./X                                                    BESJ  23
   70 MB=N+IFIX(X)/4+2                                                  BESJ  24
      MZERO=MA                                                          BESJ  25
      IF(MA-MB)80,90,90                                                 BESJ  26
   80 MZERO=MB                                                          BESJ  27
C        SET UPPER LIMIT OF M                                           BESJ  28
   90 MMAX=NTEST                                                        BESJ  29
  100 DO 190 M=MZERO,MMAX,3                                             BESJ  30
C        SET F(M),F(M-1)                                                BESJ  31
      FM1=1.0E-28                                                       BESJ  32
      FM=.0                                                             BESJ  33
      ALPHA=.0                                                          BESJ  34
      IF(M-(M/2)*2)120,110,120                                          BESJ  35
  110 JT=-1                                                             BESJ  36
      GO TO 130                                                         BESJ  37
  120 JT=1                                                              BESJ  38
  130 M2=M-2                                                            BESJ  39
      DO 160 K=1,M2                                                     BESJ  40
      MK=M-K                                                            BESJ  41
      BMK=2.*FLOAT(MK)*FM1/X-FM                                         BESJ  42
      FM=FM1                                                            BESJ  43
      FM1=BMK                                                           BESJ  44
      IF(MK-N-1)150,140,150                                             BESJ  45
  140 BJ=BMK                                                            BESJ  46
  150 JT=-JT                                                            BESJ  47
      S=1+JT                                                            BESJ  48
  160 ALPHA=ALPHA+BMK*S                                                 BESJ  49
      BMK=2.*FM1/X-FM                                                   BESJ  50
      IF(N)180,170,180                                                  BESJ  51
  170 BJ=BMK                                                            BESJ  52
  180 ALPHA=ALPHA+BMK                                                   BESJ  53
      BJ=BJ/ALPHA                                                       BESJ  54
      IF(ABS(BJ-BPREV)-ABS(D*BJ))200,200,190                            BESJ  55
```

```
000056          190 BPREV=BJ                                    BESJ  56
000057              IER=3                                       BESJ  57
000058          200 RETURN                                      BESJ  58
000059              END                                         BESJ  59
```

```
@ ELT BESSEL,1,690716, 76335

      SUBROUTINE BESSEL(J,Y,V,X,K)
      INTEGER V                                                         *NEW
      REAL J,Y                                                          **-1
      DIMENSION J(1),Y(1)
      D=1.E-6                                                           *NEW
      NV=V+1
      DO 1 I=1,NV
      CALL BESJ(X,I-1,J(I),D,IER )
      IF(IER.NE.0) GO TO 10
      CALL BESY(X,I-1,Y(I),IER)                                         *NEW
      IF(IER.NE.0) GO TO 11                                             **-1
1     CONTINUE
      RETURN
10    WRITE(6,100)X,V
      GO TO 12
11    WRITE(6,101)X,V
12    K=1
      RETURN
100   FORMAT(10X,28HERROR IN BESJ, X AND V ARE. ,2E15.7)
101   FORMAT(10X,28HERROR IN BESY, X AND V ARE. ,2E15.7)
      END
```

@ ELT BESY,1,690714, 35961

```
      SUBROUTINE BESY(X,N,BY,IER)                                       BESY   1
C        CHECK FOR ERRORS IN N AND X                                    BESY   2
      IF(N)180,10,10                                                    BESY   3
   10 IER=0                                                             BESY   4
      IF(X)190,190,20                                                   BESY   5
   20 PI=3.141592653                                                    BESY   6
C        BRANCH IF X LESS THAN OR EQUAL 4                               BESY   7
      IF(X-4.)40,40,30                                                  BESY   8
C       COMPUTE Y0 AND Y1 FOR X GREATER THAN 4                          BESY   9
   30 T=4./X                                                            BESY  10
      P0=.3989422793                                                    BESY  11
      Q0=-.0124669441                                                   BESY  12
      P1=.3989422819                                                    BESY  13
      Q1=.0374008364                                                    BESY  14
      A=T*T                                                             BESY  15
      B=A                                                               BESY  16
      P0=P0-.0017530620*A                                               BESY  17
      Q0=Q0+.0004564324*A                                               BESY  18
      P1=P1+.0029218256*A                                               BESY  19
      Q1=Q1-.00063904*A                                                 BESY  20
      A=A*A                                                             BESY  21
      P0=P0+.00017343*A                                                 BESY  22
      Q0=Q0-.0000869791*A                                               BESY  23
      P1=P1-.000223203*A                                                BESY  24
      Q1=Q1+.0001064741*A                                               BESY  25
      A=A*B                                                             BESY  26
      P0=P0-.0000487613*A                                               BESY  27
      Q0=Q0+.0000342468*A                                               BESY  28
      P1=P1+.0000580759*A                                               BESY  29
      Q1=Q1-.0000398708*A                                               BESY  30
      A=A*B                                                             BESY  31
      P0=P0+.0000173565*A                                               BESY  32
      Q0=Q0-.0000142078*A                                               BESY  33
      P1=P1-.000020092*A                                                BESY  34
      Q1=Q1+.00001622*A                                                 BESY  35
      A=A*B                                                             BESY  36
      P0=P0-.0000037043*A                                               BESY  37
      Q0=Q0+.0000032312*A                                               BESY  38
      P1=P1+.0000042414*A                                               BESY  39
      Q1=Q1-.0000036594*A                                               BESY  40
      A=SQRT(2.*PI)                                                     BESY  41
      B=4.*A                                                            BESY  42
      P0=A*P0                                                           BESY  43
      Q0=B*Q0/X                                                         BESY  44
      P1=A*P1                                                           BESY  45
      Q1=B*Q1/X                                                         BESY  46
      A=X-PI/4.                                                         BESY  47
      B=SQRT(2./(PI*X))                                                 BESY  48
      Y0=B*(P0*SIN(A)+Q0*COS(A))                                        BESY  49
      Y1=B*(-P1*COS(A)+Q1*SIN(A))                                       BESY  50
      GO TO 90                                                          BESY  51
C       COMPUTE Y0 AND Y1 FOR X LESS THAN OR EQUAL TO 4                 BESY  52
   40 XX=X/2.                                                           BESY  53
      X2=XX*XX                                                          BESY  54
      T=ALOG(XX)+.5772156649                                            BESY  55
```

```
000056          SUM=0.                                                  BESY  56
000057          TERM=T                                                  BESY  57
000058          Y0=T                                                    BESY  58
000059          DO 70 L=1,15                                            BESY  59
000060          IF(L-1)50,60,50                                         BESY  60
000061       50 SUM=SUM+1./FLOAT(L-1)                                   BESY  61
000062       60 FL=L                                                    BESY  62
000063          TS=T-SUM                                                BESY  63
000064          TERM=(TERM*(-X2)/FL**2)*(1.-1./(FL*TS))                 BESY  64
000065       70 Y0=Y0+TERM                                              BESY  65
000066          TERM = XX*(T-.5)                                        BESY  66
000067          SUM=0.                                                  BESY  67
000068          Y1=TERM                                                 BESY  68
000069          DO 80 L=2,16                                            BESY  69
000070          SUM=SUM+1./FLOAT(L-1)                                   BESY  70
000071          FL=L                                                    BESY  71
000072          FL1=FL-1.                                               BESY  72
000073          TS=T-SUM                                                BESY  73
000074          TERM=(TERM*(-X2)/(FL1*FL))*((TS-.5/FL)/(TS+.5/FL1))     BESY  74
000075       80 Y1=Y1+TERM                                              BESY  75
000076          PI2=2./PI                                               BESY  76
000077          Y0=PI2*Y0                                               BESY  77
000078          Y1=-PI2/X+PI2*Y1                                        BESY  78
000079    C        CHECK IF ONLY Y0 OR Y1 IS DESIRED                    BESY  79
000080       90 IF(N-1)100,100,130                                      BESY  80
000081    C        RETURN EITHER Y0 OR Y1 AS REQUIRED                   BESY  81
000082      100 IF(N)110,120,110                                        BESY  82
000083      110 BY=Y1                                                   BESY  83
000084          GO TO 170                                               BESY  84
000085      120 BY=Y0                                                   BESY  85
000086          GO TO 170                                               BESY  86
000087    C       PERFORM RECURRENCE OPERATIONS TO FIND YN(X)           BESY  87
000088      130 YA=Y0                                                   BESY  88
000089          YB=Y1                                                   BESY  89
000090          K=1                                                     BESY  90
000091      140 T=FLOAT(2*K)/X                                          BESY  91
000092          YC=T*YB-YA                                              BESY  92
000093          K=K+1                                                   BESY  93
000094          IF(K-N)150,160,150                                      BESY  94
000095      150 YA=YB                                                   BESY  95
000096          YB=YC                                                   BESY  96
000097          GO TO 140                                               BESY  97
000098      160 BY=YC                                                   BESY  98
000099      170 RETURN                                                  BESY  99
000100      180 IER=1                                                   BESY 100
000101          RETURN                                                  BESY 101
000102      190 IER=2                                                   BESY 102
000103          RETURN                                                  BESY 103
000104          END                                                     BESY 104
```

II, Programming (cont.)

D. METHODS OF VERIFICATION

For most sections of this program, the only method of verification is the "reasonableness" of the numbers output. This is a nebulous statement and the only way an engineer can know what is reasonable is from experience with the sensitive time lag theory and its application. There are some guidelines that can be given, however, that may help those new to the program.

1. If $A_{\nu\eta}$, $B_{\nu\eta}$, and $C_{\nu\eta}$ are 1.0, the n minimum will be on the order of 0.5 to 1.0. It will always be positive.

2. The frequency of the n minimum is near the acoustic mode frequency of a cylinder. This frequency is given in a formula on Figure 2.

3. The calculation of $A_{\nu\eta}$, $B_{\nu\eta}$, and $C_{\nu\eta}$ can be checked by running a case with combustion concentrated at a particular location. The answer can then be easily checked using the formulas in Section I,B,(5) and Figure 8.

4. When τ at n minimum is given in seconds, it can be converted to an equivalent frequency by the relation $\tau^* = \frac{1}{2f^*}$.

5. The test cases given in this manual are a convenient reference to establish whether the program and computer are working correctly.

Section III, Deck Setup

Section III Deck Setup

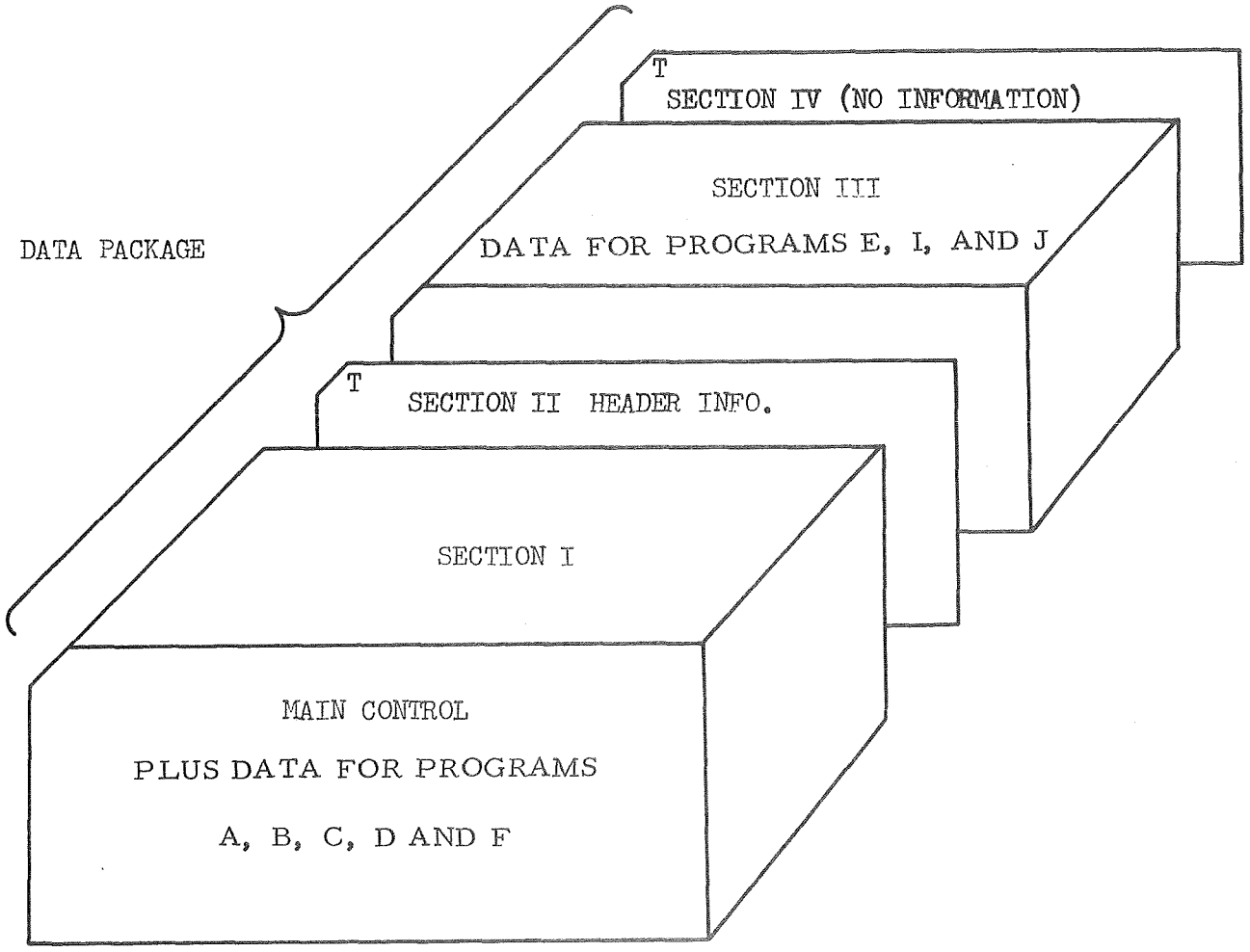
A. COMPUTER CONFIGURATION

1. Univac 1108 computer, 65K of core minimum
2. 46211_8 for code, 72245_8 for data
3. FORTRAN V
4. Executive II monitor system
5. No plot output required
6. No punch output required
7. Units 12, 13, 14 are used for temporary storage.

B. ESTIMATED RUNNING TIME

Because of the extremely large number of ways of running this program, it would be very difficult to give a formula for running time. As a guide, the sample case given in Section III,L ran in 2.06 minutes. The nozzle admittance calculation is the single most time consuming portion of the program.

III, Deck Setup (cont.)



IF SECTION III IS NOT USED, SECTION IV MUST NOT BE USED.

Figure 18 -- Input Load Sequence Required by the Computer Program

III, Deck Setup (cont.)

C. DECK SEQUENCE

It is necessary to discuss the general organization of the data as well as how the data actually get into the computer before proceeding with any further discussion of the computer program. Hereafter, the input data deck will be referred to as a set of data packages.

The manner in which the data deck is assembled is shown in Figure 18. It can be seen that the data package (one package required per case), is divided into four sections. The first section contains the data for MAIN CONTROL and for Programs A, B, C, D and F. The second section is one card that has the letter T punched in card column one. This card serves the purpose of an end-data signal and of a header card such that all information that follows the T will be printed on the top of each output page. The third section contains the data for Programs E, I, and J. The fourth section is a T-card that is used only to signal the end of that data.

It should be noted that if neither E, I, or J are run, Sections III and IV are not needed. However, Sections I and II must always be on the data package.

Running Multiple Cases

The flexibility of the program is such that stacking cases (i.e., running multiple cases) is an easy task. All that is required is to add the required number of data packages to the data deck. There is no restriction as to the flow paths of individual data packages; therefore, data packages of parametric studies involving the use of one program can be intermingled with data packages that use any of the other program combinations for an analysis.

III, C, Deck Sequence (cont.)

Getting the Data Onto the Card

The inputting of the data is accomplished in a flexible fashion. The method employed is called scatter load.* This method has a minimum number of restrictions as to how and in what manner the data are punched on the card. Examples are given below that will illustrate the flexibility of scatter load.

Load and Terminal Flags

The first thing that must be punched on a card is the letter L or the letter T. The L signals the computer that data are on the card whereas the T signifies that the computer has received all of the data for that section of the data package.

Data Input

Immediately after the L will appear 1 to 4 numbers; therefore, the card thus far has been punched with L followed by 4 digits, e.g., L4175. This tells the computer to start loading the data that will follow into computer core starting at Location 4175. Following this number will be a plus or minus sign and data, another plus or minus sign and data, etc. Since the signs serve to separate the data, the second data point will automatically be loaded into core location 4176. This process continues across the first 72 columns of the data card.

Consider the following example of input data

*Except for the input to main control.

III, C, Deck Sequence (cont.)

L0 + 10.0
L1 + 19.4
L2 + 0.0
L3 - 0.92
L8 + 6.4

This may be punched on a single card as

(Example 1) L0 + 10.0 + 19.4 + 0.0 - 0.92 L8 + 6.4
(Example 2) L0 + 10.0 + 19.4 + -0.92 + + + + + 6.4
(Example 3) L8 + 6.4 L0 + 10.0 + 19.4 + -0.92
(Example 4) L39 + 0.21 + 3.14 + 5.0 + 1.5 -35.5 L39 1545.

Example 1 illustrates a normal load sequence for the given input. No data are transferred into core locations L4 thru L7; therefore, any previous data stored there remains there. Example 2 illustrates how algebraic signs can be used to index the core location to the proper station. Note also the L2, which is identically zero, has no number punched on the card. This illustrates that the computer, when it sees no number following the sign, loads the value of zero into that core location. If data have been previously stored in Locations L4 thru L7 and are to be used again, the use of indexing presented in Example 2 will load zeros into those core locations; consequently, the data will be lost.

Example 3 illustrates that the L-numbers do not have to be punched in sequential order. Example 4 illustrates the method of correcting data. Specifically, L39 was initially loaded with 0.21 and later loaded with 1545.0; therefore, the former number is erased on core and the latter included in its place. The most convenient method for correcting data cards is to punch all the corrections on one or more cards and place these cards immediately before the T-card of that data section.

III, C, Deck Sequence (cont.)

Presented below are some basic rules to employ when punching data cards:

1. DO start each input card with L. The L does not have to be punched in card column 1 but it must appear before the data.

2. DO pay close attention to the sequence of the remaining data included on the card so that data are not loaded into the wrong core location.

3. DO NOT use more than 8 significant digits (including decimal point) for the input data. Exponential notion is permitted. That is, the number 0.0625 can be loaded as 6.25 E-02.

4. DO NOT start the data on one card and complete it on another.

5. DO NOT use more than 72 card columns for data input. The computer looks at 73 to 80 but does not transfer that information to core. Therefore, columns 73 and 80 can be used for the card sequence number in the data deck or identification of some significant aspect of the data so that it can be identified at some later date.

6. DO include a T-card at the end of a data section in the data package. The T must be punched in card column 1. If the T appears anywhere else on the card, the computer will dump the entire run.

7. DO include a description of the case on the T-card of Section 2. This information serves as a header for each output page. This is a convenience more than a necessity.

III, C, Deck Sequence (cont.)

8. DO NOT use two or more T cards for a header. This can confuse the computer's input logic.

Thus far the storage locations for the individual data bits have not been noted. They will be provided in Section III,E. It is sufficient to state here that the input data have reserved locations in core and that these data remain in those locations unless over-written by the next set of input data. Therefore, it is not necessary to input all the data on the next run if only one parameter (e.g., the ratio of the specific heats)is to be changed. Only the data that changes from one case to the next have to be input on successive data packages (except for main control).

Operation of MAIN CONTROL

Since the computer obeys every command explicitly, it is necessary to indicate correctly to the computer the programs that are desired for a particular case. Furthermore, this must be done for every case because the computer will turn off the switch that activated the program after it is through with the program. This is done purposely to avoid using a program that is not needed for the second case.

The first 10 core locations are reserved for MAIN CONTROL in the following order:

L0: Program A, Longitudinal Mode Chamber Analysis and Stability Zones

L1: Program B, Transverse Mode Chamber Analysis

L2: Program C, Exhaust Nozzle Admittance Coefficients for Longitudinal and Transverse Modes

III, C, Deck Sequence (cont.)

L3: Program D, Expansion of Results from Program B.
L4: Program E, Injector Nonuniformity Coefficients
L5: Program F, Final Solution of Instability Zones
L6: Program G, Not used in this package
L7: Program H, High Combustion Chamber Mach Number Analysis
L8: Program I, Nonlinear Combustion Response Analysis
L9: Program J, Injected Mass Distribution Effects

A zero in any of the locations indicates that this program will not be used. A number greater than zero instructs the computer to execute this program at the time it is required. The program knows when to execute the program and a number in the proper place tells the computer whether or not to execute the program.

Program Options

Most programs have various options concerning the desired output to be printed. These options are exercised by the same control number that executes the program and are keyed by the magnitude of the number. These print options are presented in the discussion of the individual programs. However, a few examples are presented here to illustrate this point:

EXAMPLE 1: EXECUTE PROGRAM C - PRINT NO OUTPUT

LO + + + 9.0 + + + + + + (0<L2≤9.0)

EXAMPLE 2: EXECUTE PROGRAM C - PRINT OUTPUT

LO + + + 99.0 + + + + + + + (10<L2 ≤ 99.0)

III, C, Deck Sequence (cont.)

EXAMPLE 3: EXECUTE PROGRAM C - PRINT INPUT AND OUTPUT

LO + + + 199.0 + + + + + + + + (100 < L2 $\leq$ 199.0)

Determination of Design Criteria

Table III shows the program combinations that are required to obtain stability maps for the longitudinal and transverse modes and to make certain parameter studies.

TABLE III

PROGRAM COMBINATIONS FOR DESIGN CRITERIA

Desired Output	Critical Data Requirements		Required Program
n, τ Map for Longitudinal Modes	Nozzle Admittance Coefficient, α_N	Known	A
		Not Known	A, C
n, τ Map for Transverse Modes	Nozzle Admittance Coefficients, A, B, C,	A, B, C Known	B, F
		One not known	B, C, F
	Non Uniformity Coefficients, $A_{\nu\eta}$, $B_{\nu\eta}$, $C_{\nu\eta}$	All Known	B, F
		One not known	B, E, F
	Number of Data Points	10 Sufficient	B, F
		More than 10 required	B, D, F
	Nozzle Effects		C
	Variation of Nonuniformity Effects with Respect to Mass Distribution		J, E
Parameter Studies	Variation of Nonuniformity Effects with Respect to Nonlinear Combustion Response		I, E
	Variation of Stability Zones with Respect to Nozzle Effects		A, C or B,C,D,F
	Variation of Stability Zones with Respect to Nonuniformity Coefficients		B,D,E,F

D. INPUT DATA

PROGRAM INDEX

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III, Deck Setup (cont.)

D. INPUT DATA

1. Program A: Longitudinal Mode Chamber Analysis and Instability Zones

a. Input Requirements: the following data go into Section I of data package.

Core Location	Mnemonic	Description
L0	-	Make greater than zero to execute Program A.
L10	γ	Ratio of the specific heats.
L11	M_e	Steady-state Mach number at the entrance to the exhaust nozzle. This can be determined by the contraction ratio or by Program C. In the latter case, leave L11 blank.
L13	r_c*	Chamber radius, in. also loaded in L3804, Program C.
L14	L_c*	Length of cylindrical portion of chamber, in.
L15	c_o*	Speed of sound in the chamber, ft/sec.
L16	$\bar{u}^*_{LO}$	Weighted liquid injection velocity, ft/sec. See equation (56) at the end of this section.
L17	κ	Gas/liquid momentum interchange coefficient. (κ = 0 for no droplet momentum effects)
L20	$s_{\nu\eta}$	Set equal to zero.
L21	$N_{\omega c}$	Number of chamber frequencies to be used. Leaving this column blank will turn on Program GENMEC which will select 10 frequencies according to the relationship given by Eq. (57).
L22 . . . . . L49	ω	Table of nondimensional, chamber frequencies arranged in ascending order. A zero must be included at the end of the table. The maximum number of frequencies is 28 (including the zero point). This is left blank if L21 is blank.

III, D, Input Data (cont.)

Core Location	Mnemonic	Description
L50 . . . L69	Z*	Table of ascending axial positions at which the combustion distribution (i.e., the variation of the local Mach number with respect to Z) is known. Dimensioned in inches. A zero value must appear at the last point. Minimum of four real data points is required.
L70 . . . L89	M(Z*)	The local steady-state Mach number that corresponds to the given L_z. A zero must appear as the last value.
L600 . . . . L629	ω	The ascending table of chamber frequencies for which the longitudinal, real and imaginary parts of the nozzle admittance coefficients (to be input next) are known. If Program C is run to determine the admittances, these frequencies will be automatically transferred. The last point in the table must be zero.
L630 . . . L659	α_{Nr}	The real part of the admittances corresponding to the above frequencies. The last point in the table must be zero. These can be determined by running Program C.
L660 . . . L689	α_{Ni}	The imaginary part of the admittances corresponding to the above frequencies. The last point in the table must be zero. These can be determined by running Program C.

b. Print Options

There are no print options available with this program. Any LO number greater than zero will give a program execution as well as an output of the input data and the results of the program.

c. Placement of the Data into the Data Package

These data are inserted anywhere in Section I of the data package.

III, D, Input Data (cont.)

d. Output

The following output results from the efforts of this program:

Label in Output	Symbol in Analysis
GAMMA	γ
DESIRED MACH NUMBER	M_e
CHAMBER RADIUS	R^*_{AC}
CHAMBER LENGTH	L^*_c
SPEED OF SOUND	c^*_o
CHAMBER MODE DESCRIPTION	$s_{\nu\eta}$
MACH DISTRIBUTION	$M(Z^*)$
UIBAR	M_e
K	κ
X	ξ_1
FC(CPS)	f^*
OMEGA	ω
TAU (MS)	τ^*
N	
ULM	$\bar{u}^*_{LO}$
WC	ω

III, D, Input Data (cont.)

e. Auxiliary Equations

(1) Axial Liquid Velocity (Weighted)

$$\bar{u}^*_{LO} = \frac{(MR)\nu_x \cos\theta_x + \nu_F \cos\theta_F}{MR+1}, \text{ ft/sec} \qquad (56)$$

MR = mixture ratio = $\dot{w}_x/\dot{w}_F$

ν_x = oxidizer injection velocity, ft/sec

ν_F = fuel injection velocity, ft/sec

$\theta_{x,F}$ = oxidizer and fuel impingement angle

(2) Selection of Frequencies by GENMEG

$$\begin{aligned} \text{(Longitudinal)} &= (1 \pm 0.10)\ \pi \\ \text{(Transverse)} &= (1 \pm 0.10)\ s_{\nu\eta} \end{aligned} \qquad (57)$$

where

π = 3.14159 + = resonant frequency (non-dimensional) for longitudinal modes

$s_{\nu\eta}$ = transverse acoustic mode number given in the Program B writeup.

(3) Other Information

For a longitudinal mode a resonant frequency of π is true for a very short nozzle. It may be necessary to override GENMEG to find an n minimum. Also GENMEG gives only the first mode. Other modes can be obtained by specifying the frequencies to be run.

III, D, Input Data (cont.)

2. Program B: Transverse Mode Chamber Analysis

a. Input Requirements: the following data go into Section I of the data package.

Core Location	Mnemonic	Description
L1	-	Execute Program B. Magnitude of number depends on print options given in Paragraph b.
L20	$s_{\nu\eta}$	Transverse acoustic mode number given for various modes at the end of this section for cylindrical chambers. For annular chambers, see Figure 9.
L10 ⋮ L89		These are identical to Program A. Refer to the writeup of Program A for these requirements.
L3017	N_ω	The number of input frequencies at which the transverse nozzle admittance coefficients are known. This number must be greater than 2 and less than 30. If the admittance for a nozzle is unknown and Program C is run, C will provide this number
L3019 ⋮ L3048	ω	The values of the chamber frequencies, arranged in ascending order, for which the transverse admittances are known. Program C will provide them if it is run. The last value must be zero.
L3049 ⋮ L3078	E_r	The values of the real part of the transverse nozzle admittance coefficient. The last value must be zero. Program C will supply these values.
L3079 ⋮ L3108	E_i	The values of the imaginary part of the transverse nozzle admittance coefficient. The last value <u>must</u> be zero. Program C will supply these values.

b. Print Options

$0 < L1 \leq 9$: Execute B, do not print input or output

$10 \leq L1 \leq 99$: Execute B, print output

III, D, Input Data (cont.)

$100 \leq L1 \leq 199$: Execute B, print input and output (recommended)

$200 \leq L1 \leq 299$: Execute B, print input and output, print steady state tables and values of integrals associated with high Mach number cases.

c. Placement of the Data into the Data Package

These data are inserted anywhere in Section I of the data package.

d. Output

Label in Output	Symbol in Analysis
GAMMA	γ
DESIRED MACH NUMBER	M_e
CHAMBER RADIUS	R^*_{AC}
CHAMBER LENGTH	L^*_c
SPEED OF SOUND	c^*_o
CHAMBER MODE DESCRIPTION	$s_{\nu\eta}$
CHAMBER FREQUENCIES	ω
WC	ω
MACH DISTRIBUTION	$M(Z^*)$
SNH	$s_{\nu\eta}$
ZE	L_c
UE	M_e
SOUND	c^*_o

III, D, Input Data (cont.)

Label In Output	Symbol in Analysis
ULM	$\bar{u}^*_{LO}$
XK	κ
OMEGA (CH)	ω
ERT	E_r
EIT	E_i
H REAL	h_r
H IMAG	h_i

e. Tabulation of Transverse Acoustic Mode Number ($s_{\nu\eta}$)

(1) Tangential Modes

First tangential: $s_{11} = 1.8413$
Second tangential: $s_{21} = 3.0543$
Third tangential: $s_{31} = 4.2012$
Fourth tangential: $s_{41} = 5.3175$
Fifth tangential: $s_{51} = 6.4154$

(2) Radial Modes

First radial: $s_{02} = 3.8317$
Second radial: $s_{03} = 7.0156$
Third radial: $s_{04} = 10.1734$

(3) Combined tangential-radial modes

IT-1R: $s_{12} = 5.3313$
IT-2R: $s_{13} = 8.5263$
IT-3R: $s_{14} = 11.7059$

III, D, Input Data (cont.)

2T-1R:	s_{22}	=	6.7060
2T-2R:	s_{23}	=	9.9695
2T-3R:	s_{24}	=	13.1705
3T-1R:	s_{32}	=	8.0151
3T-2R:	s_{33}	=	11.3459
3T-3R:	s_{34}	=	14.5858

3. Program C: Exhaust Nozzle Admittance Coefficients for Longitudinal and Transverse Modes

a. Input Requirements: The following data go into Section I of the data package.

Core Location	Mnemonic	Description
L3801	M	= 1.: the table of velocity potential values within the nozzle is input and the Mach number to the entrance of the nozzle is input. = 2.: the Mach number at the entrance to the nozzle is input but the velocity potential table must be calculated. = 3.: the Mach number and the velocity potential table must be calculated.
L3803	R^*_{ATO}	Radius of the throat, in.
L3804	R^*_{ACO}	Radius of the chamber, in., also loaded in L13, Program A.
L3805	R^*_{CCO}	Radius of chamber curvature at the nozzle entrance, in.
L3806	R^*_{CTO}	Radius of curvature at the throat, in.
L3807	α_o	Nozzle convergent half-angle, deg.
L90*	R^*_{ATi}	Radius of centerbody throat, in.
L91*	R^*_{CTi}	Radius of curvature of the centerbody throat, in.

*Note 1: These values may be plus or minus, see Figures 14 and 15.
Note 2: For cylindrical chambers, leave L90 through L94 blank.

III, D, Input Data (cont.)

Core Location	Mnemonic	Description Description
L92*	R^*_{ACi}	Radius of chamber of centerbody, in.
L93*	R^*_{CCi}	Radius of curvature of centerbody at the nozzle entrance.
L94*	α_i	Centerbody nozzle convergent half-angle, deg.
L20	$s_{\nu\eta}$	Transverse acoustic mode number is given on the previous page for cylindrical chambers. For annular chambers see Table 1, Section I,B.
L3808	KN	If L3801 $\geq$ 2, then KN is either (1) An odd integer less than 200 telling the desired size of the program generated velocity potential table, or (2) Blank and program will assume K_N = 101 (recommended)
L3809 L3811 L3813 . L4205	$\phi(Z)$	Dimensionaless velocity potential table (199 values maximum) in the odd numbered locations only. If L3801 $\geq$ 2, this is not necessary.
L3810 L3812 L3814 . L4206	$\bar{q}^2(Z)$	Squares of the reduced velocity table (199 values maximum) in the even numbered locations only. If L3801 $\geq$ 2, this not necessary.

*Note 1: These values may be plus or minus, see Figures 14 and 15.
Note 2: For cylindrical chambers, leave L90 through L94 blank.

When this program is run by itself the frequencies to be run must either be input or generated by GENMEG. As discussed later this admittance calculation is done for every other input or generated frequency. To run Program C by itself the above data must be supplemented as follows.

Core Location	Mnemonic	Description
L10	γ	Ratio of specific heats
L11	M_e	Steady state Mach number at the entrance to the nozzle. Not needed if L3801 is 3.

III, D, Input Data (cont.)

Core Location	Mnemonic	Description
L13	r_c^*	Chamber radius, in.
L14	L_c^*	Chamber length, in.
L15	c_o^*	Speed of sound in the chamber, ft/sec.
L21	$N_{\omega c}$	Number of chamber frequencies to be used leaving this column blank will turn on Program GENMEG. Admittances will actually be calculated for every other frequency as discussed later.
L22 · L49	ω	Table of non-dimensional chamber frequencies arranged in ascending order. Last point must be zero.

b. Print Options

$0 < L2 \leq 9$:	Execute Program C, print no output
$10 \leq L2 \leq 99$:	Execute Program C, print output
$100 \leq L2 \leq 199$:	Execute Program C, print input and output (recommended)
$200 \leq L2 \leq 299$:	Execute Program C, print input and output, and print the nondimensional velocity potential table.

c. Placement of the Data in the Data Package

This data is inserted anywhere in Section I of the data package.

d. Output

Label In Output	Symbol In Analysis
(SNH)C	$s_{\nu\eta}$
(SNH)N	$\hat{s}_{\nu\eta}$
WC	ω
WN	$\hat{\omega}$

III, D, Input Data (cont.)

Label In Output	Symbol In Analysis
MACH NO.	M_e
G	γ
AR	A_r
AI	A_i
-AR/(MACH NO.)	α_{Nr}
-AI/(MACH NO.)	α_{Ni}
BR	B_r
BI	B_i
T1	E_r
T2	E_i
CR	C_r
CI	C_i
-CR/(MACH NO.)	β_{Nr}
-CI/(MACH NO.)	β_{Ni}
FC (CPS)	f*

e. Auxiliary Equations

(1) The Selection of the Chamber Frequencies to be Used

Because of the long execution time of this program for a given value of ω, the program starts with the first chamber frequency and uses every other frequency thereafter; that is, if n is the total number of chamber frequencies, Program C will use m number of frequencies according to the relationship

III, D, Input Data (cont.)

$$m = \frac{n}{2} + 1$$

In computer language, m and n are whole numbers.

Therefore, if n = 11

$$m = \frac{11}{2} + 1$$

$$m = 5 + 1 \text{ (where 0.5 has been truncated out)}$$

$$m = 6$$

(2) Nondimensional chamber frequency

$$\omega = \frac{(2\pi f^*)\ (\nu^*_{AC})}{c^*_o} \tag{58}$$

where

$*$ = denotes dimensional variables
subscript c denotes chamber conditions

f^* = chamber frequency, cps

c^*_o = chamber speed of sound ft/sec

ν_{AC} = chamber length L^*_c or radius r^*_c (depending if longitudinal or transverse modes respectively are desired).

(3) Nondimensional nozzle frequency

$$\hat{\omega} = \frac{\omega}{\hat{\kappa}} \tag{59}$$

where

$$\hat{\kappa} = R^*_{ATO}\left[\frac{2}{\gamma+1}\left(\frac{R^*_{ATo}}{R^*_{CTo}} - \frac{R^*_{ATi}}{R^*_{CTi}}\right)\Big/\left(R^{*\,2}_{ATo} - R^{*\,2}_{ATi}\right)\right]^{1/2}$$

(4) Nozzle transverse acoustic nozzle number

$$\hat{s}_{\nu\eta} = \frac{s_{\nu\eta}}{\hat{\kappa}} \tag{60}$$

III, D, Input Data (cont.)

4. Program D: Expansion of Results from Program B

a. Input Requirements

The following data go into Section of the data package:

Core Location	Mnemonic	Description
L3		Must be greater than zero to run this program,
L3405	$1_r/\eta$	The ratio of the radial velocity coefficient to the pressure interaction index. Generally set equal to zero.
L3406	$1_\theta/\eta$	The ratio of the tangential velocity coefficient to the pressure interaction index. Generally set equal to zero.
L3407		= 1 for linear combustion response. >1 for nonlinear combustion response. This parameter indicates the number of frequencies for which the injector nonuniformity coefficients, $A_{\nu\eta}$, $B_{\nu\eta}$, and $C_{\nu\eta}$, are known. The running of Program I will determine this number. (Not required if Program B is run.)
L3408		The number of chamber frequencies (Not required if Program B is run.)
L3409 ⋮ L3437	ω	The table of frequencies arranged in ascending order. The last value must be zero. (Not required if Program B is run.)
L3439 ⋮ L3467	$h_r(\omega)$	Real part of the damping effects computed in Program B. The last value must be zero. (Not required if Program B is run.)
L3469 ⋮ L3497	$h_i(\omega)$	Imaginary part of the damping effects computed in Program B. The last value must be zero. (Not required if Program B is run.)
L4522 ⋮ L4538	ω	The values of chamber frequencies for which the nonuniformity coefficients are known. Use only if data are available.

III, D, Input Data (cont.)

Core Location	Mnemonic	Description
L4539 ⋮ L4555	$A_{\nu\eta}$	The pressure nonuniformity coefficient corresponding to the above frequencies (ω). $A_{\nu\eta}$ = 1.0 for uniform injection distribution.
L4556 ⋮ L4572		The radial velocity nonuniformity coefficient corresponding to the above frequencies ω. Generally set equal to zero.
L4573 ⋮ L4589	$C_{\nu\eta}$ R	The real part of the tangential velocity nonuniformity coefficient corresponding to the above frequencies ω. Generally set equal to zero.
L4590 ⋮ L4606	$C_{\nu\eta}$ i	The imaginary part of the tangential velocity non-uniformity coefficient corresponding to the above frequencies ω. Generally set equal to zero.

NOTES: a. All these data, with the exception of l_r/η and l_θ/η, can be calculated using Programs B, E, and I.

b. This program was constructed specifically to include the effects of the nonunfiromity coefficients for the low Mach number cases.

b. Print Options

$0 < L3 \leq 9$:	Execute D, print no output or input
$10 \leq L3 \leq 99$:	Execute D, print output only
$100 \leq L3 \leq 199$:	Execute D, print input and output

c. Placement of the Data into the Data Package

These data can be inserted anywhere in Section I of the data package.

III, D, Input Data (cont.)

d. Output

Label on Output	Symbol in Analysis
LR/N	$\frac{l_r}{n}$
LT/N	$\frac{l_\theta}{n}$
ERT	E_r
EIT	E_i
CRT	C_r
CIT	C_i
OMEGA (C)	ω
OMEGA (CH)	ω
HTR	$\tilde{h}_r$
HTI	$\tilde{h}_i$
HTRINT	$\tilde{h}_r$ (interpolated)
HTIINT	$\tilde{h}_i$ (interpolated)
OMEGA	ω

5. Program E: Injector Nonuniformity Coefficients: $A_{\nu\eta}$, $B_{\nu\eta}$, $C_{\nu\eta}$

a. Input Requirements (not programmed for annular chambers)

MAIN CONTROL requires L4 in Section I of data package. The remaining data go into Section III of the data package.

III, D, Input Data (cont.)

Core Location	Mnemonic	Description
L1	IZZIT	Indicates whether the mode is standing or spinning: Standing: IZZIT <0 Spinning: IZZIT >0
L2	X_M	The number of radial divisions desired on the injector face ($10 \leq X_M \leq 21$).
L3	X_N	The number of angular divisions desired around the injector face ($20 \leq X_N \leq 181$).
L4	SECTOR	The number of symmetrical sectors that the injector can be divided into, ($1 \leq$ SECTOR ≤ 180).
L5	ν	Order of transverse mode in tangential direction 1, 2, 3, etc. For radial modes $\nu = 0$.
L7	$s_{\nu\eta}$	Transverse acoustic mode number given by tabulation presented in Program B write-up.
L9573	R_{inj}	Injector radius, in.
L9570	NE	Number of elements per symmetrical sector. The maximum number of elements is 1000. Ignore if Program J is run.
L1920 ⋮ L2919	r	The radial position of each element within the symmetrical sector, in. Program J supplies these data when they are run.
L2920 ⋮ L3919	θ	The angular displacement (from any convenient reference line on the injector face) of each element within the symmetrical sector, radians. Program J supplies these data when they are run.
L3920 ⋮ L4919	μ	The element injection distribution given by equation (6) at the end of this section. Usually Program J provides this information to Program E.

III, D, Input Data (cont.)

b. Print Options

$0 \leq L4 \leq 9$: Execute E, do not print input or output

$10 \leq L4 \leq 99$: Execute E, print output only

$100 \leq L4 \leq 199$: Execute E, print input and output

c. Placement of the Data into the Data Package

Main control data: Section I of data package.

All other data: Section III of data package. Section IV must be included in the data package.

d. Output

Label on Output	Symbol in Analysis
AVN	$A_{\nu\eta}$
BVN	$B_{\nu\eta}$
CVN	$C_{\nu\eta}$
MU	μ

e. Auxiliary Equations

Distribution coefficient, μ_E

$$\mu_E = \frac{(\dot{w}_{T_s})_E/(A_s)_E}{\dot{w}_T/A_{inj}} = \left(\frac{1}{x_M \cdot x_N}\right)^{-1} \frac{(W_T)_E}{\dot{w}_T} \qquad (6)$$

III, D, Input Data (cont.)

where

$(w_T)_E$ = total weight flow rate of element, lb/sec

w_T = total weight flow rate of injector, lb/sec

$(A_s)_E$ = surface area serviced by the element, in.^{2}

A_{inj} = total surface area of injector, in.^{2}

6. Program F: Final Solution for Instability Zones

a. Input Requirements

The input for this program comes directly from Program D and consists of the following parameters:

The frequency in the chamber, ω

The radius of the chamber R^*_{AC}, in.

Speed of sound in the chamber, c^*_o, ft/sec

Real and imaginary parts of the damping parameters $\tilde{h}$ corresponding to the above frequencies.

This program can be run by itself if the data are inserted into those locations specified by Program D.

b. Print Options

$0 < L5 \leq 9$:	Execute Program F, print no input and output
$10 \leq L5 \leq 99$:	Execute Program F, print output only
$100 \leq L5 \leq 199$:	Execute Program F, print input and output

III, D, Input Data (cont.)

c. Placement of the Data into the Data Package

These data are included into Section I of the data package.

d. Output

The following output results from this program:

f^* = frequency of oscillation, Hz

ω = nondimensional frequency

τ^* = sensitive time lag corresponding to the above frequency, millisec

n = pressure interaction index

At the bottom of the page, an effort is made to locate the minimum interaction index. In most cases, this information is valid. However, effects from an adjacent mode will intervene occasionally thereby invalidating this information.

e. Other Information

This program obtains its result by the solution of the following equations:

Frequency, cps

$$f^* = \frac{\omega}{2\pi} \, , \frac{c^*_o 12}{R^*_{AC}}$$

III, D, Input Data (cont.)

Pressure interaction index, n

$$n = \frac{\tilde{h}_r^2 + \tilde{h}_i^2}{2\tilde{h}_r}$$

Sensitive time lag, τ, millisec

$$\tau^* = (83.33) \frac{R^*_{ACo}}{c^*_o 12} \frac{1}{f^*} \tan^{-1} \left(\frac{h_i}{n-h_r} \right)$$

7. Program G: Obsolete and deleted from the listing.

8. Program H: High Combustion Chamber Mach Number Analysis

Program H is not operational. Recommended procedure is to place a negative number in load location L7 of MAIN CONTROL.

9. Program I: Nonlinear Combustion Response (Option for Program E)

a. Input Requirements

MAIN CONTROL requires L8 for Section I of data package. The remaining data go into Section III of data package:

III, D, Input Data (cont.)

Core Location	Mnemonic	Description
ALL THE DATA REQUIRED TO RUN PROGRAM E AS WELL AS:		
L0	E1	The permissible error. If blank, the program will assume E1 = 0.001.
L12	P_{oo}	The ratio of the maximum pressure amplitude at the injector face to the steady-state pressure value.
L19 L68	IPP	The values of the pressure perturbation associated with the pressure-dependent nonlinear element.
L69 L118	OPP	The values of the combustion perturbation corresponding to the above IPP values.
L119 L168	IPR	The values of the radial velocity perturbation associated with the velocity-dependent nonlinear element.
L169 L218	OPR	The values of the combustion perturbation corresponding to the above IPR values.
L219 L268	IPT	The values of the tangential velocity perturbation associated with the velocity dependent nonlinear element.
L269 L318	OPT	The values of the combustion perturbation corresponding to the above IPT values.
L9595	TFLP	The linear transfer function for equivalent linear operation associated with the pressure-dependent non-linear element.
L9596	TFLR	The same as TFLP except for radial velocity-dependent nonlinear element.
L9597	TFLT	The same as TFLP except for tangential velocity-dependent nonlinear elements.
L9598	NUMBR	The number of steps to be used in the integration scheme associated with this problem. If left blank, the computer will assume 20, which is sufficient for most cases.

III, D, Input Data (cont.)

b. Print Options

$0 \leq L8 \leq 9$:	Execute I, print no input or output data
$10 \leq L8 \leq 99$:	Execute I, print output only
$100 \leq L8 \leq 199$:	Execute I, print input and output

c. Placement of the Data into the Data Package

These data are included in Section III of the data package. Along with these data, Section Iv must be included.

d. Output

The output of this program is as follows:

The frequency, ω
The element number, location, fractional flow rate, F_p, F_R, and F_T necessary for Program E.

This will automatically change the output from Program E as follows:

The frequency, ω
The frequency dependent expansion coefficients $A_{\nu\eta}$, $B_{\nu\eta}$, and $C_{\nu\eta}$.

III, D, Input Data (cont.)

10. Program J: Injected Mass Distribution Effects (Not Programed for Annular Chambers)

a. Input Requirements

MAIN CONTROL requires L9 in Section I of data package. The remaining data go in Section III of data package.

Core Location	Mnemonic	Description
L319		Element number (maximum = 1000) within symmetrical sector.
L323	n	
L327 L319 + 4n		
L320 L324 L328 L320 + 4n	X_n or r_n	Element location, in.
L321 L325 L329 L321 + 4n	Y_n or θ_n	Element location, in. or degrees
L322 L326 L330 L322 + 4n	T_n	Type of injection element. The details concerning this type number are given next.
L4	DX	Number of symmetrical sectors, DX = 1 for no symmetry.
L4944 to L9568	-	The data input in this section serves to define the element types and consists of a maximum of 100 variable length data sets. Each set contains:

III, D, Input Data (cont.)

a. The element type number ($\leq$ 100)
b. Number of oxidizer orifices for that type
c. Diameters of all the oxidizer orifices
d. Number of fuel orifices for that type
e. Diameters of all the fuel orifices

EXAMPLE

let T_i = i^{th} element type
NX_i = number of oxidizer orifices for the ith type element
DX_{ij} = diameter of the jth oxidizer orifice in the ith type element
NF_i = number of fuel orifices for the ith type element
DF_{ij} = diameter of the jth fuel orifice in the ith type element

Then a typical input would read

$$L4944 + T_1 + NX_1 + DX_{1,1} + DX_{1,2} + DX_{1,3} + NF_1 + DF_{1,1} + DF_{1,2} + T_2 + NX_2 + DX_{2,1} + \ldots.$$

If NF_i or NX_i is zero, then do not set $DF_{i,1} = 0$ or $DX_{i,1} = 0$.

Assume $NX_1 \equiv 0.0$, then

$$L4944 + T_1 + NX_1 + NF_1 + DF_{1,1} + DF_{1,2} + DF_{1,3} + T_2 + NX_2 + DX_{2,1} + \ldots$$

III, D, Input Data (cont.)

Core Location	Mnemonic	Description
L9569	NT	Total number of injection types
L9570	NE	Number of elements per symmetrical sector
L9571	COORD	COORD = 0: elements are located using polar coordinates
		COORD > 0: elements are located using cartesian coordinates
L9572	WT	Total injector weight flow, lb/sec
L9573	R_{inj}	Injector radius, in.
L9574	MR	Injector mixture ratio
L9575	NFFC	Total number of fuel film cooling holes
L9576	DFFC	Diameter of fuel film cooling holes

In the event of fuel or oxidizer film cooling, either the percent film cooling or the actual orifice dimensions can be used to describe the cooling. Place a zero(s) in the one(s) not used.

L9578	ROX	Oxidizer density, lb/ft^3
L9579	ROF	Fuel density, lb/ft^3
L9584	CDX	Oxidizer orifice loss coefficient
L9585	CDF	Fuel orifice loss coefficient
L9588	PFFC	Percent fuel film cooling
L9589	PXFC	Percent oxidizer film cooling
L9590	XFC	Total number of oxidizer film cooling orifices
L9591	DFFX	Diameter of film cooling orifices

L2, L3, and L4 from Program E.

III, D, Input Data (cont.)

b. Print Options

$0 < L9 \leq 9$:	Execute J, do not print output or input data
$10 \leq L9 \leq 99$:	Execute J, print output only
$100 \leq L9 \leq 199$:	Execute J, print input and output
$L9 \leq 500$:	Execute J, print input and output, and, if error occurs in J, dump error message with input data.

c. Placement of the Data into the Data Package

Main control data: Section I of the data package.

All other data: Section III of the data package.

Section IV must be included in the data package.

d. Output

The following output results as a consequence of this program:

Miscellaneous information concerning the total orifice area, circuit pressure drops, overall mixture ratio, etc.

Element number, injection type, and location.

Description of various parameters associated with the different types of injection elements.

Element number, location, and distribution coefficient.

The distribution coefficient as a function of the radius across the face of the injector.

III, Deck Setup (cont.)

E. RESTRICTIONS AND LIMITATIONS

1. One limitation which cannot easily be implied from the information given in this manual is the frequency limit in transverse mode analysis. This limit is implied from the relationship

$$\Omega \sinh \Omega Z \leq 0 \ (M_e)$$

This limitation means that combined transverse-longitudinal modes cannot be analyzed with this program. Long chambers (long compared to their diameter) may also produce erroneous results for the pure transverse modes.

2. The restrictions of the annular nozzle analysis have already been discussed in Section I,B,1,b,(6) of this manual.

3. The transverse mode analysis is restricted to low Mach numbers, those less than approximately 0.3.

4. The sensitive time lag theory is developed for liquid propellant rocket engines. Before applying it to gas injection, many assumptions must be examined critically.

5. Calculations of the distribution coefficients $A_{\nu\eta}$, $B_{\nu\eta}$, and $C_{\nu\eta}$ are not applicable to annular chambers.

III, Deck Setup (cont.)

F. OUTPUT DEFINITION

1. Program A

Label in Output	Symbol in Analysis	
GAMMA	γ	
DESIRED MACH NUMBER	M_e	
CHAMBER RADIUS	R^*_{AC}	
CHAMBER LENGTH	L^*_c	
SPEED OF SOUND	c^*_o	
CHAMBER MODE DESCRIPTION	$s_{\nu\eta}$	
MACH DISTRIBUTION	$M(Z)^*$	
UIBAR	M_e	
K	κ	
x	ξ_1	
FC(CPS)	f^*	
OMEGA	ω	
TAU (MS)	τ^*	c x 45
N	n	
ULM	$\bar{u}^*_{LO}$	
WC	ω	

2. Program B

Label in Output	Symbol in Analysis
GAMMA	γ
DESIRED MACH NUMBER	M_e
CHAMBER RADIUS	R^*_{AC}
CHAMBER LENGTH	L^*_c
SPEED OF SOUND	c^*_o

III, F, Output Definition (cont.)

Label in Output	Symbol in Analysis
CHAMBER MODE DESCRIPTION	$s_{\nu\eta}$
CHAMBER FREQUENCIES	ω
WC	ω
MACH DISTRIBUTION	$M(Z^*)$
SNH	$s_{\nu\eta}$
ZE	L_c
UE	M_e
SOUND	c_o^*
ULM	$\bar{u}_{LO}^*$
XK	κ
OMEGA (CH)	ω
ERT	E_r
EIT	E_i
H REAL	h_r
H IMAG	h_i

3. Program C

Label in Output	Symbol in Analysis
(SNH)C	$s_{\nu\eta}$
(SNH)N	$s_{\nu\eta}$
WC	ω
WN	$\hat{\omega}$

III, F, Output Definition (cont.)

Label in Output	Symbol in Analysis
MACH NO.	M_e
G	γ
AR	A_r
AI	A_i
-AR/(MACH NO.)	α_r
-AI/(MACH NO.)	α_i
BR	B_r
BI	B_i
T1	E_r
T2	E_i
CR	C_r
CI	C_i
-CR/(Mach No.)	β_{nr}
-CI/(Mach No.)	β_{ni}
FC (CPS)	f^*

4. Program D

Label on Output	Symbol in Analysis
LR/N	$\frac{lr}{n}$
LT/N	$\frac{l\theta}{n}$
ERT	E_r
EIT	E_i
CRT	C_r
CIT	C_i
OMEGA (C)	ω
OMEGA (CH)	ω

III, F, Output Definition (cont.)

Label On Output	Symbol in Analysis
HTR	$\tilde{hr}$
HTI	$\tilde{hi}$
HTRINT	$\tilde{hr}$ (interpolated)
HTIINT	$\tilde{hi}$ (interpolated)
OMEGA	ω

5. Program E

Label on Output	Symbol in Analysis
AVN	$A_{\nu\eta}$
BVN	$B_{\nu\eta}$
CVN	$C_{\nu\eta}$
MU	μ

6. Program F

Label on Output	Symbol in Analysis
FC(CPS)	f^*
(OMGA)D	ω
TAU(MS)	τ^*
N	n
NMIN	n_{min}

III, F, Output Definition (cont.)

7. Program I

Label on Output	Symbol in Analysis
PRESSURE PERTURBATION	p'
COMBUSTION GAIN	ϕ_p
RADIAL VELOCITY PERTURBATION	v'
COMBUSTION GAIN	ϕ_R
TANGENTIAL VELOCITY PERTURBATION	w'
COMBUSTION GAIN	ϕ_T
OMEGA	ω
FP	F_p
FR	F_R
FT	F_T
AVN REAL	$A_{\nu\eta}$
BVN REAL	$B_{\nu\eta}$
CVN REAL	$C_{\nu\eta}$ R
CVN IMAG	$C_{\nu\eta}$

8. Program J

Label on Output	Symbol in Analysis
PRESSURE (TFLP)	TF_{LP}
RADIAL VELOCITY (TFLR)	TF_{LR}
TANGENTIAL VELOCITY (TFLT)	TF_{LT}
DISTRIBUTION COEFFICIENT MU	μ

III, Deck Setup (cont.)

G. INPUT FORM

A sample input sheet has been prepared on page for the case given below:

1. Illustrative Design Problem

a. Longitudinal Mode Analysis

The following data concerning a hypothetical engine will be used for this analysis:

Engine geometry: see Figure 19

$\gamma = 1.218$

$C_o^* = 3800$ ft/sec

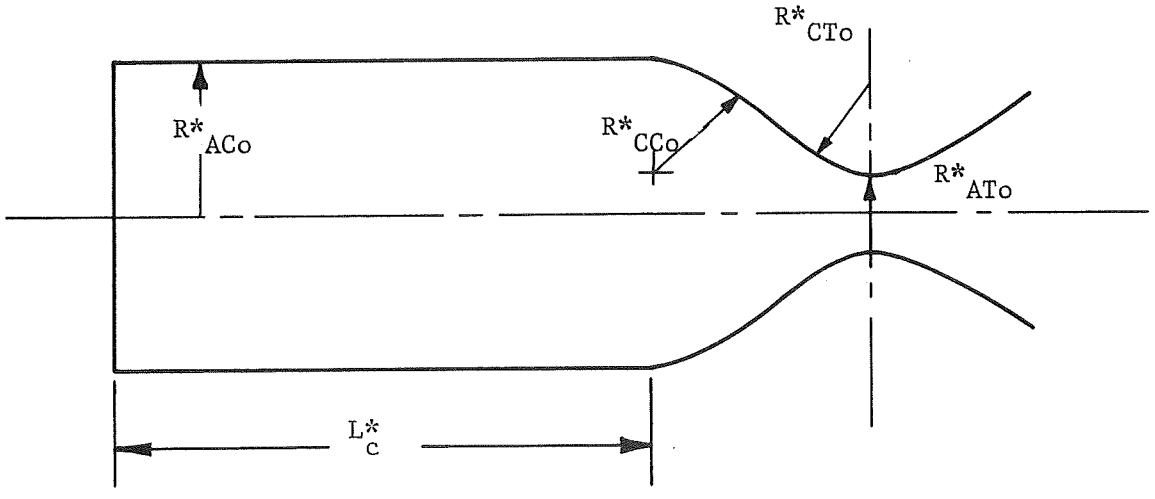
Mach number: unknown

Momentum interchange coefficient = 0.0

Combustion distribution: a linear combustion distribution with complete combustion occurring at 6.4 in.

$P_c = 600$ psia

The problem is to find the n, τ zone for the first longitudinal mode.



L^*_c = 14.8, in.

R^*_{ACo} = 6.4, in.

R^*_{CCo} = 3.0, in.

R^*_{CTo} = 7.16, in.

R^*_{ATo} = 3.58, in.

α = 15.0°

Figure 19 -- Definition of the Geometrical Factors used in Example Problem

III, G, Input Form (cont.)

b. Transverse Mode

For the transverse case, the problem will be to find the n, τ zones for the first tangential and the second tangential modes. The data given in the longitudinal case will be supplemented by the following information:

$$s_{11} = 1.8413 \text{ and } s_{12} = 3.0543$$

Injector
Number of radial baffle compartments = 180
Total weight flow = 150 lb/sec
Mixture ratio = 2.0
Injection occurs at three radii:

Unlike doublets at r = 2.0 in.
Triplets (X-F-X) at r = 4.0 in.
Pentads (4F-X) at r = 6.0 in.

Injector radius = chamber radius
No film cooling
Storable propellants
Fuel and oxidizer loss coefficients = 0.75
Spinning modes
Tangential mode numbers = 1 and 2
No radial or tangential velocity effects

c. Nonlinear Combustion Response

For this case, the first tangential mode will be examined using a deadband nonlinear element. In addition to the above injector data the following additional information will be used:

$$P_{oo} = 1.0$$
$$TFLP = 1.0$$

III, Deck Setup (cont.)

H. SAMPLE OUTPUT

The following output is run from the sample input given in the previous section:

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A	B	C	D	E	F	G	H	I	J
100.	0.	100.	0.	0.	0.	0.	0.	0.	0.

********** THE FOLLOWING MAIN CONTROL DATA WILL BE USED IN THIS CASE **********

RATIO OF SPECIFIC HEAT (GAMMA) = 1.2180

DESIRED MACH NUMBER = .00000 (=0 IF BEING CALCULATED)

CHAMBER RADIUS = 6.400 (INCHES)

CHAMBER LENGTH = 14.800 (INCHES)

SPEED OF SOUND = 3800.000 (FT/SEC)

CHAMBER MODE DESCRIPTION = .00000 (=0 FOR LONGITUDINAL MODES)

********** CHAMBER FREQUENCIES (WC) **********

2.00000	2.50000	3.00000	3.25000	3.50000
3.75000	4.00000	4.25000	4.50000	4.75000
5.00000	5.50000	6.00000	6.50000	7.00000

***** MACH DISTRIBUTION IN CHAMBER AS A FUNCTION OF LENGTH *****

CHAMBER LENGTH	MACH DISTRIBUTION	CHAMBER LENGTH	MACH DISTRIBUTION	CHAMBER LENGTH	MACH DISTRIBUTION
.00000	.00000	6.40000	6.39500	25.00000	6.40000
2.50000	2.50000	6.41000	6.40000	50.00000	6.40000
5.00000	5.00000	6.42000	6.40000	.00000	.00000
6.30000	6.30000	6.43000	6.40000	.00000	.00000
6.35000	6.35000	6.50000	6.40000	.00000	.00000
6.38000	6.38000	7.50000	6.40000	.00000	.00000
6.39000	6.39000	12.50000	6.40000		

PROGRAM C INPUT - CALCULATES NOZZLE ADMITTANCE COEFFICIENTS USING 8052

G = 1.216 , MBESTR = 3
RAT = 3.580,RAC = 6.400,RCC = 3.000,RCT = 7.160,ALFA = 15.000,KM = 101

WN	(SNH)N	DES
.753748+00	.000000	.000000
.113812+01	.000000	.000000
.132781+01	.000000	.000000
.151750+01	.000000	.000000
.170718+01	.000000	.000000
.189687+01	.000000	.000000
.227625+01	.000000	.000000
.614112+01	.000000	.000000

PROGRAM C OUTPUT

(SNH)C (SNH)N	WC WN	MACH NO G	AR -AR/(MACH NO)	AI -AI/(MACH NO)	BR T1	BI T2	CR -CR/(MACH NO)	CI -CI/(MACH NO)
.0000	2.0000	.1885	-.83951+00	-.12120+01	.00000+00	.00000+00	-.10709+00	.66309-03
.0000	.7587	1.2180	.44530+01	.64285+01	.00000	.00000	.56803+00	-.35172-02
FC(CPS)= 980.7386								
.0000	3.0000	.1885	-.14485+01	-.35432-01	.00000+00	.00000+00	.41367-01	-.60754-01
.0000	1.1381	1.2180	.76831+01	.18794+00	.00000	.00000	-.21942+00	.32226+00
FC(CPS)= 1471.1079								
.0000	3.5000	.1885	-.10632+01	.45579-01	.00000+00	.00000+00	-.45013-01	-.12225-01
.0000	1.3278	1.2180	.56396+01	-.24176+00	.00000	.00000	.23876+00	.64846-01
FC(CPS)= 1716.2925								
.0000	4.0000	.1885	-.89968+00	-.77292-01	.00000+00	.00000+00	-.38491-02	.35508-01
.0000	1.5175	1.2180	.47721+01	.40998+00	.00000	.00000	.20417-01	-.18835+00
FC(CPS)= 1961.4772								
.0000	4.5000	.1885	-.38698+00	-.21135+00	.00000	.00000	.27857-01	.21121-02
.0000	1.7072	1.2180	.47047+01	.11211+01	.00000	.00000	-.14776+00	-.11203-01
FC(CPS)= 2206.6618								
.0000	5.0000	.1885	-.96782+00	-.29622+00	.00000	.00000	-.90676-03	-.20969-01
.0000	1.8969	1.2180	.51336+01	.15712+01	.00000	.00000	.48097-02	.11123+00
FC(CPS)= 2451.8464								
.0000	6.0000	.1885	-.11663+01	-.20603+00	.00000	.00000	.72719-02	.14955-01
.0000	2.2762	1.2180	.61862+01	.10928+01	.00000	.00000	-.38572-01	-.79327-01
FC(CPS)= 2942.2157								
.0000	7.0000	.1885	-.10462+01	-.35016-01	.00000	.00000	-.16828-01	-.42143-02
.0000	6.1411	1.2180	.55494+01	.18573+00	.00000	.00000	.89261-01	.22354-01
FC(CPS)= 3432.5850								

U1B4R = .18052762+00 GAMMA = .12180000+01 K = .00000000+00 X = .21651235+00 ULM = .20420000+02

RESULTS FOR LONGITUDINAL MODE

FC(CPS)	OMEGA	TAU(MS)	N
980.7	2.00000	.43362	1.25483
1029.8	2.10000	.35794	1.45551
1078.8	2.20000	.30068	1.73711
1127.8	2.30000	.25804	2.07726
1176.9	2.40000	.22678	2.45271
1225.9	2.50000	.20395	2.83985
1275.0	2.60000	.18742	3.21606
1324.0	2.70000	.17565	3.56120
1373.0	2.80000	.16750	3.85876
1422.1	2.90000	.16211	4.09681
1471.1	3.00000	.15876	4.26657
1495.6	3.05000	.15772	4.32019
1520.1	3.10000	.15699	4.34120
1544.7	3.15000	.15632	4.33802
1569.2	3.20000	.15548	4.31784
1593.7	3.25000	.15425	4.28852
1618.2	3.30000	.15245	4.25677
1642.7	3.35000	.14999	4.23684
1667.3	3.40000	.14685	4.23075
1691.8	3.45000	.14312	4.24658
1716.3	3.50000	.13903	4.28585
1740.8	3.55000	.13462	4.35705
1765.3	3.60000	.12986	4.45234
1789.8	3.65000	.12489	4.57541
1814.4	3.70000	.11987	4.72577
1838.9	3.75000	.11493	4.90170
1863.4	3.80000	.11017	5.10032
1887.9	3.85000	.10569	5.31781
1912.4	3.90000	.10154	5.54971
1937.0	3.95000	.09773	5.79130
1961.5	4.00000	.09428	6.03807
1986.0	4.05000	.09117	6.28815
2010.5	4.10000	.08841	6.53915
2035.0	4.15000	.08599	6.78644
2059.6	4.20000	.08389	7.02690
2084.1	4.25000	.08208	7.25456
2108.6	4.30000	.08053	7.46986
2133.1	4.35000	.07919	7.67675
2157.6	4.40000	.07802	7.85724
2182.1	4.45000	.07697	8.03053
2206.7	4.50000	.07601	8.19293
2231.2	4.55000	.07511	8.34374
2255.7	4.60000	.07429	8.48226
2280.2	4.65000	.07347	8.61268
2304.7	4.70000	.07262	8.74054
2329.3	4.75000	.07167	8.87247
2353.8	4.80000	.07058	9.01510
2378.3	4.85000	.06933	9.17953
2402.8	4.90000	.06787	9.37265
2427.3	4.95000	.06620	9.60393

2451.8	5.00000	.06431	9.88329
2500.9	5.10000	.06001	10.61243
2549.9	5.20000	.05517	11.62190
2599.0	5.30000	.05007	12.98562
2648.0	5.40000	.04499	14.77940
2697.0	5.50000	.04015	17.08252
2746.1	5.60000	.03569	19.96102
2795.1	5.70000	.03169	23.57412
2844.1	5.80000	.02814	27.98557
2893.2	5.90000	.02503	33.38315
2942.2	6.00000	.02228	40.01144
2991.3	6.10000	.01983	48.28128
3040.3	6.20000	.01762	58.80177
3089.3	6.30000	.01561	72.45483
3138.4	6.40000	.01377	90.65824
3187.4	6.50000	.01204	115.81549
3236.4	6.60000	.01041	152.27425
3285.5	6.70000	.00884	208.56000
3334.5	6.80000	.00730	303.49994
3383.5	6.90000	.00576	485.27914
3432.6	7.00000	.00419	912.11401

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A	B	C	D	E	F	G	H	I	J
0.	100.	10.	10.	100.	10.	0.	-100.	0.	100.

********** THE FOLLOWING MAIN CONTROL DATA WILL BE USED IN THIS CASE **********

RATIO OF SPECIFIC HEAT (GAMMA) = 1.2180

DESIRED MACH NUMBER = .00000 (=0 IF BEING CALCULATED)

CHAMBER RADIUS = 6.400 (INCHES)

CHAMBER LENGTH = 14.800 (INCHES)

SPEED OF SOUND = 3800.000 (FT/SEC)

CHAMBER MODE DESCRIPTION = 1.84118 (=0 FOR LONGITUDINAL MODES)

********** CHAMBER FREQUENCIES (WC) **********

1.69389	1.73071	1.76754	1.80436	1.84118
1.87800	1.91483	1.95165	1.98848	2.02530

***** MACH DISTRIBUTION IN CHAMBER AS A FUNCTION OF LENGTH *****

CHAMBER LENGTH	MACH DISTRIBUTION	CHAMBER LENGTH	MACH DISTRIBUTION	CHAMBER LENGTH	MACH DISTRIBUTION
.00000	.00000	6.40000	6.39500	25.00000	6.40000
2.50000	2.50000	6.41000	6.40000	50.00000	6.40000
5.00000	5.00000	6.42000	6.40000	.00000	.00000
6.30000	6.30000	6.43000	6.40000	.00000	.00000
6.35000	6.35000	6.50000	6.40000	.00000	.00000
6.38000	6.38000	7.50000	6.40000	.00000	.00000
6.39000	6.39000	12.50000	6.40000		

SECTION 1....MISCELLANEOUS INFORMATION FOR INJECTOR DESIGNED BY PROJECTS

A....PROPELLENT ORIFICE AREAS

ELEMENT TOTAL OXIDIZER AREA = 3.48462972 SQ. IN.
TOTAL OXIDIZER FILM COOLING AREA = .00000000 SQ. IN.
INJECTOR TOTAL OXIDIZER AREA = 3.48462972 SQ. IN.

ELEMENT TOTAL FUEL AREA = 5.22700441 SQ. IN.
TOTAL FUEL FILM COOLING AREA = .00000000 SQ. IN.
INJECTOR TOTAL FUEL AREA = 5.22700441 SQ. IN.

B....INJECTOR PRESSURE DROPS FOR ABOVE INJECTOR DESIGN

OXIDIZER PRESSURE DROP = 36.6PSI

FUEL PRESSURE DROP = 6.5 PSI

C....PROPELLANT FLOWS AND INJECTOR VELOCITIES FOR ABOVE INJECTOR DESIGN

TOTAL WEIGHT FLOW = 150.0 LB/SEC
AVERAGE MIXTURE RATIO OF THE ELEMENTS = 2.000
OVERALL MIXTURE RATIO FOR THE INJECTOR = 2.000

ELEMENT TOTAL OXIDIXER FLOW = 100.0 LB/SEC
TOTAL OXIDIZER FILM COOLING FLOW = .0 LB/SEC
INJECTOR TOTAL OXIDIZER FLOW = 100.0 LB/SEC
OXIDIZER OVERALL INJECTION VELOCITY = 61.5 FT/SEC

ELEMENT TOTAL FUEL FLOW = 50.0 LB/SEC
TOTAL FUEL FILM COOLING = .0 LB/SEC
INJECTOR TOTAL FUEL FLOW= 50.0 LB/SEC
FUEL OVERALL INJECTION VELOCITY = 32.7 FT/SEC

D.....INPUT INFORMATION USED IN COMPUTATIONS

TOTAL PROPELLENT FLOW = 150.0 LB/SEC
TOTAL NUMBER OF ELEMENT TYPES (SYMMETRICAL SECTION ONLY) = 3
TOTAL NUMBER OF ELEMENTS (SYMMETRICAL SECTION ONLY) = 3
OXIDIZER LOSS COEFFICIENT = .750
FUEL LOSS COEFFICIENT = .750
PERCENT FUEL FILM COOLING = .0
PERCENT OXIDIZER FILM COOLING = .0
DIAMETER OF FUEL FILM COOLING ORFICE = .00000 IN. (NOTE..THIS MIGHT BE AN EQUIVALENT DIAMETER FOR MULTIPLE-ROW COOLING
DIAMETER OF OXIDIZER FILM COOLING ORFICE = .00000 IN. (SEE ABOVE NOTE)
NUMBER OF FUEL FILM COOLING ORIFICES PER INJECTOR = 0.
NUMBER OF OXIDIZER FILM COOLING ORFICES PER INJECTOR = 0.
OXIDIZER DENSITY = 89.59 PCF
FUEL DENSITY = 56.1 PCF

SECTION 2.... ELEMENT LOCATION AND INJECTION TYPE

ELEMENT NO.	TYPE NO.	R (INCHES)	THETA (DEGREE)	X (INCHES)	Y (INCHES)
1	1	2.00000	1.00000	1.99970	.03490
2	2	4.00000	1.00000	3.99939	.06981
3	3	6.00000	1.00000	5.99909	.10471

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SECTION 3....TYPE DESCRIPTION,ORIFICE AREA, PROPELLANT FLOW, AND MIXTURE RATIO

TYPE *-------- OXIDIZER ORIFICE DATA -----**---------- FUEL ORIFICE DATA --------*

	NUMBER OF ORIFICE	DIAMETER IN.	AREA SQ. IN.	FLOW LB/SEC	NUMBER OF ORIFICES	DIAMETER IN.	AREA SQ. IN.	FLOW LB/SEC	TOTAL OXIDIZER AREA SQ. IN.	TOTAL FUEL AREA SQ. IN.	TOTAL PROPELLENT FLOW RATE LB/SEC	MIXTUR RATIO
1	1											
		.0785	.004840	.138889								
					1							
						.0785	.004840	.046296				
									.00484	.00484	.1852	3.000
2	2											
		.0785	.004840	.138889								
		.0785	.004840	.138889								
					1							
						.0785	.004840	.046296				
									.00968	.00484	.3241	6.000
3	1											
		.0785	.004840	.138889								
					4							
						.0785	.004840	.046296				
						.0785	.004840	.046296				
						.0785	.004840	.046296				
						.0785	.004840	.046296				
									.00484	.01936	.3241	.750

ELEMENT RESULTS

ELEMENT NO.	RADIUS	ANGLE RADIANS	DISTRIBUTION COEFFICIENT MU
1	2.000	.0175	4.4444
2	4.000	.0175	7.7778
3	6.000	.0175	7.7778

SECTION 4..RESULTANT FLOW DISTRIBUTION (MU) AS A FUNCTION OF ONLY THE RADIUS, I.E.. AVERAGE OF MU IN A RADIAL BAND

RADIUS IN.	MU(R)	MU(R)/MU(MAX)
1.431	.000	.0000
2.024	4.444	.5714
2.479	.000	.0000
2.862	.000	.0000
3.200	.000	.0000
3.505	.000	.0000
3.786	.000	.0000
4.048	7.778	1.0000
4.293	.000	.0000
4.525	.000	.0000
4.746	.000	.0000
4.957	.000	.0000
5.160	.000	.0000
5.355	.000	.0000
5.543	.000	.0000
5.724	.000	.0000
5.901	.000	.0000
6.072	7.778	1.0000
6.238	.000	.0000
6.400	.000	.0000

```
INPUT TO INJECTION DISTRIBUTION PROGRAM

     CONSTANTS

         NUMBER OF OMEGAS =  1

         NUMBER OF ELEMENTS =    3 FOR EACH OF  180 SYMMETRIC SECTIONS.

         RADIAL DIVISIONS(XM) =  20.

         ANGULAR DIVISIONS (XN) = 180.

         ACOUSTIC MODE NUMBER(SVN) = 1.8412

         ORDER OF BESSEL FUNCTIONS(V) = 1.

         INJECTOR RADIUS =   6.400, IN.

         RATIO OF SPECIFIC HEATS(GAMMA) = 1.2180

         MAXIMUM PRESSURE AMPLITUDE RATIO(PCO) =   .000

         TRANSFER FUNCTIONS FOR LINEAR OPERATION

               PRESSURE(TFLP) =   .000

               RADIAL VELOCITY(TFLR) =   .000

               TANGENTIAL VELOCITY(TFLT) =   .000
```

ELEMENT INFORMATION

ELEMENT NO.	RADIUS IN.	ANGLE RADIANS	DISTRIBUTION COEFFICIENT MU
1	2.000	.0175	4.4444
2	4.000	.0175	7.7773
3	6.000	.0175	7.7778

RESULTS OF INJECTION DISTRIBUTION EFFECTS

OMEGA	AVN REAL	BVN REAL	CVN REAL	CVN IMAG
ALL	1.2745	.8766	.0000	-1.8125

********** THESE VALUES PERTAIN TO A SPINNING MODE **********

PROGRAM C OUTPUT

(SNH)C (SNH)N	WC WN	MACH NO G	AR -AR/(MACH NO)	AI -AI/(MACH NO)	BR T1	BI T2	CR -CR/(MACH NO)	CI -CI/(MACH NO)
1.8412	1.6939	.1885	-.60983-03	.48540+00	-.22887-01	-.21780+00	.43915-02	-.38873-03
2.7421	1.4861	1.2180	.32347-02	-.25747+01	.21724+00	.42368+00	-.23294-01	.20619-02

FC(CPS)= 1920.8346

1.8412	1.7675	.1885	.12592-01	.40557+00	-.27694-01	-.20090+00	.35139-02	-.28287-02
2.7421	1.5507	1.2180	-.66792-01	-.21513+01	.21299+00	.36166+00	-.18639-01	.15004-01

FC(CPS)= 2004.3491

1.8412	1.8412	.1885	.26283-01	.32326+00	-.30799-01	-.18321+00	.12002-02	-.34923-02
2.7421	1.6153	1.2180	-.13941+00	-.17147+01	.20950+00	.29246+00	-.63661-02	.18524-01

FC(CPS)= 2087.8636

1.8412	1.9148	.1885	.41969-01	.23916+00	-.34388-01	-.16317+00	-.63995-03	-.79534-03
2.7421	1.6799	1.2180	-.22261+00	-.12686+01	.20681+00	.21434+00	.33945-02	.42187-02

FC(CPS)= 2171.3781

1.8412	1.9885	.1885	.65749-01	.13721+00	-.23057-01	-.13333+00	.23384-02	-.74945-03
2.7421	1.7445	1.2180	-.34875+00	-.72779+00	.20433+00	.12513+00	-.12404-01	.39753-02

FC(CPS)= 2254.8926

1.8412	2.0253	.1885	.70360-01	.76014-01	-.79474-02	-.12608+00	.16016-02	-.32095-02
2.7421	1.7766	1.2180	-.37321+00	-.40320+00	.20348+00	.75668-01	-.84956-02	.17024-01

FC(CPS)= 2296.6498

DATE 03 NOV 69 EXAMPLE PROBLEM - FIRST TANGENTIAL MODE FOR HYPOTHETICAL ENGINE PAGE 16

TRANSVERSE STABILITY PROGRAM... CALCULATES HR, HI OR HTR, HTI

INPUT DATA

SNB	ZE	GAMMA	UE	SOUND (FT/SEC)	ULM (FT/SEC)	XK (DRAG)	XCOMPL (IN)
1.84118374	2.31250000	1.21800	.18852762	3800.00	20.420000	.000000	.000000

INCREMENTS	LR/N	LT/N
.0	.0000000	.0000000

NOZZLE ADMITTANCES INPUT

OMEGA(CH)	ERT	EIT	CRT	CIT
1.6938890	.21723997+00	.42368060+00	.43915419-02	-.38872861-03
1.7675363	.21299294+00	.36165724+00	.35139393-02	-.28287281-02
1.8411837	.20949743+00	.29246183+00	.12001764-02	-.34922587-02
1.9148310	.20681402+00	.21434183+00	-.63995426-03	-.79533766-03
1.9884783	.20433431+00	.12512822+00	.23384384-02	-.74945183-03
2.0253019	.20347937+00	.75667907-01	.16016490-02	-.32095248-02

CALCULATED RESULTS...

	FIRST-ORDER SOLN (UNIF INJ)		SECOND-ORDER SOLUTION	
OMEGA	H REAL	H IMAG	HT REAL	HT IMAG
1.6938890	.17957059+01	-.27574364+01		
1.7307127	.17782917+01	-.22796713+01		
1.7675364	.17530309+01	-.17919479+01		
1.8043600	.17150791+01	-.12867290+01		
1.8411837	.16552088+01	-.75276300+00		
1.8780073	.15548406+01	-.17326547+00		
1.9148310	.13731123+01	.47663003+00		
1.9516547	.10097995+01	.12250634+01		
1.9884783	.21071993+00	.20269546+01		
2.0253020	-.14794744+01	.22718191+01		

PROGRAM D OUTPUT

OMEGA(C)	HTR	HTI
1.693889	1.408977	-2.163586
1.730713	1.395313	-1.788714
1.767536	1.375492	-1.406028
1.804360	1.345714	-1.009615
1.841184	1.298738	-.590645
1.878007	1.219985	-.135950
1.914831	1.077394	.373981
1.951655	.792326	.961230

EXAMPLE PROBLEM - FIRST TANGENTIAL MODE FOR HYPOTHETICAL ENGINE

1.988478	.165339	1.590423
2.025302	-1.160850	1.782553

FOLLOWING WILL BE INTERPOLATION WITHIN HTR HTI TABLE GIVEN ABOVE

OMEGA	HTRINT	HTIINT
1.693889	1.408977	-2.163586
1.702387	1.406370	-2.077770
1.710885	1.403435	-1.991539
1.719382	1.400173	-1.904891
1.727880	1.396583	-1.817828
1.736378	1.392702	-1.730407
1.744876	1.388591	-1.642721
1.753373	1.384121	-1.554571
1.761871	1.379152	-1.465738
1.770369	1.373575	-1.376047
1.778867	1.367628	-1.285807
1.787364	1.361180	-1.194872
1.795862	1.353964	-1.102917
1.804360	1.345714	-1.009616
1.812858	1.336698	-.915203
1.821355	1.327006	-.819804
1.829853	1.316099	-.722934
1.838351	1.303440	-.624108
1.846849	1.289011	-.523215
1.855346	1.273668	-.420881
1.863844	1.256370	-.316484
1.872342	1.235935	-.209306
1.880840	1.211498	-.098749
1.889338	1.185488	.014342
1.897835	1.156400	.130284
1.906333	1.121336	.249892
1.914831	1.077395	.373978
1.923329	1.028341	.503359
1.931826	.974968	.637437
1.940324	.909922	.774907
1.948822	.825851	.914467
1.957320	.721702	1.060091
1.965817	.607907	1.220061
1.974315	.472976	1.378341
1.982813	.303737	1.517271
1.991311	.088156	1.620716
1.999808	-.168239	1.696089
2.008306	-.461870	1.748186
2.016804	-.792735	1.777007
2.025302	-1.160835	1.782553

PROGRAM F OUTPUT

FC(CPS)	(OMGA)D,	TAU(MS)	N
1920.8	1.69389	.42495	2.36566
1930.5	1.70239	.41990	2.23803
1940.1	1.71088	.41472	2.11476
1949.7	1.71938	.40941	1.99586
1959.4	1.72788	.40394	1.88136
1969.0	1.73638	.39831	1.77135
1978.7	1.74488	.39250	1.66598
1988.3	1.75337	.38648	1.56507
1997.9	1.76187	.38024	1.46846
2007.6	1.77037	.37373	1.37605
2017.2	1.77887	.36694	1.28825
2026.8	1.78736	.35983	1.20503
2036.5	1.79586	.35237	1.12619
2046.1	1.80436	.34450	1.05159
2055.7	1.81286	.33618	.98156
2065.4	1.82136	.32737	.91673
2075.0	1.82985	.31802	.85660
2084.7	1.83835	.30803	.80114
2094.3	1.84685	.29735	.75069
2103.9	1.85535	.28594	.70637
2113.6	1.86384	.27373	.66805
2123.2	1.87234	.26064	.63569
2132.8	1.88084	.24657	.60977
2142.5	1.88934	.23158	.59283
2152.1	1.89784	.21574	.58554
2161.7	1.90633	.19901	.58851
2171.4	1.91483	.18129	.60360
2181.0	1.92333	.16282	.63756
2190.7	1.93183	.14411	.69586
2200.3	1.94032	.12519	.78492
2209.9	1.94882	.10580	.91922
2219.6	1.95732	.08572	1.13942
2229.2	1.96582	.06601	1.52828
2238.8	1.97432	.04700	2.24486
2248.5	1.98281	.02797	3.94152
2258.1	1.99131	.00766	14.94228
2267.7	1.99981	.20861	-8.63362
2277.4	2.00831	.18345	-3.53939
2287.0	2.01680	.16022	-2.38805
2296.6	2.02530	.13771	-1.94904

THE FOLLOWING ARE VALUES INTERPOLATED AT SLOPE OF N=0.0

NMIN= .58525
TAU(MS)= .21238
(OMEGA)D= 1.89958
FC(CPS)= 2154.1

A	B	C	D	E	F	G	H	I	J
0.	100.	10.	10.	100.	10.	0.	-100.	0.	0.

********** THE FOLLOWING MAIN CONTROL DATA WILL BE USED IN THIS CASE **********

RATIO OF SPECIFIC HEAT (GAMMA) = 1.2180

DESIRED MACH NUMBER = .00000 (=0 IF BEING CALCULATED)

CHAMBER RADIUS = 6.400 (INCHES)

CHAMBER LENGTH = 14.800 (INCHES)

SPEED OF SOUND = 3800.000 (FT/SEC)

CHAMBER MODE DESCRIPTION = 3.05424 (=0 FOR LONGITUDINAL MODES)

********** CHAMBER FREQUENCIES (WC) **********

2.80990	2.87098	2.93207	2.99315	3.05424
3.11532	3.17641	3.23749	3.29858	3.35966

***** MACH DISTRIBUTION IN CHAMBER AS A FUNCTION OF LENGTH *****

CHAMBER LENGTH	MACH DISTRIBUTION	CHAMBER LENGTH	MACH DISTRIBUTION	CHAMBER LENGTH	MACH DISTRIBUTION
.00000	.00000	6.40000	6.39500	25.00000	6.40000
2.50000	2.50000	6.41000	6.40000	50.00000	6.40000
5.00000	5.00000	6.42000	6.40000	.00000	.00000
6.30000	6.30000	6.43000	6.40000	.00000	.00000
6.35000	6.35000	6.50000	6.40000	.00000	.00000
6.38000	6.38000	7.50000	6.40000	.00000	.00000
6.39000	6.39000	12.50000	6.40000		

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INPUT TO INJECTION DISTRIBUTION PROGRAM

     CONSTANTS

         NUMBER OF OMEGAS =  1

         NUMBER OF ELEMENTS =     4 FOR EACH OF  180 SYMMETRIC SECTIONS.

         RADIAL DIVISIONS(XM) =  20.

         ANGULAR DIVISIONS (XN) = 180.

         ACOUSTIC MODE NUMBER(SVN) = 3.0542

         ORDER OF BESSEL FUNCTIONS(V) = 2.

         INJECTOR RADIUS =   6.400, IN.

         RATIO OF SPECIFIC HEATS(GAMMA) = 1.2180

         MAXIMUM PRESSURE AMPLITUDE RATIO(PO2) =    .000

         TRANSFER FUNCTIONS FOR LINEAR OPERATION

               PRESSURE(TFLP) =    .000

               RADIAL VELOCITY(TFLR) =    .000

               TANGENTIAL VELOCITY(TFLT) =    .000
```

ELEMENT INFORMATION

ELEMENT NO.	RADIUS IN.	ANGLE RADIANS	DISTRIBUTION COEFFICIENT MU
1	2.000	.0175	4.4444
2	4.000	.0175	7.7778
3	6.000	.0175	7.7778

RESULTS OF INJECTION DISTRIBUTION EFFECTS

OMEGA	AVN REAL	BVN REAL	CVN REAL	CVN IMAG
ALL	1.2761	1.2828	.0000	-3.2524

********** THESE VALUES PERTAIN TO A SPINNING MODE **********

PROGRAM C OUTPUT

(SNH)C (SNH)N	WC WN	MACH NO G	AR -AR/(MACH NO)	AI -AI/(MACH NO)	BR T1	BI T2	CR -CR/(MACH NO)	CI -CI/(MACH NO)
3.0542	2.6099	.1885	.14637-01	.45547+00	-.50957-02	-.20204+00	.68186-03	-.20889-03
4.5487	2.4651	1.2180	-.77641-01	-.24159+01	.21550+00	.41394+00	-.36168-02	.11080-02

FC(CPS)= 3186.3651

3.0542	2.9321	.1885	.19685-01	.36188+00	-.46909-02	-.19214+00	.67167-03	-.64559-03
4.5487	2.5723	1.2180	-.10441+00	-.19195+01	.21103+00	.34271+00	-.35627-02	.34244-02

FC(CPS)= 3324.9026

3.0542	3.0542	.1885	.24287-01	.26445+00	-.39316-02	-.18399+00	-.19082-03	-.66101-03
4.5487	2.6735	1.2180	-.12882+00	-.14027+01	.20827+00	.26052+00	.10122-02	.35062-02

FC(CPS)= 3463.4402

3.0542	3.1764	.1885	.31553-01	.16051+00	-.35605-02	-.17486+00	-.22172-03	.27431-03
4.5487	2.7867	1.2180	-.16737+00	-.85140+00	.20768+00	.16337+00	.11761-02	-.14550-02

FC(CPS)= 3601.9778

3.0542	3.2986	.1885	.39549-01	.40666-01	.11319-02	-.16749+00	.83306-04	.41939-04
4.5487	2.8939	1.2180	-.20978+00	-.21571+00	.21020+00	.45052-01	-.44188-03	-.22245-03

FC(CPS)= 3740.5154

3.0542	3.3597	.1885	.42122-01	-.24369-01	.13055-02	-.16696+00	-.44631-03	.77124-03
4.5487	2.9474	1.2180	-.22343+00	.12926+00	.21029+00	-.25501-01	.23674-02	-.40909-02

FC(CPS)= 3809.7641

EXAMPLE PROBLEM - SECOND TANGENTIAL MODE FOR HYPOTHETICAL ENGINE

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TRANSVERSE STABILITY PROGRAM... CALCULATES HR, HI OR HTR, HTI

INPUT DATA

SNH	ZF	GAMMA	UE	SOUND (FT/SEC)	ULM (FT/SEC)	XK (DRAG)	XCOMPL (IN)
3.05423680	2.31250000	1.21800	.18852762	3800.00	20.420000	.000000	.000000

INCREMENTS	LR/N	LT/N
.0	.0000000	.0000000

NOZZLE ADMITTANCES INPUT

OMEGA(CH)	ERT	EIT	CRT	CIT
2.8098978	.21550144+00	.41393717+00	.68185882-03	-.20889010-03
2.9320672	.21103374+00	.34271131+00	.67167071-03	-.64559413-03
3.0542367	.20827204+00	.26051653+00	-.19082022-03	-.66101016-03
3.1764061	.20767955+00	.16337189+00	-.22172432-03	.27430632-03
3.2985756	.21019855+00	.45051624-01	.83306136-04	.41938501-04
3.3596603	.21329456+00	-.25500607-01	-.44631177-03	.77123835-03

CALCULATED RESULTS... FIRST-ORDER SOLN (UNIF INJ) SECOND-ORDER SOLUTION

OMEGA	H REAL	H IMAG	HT REAL	HT IMAG
2.8098978	.18477270+01	-.33330533+01		
2.8709826	.18420358+01	-.26730276+01		
2.9320673	.18303127+01	-.20026718+01		
2.9931520	.18046849+01	-.13051752+01		
3.0542367	.17417167+01	-.54798279+00		
3.1153214	.15558282+01	.33303596+00		
3.1764061	.85958605+00	.13542701+01		
3.2374909	-.74346371+00	.94920009+00		
3.2985756	.19671684+00	-.42130306-02		
3.3596603	.94748557+00	.65183567+00		

PROGRAM D OUTPUT

OMEGA(C)	HTR	HTI
2.809898	1.447911	-2.611835
2.870983	1.443451	-2.094630
2.932067	1.437264	-1.569328
2.993152	1.414182	-1.022758
3.054237	1.264839	-.429409
3.115321	1.219174	.260973
3.176406	.673586	1.061229
3.237491	-.562591	.743809

3.298576	.155718	-.003301
3.359660	.742466	.510790

FOLLOWING WILL BE INTERPOLATION WITHIN HTR HTI TABLE GIVEN ABOVE

OMEGA	HTRINI	HTIINI
2.866898	1.447911	-2.611838
2.820962	1.447458	-2.519502
2.851826	1.446853	-2.427105
2.842790	1.446097	-2.334347
2.833754	1.445187	-2.241329
2.864717	1.444126	-2.148050
2.875681	1.442929	-2.054546
2.886645	1.441697	-1.961031
2.897609	1.440358	-1.867354
2.908573	1.438806	-1.773285
2.919537	1.436934	-1.678596
2.930501	1.434634	-1.583059
2.941465	1.432068	-1.486881
2.952429	1.429461	-1.390447
2.963393	1.426503	-1.293327
2.974357	1.422876	-1.195080
2.985321	1.418260	-1.095263
2.996284	1.412647	-.993531
3.008248	1.406766	-.891013
3.018212	1.400807	-.787487
3.029176	1.393407	-.682079
3.040140	1.383402	-.573920
3.051104	1.369629	-.462136
3.062068	1.353722	-.346415
3.073032	1.340228	-.227741
3.083996	1.324383	-.105974
3.094960	1.300921	.019111
3.105924	1.264575	.147735
3.116888	1.210281	.280510
3.127851	1.145059	.436696
3.138815	1.070803	.611631
3.149779	.982123	.784023
3.160743	.873631	.932577
3.171707	.779937	1.035998
3.182671	.564687	1.076864
3.193635	.313983	1.065218
3.204599	.026978	1.014156
3.215563	-.249402	.935611
3.226527	-.468232	.841516
3.237491	-.582590	.743812

FC(CPS)	(OMEGA)D	TAU(MS)	N
3186.4	2.50993	.26327	3.07966
3198.9	2.53086	.26073	2.91667
3211.3	2.55183	.25812	2.75917
3223.7	2.57279	.25544	2.60715
3236.1	2.59375	.25268	2.46062
3248.5	2.61470	.24983	2.31961
3261.0	2.63568	.24689	2.18417
3273.4	2.65665	.24385	2.05457
3285.8	2.67761	.24069	1.93065
3298.3	2.69857	.23741	1.81216
3310.7	2.71954	.23398	1.69892
3323.1	2.74051	.23040	1.59074
3335.6	2.76146	.22664	1.48793
3348.0	2.78243	.22270	1.39048
3360.4	2.80339	.21855	1.29954
3372.9	2.82436	.21417	1.21331
3385.3	2.84532	.20953	1.13204
3397.7	2.86628	.20459	1.05565
3410.2	3.88725	.19932	.98556
3422.6	3.01821	.19372	.92175
3435.0	3.02918	.18774	.86364
3447.5	3.04014	.18134	.81075
3459.9	3.05110	.17445	.76278
3472.3	3.06207	.16696	.72118
3484.8	3.07303	.15886	.68946
3497.2	3.08400	.15024	.66643
3509.6	3.09496	.14113	.65060
3522.1	3.10592	.13145	.64092
3534.5	3.11689	.12095	.63765
3546.9	3.12785	.10827	.65580
3559.4	3.13882	.09456	.71008
3571.8	3.14978	.07995	.80400
3584.2	3.16074	.06685	.93457
3596.6	3.17171	.05489	1.09523
3609.1	3.18267	.04260	1.30914
3621.5	3.19363	.02519	1.96392
3633.9	3.20460	.00233	19.07532
3646.4	3.21556	.11438	-1.87964
3658.8	3.22653	.09248	-.99031
3671.2	3.23749	.07858	-.76612

THE FOLLOWING ARE VALUES INTERPOLATED AT SLOPE OF N=0.0

NMIN= .63752
TAU(MS)= .12561
(OMEGA)D= 3.11224
FC(CPS)= 3529.2

A	B	C	D	E	F	G	H	I	J
0.	0.	0.	0.	200.	0.	0.	0.	50.	0.

********** THE FOLLOWING MAIN CONTROL DATA WILL BE USED IN THIS CASE **********

RATIO OF SPECIFIC HEAT (GAMMA) = 1.2180

DESIRED MACH NUMBER = .00000 (=0 IF BEING CALCULATED)

CHAMBER RADIUS = 6.400 (INCHES)

CHAMBER LENGTH = 14.800 (INCHES)

SPEED OF SOUND = 3800.000 (FT/SEC)

CHAMBER MODE DESCRIPTION = 1.64118 (=0 FOR LONGITUDINAL MODES)

********** CHAMBER FREQUENCIES (WC) **********

1.69389	1.73071	1.76754	1.80436	1.84118
1.87801	1.91483	1.95165	1.98848	2.02530

***** MACH DISTRIBUTION IN CHAMBER AS A FUNCTION OF LENGTH *****

CHAMBER LENGTH	MACH DISTRIBUTION	CHAMBER LENGTH	MACH DISTRIBUTION	CHAMBER LENGTH	MACH DISTRIBUTION
.00000	.00000	6.40000	6.39500	25.00000	6.40000
2.50000	2.50000	6.41000	6.40000	50.00000	6.40000
5.00000	5.00000	6.42000	6.40000	.00000	.00000
6.30000	6.30000	6.43000	6.40000	.00000	.00000
6.35000	6.35000	6.50000	6.40000	.00000	.00000
6.38000	6.38000	7.50000	6.40000	.00000	.00000
6.39000	6.39000	12.50000	6.40000		

INPUT TO INJECTION DISTRIBUTION PROGRAM

CONSTANTS

NUMBER OF OMEGAS = 6

NUMBER OF ELEMENTS = 3 FOR EACH OF 180 SYMMETRIC SECTIONS.

RADIAL DIVISIONS(XM) = 20.

ANGULAR DIVISIONS (XN) = 180.

ACOUSTIC MODE NUMBER(SVN) = 1.8412

ORDER OF BESSEL FUNCTIONS(V) = 1.

INJECTOR RADIUS = 6.400, IN.

RATIO OF SPECIFIC HEATS(GAMMA) = 1.2180

MAXIMUM PRESSURE AMPLITUDE RATIO(POO) = 1.000

TRANSFER FUNCTIONS FOR LINEAR OPERATION

PRESSURE(TFLP) = .000

RADIAL VELOCITY(TFLR) = 1.000

TANGENTIAL VELOCITY(TFLT) = .000

INPUT FREQUENCIES

1.6939	1.7675	1.8412	1.9148	1.9885
2.0253				

ELEMENT INFORMATION

ELEMENT NO.	RADIUS IN.	ANGLE RADIANS	DISTRIBUTION COEFFICIENT MU
1	2.000	.0175	4.4444
2	4.000	.0175	7.7778
3	6.000	.0175	7.7778

TABULAR NONLINEAR EFFECTS

PRESSURE PERTURBATION	COMBUSTION GAIN	RADIAL VELOCITY PERTURBATION	COMBUSTION GAIN	TANGENTIAL VELOCITY PERTURBATION	COMBUSTION GAIN
.000	.000	-5.100	-5.000	.000	.000
.000	.000	-2.100	-2.000	.000	.000
.000	.000	-1.100	-1.000	.000	.000
.000	.000	-.600	-.500	.000	.000
.000	.000	-.200	-.100	.000	.000
.000	.000	-.150	-.050	.000	.000
.000	.000	-.110	-.010	.000	.000
.000	.000	-.100	.000	.000	.000
.000	.000	-.090	.000	.000	.000
.000	.000	-.050	.000	.000	.000
.000	.000	-.010	.000	.000	.000
.000	.000	.010	.000	.000	.000
.000	.000	.050	.000	.000	.000
.000	.000	.090	.000	.000	.000
.000	.000	.100	.000	.000	.000
.000	.000	.110	.010	.000	.000
.000	.000	.150	.050	.000	.000
.000	.000	.200	.100	.000	.000
.000	.000	.600	.500	.000	.000
.000	.000	1.100	1.000	.000	.000
.000	.000	2.100	2.000	.000	.000
.000	.000	5.100	5.000	.000	.000
.000	.000	.000	.000	.000	.000
.000	.000	.000	.000	.000	.000
.000	.000	.000	.000	.000	.000
.000	.000	.000	.000	.000	.000
.000	.000	.000	.000	.000	.000
.000	.000	.000	.000	.000	.000
.000	.000	.000	.000	.000	.000
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.000	.000	.000	.000	.000	.000
.000	.000	.000	.000	.000	.000
.000	.000	.000	.000	.000	.000

RESULTS OF DESCRIBING FUNCTION

OMEGA	ELEMENT NO.	RADIUS	ANGLE RAD	FRACTIONAL FLOW-RATE	FP	FR	FT
1.6939	1	.313	.0175	.00123	1.000000	.678814	1.000000
1.6939	2	.625	.0175	.00216	1.000000	.493693	1.000000
1.6939	3	.938	.0175	.00216	1.000000	.000000	1.000000

RESULTS OF DESCRIBING FUNCTION

OMEGA	ELEMENT NO.	RADIUS	ANGLE RAD	FRACTIONAL FLOW-RATE	FP	FR	FT
1.7675	1	.313	.0175	.00123	1.000000	.665192	1.000000
1.7675	2	.625	.0175	.00216	1.000000	.472795	1.000000
1.7675	3	.938	.0175	.00216	1.000000	.000000	1.000000

RESULTS OF DESCRIBING FUNCTION

OMEGA	ELEMENT NO.	RADIUS	ANGLE RAD	FRACTIONAL FLOW-RATE	FP	FR	FT
1.8412	1	.313	.0175	.00123	1.000000	.651640	1.000000
1.8412	2	.625	.0175	.00216	1.000000	.452589	1.000000
1.8412	3	.938	.0175	.00216	1.000000	.000000	1.000000

RESULTS OF DESCRIBING FUNCTION

OMEGA	ELEMENT NO.	RADIUS	ANGLE RAD	FRACTIONAL FLOW-RATE	FP	FR	FT
1.9148	1	.313	.0175	.00123	1.000000	.637977	1.000000
1.9148	2	.625	.0175	.00216	1.000000	.432330	1.000000
1.9148	3	.938	.0175	.00216	1.000000	.000000	1.000000

RESULTS OF DESCRIBING FUNCTION

OMEGA	ELEMENT NO.	RADIUS	ANGLE RAD	FRACTIONAL FLOW-RATE	FP	FR	FT
1.9885	1	.313	.0175	.00123	1.000000	.624504	1.000000
1.9885	2	.625	.0175	.00216	1.000000	.412330	1.000000
1.9885	3	.938	.0175	.00216	1.000000	.000000	1.000000

RESULTS OF DESCRIBING FUNCTION

OMEGA	ELEMENT NO.	RADIUS	ANGLE RAD	FRACTIONAL FLOW-RATE	FP	FR	FT
2.0253	1	.313	.0175	.00123	1.000000	.617796	1.000000
2.0253	2	.625	.0175	.00216	1.000000	.402424	1.000000
2.0253	3	.938	.0175	.00216	1.000000	.000000	1.000000

RESULTS OF INJECTION DISTRIBUTION EFFECTS

OMEGA	AVN REAL	BVN REAL	CVN REAL	CVN IMAG
1.6939	1.2745	.4300	.0000	-1.8125
1.7675	1.2745	.4158	.0000	-1.8125
1.8412	1.2745	.4020	.0000	-1.8125
1.9148	1.2745	.3881	.0000	-1.8125
1.9885	1.2745	.3744	.0000	-1.8125
2.0253	1.2745	.3676	.0000	-1.8125

********** THESE VALUES PERTAIN TO A SPINNING MODE **********

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EXECUTION TERMINATED BY AN ATTEMPT TO READ THRU AN END OF FILE
   I/O CALLED  AT  SEQUENCE  NUMBER  00131  OF  AS138
AS138  CALLED  AT  SEQUENCE  NUMBER  00161  OF  CHAMBR
CHAMBR CALLED  AT  SEQUENCE  NUMBER  00104  OF  MAIN PROGRAM
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