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User's Manual for Rocket Combustor Interactive Design (ROCCID) and Analysis Computer Program

Volume II—Appendixes A-K

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APPENDIX A

INSTRUCTION SUMMARY

Instruction Summary

-- **GENERAL** --
  * All input must be in UPPER CASE.
  * You will be prompted for all input data.
  * You need only enter data you wish to change.
  * You can go back and make corrections to input data
    at any time.

-- **TO ABORT** --
  * CONTROL Y kills everything.
  * Tilde (~) saves results already completed.

-- **DATA ENTRY** --
  * General form is NAME[(index)] = data1 [,data2,...]
    Note : a quantity in brackets indicates optional input
    where : "NAME" is a variable name which is prompted for
    where : "data" can be any of the following:
    __ value   (a real/integer number)
       i.e., RCHAMB=2.5 ; ICAV=1
    __ N*value   (a repeated value)
       i.e., TQW=3*2000...equivalent to TQW=2000,2000,2000
    __ N(value1,value2,...) (a repeated group of values)
       i.e., XP=2(.96,.95)...equivalent to
          XP=.96,.95,.96,.95
    __ ,,   (an unchanged array value)
       i.e., XTQW=0,,3.5,...changes the 1st value to 0,
          leaves the 2nd value unchanged, and changes
          the 3rd value to 3.5
    __ N*,   (a block of unchanged values)
       i.e., UEO=10,5*,90...changes the 1st value to 10,
          leaves the 2nd thru 6th values unchanged and
          changes the 7th value to 90 and continues
          filling the array from there.

  * A line ending with a COMMA signals more input for this array.
    Note: If a COMMA is inadvertently input at the end of a line,
      a <RET> input on the following line will terminate
      input.
  * <RET> in place of a value signals no change for this variable
     i.e., the current or last input value is retained.
  * <BACKSPACE> backspaces over characters which have been
       displayed.
     i.e., ==>UEO= is printed on the screen, to start
       changing input at the 9th value, enter a
       <BACKSPACE>, followed by: (9)=400,500,... which
       will appear as ==>UEO(9)=400,500..
    NOTE: <CTRL>H can be used on terminals without a <BACKSPACE>.
  * @INSERT in place of a value allows the user to INSERT data
      into a table.
  * @SKIP in place of a value signals the program to skip the
     remaining variables in that application and proceed to
     the next application.
  * @HELP in place of a value will cause these instructions to be
     repeated.

-- **OVERVIEW** --

* The structure of this code is menu driven. Upon picking an application you will be shown the NAMELIST for that application, a description and the VARIABLES in that namelist. You then have the option to proceed, or return.

-- **REPLAY FILES** --

* A replay file contains all of the input entered from the terminal. This file can be edited using the EDT editor and used as the input for a subsequent run.
* Four special commands are available in the replay input alter mode:
  - @OFF - Stop input from the replay file. (This command can aid in keeping the replay file in-sink when entering a new menu option).
  - @ON - Resume alter input from the replay file (after the next input from the terminal).
  - @GO - Finish processing using the replay file without further keyboard input.
  - @SEARCH 'NAME' - Search through the replay file for 'NAME'. This may be used to get the REPLAY file back in sync. Must be proceeded with the @ON command if @OFF was entered.
* Please refer any comments, problems, bugs, etc. to :

  Software and Engineering Associates, Inc.
  Stu Dunn or Curtis Johnson
  (702) 882-1966

<u>APPENDIX B</u>

ERROR MESSAGES

INTERPRETATION OF ERROR MESSAGES

Message: ALEN NOT CONVERGENT IN SUBROUTINE SWIRL, ALEN=xxx FOR ELEMENT TYPE=xxx

Remedy: ALEN is the "fan" length in SWIRL, the Aerojet swirl coaxial atomization routine. The user should check element inputs for consistency. The iteration counter can be increased in SWIRL, if this problem persists.

Message: AX BEYOND THROAT IN SUBROUTINE SHEAR; RUN STOPPED

Remedy: AX is the downstream axial position in SHEAR, the Aerojet shear coaxial atomzation routine. The message often results when inconsistent element geometry is input. Output contained in the debug file may aid in evaluating the cause of this error.

Message: CHAMBR CALLED WITH INVALID MODEL, MCHAM=xxx

Remedy: An invalid chamber response model indicator input.

Message: COAXIAL ELEMENT FUEL VELOCITY - GAP ITERATION FAILED TO CONVERGE IN SUBROUTINE REDESIGN

Remedy: REDESIGN tries to balance the injector design for a directed change operating condition or element design (Section 3.6). This message occurs when the new velocity ratio (Vf_j/Vo_j) is less than the minimum (**VRATMI**), and REDESIGN can not find an annulus gap which satisfies **VRATMI**. The simplest solution is to reduce **VRATMI**, but the output and history files should be reviewed first, to determine if the requested design change is reasonable. The iteration counter may also be increased from 20, if it is felt that convergence is slow.

Message: COAXIAL ELEMENT LOX FLOWRATE ITERATION CONVERGENCE FAILURE IN SUBROUTINE REDESIGN

Remedy: REDESIGN is trying to determine the LOX pressure drop required to meet the engine flowrate with the new fuel annulus design. An iteration counter has been included to prevent ROCCID from getting lost. This condition will result from a slowly converging solution, or more likely from a physically unrealistic fuel annulus size or pressure drop. Check these inputs.

Message: COAXIAL ELEMENT LOX FLOWRATE ITERATION CONVERGENCE FAILURE IN SUBROUTINE PDESIGN

Remedy: Subroutine PDESIGN calculates the design changes required to satisfy the performance goal. When the new required lox injection velocity has been determined, PDESIGN determines the injection pressure drop required to achieve the new injection velocity, with the existing lox post. This is an iterative process, and a counter has been included to preclude ROCCID from getting into an infinite loop.

Message: COMBR CALLED WITH INVALID MODEL, MBURN=xxx

Remedy: An invalid burning response model indicator input.

Message: COMBUST NONCONVERGENT IN C*/FLOWRATE CALCULATIONS

Remedy: The delivered C*-C* efficiency-flowrate iteration in COMBUST utilizes a simple replacement iteration technique. While this technique works well for high performance combustors (Eta-C*>0.85) convergence can be slow for lower performing combustors.

Message: COMBUST NONCONVERGENT IN TOTAL PRESSURE CALCULATIONS

Remedy: The total pressure loss iteration in COMBUST utilizes a simple replacement iteration technique. The maximum number of iterations can be increased if convergence is a persistent problem.

Message: CONVERGENCE ERROR IN ANNULAR GAP ITERATION FOR SWIRL COAX ELEMENTS IN SUBROUTINE CORESIZE AFTER xxx ITERATIONS NEL=xxx, GAP=xxx IN

Remedy: Subroutine CORESIZE determines the annular gap iteratively for swirl coaxial elements, as discussed in Section 3.2. This message occurs when the specified iteration limit is exceeded. Increasing this limit may resolvve this problem, but the iteration history in the debug file (file type **.DBG**) should be examined.

Message: CONVERGENCE ERROR IN ANNULAR GAP ITERATION FOR SHEAR COAX ELEMENTS IN SUBROUTINE CORESIZE AFTER xxx ITERATIONS NEL=xxx, GAP=xxx IN

Remedy: Subroutine CORESIZE determines the annular gap iteratively for shear coaxial elements, as discussed in Section 3.2. This message occurs when the specified iteration limit is exceeded. Increasing this limit may resolve this problem, but the iteration history in the debug file (file type **.DBG**) should be examined.

Message: CONVERGENCE ERROR IN ENTROPY ITERATION IN SUBROUTINE VGCALC
MANIFOLD P (MPA),T (R), S(J/MOLE-K)=xxx, xxx, xxx
INJECTED P (MPA),T (R), S(J/MOLE-K)=xxx, xxx, xxx

Remedy: Subroutine VGCALC iteratively calculates the injection properties of gaseous propellants given the chamber pressure and the manifold pressure and temperature. This message comes from the iteration that determines the injection temperature by matching the injected entropy with the manifold value. The most common cause of this error is that the injected condition lies in the two-phase region of the H-S diagram, i.e. within the dome. This is only a problem because MIPROPS is not capable of determining the fluid quality. The user should check the operating conditions relative to the dome on an H-S diagram. The iteration process can be followed by examining the iteration record contained in the debug file (file type **.DBG**).

Message: CONVERGENCE ERROR IN ENTROPY ITERATION IN SUBROUTINE GASV
MANIFOLD P (MPA),T (R), S(J/MOLE-K)=xxx, xxx, xxx
INJECTED P (MPA),T (R), S(J/MOLE-K)=xxx, xxx, xxx

Remedy: Subroutine GASV iteratively calculates the injection properties of gaseous propellants given the chamber pressure and manifold temperature. This message comes from the iteration that determines the injection temperature by matching the injected entropy with the manifold value, which was calculated for the guessed manifold pressure. The most common causes of this error are 1) insufficient flow area for the required flow, thereby causing the velocity to become sonic, and 2) the injected condition lies in the two-phase region of the H-S diagram, i.e. within the dome. The latter is a problem because MIPROPS is not capable of determining the fluid quality. The user should check the flow area input. The iteration process can be followed by examining the iteration record contained in the debug file (file type **.DBG**).

Message: CONVERGENCE ERROR IN FLOWRATE ITERATION IN SUBROUTINE GASV MANIFOLD P (MPA)=xxx, T (R)= xxx
INJECTED P (MPA)=xxx, T (R)= xxx
DESIRED WDOT (LB/S)=xxx, CALCULATED WDOT=xxx

Remedy: Subroutine GASV iteratively calculates the injection properties of gaseous propellants given the chamber pressure and manifold temperature. This message comes from the iteration that determines the injected flowrate by adjusting the manifold pressure. The most common causes of this error are 1) insufficient flow area for the required flow, thereby causing the velocity to become sonic, and 2) the injected condition lies in the two-phase region of the H-S diagram, i.e. within the dome. The latter is a problem because MIPROPS is not capable of determining the fluid quality. The user should check the flow area input. The iteration process can be followed by examining the iteration record contained in the debug file (file type **.DBG**).

Message: CONVERGENCE ERROR IN FUEL PRESSURE DROP ITERATION.FOR SHEAR COAX ELEMENTS IN SUBROUTINE CORESIZE AFTER xxx ITERATIONS

Remedy: As discussed in Section 3.2, the core sizing routine, CORESIZE, tries to determine a fuel injection pressure that will increase the fuel injection velocity, thereby satisfying the minimum velocity ratio constraint. Since this process is iterative, a counter has been included to prevent the code from getting caught in a loop. The above message is the result of the number of iterations exceeding the counter, a condition often caused by either a very high oxidizer injection velocity or a large minimum velocity ratio, **VRATMIN**.

Message: CONVERGENCE ERROR IN FUEL PRESSURE DROP ITERATION FOR SWIRL COAX ELEMENTS IN SUBROUTINE CORESIZE AFTER xxx ITERATIONS

Remedy: As discussed in Section 3.2, the core sizing routine, CORESIZE, tries to determine a fuel injection pressure that will increase the fuel injection velocity, thereby satisfying the minimum velocity ratio constraint. Since this process is iterative, a counter has been included to prevent the code from getting caught in a loop. The above message is the result of the number of iterations exceeding the counter, a condition often caused by either a very high oxidizer injection velocity or a large minimum velocity ratio, **VRATMIN**.

Message: CONVERGENCE ERROR IN MACH NUMBER ITERATION IN SUBROUTINE RAYLEE: NEW MACH=xxx, OLD MACH=xxx,CALCULATIONS PROCEEDING WITH OLD TOTAL PRESSURE LOSS

Remedy: Subroutine RAYLEE calculates the change in total pressure due to change in total temperature, area ratio and mass flowrate. It numerically integrates Shapiro's influence coefficient equations from the chamber throat, using the input temperature, mass flow and area profiles. At each spacial location, RAYLEE iterates on the new mach number, using the mach number for the downstream condition. This message occurs when the iteration fails to converge, causing RAYLEE to use the old mach number for the mach number at the current station. There is no fix for this condition, and the message is included for informational purposes.

Message: CONVERGENCE FAILURE IN SUBROUTINE FRICTION; F,F1=xxx, xxx

Remedy: Subroutine FRICTION iteratively determines the Fanning friction factor from the input nondimensional roughness and Reynold's number using the Coolbrook correlation. A convergence error in FRICTION will cause this message to be printed, where F and F1 are the current and most recent past values of the friction factor.

Message: CONVERGENCE ERROR IN SUBROUTINE LEINJ AFTER 50 ITERATIONS FREQUENCY=xxx, IEL=xxx, INDX=xxx TRY INCREASING USGF, OGF AND/OR DSGF

Remedy: USGF, OGF and DSGF control the number of grid points used in the spatial integration in LEINJ. Adjusting any of these parameters in the model control file (file type **.CNT**) will effect model convergence. IEL refers to the element category, i.e. core (1), baffle (2), barrier (3) or FFC (4), while indx refers to propellant circuit, i.e. fuel (1) or ox (2).

Message: CONVERGENCE ERROR IN SUBROUTINE PRESSD FOR INDX=xxx

Remedy: Subroutine PRESSD calculates the pressure drop required to achieve the input total flowrate for propellant circuit INDX (INDX=1 for fuel, =2 for ox). Since mixed element patterns can be accomodated, this procedure must be iterative. An iteration counter has been included in PRESSD to prevent the code from running away. The convergence history is contained in the debug file (file type **.DBG**), and should be examined to diagnose the cause of the convergence failure.

Message: CONVERGENCE ERROR IN SUBROUTINE SWIRLPD "a" NOT CONVERGED AFTER 1000 ITERATIONS

Remedy: SWIRLPD calculates the flowrate, tip Cd, injection velocity and resultant spray cone angle for a swirl coaxial element of prescribed geometry and injection pressure drop. The variable **a** is used in this calculation procedure, and refers to the same value in the reference by Doumas and Laster. The most common cause of this error is incorrect element geometry input definitions, including NINLETS, CDINLET, DRATIO and AINLET (See Section 4.2 for more description of these input variables).

Message: CONVERGENCE ERROR IN SUBROUTINE SWIRLPD,"aPRIME" NOT CONVERGED AFTER 1000 ITERATIONS

Remedy: SWIRLPD calculates the flowrate, tip Cd, injection velocity and resultant spray cone angle for a swirl coaxial element of prescribed geometry and injection pressure drop. The variable aPRIME (or a') is used in this calculation procedure, and refers to the same value in the reference by Doumas and Laster. The most common cause of this error is incorrect element geometry input definitions, including NINLETS, CDINLET, DRATIO and AINLET (See Section 4.2 for more description of these input variables).

Message: CONVERGENCE FAILURE ERROR IN SUBROUTINE EMEST ETAMIX REQUIRED=xxx, ETAMIX CALCULATED=xxx, ETAM=xxx

Remedy: Subroutine EMEST determines the ETAM (related to Em) required to achieve the input Etamix. This message occurs when the iteration counter exceeds its maximum value. The error message output includes the current value of ETAM and the corresponding value of ETAMIX.

Message: CONVERGENCE FAILURE IN CHAMBER LENGTH (OR ORIFICE DIAMETER OR INJECTION VELOCITY) ITERATION IN SUBROUTINE PDESIGN

Remedy: PDESIGN is used to calculate the change in the injector design and operating parameters which will result in the performance goal being met. The change in the parameter is determined by iteratively solving for the effect of the variable change on vaporization efficiency. The above message will result typically unrealistically high or low performance requirements combined with length and/or pressure drop constraints. Review output and history file output along with your inputs (file type **.DES**) to evaluate if they are 1) consistent, 2) realistic.

Message: *** DIST3D FREQUENCY ITERATION NONCONVERGENT AFTER xx ITERATIONS, CONSIDER INCREASING "IDMAX" ***

Remedy: IDMAX is the maximum number of successive approximations permitted by DIST3D. IDMAX is contained in the Model Control Variables (file type **.CNT**). As the message indicates, increasing IDMAX can sometimes permit convergence of the iteration, although large values of IDMAX may result in error accumulation and invalid, negative frequencies.

Message: ELEMENT PRESSURE DROP CONVERGENCE FAILURE IN SUBROUTINE DPOST

Remedy: DPOST is trying to size the internal geometry of a shear coaxial element Lox circuit, so as to meet design constraints, e.g., DIVANG, the specified pressure drop and exit diameter, while providing for repeatable, attached flow conditions at the post exit. An iteration counter has been included to preclude getting caught in an infinite loop., This counter can be increased, but the reasonableness of model inputs should <u>first</u> be evaluated by examining the debug output of the iteration convergence process in the Debug file.(**.DBG**).

Message: ERROR IN CORESPAC, UNKNOWN ELEMENT TYPE=xxx

Remedy: Subroutine CORESPAC spaces the injection elements radially and circumferentially. This message occurs when the element type is not one of those permited, i.e. LOL, OFO, FOF, SHD, SHC or SWC.

Message: ERROR IN CORESPAC, # ELEMENTS NOT DIVISIBLE BY # BAFFLE BLADES; NEL,NBAF=xxx, xxx

Remedy: Although this error is not likely, the error checking has been included to preclude non-symmetric injector designs.

Message: *** ERROR ENCOUNTERED IN NOZZLE GEOMETRY IN SUBROUTINE NOZINI ***

Remedy: This message indicates that the input nozzle geometry is inconsistent, e.g. tangency points don't meet. This error is most likely to result when the user has created an input file without the assistance of the IFE, since it checks this condition during input.

Message: *** ERROR IN HCAVEF FOR F=xxx, PHIF SET TO 0.0

Remedy: HCAVEF is the HIFI subroutine which determines the wave circumferential orientation, relative to the cavity orientation, that result in minimum damping. F is the frequency, in hz, and PHIF is the injector face admittance for the minimally damped orientation. PHIF=0 is equivelant to no cavities being present. This message is mainly information, indicating that the user should consider the results suspect.

Message: *** ERROR IN HFCS, CHAMBER RESPONSE MINIMUM NOT FOUND FOR MODE M=xxx, N=xxx ***

Remedy: As discussed in Section 3.4, HFCS centers the chamber response frequency sweep about the calculated resonant frequency of the mode, neglecting any influences of damping devices. When the frequency sweep is complete, HFCS checks that a minimum exists in chamber response curve (not necessarily the fundamental mode, just a minimum). If the minimum is not found, HFCS shifts the center of the frequency sweep to a lower frequency and tries again. If the minimum is not found this time, the error message above is printed. The user should check the chamber response model output in the history file (file type **.HIS**) to confirm that this is the problem. While there is no remedy for this condition, the last value of the decay coefficient, AL, may be adequate to determine the high frequency stability characteristics for the subject mode, M tangential + N radial.

Message: *** ERROR IN HFCS, COMBUSTION RESPONSE PEAK NOT FOUND ***

Remedy: HFCS begins by determining the burning response curve versus frequency, as discussed in Section 3.4. To ensure that a large enough frequency range has been covered, it checks that the burning response magnitude reaches a maximum. If it is not found, HFCS will coarsen the frequency stepsize and look once more for the peak. If it still can't find the peak, this message is printed. The user should examine the burning response model output contained in the history file (file type **.HIS**), to ensure that this is the case. The user should also check the input model parameters, checking that the frequency range examined includes 0.5/Tau hz, where Tau=Tausen if the N-Tau model was used, or Tau is the estimated droplet lifetime calculated by CRP.

Message: *** ERROR IN HFCS, STABILITY CONDITION NOT FOUND IN SUBROUTINE STABC *** AL=xxx, M=xxx, N=xxx

Remedy: As discussed in Section 3.4, HFCS uses the subroutine STABC to determine the frequency at which the maximum in-phase gain occurs. This message occurs when STABC can not find where the gain function passes between 180 and -180 degrees. The user should verify that the crossing does not exist by examining the STABC output in the history file (file type **.HIS**). While there is no remedy for this condition, the last value of the decay coefficient, AL, may be adequate to determine the high frequency stability characteristics for the subject mode, M tangential + N radial.

Message: *** ERROR IN LFCS, ITERATION COUNTER EXCEEDED BEFORE MARGINAL CONDITION WAS FOUND ***

Remedy: In an effort to prevent LFCS from getting lost, and thereby pointlessly using excessive amounts of computer time, LFCS is only allowed to adjust the chamber pressure 100 times in its search for the marginal operating pressure (See Section 3.3 for more details). This message occurs when the counter has been exceeded. The user should check that 1) the chamber pressure iteration has not gotten lost or stuck, or 2) the calculations do not indicate that the configuration is either extremely stable or unstable, i.e. throttled to pressures excessively higher or lower than the nominal.

Message: *** ERROR IN LFCS, LONGITUDINAL MODE NOT FOUND ***

Remedy: LFCS begins by determining the chamber response versus frequency, as discussed in Section 3.3. The frequency range is intended to exceed the first longitudinal (1L) resonant frequency. LFCS can confirm that this has occured by checking for a chamber response minimum. If the minimum is not found, LFCS increases the chamber response frequency stepsize and tries to find the 1L minimum again. If the minimum is not found the second time, this message is printed, and LFCS stops. The user should ensure that the 1L was actually not found by examining the chamber response model output contained in the history file (file type **.HIS**), the user should also examine the frequency stepsize used in both the first and second frequency sweeps.

Message: *** ERROR IN LFCS, STABILITY CONDITION NOT FOUND 15 TIMES SUBROUTINE STABC ***

Remedy: LFCS uses the subroutine STABC to determine the frequency at which the maximum in-phase gain occurs (See Secton 3.3). If the system is highly chug stable, a crossing of the gain function between 180 and -180 degrees may not occur. Each time the condition is not found, LFCS will continue to throttle the engine, in an effort to find the marginally stable chamber pressure. LFCS has been designed to accept this error 15 times, before printing the above message and terminating execution. The user should verify that the crossing does not exist by examining the STABC output in the history file (file type **.HIS**). Since this message usually implies extremely large chug stability margins, the user should beware of extremely unstable injection-coupled longitudinal mode stability, i.e. the chamber length is excessively long, so the timelags can not couple with the bulk-flow (low frequency) oscillations.

Message: *** ERROR *** MACH NUMBER GREATER THAN UNITY

Remedy: This error comes from subroutine MACH, which calculates the mach number for an input area ratio and gamma using the successive approximation technique. The routine is limited to calculations for the subsonic branch, so this message indicates an error in the iteration process.

Message: ERROR IN PRELIMD, BOTH PROPELLANTS GASEOUS

Remedy: ROCCID is currently not capable of handling gas-gas combustors. This is due to the problems which would arise during the calculation of total timelags

Message: ERROR IN REDESIGN, FUEL ORIFICE SIZE CAN NOT BE SPECIFIED FOR SHEAR OR SWIRL ELEMENTS

Remedy: Specifying a new fuel orifice diameter for coaxial elements has been avoided in the current code, since this can result in an interminable loop (See Section 3.6). This is message will only occur if the user has modified the code to vary this parameter.

Message: ERROR IN SUBROUTINE ALOAD, BAFFLE ELEMENT TYPE xxx NOT RECOGNIZED

Remedy: Input baffle element type invalid, i.e. not LOL, OFO, FOF, SHD, SHC or SWC. This error is most common when the user creates input files without the assistance of the IFE. The most likely cause is that the value of the character variable TYPE is not in single quotes (').

Message: ERROR IN SUBROUTINE ALOAD, BARRIER ELEMENT TYPE xxx NOT RECOGNIZED

Remedy: Input barrier element type invalid, i.e. not LOL, OFO, FOF, SHD, SHC or SWC. This error is most common when the user creates input files without the assistance of the IFE. The most likely cause is that the value of the character variable TYPE is not in single quotes (').

Message: ERROR IN SUBROUTINE ALOAD, CORE ELEMENT TYPE xxx NOT RECOGNIZED

Remedy: Input core element type invalid, i.e. not LOL, OFO, FOF, SHD, SHC or SWC. This error is most common when the user creates input files without the assistance of the IFE. The most likely cause is that the value of the character variable TYPE is not in single quotes (').

Message: ERROR IN SUBROUTINE CORESIZE, COAXIAL ELEMENT SPECIFIED WITH LIQUID FUEL

Remedy: As indicated in Sections 2.0 and 5.0, coaxial elements require that the fuel is gaseous, i.e. that the manifold temperature be above the propellant critical temperature. Check the input fuel temperature.

Message: *** ERROR IN SUBROUTINE DCAVEF FOR OMEGA=xxx BETAC SET TO 0.0

Remedy: DCAVEF is the DIST3D subroutine which determines the wave circumferential orientation, relative to the cavity orientation, that result in minimum damping. OMEGA is the frequency, in hz, and BETAC is the effective cavity admittance. BETAC=0 is equivelant to no cavities being present. This message is mainly information, indicating that the user should consider the results suspect.

Message: *** ERROR IN SUBROUTINE DINPUT *** NO DATA AVAILABLE FOR ELEMENT TYPE=xxx

Remedy: Subroutine DINPUT reads the design definition files at the beginning of a POINTD run (file types **.DES** and **.DEF**). This message occurs when the element type is not one of those permited, i.e. LOL, OFO, FOF, SHD, SHC or SWC.

Message: *** ERROR IN SUBROUTINE DLOAD *** NO DATA AVAILABLE FOR ELEMENT TYPE xxx

Remedy: Input core element type invalid, i.e. not LOL, OFO, FOF, SHD, SHC or SWC. This error is most common when the user creates input files without the assistance of the IFE. The most likely cause is that the value of the character variable TYPE is not in single quotes (').

Message: *** ERROR IN SUBROUTINE NOZADM, CAN NOT GET OUT OF THROAT AFTER xxx ATTEMPTS ***

Remedy: Subroutine NOZADM numerically calculates the nozzle admittance by integrating from the nozzle throat to the beginning of the constant diameter section of the chamber (nozzle entrance). The first integration step is a pure Newton step (See Appendix K), so a small initial stepsize is desired. Unfortunately, if the stepsize is too small, the integration step occurs within the throat and terms like $1/(1-M^2)$ become undefined. To avoid this error, NOZADM increases the initial stepsize. If NOZADM can not get out of the throat after several attempts, this message is printed, and the calculations stopped. This error is most common in large diameter nozzles with a large throat entrance radius.

Message: ERROR IN PRELIMD, CALCULATED CR=xxx <1.0

Remedy: Although this message is not likely, it as been included to preclude the user from continuing into more detailed analyses if this condition exists. It is most likely to occur with portions of the chamber geometry fixed, and insufficient flowrate or chamber pressure.

Message: ERROR IN SUBROUTINE PRELIMD, GASEOUS PRESSURE DROP ITERATIONS FOR DPMIN DID NOT CONVERGE AFTER xxx ITERATIONS

Remedy: PRELIMD must solve the injection pressure drop required for a specified gaseous propellant injection velocity iteratively. This message occurs when the iteration fails to converge at the minimum pressure drop.

Message: ERROR IN SUBROUTINE PRELIMD, GASEOUS PRESSURE DROP ITERATIONS FOR DPNOM DID NOT CONVERGE AFTER xxx ITERATIONS

Remedy: PRELIMD solves the injection pressure drop required for a specified gaseous propellant injection velocity iteratively. This message occurs when the iteration fails to converge at the minimum pressure drop.

Message: ERROR IN SUBROUTINE PRELIMD, PCNOM NOT CONVERGED AFTER xx ITERATIONS

Remedy: If the user specifies the manifold pressures, PRELIMD solves for the nominal chamber pressure iteratively. The iteration scheme tries to use all the available pressure drop. This message occurs when the iteration fails to converge. Further insight into the convergence iteration can be found in the debug output file (file type **.DBG**).

Message: *** ERROR IN SUBROUTINE SHEAR, LIQUID FUEL DETECTED ***

Remedy: Adjust fuel temperature and or pressure to adhere to constraints outlined in Section 2.2 or change injector element type

Message: ERROR IN SUBROUTINE SHEARPD DUE TO ERROR IN SUBROUTINE FRICTION

Remedy: Subroutine FRICTION is used by SHEARPD to iteratively determine the Fanning friction factor from the input nondimensional roughness and Reynold's number using the Coolbrook correlation. A convergence error in FRICTION will cause this fatal error in SHEARPD.

Message: *** ERROR IN SUBROUTINE SWIRL, LIQUID FUEL DETECTED ***

Remedy: Adjust fuel temperature and or pressure to adhere to constraints outlined in Section 2.2 or change injector element type

Message: ERROR IN SUBROUTINE SPLINT: KHI=KLO - STOPPED

Remedy: SPLINT is the cubic spline interpolation routine in Subroutine RAYLEE. This message occurs when the table contains an invalid array of derivative values. It is most likely to occur if this routine is improperly accessed by a user-added analysis model.

Message: ERROR IN SUBROUTINE SWIRLSZR, "a" ITERATION DID NOT CONVERGE AFTER 1000 ITERATIONS

Remedy: SWIRLSIZR determines the geometry of the swirl coaxial post, given element flowrate and injection pressure drop. The variable **a** is used in this calculation procedure, and refer to the same value in the reference by Doumas and Laster. The most common cause of this error is incorrect element geometry input definitions, including CDINLET and DRATIO (See Section 4.2 for more description of these input variables).

Message: ERROR IN SUBROUTINE SWIRLSZR, CONVERGENCE FAILURE IN SWIRL HOLE DIAMETER ITERATION

Remedy: SWIRLSIZR determines the geometry of the swirl coaxial post, given element flowrate and injection pressure drop. This message occurs when the program is unable to determine a swirl chamber inlet orifice diameter which satisfies other flow constraints (See reference by Doumas and Laster). The user may want to try adjusting the element geometry input definitions CDINLET and DRATIO (See Section 4.2 for more description of these input variables).

Message: ERROR IN SUBROUTINE SWILRSZR, aPRIME ITERATION DID NOT CONVERGE AFTER 1000 ITERATIONS

Remedy: SWIRLSIZR determines the geometry of the swirl coaxial post, given element flowrate and injection pressure drop. The variable aPRIME (or a') is used in this calculation procedure, and refers to the same value in the reference by Doumas and Laster. The most common cause of this error is incorrect element geometry input definitions, including CDINLET and DRATIO (See Section 4.2 for more description of these input variables).

Message: ERROR WITH AMINE FLAME CALCULATIONS IN SUBROUTINE VAPRO, RUN STOPPED

Remedy: As noted in Section 3.2, COMBUST still contains the dual-flame, monopropellant amine vaporization correction. This message can only occur when an amine fuel is used. It indicates that the calculated generalized length correction term is in some way inconsistent.

Message: ERROR WITH CHAMBER GEOMETRY INPUT, BARREL SECTION LESS OR EQUAL 0
CALCULATED BARREL LENGTH, IN=xxx
CALCULATED CONVERGENT SECTION LENGTH, IN=xxx
CHECK GEOMETRY INPUTS, INCLUDING UNITS:
RCHAMB, FT=xxx, RTHRT, FT=xxx,
RNE, FT=xxx, RTE, FT=xxx, ALPHA, DEG=xxx,

Remedy: This error message is generated by subroutine PINPUT. Since ROCCID, in particular the chamber response models can not handle purely conical chambers, this error message has been added. It should be noted that this error may also occur due to inconsistencies in geometry inputs, i.e. barrel lengths less than 0. This error is most likely to result when the user has created an input file without the assistance of the IFE, since it checks this condition during input.

Message: ERROR WITH NOZZLE GEOMETRY AT TANGENT POINT ALPHA=xxx DEG

Remedy: This message, generated by subroutine PINPUT, indicates that the input nozzle geometry is inconsistent, especially where the tangency points should meet. This error is most likely to result when the user has created an input file without the assistance of the IFE, since it checks this condition during input.

Message: ERROR WITH VAPORIZATION INTERPOLATION IN SUBROUTINE VAPRO,RUN STOPPED

Remedy: Subroutine VAPRO performs the propellant droplet vaporization using Priem's Generalized Length Correlation (See Section 2.2). This message indicates that the calculated generalized length correction term is in some way inconsistent.

Message: EXPANSION PRESSURE DROP CALCULATION FAILED IN SUBROUTINE DPOST

Remedy: DPOST is trying to size the internal geometry of a shear coaxial element Lox circuit, so as to meet design constants, e.g., DIVANG, the specified pressure drop and exit diameter, while providing for repeatable, attached flow conditions at the post exit. An iteration counter has been included to preclude getting caught in an infinite loop., This counter can be increased, but the reasonableness of model inputs should first be evaluated by examining the debug output of the iteration convergence process in the Debug file.(**.DBG**).

Message: INJR CALLED WITH INVALID MODEL, MINJ=xxx

Remedy: Invalid injector response model index input.

Message: INPUT ERROR TO FUNCTION AINTP, "X" ARRAY NOT MONOTONICALLY INCREASING X(1)=xxx, xxx, ...

Remedy: AINTP performs 1-D interpolations, but requires the independent array, X, to be monotonically increasing. This message usually results when the user has input arrays, i.e. XNOZ, XMRA, PCA, without using the IFE, which checks them.

Message: INPUT ERROR TO FUNCTION GETVAL, ARRAY "XA" NOT MONOTONICALLY DECREASING XA(1)=xxx, xxx, ...

Remedy: GETVAL performs 1-D power-law interpolations, but requires the independent array, XA, to be monotonically increasing. This message usually results when the user has input array PCA without using the IFE, which checks them.

Message: INVALID NUMBER OF INPUTS TO SUBROUTINE GETVAL, N=xxx

Remedy: GETVAL performs 1-D power-law interpolations. The independent and dependent arrays must be contain at least 2 points.

Message: LESS THAN ONE DROP FORMED OR NEGATIVE RJET IN SUBROUTINE SHEAR

Remedy: This error is most likely to result from inconsistent element geometry or during application of the model (SHEAR) to unusual element designs (Section 2.1). Check input element dimensions.

Message: LVAP NOT CONVERGED FOR TRIPLET IN SUBROUTINE TIMELAG, RUN STOPPED

Remedy: Because of the potential for a dropsize distribution when triplet injection elements are used, the subroutine TIMELAG must calculate the 20% vaporization length, LVAP, iteratively (See Section 5.1 for more details). This error message occurs when the iteration counter, which is included to prevent the program from getting lost in an infinite loop, is exceeded.

Message: MACH CALLED WITH ISUB=0, RUN ABORTED

Remedy: Older versions of subroutine MACH contained a flag ISUB which determined whether the calculation was for the subsonic (ISUB=1) or the supersonic (ISUB=0) branch of the area ratio-mach number calculation. The current routine has retained the flag for compatability, but is only capable of calculating Mach numbers for the subsonic branch.

Message: MORE DROPS PRODUCED IN SUBROUTINE SHEAR THAN DIMENSIONED FOR

Remedy: This message is often the result of an incorrectly input element geometry, e.g., too small of a fuel annulus gap. If these values are OK, the size of the arrays R, XD, ATLEN and VJL can be increased in subroutine SHEAR from 500.

Message: READ ERROR ENCOUNTERED ON UNIT 9 BEFORE THIRD $END FOUND IN SUBROUTINE VSAVE

Remedy: Subroutine VSAVE reads the namelist $SAVE, contained at the end of the design input file (file type **.DES**). It reads the the current design variables, contained is $SAVE, which are not contained in the input file, e.g. injection pressure, dropsizes, etc. It must exist, even if there are no values, i.e. PRELIMD hasn't been run yet. The primary cause of the error message is the incorrect manual creation of the **.DES** file, i.e. without the use of the IFE.

Message: RJET NOT CONVERGENT IN SUBROUTINE SHEAR

Remedy: This error is most likely to result from inconsistent element geometry or during application of the model (SHEAR) to unusual element designs (Section 2.1). Check input element dimensions.

Message: SHARP-EDGED ORIFICE CALCULATIONS FAIL IN SUBROUTINE DPOST FOR DMS,DSE,CC0SE=xxx, xxx, xxx

Remedy: Subroutine DPOST sizes the lox post internal geometry for shear coaxial elements. This iteration tries to determine the sharp-edged orifice diameter (DSE) with an equivalent contraction coefficient (CC0SE) as the metering section diameter (DMS). The iteration counter is included to prevent the code from entering an infinite loop. Progress of the iteration can be checked in the debug file (file type **.DBG**)

Message: *** SUCCESIVE APPROXIMATIONS IN DIST3D LEAD TO NEGATIVE REAL FREQUENCY FOR M=xxx AND N=xxx, RUN STOPPED

Remedy: The iteration process in DIST3D can result in an invalid, negative frequency, which will predict negative dissipation. There is currently no solution for this error.

Message: TERMINAL ERROR IN SUBROUTINE GASV, TABLES NOT AVAILABLE FOR GAS PHASE PROPERTIES OF xxx

Remedy: GASV utilizes the MIPROPS routines, packaged in FLUIDP. If the MIPROPS propellant data doesn't exist, GASV must stop.

Message: TERMINAL ERROR IN SUBROUTINE VGCALC, TABLES NOT AVAILABLE FOR GAS PHASE PROPERTIES OF xxx

Remedy: VGCALC utilizes the MIPROPS routines, packaged in FLUIDP. If the MIPROPS propellant data doesn't exist, VGCALC must stop.

Message: TOO MANY TIME STEPS INPUT TO SUBROUTINE LEINJ, NTINJ=xxx,>LIMIT(50), RETRY WITH SMALLER VALUE

Remedy: Hardwired matrix sizing in LEINJ limits the number of time integrations per oscillation to 50. Reduce the value in the model control file (file type .CNT) and try again.

Message: *** WARNING FROM LFCS, PC CONVERGED WITHOUT MARGINAL CONDITION BEING SATISFIED, FOLLOWING RESULTS SHOULD BE CONSIDERED SUSPECT:

Remedy: The throttling procedure included in LFCS will occasionally get stuck in the chamber pressure iteration, homing in on a chamber pressure which does not result in a marginally stable system gain (a maximum in-phase magnitude of 1.0). The user should ensure that 1) the converged Pc is adequate for their minimum needs, and 2) that the system gain amplitude is not very close to 1.0, thereby indicating that the error is only a matter of numerical tolerencing.

Interactive Front End Error Messages

ERROR -- Bad integer input --try again
User input for an integer variable was not an interger.

ERROR -- Bad menu option chosen --try again
Menu option chosen was not valid.

ERROR -- Bad real input --try again
User input for a real variable was not a real number.

ERROR -- Both propellants in gaseous state
For the given operating conditions both propellants are gaseous.

ERROR -- Cavity geometry not compatible with chamber radius
Chamber geometry failed the following test:

```
IF ICAV=2 THEN
   2*Pi*RCHAMB .GE. [NCAV(1)*SQRT(4*AC(1)/Pi) +
                     NCAV(2)*SQRT(4*AC(2)/Pi) +
                     (NCAV(1)+NCAV(2))*TPART]
OTHERWISE
   2*Pi*RCHAMB .GE. [NCAV(1)*(AC(1)/WC(1)+TPART) +
                     NCAV(2)*(AC(2)/WC(2)+TPART)]
```

ERROR -- CCAV array; NCAV entries must be greater than 0.0
The aperture length for this particular cavity is nonzero, but the sound speed (CCAV*) is zero for the cavity.

ERROR -- CGAM array; NCAV entries must be greater than 0.0
The aperture length for this particular cavity is nonzero, but the specific heat ratio (CGAM*) is zero for the cavity.

ERROR -- Chamber diameter bigger than DCMAX
RCHAMB was entered at a value larger than DCMAX/2.0.

ERROR -- Chamber length longer than XLEMAX
CHAMBL was entered at a value larger than XLEMAX.

ERROR -- Chamber pressure must be greater than zero (psia)
Neither chamber pressure nor manifold pressures were entered.

ERROR -- Contraction ratio less than 1
Chamber geometry failed the following test:
RCHAMB .GE. RTHRT

ERROR -- Could not find correct plot data
The expected plot data file could not be found. Check for file existence.

ERROR -- Could not open file
File could not be opened - either it does not exist, the path to the file is incorrect, or the file is locked by another user.

ERROR -- Data files must be opened before an analysis run can begin.
The data files have not been opened before starting an analysis run. Enter the SET VARIABLES menu option, then exit that menu. When prompted for saving the data, answer YES.

ERROR -- DDIF must be less than or equal to XDJ
Self explanatory.

ERROR -- DMS must be less than or equal to DIFF
Self explanatory.

ERROR -- During a READ
A read was unsuccessful, most commonly caused by incorrect entries to a namelist.

ERROR -- Geometry not possible --Chamber radii prevent connecting tangent
Chamber geometry failed the following test:
RTHRT+RTE*[1-COS(ALPHA)] .LE. RCHAMP-RNE*[(1-COS(ALPHA)]

ERROR -- Geometry not possible --check chamber length
Input geometry failed the following test:
CHAMBL .GE. (RTE+RNE)*SIN(ALPHA) + [RCHAMB-RTHRT + (RTE-RNE)*(1-COS(ALPHA))]/TAN(ALPHA)

ERROR -- ICTYP array; NCAV absorbers have not been entered
More absorbers (NCAV in number) have been requested,
but not all have been typed. There must be NCAV entries of absorber types in the ICTYP array.

ERROR -- Injector geometry is incompatible -check FDJ, TPOST, and XDJ
The following test failed: FDJ-XDJ-2*TPOST .GT. 0

ERROR -- Input out of bounds
User input was out of the acceptable range for that variable.

ERROR -- Manifold temperatures must be greater than zero (R)
Manifold temperatures were not entered, or entered less than -460 degrees F.

ERROR -- Nominal flow rate is less than minimum
WDNOM is less than WDMIN.

ERROR -- Problem reading plot data
When reading a plot file (*.PL1, *.PL2, *.PL3, etc), the data required to make the plot was not found. Check formatting of the plot file.

ERROR -- Problem reading plot dimension data
The program cannot read the actual plot data, check data format.

ERROR -- RE2 array; NCAV entries must be greater than RS2 and less than the chamber radius
Either the chamber radius has been set nonzero, and the radius to the outer edge of the absorber segment (RE2) is greater than the chamber radius, or the absorber segment outer radius (RE2) is less than the absorber segment inner radius (RS2).

ERROR -- Required propellant properties not available
Required propellant properties do not exist for this operating condition. Most commonly seen when running fuel through a coaxial injection element.

ERROR -- RHOAP array; NCAV entries must be greater than 0.0
For this particular cavity, the cavity type is either a quarterwave, or user defined (ICTYP*=1 or 4), the cavity has finite size, but the density (RHOAP*) is zero.

ERROR -- RS2 array; NCAV entries must be greater than 0.0 and less than the chamber radius
The chamber radius has been set nonzero, and the start of the absorber segment (RS2) has been set greater than the chamber radius or less than zero.

ERROR -- There are not NCAV(1) 1s in IDCAV
There must be NCAV(1) ones in the IDCAV array.

ERROR -- There are not NCAV(2) 2s in IDCAV
There must be NCAV(2) twos in the IDCAV array.

ERROR -- Unrecognized element type, please try again.
The element type entered was not recognized, the type must be: LOL, OFO, FOF, SHD, SHC, SWC.

ERROR -- Value must be greater than zero
A variables was set to zero, when zero is not permitted.

ERROR -- XMWC array; NCAV entries must be greater than 0.0
The aperture length for this particular cavity is nonzero, but the molecular weight (XMWC*) is zero for the cavity.

ERROR -- ZCOMB must be less than chamber length
The chamber length has been set to a nonzero length, and then combustion plane (ZCOMB) has been set larger than the chamber length.

ERROR -- ZE1 array; NCAV entries must be greater than ZS1 and less than the chamber length
Either the chamber length has been set nonzero, and the distance from the injector face to the end of the absorber segment (ZE1) is greater than the chamber length, or the absorber segment end (ZE1) is less than the absorber segment start (ZS1).

ERROR -- ZLOW array; NCAV entries must be set (less than backing cavity width - WC)
Cavity type is 1, 2, or 3 and ZLOW is either larger than ZUP, or larger than the backing cavity width (WC*).

ERROR -- ZS1 array; NCAV entries must be greater than 0.0 and less than the chamber length
The chamber length has been set nonzero, and the start of the absorber segment (ZS1) has been set greater than the chamber length or less than zero.

ERROR -- ZUP array; NCAV entries must be set (less than backing cavity width - WC and greater than ZLOW)

Cavity type is 1, 2, or 3 and ZUP has been set larger than the backing cavity width (WC*).

APPENDIX C

NAMELIST VARIABLE DEFINITIONS

NAMELIST VARIABLE DEFINITIONS

POINT ANALYSIS

Namelist	Variable	Type	Range	Default	Path	Size	Description
$MODELS:							
	MCHAM	INTEGER	1-3	1	1	1	CHAMBER RESPONSE MODEL FLAG; 1-HIFI, 2-DIST3D 3-FDORC
	MBURN	INTEGER	1-2	2	1	1	COMBUSTION RESPONSE MODEL FLAG; 1-CRP, 2-N-TAU
	MINJ	INTEGER	1-2	1	1	1	CHAMBER MODE FLAG; 1-INJ, 2-LEINJ
$OPCOND							
	FUEL	CHAR*8	N/A		1	1	FUEL NAME, E.G. RP-1, H2, METHANE, PROPANE
	OX	CHAR*8	N/A	LOX	1	1	OXIDIZER NAME, E.G. LOX
	PC	REAL	>0	0.0	1	1	INJECTOR FACE STAGNATION PRESSURE (PSIA)
	XMR	REAL	>0	0.0	1	1	OX/FUEL MIXTURE RATIO
	HGMR*	REAL	>=0	0.0	5	1	OX/FUEL MIXTURE RATIO OF FUEL, IF STAGED COMBUSTION IS USED
	FTMAN	REAL	>-460	-500.0	1	1	FUEL MANIFOLD TEMPERATURE (DEG F)
	XTMAN	REAL	>-460	-500.0	1	1	OXIDIZER MANIFOLD TEMPERATURE (DEF F)
	FBLEED	REAL	0-1	0.0	5	1	FRACTION OF TOTAL FUEL USED FOR UNIFORM FACE BLEED
	EMMAN	REAL	0-1	1.0	1	1	MIXING NONUNIFORMITY DUE TO MANIFOLD MALDISTRIBUTION (1-UNIFORM, NO EFFECT)
	NPERFP	INTEGER	2-30	2	1	1	NUMBER OF POINTS INPUT FOR ISP AND C* VS. MR TABLES
	PMRA	REAL	MONO.	0.0	1	30	ARRAY OF MIXTURE RATIO POINTS FOR PERFORMANCE TABLES (RECOMMEND MR'S FROM COMBUSTION TABLES)
	PISPA	REAL	>=0	0.0	1	30	ARRAY OF ODK-ISP POINTS FOR PERFORMANCE TABLES (SEC)
	PCSA	REAL	>=0	0.0	1	30	ARRAY OF ODK-C* POINTS FOR PERFORMANCE TABLES (FT/SEC)

*Not used in February 1991 ROCCID version, for future use

POINT ANALYSIS (Continued)

Namelist	Variable	Type	Range	Default	Path	Size	Description
$GEOM							
	RCHAMB	REAL	>0	0.0	1	1	CHAMBER RADIUS (FT.)
	RTHRT	REAL	>0	0.0	1	1	THROAT RADIUS (FT.)
	RNE	REAL	>0	0.0	1	1	RADIUS OF CURVATURE AT THE NOZZLE ENTRANCE (FT.)
	RTE	REAL	>0	0.0	1	1	RADIUS OF CURVATURE AT THE THROAT ENTRANCE (FT.)
	ALPHA	REAL	<90	0.0	1	1	CONVERGENCE HALF ANGLE (DEG.)
	CHAMBL	REAL	>0	0.0	1	1	INJECTOR FACE TO THROAT LENGTH (FT.)
	XC	REAL	>0	0.0	4	1	CHAMBER CYLINDRICAL LENGTH (CALCULATED) (FT.)
$CORE							
	TYPE	CHAR*8	N/A		1	1	CORE ELEMENT TYPE: LOL, OFO, FOF, SHD, SHC, SWC
	NEL	INTEGER	>=0	0	1	1	NUMBER OF ELEMENTS
	FDJ	REAL	>=0	0.0	1	1	FUEL ORIFICE OR ANNULUS DIAMETER (IN.)
	FCD	REAL	0-1	1.0	1	1	FUEL ORIFICE Cd
	FIH	REAL	>=0	0.0	1	1	FUEL IMPINGEMENT HEIGHT (IN.)
	FIA	REAL	<45	0.0	1	1	FUEL IMPINGEMENT HALF-ANGLE (DEG.)
	FCANT	REAL	0-45	0.0	1	1	FUEL UNLIKE CANT ANGLE (DEG.)
	FFACET	REAL	>0	0.001	1	1	FUEL FACEPLATE THICKNESS OR ANNULUS LENGTH (IN.)
	XDJ	REAL	>=0	0.0	1	1	OX ORIFICE OR POST DIAMETER (IN.)
	XCD	REAL	0-1	1.0	1	1	OX ORIFICE Cd (IMPINGING ELEMENTS ONLY)
	XIH	REAL	>=0	0.0	1	1	OX IMPINGEMENT HEIGHT (IN.)
	XIA	REAL	<45	0.0	1	1	OX IMPINGEMENT HALF-ANGLE (DEG.)
	XCANT	REAL	0-45	0.0	1	1	OX UNLIKE CANT ANGLE (DEG.)
	XFACET	REAL	>0	0.001	1	1	OX FACEPLATE THICKNESS FOR IMPINGING ELEMENTS OR POST LENGTH SWIRL COAX (IN.)
	TPOST	REAL	>0	0.0	1	1	OX POST WALL THICKNESS FOR COAX ELEMENTS (IN.)
	RECESS	REAL	>=0	0.0	1	1	OX POST RECESS FOR SHEAR COAX ELEMENTS (IN.)
	DMS	REAL	>0	0.0	1	1	OX METERING SECTION DIAMETER FOR SHEAR COAX ELEMENTS (IN.)

POINT ANALYSIS (Continued)

Namelist	Variable	Type	Range	Default	Path	Size	Description
	XMS	REAL	>0	0.0	1	1	OX METERING SECTION LENGTH FOR SHEAR COAX ELEMENTS (IN.)
	DDIF	REAL	>0	0.0	1	1	OX DIFFUSER SECTION DIAMETER FOR SHEAR COAX ELEMENTS (IN.)
	XDL	REAL	>0	0.0	1	1	OX POST DIFFUSER SECTION LENGTH FOR SHEAR COAX ELEMENTS (IN.)
	AINLET	REAL	>0	0.0	1	1	SWIRL COAS SWIRL CHAMBER FEED ORIFICE AREA (PER HOLE) (IN**2)
	CDINLET	REAL	>0	1.0	1	1	SWIRL CHAMBER FEED ORIFICE Cd
	NINLET	INTEGER	>0	0	1	1	NUMBER OF SWIRL CHAMBER FEED ORIFICES (SWIRL COAX ELEMENTS ONLY)
	DRATIO	REAL	>1	1.0	1	1	SWIRL CHAMBER TO ELEMENT EXIT DIAMETER RATIO (DS/XDJ)
	EMUNI	REAL	<1	0.0	4	1	UNIELEMENT RUPE MIXING EFFICIENCY
	CBINT	REAL	0-1	0.0	5	1	INTERACTION INDEX FOR MIXING BETWEEN CORE AND BARRIER
$BAFFLE							
	TYPE	CHAR*8	N/A		1	1	BAFFLE INJECTOR ELEMENT TYPE, E.G. LOL, FOF, OFO, SHC, SWC, SHD
	NEL	INTEGER	>=0	0	1	1	NUMBER OF ELEMENTS
	FDJ	REAL	>=0	0.0	1	1	FUEL ORIFICE OR ANNULUS DIAMETER (IN.)
	FCD	REAL	0-1	1.0	1	1	FUEL ORIFICE Cd
	FIH	REAL	>=0	0.0	1	1	FUEL IMPINGEMENT HEIGHT (IN.)
	FIA	REAL	<45	0.0	1	1	FUEL IMPINGEMENT HALF-ANGLE (DEG.)
	FCANT	REAL	0-45	0.0	1	1	FUEL UNLIKE CANT ANGLE (DEG.)
	FFACET	REAL	>0	0.001	1	1	FUEL FACEPLATE THICKNESS OR ANNULUS LENGTH (IN.)
	FINJ	REAL	>=0	0.0	1	1	FUEL INJECTION POINT RELATIVE TO INJECTOR FACE (IN.)
	XDJ	REAL	>=0	0.0	1	1	OX ORIFICE OR POST DIAMETER (IN.)
	XCD	REAL	0-1	1.0	1	1	OX ORIFICE Cd (IMPINGING ELEMENTS ONLY)
	XIH	REAL	>=0	0.0	1	1	OX IMPINGEMENT HEIGHT (IN.)
	XIA	REAL	<45	0.0	1	1	OX IMPINGEMENT HALF-ANGLE (DEG.)
	XCANT	REAL	0-45	0.0	1	1	OX UNLIKE CANT ANGLE (DEG.)

POINT ANALYSIS (Continued)

Namelist	Variable	Type	Range	Default	Path	Size	Description
	XFACET	REAL	>0	0.001	1	1	OX FACEPLATE THICKNESS FOR IMPINGING ELEMENTS OR POST LENGTH SWIRL COAX (IN.)
	XINJ	REAL	>=0	0.0	1	1	OX INJECTION POINT RELATIVE TO INJECTOR FACE (IN.)
	TPOST	REAL	>0	0.0	1	1	OX POST WALL THICKNESS FOR COAX ELEMENTS (IN.)
	RECESS	REAL	>=0	0.0	1	1	OX POST RECESS FOR SHEAR COAX ELEMENTS (IN.)
	DMS	REAL	>0	0.0	1	1	OX METERING SECTION DIAMETER FOR SHEAR COAX ELEMENTS (IN.)
	XMS	REAL	>0	0.0	1	1	OX METERING SECTION LENGTH FOR SHEAR COAX ELEMENTS (IN.)
	DDIF	REAL	>0	0.0	1	1	OX DIFFUSER SECTION DIAMETER FOR SHEAR COAX ELEMENTS (IN.)
	XDL	REAL	>0	0.0	1	1	OX POST DIFFUSER SECTION LENGTH FOR SHEAR COAX ELEMENTS (IN.)
	AINLET	REAL	>0	0.0	1	1	SWIRL COAS SWIRL CHAMBER FEED ORIFICE AREA (PER HOLE) (IN**2)
	CDINLET	REAL	>0	1.0	1	1	SWIRL CHAMBER FEED ORIFICE Cd
	NINLET	INTEGER	>0	0	1	1	NUMBER OF SWIRL CHAMBER FEED ORIFICES (SWIRL COAX ELEMENTS ONLY)
	DRATIO	REAL	>1	1.0	1	1	SWIRL CHAMBER TO ELEMENT EXIT DIAMETER RATIO (DS/XDJ)
	EMUNI	REAL	<1	0.0	5	1	UNIELEMENT RUPE MIXING EFFICIENCY
$BARRIER							
	TYPE	CHAR*8	N/A		1	1	BARRIER INJECTOR ELEMENT TYPE, E.G. LOL, FOF, OFO, SHC, SWC, SHD
	NEL	INTEGER	>=0	0	1	1	NUMBER OF ELEMENTS
	FDJ	REAL	>=0	0.0	1	1	FUEL ORIFICE OR ANNULUS DIAMETER (IN.)
	FCD	REAL	0-1	1.0	1	1	FUEL ORIFICE Cd
	FIH	REAL	>=0	0.0	1	1	FUEL IMPINGEMENT HEIGHT (IN.)
	FIA	REAL	<45	0.0	1	1	FUEL IMPINGEMENT HALF-ANGLE (DEG.)
	FCANT	REAL	0-45	0.0	1	1	FUEL UNLIKE CANT ANGLE (DEG.)
	FFACET	REAL	>0	0.001	1	1	FUEL FACEPLATE THICKNESS OR ANNULUS LENGTH (IN.)
	XDJ	REAL	>=0	0.0	1	1	OX ORIFICE OR POST DIAMETER (IN.)

POINT ANALYSIS (Continued)

Namelist	Variable	Type	Range	Default	Path	Size	Description
	XCD	REAL	0-1	1.0	1	1	OX ORIFICE Cd (IMPINGING ELEMENTS ONLY)
	XIH	REAL	>=0	0.0	1	1	OX IMPINGEMENT HEIGHT (IN.)
	XIA	REAL	<45	0.0	1	1	OX IMPINGEMENT HALF-ANGLE (DEG.)
	XCANT	REAL	0-45	0.0	1	1	OX UNLIKE CANT ANGLE (DEG.)
	XFACET	REAL	>0	0.001	1	1	OX FACEPLATE THICKNESS FOR IMPINGING ELEMENTS OR POST LENGTH SWIRL COAX (IN.)
	TPOST	REAL	>0	0.0	1	1	OX POST WALL THICKNESS FOR COAX ELEMENTS (IN.)
	RECESS	REAL	>=0	0.0	1	1	OX POST RECESS FOR SHEAR COAX ELEMENTS (IN.)
	DMS	REAL	>0	0.0	1	1	OX METERING SECTION DIAMETER FOR SHEAR COAX ELEMENTS (IN.)
	XMS	REAL	>0	0.0	1	1	OX METERING SECTION LENGTH FOR SHEAR COAX ELEMENTS (IN.)
	DDIF	REAL	>0	0.0	1	1	OX DIFFUSER SECTION DIAMETER FOR SHEAR COAX ELEMENTS (IN.)
	XDL	REAL	>0	0.0	1	1	OX POST DIFFUSER SECTION LENGTH FOR SHEAR COAX ELEMENTS (IN.)
	AINLET	REAL	>0	0.0	1	1	SWIRL COAS SWIRL CHAMBER FEED ORIFICE AREA (PER HOLE) (IN**2)
	CDINLET	REAL	>0	1.0	1	1	SWIRL CHAMBER FEED ORIFICE Cd
	NINLET	INTEGER	>0	0	1	1	NUMBER OF SWIRL CHAMBER FEED ORIFICES (SWIRL COAX ELEMENTS ONLY)
	DRATIO	REAL	>1	1.0	1	1	SWIRL CHAMBER TO ELEMENT EXIT DIAMETER RATIO (DS/XDJ)
	EMUNI	REAL	<1	0.0	5	1	UNIELEMENT RUPE MIXING EFFICIENCY
	FFCINT	REAL	0-1	0.0	5	1	INTERACTION INDEX FOR MIXING BETWEEN BARRIER AND FFC
$FFC							
	TYPE	CHAR*8	N/A		1	1	FFC INJECTOR ELEMENT TYPE, E.G. LOL, SHD
	NEL	INTEGER	>=0	0	1	1	NUMBER OF ELEMENTS
	FDJ	REAL	>=0	0.0	1	1	FUEL ORIFICE OR ANNULUS DIAMETER (IN.)
	FCD	REAL	0-1	1.0	1	1	FUEL ORIFICE Cd
	FIH	REAL	>=0	0.0	1	0	FUEL IMPINGEMENT HEIGHT (IN.)
	FIA	REAL	<45	0.0	1	1	FUEL IMPINGEMENT HALF-ANGLE (DEG.)
	FCANT	REAL	0-45	0.0	1	0	FUEL UNLIKE CANT ANGLE (DEG.)

POINT ANALYSIS (Continued)

Namelist	Variable	Type	Range	Default	Path	Size	Description
	FFACET	REAL	>0	0.001	1	1	FUEL FACEPLATE THICKNESS OR ANNULUS LENGTH (IN.)
	XDJ	REAL	0	0.0	4	1	OX ORIFICE OR POST DIAMETER (IN.)
$BURN							
	GAMMA	REAL	>0	0.0	4	1	COMBUSTION GAS SPECIFIC HEAT RATIO
	AO	REAL	>0	0.0	4	1	COMBUSTION GAS STAGNATION SOUND SPEED (FT/S)
	GMW	REAL	>0	0.0	4	1	COMBUSTION GAS MOLECULAR WEIGHT (LBm/LB-Mole)
	GPR	REAL	>0	0.0	4	1	COMBUSTION GAS PRANDTL NUMBER
	GK	REAL	>0	0.0	4	1	COMBUSTION GAS THERMAL CONDUCTIVITY (BTU/FT-S-R)
	GMU	REAL	>0	0.0	4	1	COMBUSTION GAS VISCOSITY (LBm/FT-S)
	VGASI	REAL	>0	0.0	4	1	COMBUSTION GAS VELOCITY AT THE INJECTOR FACE (FT/S)
	RML	REAL	>0	0.0	4	1	MASS MEDIAN DROPLET RADIUS (MICRONS)
	VJL	REAL	>0	0.0	4	1	DROPLET INJECTION VELOCITY (FT/S)
	TJL	REAL	>0	0.0	4	1	DROPLET INJECTION TEMPERATURE (DEG. R)
	RHOL	REAL	>0	0.0	4	1	DROPLET DENSITY (LBm/FT**3)
	CPL	REAL	>0	0.0	4	1	DROPLET MEAN HEAT CAPACITY (BTU/LBm-R)
	PCRITL	REAL	>0	0.0	4	1	DROPLET CRITICAL PRESSURE (PSIA)
	TCRITL	REAL	>0	0.0	4	1	DROPLET CRITICAL TEMPERATURE (DEG. R)
	TBOILL	REAL	>0	0.0	4	1	NORMAL BOILING POINT OF DROPLET (DEG. R)
	XMWL	REAL	>0	0.0	4	1	DROPLET MOLECULAR WEIGHT (LBm/LB-Mole)
	HVAPL	REAL	>0	0.0	4	1	DROPLET HEAT OF VAPORIZATION AT NBP (BTU/LBm)
	EN	REAL	>0	0.0	4	1	PRESSURE INTERACTION INDEX
	TAUSEN	REAL	>0	0.0	4	1	SENSITIVE TIMELAG (SEC.)
	ISEN	INTEGER	1-2	0	4	1	INDEX FOR SENSITIVE PROPELLANT CIRCUIT; 1-FUEL, 2-OX

POINT ANALYSIS (Continued)

Namelist	Variable	Type	Range	Default	Path	Size	Description
$INJ							
	FMAND	REAL	>0	100.0	1	1	FUEL MANIFOLD CHARACTERISTIC DIAMETER (IN.)
	XMAND	REAL	>0	100.0	1	1	OX MANIFOLD CHARACTERISTIC DIAMETER (IN.)
	FMANL	REAL	>0	1000.0	1	1	FUEL MANIFOLD CHARACTERISTIC LENGTH (IN.)
	XMANL	REAL	>0	1000.0	1	1	OX MANIFOLD CHARACTERISTIC LENGTH (IN.)
	PCA	REAL	>0	0.0	2	3	CHAMBER PRESSURE ARRAY FOR INJECTION VARIABLES, 3 INPUTS IN DECENDING PRESSURE (PSIA)
	FRA	REAL	>0	0.0	3	3	FUEL CIRCUIT RESISTANCE, 3 INPUTS REQUIRED
	FCAPA	REAL	>0	0.0	3	3	FUEL CIRCUIT CAPACITANCE, 3 INPUTS REQUIRED
	NFE	INTEGER	1-4	4	4	1	NUMBER FOR FUEL ELEMEMT TYPES
	FTLA	REAL	>0	0.0	3	12	FUEL TOTAL TIMELAG ARRAY, 3*NFE INPUTS REQUIRED (SEC.)
	FINA	REAL	>0	0.0	3	12	FUEL ORIFICE INERTANCE ARRAY, 3*NFE INPUTS REQUIRED (SEC.)
	FFA	REAL	0-1	0.0	4	12	FRACTION OF TOTAL FUEL FLOW FOR EACH ELEMENT TYPE, 3*NFE INPUTS REQUIRED
	NXE	INTEGER	1-4	4	4	1	NUMBER FOR OX ELEMEMT TYPES
	XRA	REAL	>0	0.0	3	3	OX CIRCUIT RESISTANCE, 3 INPUTS REQUIRED
	XCAPA	REAL	>0	0.0	3	3	OX CIRCUIT CAPACITANCE, 3 INPUTS REQUIRED
	XTLA	REAL	>0	0.0	3	12	OX TOTAL TIMELAG ARRAY, 3*NXE INPUTS REQUIRED (SEC.)
	XINA	REAL	>0	0.0	3	12	OX ORIFICE INERTANCE ARRAY, 3*NXE INPUTS REQUIRED (SEC.)
	XFA	REAL	0-1	0.0	4	12	FRACTION OF TOTAL OX FLOW FOR EACH ELEMENT TYPE, 3*NXE INPUTS REQUIRED
	XUOR	REAL	>0	0.0	3	8	UPSTREAM SECTION LENGTH (DIMENSIONED 2X4 W/2->PROPELLANT (1-F,2-O) AND 4->ELEMENT TYPE) (IN)
	AUOR	REAL	>0	0.0	3	8	UPSTREAM SECTION FLOW AREA (DIMENSIONED 2X4 W/2->PROPELLANT (1-F,2-O) AND 4->ELEMENT TYPE) (IN**2)
	RUOR	REAL	>0	0.0	3	8	UPSTREAM RADIUS, FOR VISCOUS CALCULATIONS (DIMENSIONED 2X4 W/2->PROPELLANT (1-F,2-O) AND 4->ELEMENT TYPE) (IN)
	XOR	REAL	>0	0.0	3	8	ORIFICE SECTION LENGTH (DIMENSIONED 2X4 W/2->PROPELLANT (1-F,2-O) AND 4->ELEMENT TYPE) (IN)

POINT ANALYSIS (Continued)

Namelist	Variable	Type	Range	Default	Path	Size	Description
	AOR	REAL	>0	0.0	3	8	ORIFICE SECTION FLOW AREA (DIMENSIONED 2X4 W/2->PROPELLANT (1-F,2-O) AND 4->ELEMENT TYPE) (IN**2)
	ROR	REAL	>0	0.0	3	8	ORIFICE RADIUS, FOR VISCOUS CALCULATIONS (DIMENSIONED 2X4 W/2->PROPELLANT (1-F,2-O) AND 4->ELEMENT TYPE) (IN)
	XDOR	REAL	>0	0.0	3	8	DOWNSTREAM SECTION LENGTH (DIMENSIONED 2X4 W/2->PROPELLANT (1-F,2-O) AND 4->ELEMENT TYPE) (IN)
	ADOR	REAL	>0	0.0	3	8	DOWNSTREAM SECTION FLOW AREA (DIMENSIONED 2X4 W/2->PROPELLANT (1-F,2-O) AND 4->ELEMENT TYPE) (IN**2)
	RDOR	REAL	>0	0.0	3	8	DOWNSTREAM RADIUS, FOR VISCOUS CALCULATIONS (DIMENSIONED 2X4 W/2->PROPELLANT (1-F,2-O) AND 4->ELEMENT TYPE) (IN)
	WDOT	REAL	>0	0.0	4	6	PROPELLANT FLOWRATE ARRAY (DIMENSIONED 2X3 W/2->PROPELLANT (1-F,2-O) AND 3->CHAMBER PRESSURE (PCA)) (LBM/S)
$CHAMBER							
	NCAV	INTEGER	0-40	0	1	2	ARRAY OF NUMBER OF CAVITIES OF TYPE 1 & 2, TWO INPUTS REQUIRED
	XB	REAL	>=0	0.0	3	1	DISTANCE FROM INJECTOR FACE TO CONCENTRATED COMBUSTION PLANE (HIFI) (FT.)
	ZS	REAL	>=0	0.0	3	1	DISTANCE FROM INJECTOR FACE TO START OF COMBUSTION DISTRIBUTION (DIST3D) (FT.)
	ZE	REAL	>=0	0.0	3	1	DISTANCE FROM INJECTOR FACE TO END OF COMBUSTION DISTRIBUTION (DIST3D) (FT.)
	MUB	INTEGER	1-12	1	1	1	NUMBER OF EVENLY SPACED RADIAL BAFFLES
	T	REAL	>0	0.001	1	1	BAFFLE BLADE THICKNESS (FT.)
	ZB	REAL	>=0	0.0	1	1	BAFFLE LENGTH (FT.)
	TPART	REAL	>=0	0.0	1	1	CAVITY PARTITION (SEPARATOR) THICKNESS (WIDTH) (FT.)
	NSEC	INTEGER	1-5	1	3	2	ARRAY OF NUMBER OF CAVITIES PROPERTY SECTIONS FOR CAVITY TYPE 1 & 2, TWO INPUTS REQUIRED

POINT ANALYSIS (Continued)

Namelist	Variable	Type	Range	Default	Path	Size	Description
	WC	REAL	>=0	0.0	1	2	1/4 WAVE CAVITY WIDTH ARRAY FOR CAVITY TYPE 1 & 2, TWO INPUTS REQUIRED (FT.)
	AC	REAL	>=0	0.0	1	2	CAVITY SECTION CROSS-SECTIONAL AREA ARRAY FOR CAVITY TYPE 1 & 2 TWO INPUTS REQUIRED (FT**2)
	VCAV	REAL	>=0	0.0	1	2	BACKING CAVITY VOLUME FOR HELMHOLTZ RESONATORS (FT**3)
	ARATIO	REAL	0-1	1.0	1	2	INLET-TO-BACKING CAVITY AREA RATIO FOR HELMHOLTZ RESONATORS
	INLET	INTEGER	0-2	0	1	2	CAVITY INLET DESCRIPTER ARRAY FOR CAVITY TYPE 1 & 2, TWO INPUTS REQUIRED; 0-SQUARE INLET, 1-ROUNDED INLET, 2-WELL ROUNDED INLET
	IDCAV	INTEGER	0-2	0	1	40	CAVITY RELATIVE LOCATION ARRAY, NCAV(1)+NCAV(2) ENTRIES REQUIRED
	DC1	REAL	>=0	0.0	1	5	1/4 WAVE CAVITY EFFECTIVE LENGTH (DEPTH) OR HELMHOLTZ INLET ORIFICE LENGTH (FT.) ARRAY FOR CAVITY TYPE 1, NSEC(1) INPUTS REQUIRED
	CC1	REAL	>=0	0.0	2	5	CAVITY STAGNATION SOUND SPEED ARRAY FOR CAVITY TYPE 1, NSEC(1) INPUTS REQURIED (FT/S)
	GAMC1	REAL	>=0	0.0	2	5	CAVITY GAS RATIO OF SPECIFIC HEATS ARRAY FOR CAVITY TYPE 1, NSEC(1) INPUTS REQUIRED
	DC2	REAL	>=0	0.0	1	5	1/4 WAVE CAVITY EFFECTIVE LENGTH (DEPTH) OR HELMHOLTZ INLET ORIFICE LENGTH (FT.) ARRAY FOR CAVITY TYPE 2, NSEC(2) INPUTS REQUIRED (FT)
	CC2	REAL	>=0	0.0	2	5	CAVITY STAGNATION SOUND SPEED ARRAY FOR CAVITY TYPE 2, NSEC(2) INPUTS REQURIED (FT/S)
	GAMC2	REAL	>=0	0.0	2	5	CAVITY GAS RATIO OF SPECIFIC HEATS ARRAY FOR CAVITY TYPE 2, NSEC(2) INPUTS REQUIRED
	ICAV	INTEGER	0-2	0	1	1	ACOUSTIC CAVITY FLAG; 0 - NO ACOUSTIC CAVITY, 1 - 1/4 WAVE CAVITY, 2 - HELMHOLTZ RESONATOR
$FDORC							
	ZCOMB	REAL	>0-XC	0	2	1	AXIAL LOCATION WHERE COMBUSTION IS COMPLETED (FT)
	NZON	INT	1-20	5	2	1	NUMBER OF COMBUSTION ZONES
	FTER	REAL	0.0-1.0	1.0	2	20	FRACTION OF TOTAL ENERGY RELEASE AT END OF EACH COMBUSTION ZONE, NZON INPUTS REQUIRED

POINT ANALYSIS (Continued)

Namelist	Variable	Type	Range	Default	Path	Size	Description
	NCAV1	INT	0-20	0	1	1	NUMBER OF RADIAL INLET ABSORBERS
	ICTYP1	INT	1-4	0	1	20	ABSORBER TYPE FLAG: 1=1/4 WAVE, 2=HELMHOLTZ, 3=LONG APERTURE, 4-INPUT GEOMETRY AND TEMPERATURE; NCAV1 INPUTS REQUIRED
	ZS1	REAL	0-XC	0.0	1	20	DISTANCE FROM INJECTOR FACE TO START OF ABSORBER SEGMENT, NCAV1 INPUTS REQUIRED (FT)
	ZE1	REAL	ZS1-XC	0.0	1	20	DISTANCE FROM INJECTOR FACE TO END OF ABSORBER SEGMENT, NCAV1 INPUTS REQUIRED (FT)
	AS1	REAL	0.0-360.0	0.0	1	20	ANGLE AT WHICH ABSORBER SEGMENT STARTS, NCAV1 INPUTS REQUIRED (DEG)
	AE1	REAL	0.0-360.0	0.0	1	20	ANGLE AT WHICH ABSORBER SEGMENT ENDS, NCAV1 INPUTS REQUIRES (DEG)
	WC1	REAL	>=0.0	0.0	1	20	BACKING CAVITY WIDTH, =0 FOR 1/4 WAVE CAVITY; NCAV1 INPUTS REQUIRED (FT)
	APL1	REAL	>=0.0	0.0	1	20	INLET APERTURE LENGTH, NCAV1 INPUTS REQUIRED (FT)
	BCL1	REAL	>=0.0	0.0	1	20	BACKING CAVITY LENGTH, =0 FOR 1/4 WAVE CAVITY; NCAV1 INPUTS REQUIRED (FT)
	ZLOW1	REAL	0-WC1	0.0	1	20	DISTANCE FROM CAVITY BOTTOM TO UPPER POINT OF INTERSECTION OF APERTURE WITH BACKING CAVITY, =0 FOR 1/4 WAVE; NCAV1 INPUTS REQUIRED (FT)
	ZUP1	REAL	ZLOW1-WC1	0.0	1	20	DISTANCE FROM CAVITY BOTTOM TO UPPER POINT OF INTERSECTION OF APERTURE WITH BACKING CAVITY, =0 FOR 1/4 WAVE; NCAV1 INPUTS REQUIRED (FT)
	CCAV1	REAL	>0.0	1.0	2	20	BACKING CAVITY SOUND SPEED, NCAV1 INPUTS REQUIRED (FT/S)
	CGAM1	REAL	>0.0	0.0	2	20	BACKING CAVITY RATIO OF SPECIFIC HEATS, NCAV1 INPUTS REQUIRED
	XMWC1	REAL	>0.0	0.0	2	20	BACKING CAVITY GAS MOLECULAR WEIGHT, NCAV1 INPUTS REQUIRED (LBm/LB-MOLE)
	RHOAP1	REAL	>0.0	0.0	2	20	APERATURE DENSITY, NCAV1 INPUTS REQUIRED (LBM/FT**3)
	TSL1	REAL	NONE	0.0	0	20	SLOPE OF MEAN TEMPERATURE PROFILE, NCAV1 INPUTS REQUIRED (R/FT)
	TC1	REAL	>0.0	0.0	0	20	AVERAGE TEMPERATURE IN THE ABSORBER, NCAV1 INPUTS REQUIRED (R)

POINT ANALYSIS (Continued)

Namelist	Variable	Type	Range	Default	Path	Size	Description
	NCAV2	INT	0-20	0	1	1	NUMBER OF AXIAL INLET ABSORBERS
	ICTYP2	INT	1-4	0	1	20	ABSORBER TYPE FLAG: 1=1/4 WAVE, 2=HELMHOLTZ, 3=LONG APERTURE, 4=INPUT GEOMETRY AND TEMPERATURE; NCAV2 INPUTS REQUIRED
	RS2	REAL	0-RCHAMB	0.0	1	20	RADIUS TO INNER EDGE OF ABSORBER SEGMENT, NCAV2 INPUTS REQUIRED (FT)
	RE2	REAL	RS2-RCHAMB	0.0	1	20	RADIUS TO OUTER EDGE OF ABSORBER SEGMENT, NCAV2 INPUTS REQUIRED (FT)
	AS2	REAL	0.0-360.0	0.0	1	20	ANGLE AT WHICH ABSORBER SEGMENT STARTS, NCAV2 INPUTS REQUIRED (DEG)
	AE2	REAL	0.0-360.0	0.0	1	20	ANGLE AT WHICH ABSORBER SEGMENT ENDS, NCAV2 INPUTS REQUIRED (DEG)
	WC2	REAL	>=0.0	0.0	1	20	BACKING CAVITY WIDTH, =0 FOR 1/4 WAVE CAVITY; NCAV2 INPUTS REQUIRED (FT)
	APL2	REAL	>=0.0	0.0	1	20	INLET APERTURE LENGTH, NCAV2 INPUTS REQUIRED (FT)
	BCL2	REAL	>=0.0	0.0	1	20	BACKING CAVITY LENGTH, =0 FOR 1/4 WAVE; NCAV2 INPUTS REQUIRED (FT)
	ZLOW2	REAL	0-WC2	0.0	1	20	DISTANCE FROM CAVITY BOTTOM TO LOWER POINT OF INTERSECTION OF APERTURE WITH BACKING CAVITY, =0 FOR 1/4 WAVE; NCAV2 INPUTS REQUIRED (FT)
	ZUP2	REAL	ZLOW2-WC2	0.0	1	20	DISTANCE FROM CAVITY BOTTOM TO UPPER POINT OF INTERSECTION OF APERTURE WITH BACKING CAVITY, =0 FOR 1/4 WAVE; NCAV2 INPUTS REQUIRED (FT)
	CCAV2	REAL	>0.0	1.0	2	20	BACKING CAVITY SOUND SPEED, NCAV2 INPUTS REQUIRED (FT/S)
	CGAM2	REAL	>0.0	0.0	2	20	BACKING CAVITY RATIO OF SPECIFIC HEATS, NCAV2 INPUTS REQUIRED
	XMWC2	REAL	>0.0	0.0	2	20	BACKING CAVITY GAS MOLECULAR WEIGHT, NCAV2 INPUTS REQUIRED (LBm/LB-MOLE)
	RHOAP2	REAL	>0,0	0.0	2	20	APERTURE DENSITY, NCAV2 INPUTS REQUIRED (LBm/FT**3)
	TSL2	REAL	NONE	0.0	2	20	SLOPE OF MEAN TEMPERATURE PROFILE, NCAV2 INPUTS REQUIRED (R/FT)
	TC2	REAL	>0,0	0.0	2	20	AVERAGE TEMPERATURE IN THE ABSORBER, NCAV2 INPUTS REQUIRED (R)

POINT ANALYSIS (Continued)

Namelist	Variable	Type	Range	Default	Path	Size	Description
$MIX							
	EM	REAL	0-1.0	-1.0,1.0	1	2	OVERALL CORE (EM(1)) AND BARRIER (EM(2)) RUPE MIXING EFFICIENCIES
$STUFF							
	IBAF	INTEGER	0-1	0	1	1	COMBUSTOR RADIAL BAFFLE BLADES FLAG;0 - NO BAFFLES, 1 - CONTAINS BAFFLES.
$FINJ							
	IBFE	INTEGER	0-1	0	1	1	BAFFLE ELEMENT FLAG 0 - NO BAFFLE ELEMENTS, 1 - BAFFLE ELEMENTS
	IBRE	INTEGER	0-1	0	1	1	BARRIER ELEMENT FLAG 0 - NO BARRIER ELEMENTS, 1 - BARRIER ELEMENTS
	IFFE	INTEGER	0-1	0	1	1	FUEL FILM AND/OR CAVITY COOLING ELEMENT FLAG 0 - NO FFC ELEMENTS, 1 - FFC ELEMENTS

POINT DESIGN VARIABLES

Namelist	Variable	Type	Range	Default	Path	Size	Description
$DESIGN							
	TYPE	CHAR*8	N/A		1	1	CORE ELEMENT TYPE: LOL, OFO, FOF, SHD, SHC, SWC
	FUEL	CHAR*8	N/A		1	1	FUEL NAME, E.G. RP-1, H2, METHANE, PROPANE
	OX	CHAR*8	N/A	LOX	1	1	OXIDIZER NAME, E.G. LOX
	XMR	REAL	>0	0.0	1	1	OX/FUEL MIXTURE RATIO
	HGMR*	REAL	>=0	0.0	5	1	OX/FUEL MIXTURE RATIO OF FUEL, IF STAGED COMBUSTION IS USED
	FTMAN	REAL	>-460	-500.0	1	1	FUEL MANIFOLD TEMPERATURE (DEG F)
	XTMAN	REAL	>-460	-500.0	1	1	OXIDIZER MANIFOLD TEMPERATURE (DEF F)
	PCNOM	REAL	>0	0.0	1	1	INJECTOR FACE STAGNATION PRESSURE (PSIA)
	FPMAN	REAL	>0	0.0	1	1	FUEL MAXIMUM MANIFOLD PRESSURE (PSIA)
	XPMAN	REAL	>0	0.0	1	1	OXIDIZER MAXIMUM MANIFOLD PRESSURE (PSIA)
	WDNOM	REAL	>0	0.0	1	1	FLOW RATE AT NOMINAL CHAMBER PRESSURE (LBM/S)
	WDMIN	REAL	>0	0.0	1	1	FLOW RATE AT THROTTLED OR MINIMUM CHAMBER PRESSURE (LBM/S)
	EREG	REAL	<1	0.0	1	1	ISP-BASED ENERGY RELEASE EFFICIENCY GOAL
	ETACSG	REAL	<1	0.0	1	1	CSTAR EFFICIENCY GOAL
	XLEMAX	REAL	>0	10.0	1	1	MAXIMUM ENGINE LENGTH (FT)
	DCMAX	REAL	>0	10.0	1	1	MAXIMUM COMBUSTION CHAMBER DIAMETER (FT)
	NPERFP	INTEGER	2-30	2	1	1	NUMBER OF POINTS INPUT FOR ISP AND C* VS. MR TABLES
	PMRA	REAL	MONO.	0.0	1	30	ARRAY OF MIXTURE RATIO POINTS FOR PERFORMANCE TABLES (RECOMMEND MR'S FROM COMBUSTION TABLES)
	PISPA	REAL	>=0	0.0	1	30	ARRAY OF ODK-ISP POINTS FOR PERFORMANCE TABLES (SEC)
	PCSA	REAL	>=0	0.0	1	30	ARRAY OF ODK-C* POINTS FOR PERFORMANCE TABLES (FT/SEC)

*Not used in February 1991 ROCCID version, for future use

POINT DESIGN VARIABLES (Continued)

Namelist	Variable	Type	Range	Default	Path	Size	Description
	NNOZ	INTEGER	0-30	0	1	1	NUMBER OF NOZZLE LENGTH POINTS IN PERFORMACE OPTIMIZATION TABLE
	XNOZ	REAL	MONO.	0.0	1	30	NOZZLE LENGTH ARRAY (NNOZ POINTS REQUIRED) (FT)
	ETANOZ	REAL	0-1	0.0	1	30	NOZZLE EFFICIENCY ARRAY (NNOZ POINTS REQUIRED)
	IBAF	INTEGER	0-1	0	1	1	COMBUSTOR RADIAL BAFFLE BLADES FLAG; 0 - BAFFLES NOT ALLOWED, 1 - BAFFLES ALLOWED.
	ICAVT	INTEGER	-1-2	0	1	1	ACOUSTIC CAVITY FLAG; -1 - 1/4 WAVE AXIAL CAVITY ALLOWED, 0 - CAVITY NOT ALLOWED, 1 - 1/4 WAVE RADIAL CAVITY ALLOWED, 2 - HELMHOLTZ RESONATOR ALLOWED.
$FGEOM							
	RCHAMB	REAL	>=0	0.0	1	1	CHAMBER RADIUS (FT.)
	RTHRT	REAL	>=0	0.0	1	1	THROAT RADIUS (FT.)
	RNE	REAL	>=0	0.0	1	1	RADIUS OF CURVATURE AT THE NOZZLE ENTRANCE (FT.)
	RTE	REAL	>=0	0.0	1	1	RADIUS OF CURVATURE AT THE THROAT ENTRANCE (FT.)
	ALPHA	REAL	0-90	0.0	1	1	CONVERGENCE HALF ANGLE (DEG.)
	CHAMBL	REAL	>=0	0.0	1	1	INJECTOR FACE TO THROAT LENGTH (FT.)

MODEL CONTROL VARIABLES

Namelist	Variable	Type	Range	Default	Path	Size	Description
$DEBUGC							
	DEBUG	LOGICAL	T/F	F	1	1	DEBUG OUTPUT GENERATION CONTROL (L1)
$HIFIC							
	SHORT	LOGICAL	T/F	F	3	1	TRUE IF SHORT NOZZLE IS ASSUMED, FALSE IF NOT (L1)
	POC	REAL	>=0	0.20	1	2	NORMALIZED CAVITY INLET PRESSURE AMPLITUDE FOR CAVITY TYPE 1 & 2, TWO INPUTS REQUIRED
$DIST3DC							
	SHORT	LOGICAL	T/F	F	3	1	TRUE IF SHORT NOZZLE IS ASSUMED, FALSE IF NOT (L1)
	POC	REAL	>=0	0.20	1	2	NORMALIZED CAVITY INLET PRESSURE AMPLITUDE FOR CAVITY TYPE 1 & 2, TWO INPUTS REQUIRED
	PAMP	REAL	>=0	0.20	1	1	PEAK-TO-PEAK PRESSURE AMPLITUDE RATIO, P'/PC
	MX	INTEGER	0-1	0	1	1	MAIN CHAMBER OSCILLATION INDICATOR; 0-STANDING WAVE, 1-TRAVELING WAVE
	MC	INTEGER	1-20	11	1	1	# OF FOURIER SERIES TERMS TO REPRESENT THE MAIN CHAMBER SOLUTION
	LC	INTEGER	1-20	8	1	1	# OF BESSEL TERMS IN THE MAIN CHAMBER SOLUTION
	MB	INTEGER	1-20	11	1	1	# OF FOURIER SERIES TERMS TO REPRESENT THE SOLUTION IN THE BAFFLE COMP
	LB	INTEGER	1-20	8	1	1	# OF BESSEL TERMS IN THE BAFFLE COMPARTMENT SOLUTION
	IDMAX	INTEGER	1-25	10	1	1	MAXIMUM NUMBER OF ITERATIONS FOR SUCCESSIVE APPROX.

MODEL CONTROL VARIABLES (Continued)

Namelist	Variable	Type	Range	Default	Path	Size	Description
$CRPC							
	NDPC	INTEGER	>0	16	1	1	NUMBER OF DROPLETS INJECTED/CYCLE
	NDTFQ	INTEGER	>0	16	1	1	USED TO DETERMINE THE TIME STEP SIZE (DT) WHEN CALCULATING VAPORATION HISTORY OF THE DROPLET (1.0/FREQUENCY/NDTFQ)
	NDTLF	INTEGER	>0	1000	1	1	USED TO DETERMINE THE TIME STEP SIZE (DT) WHEN CALCULATING VAPORATION HISTOR OF THE DROPLET DT (TLIFE/NDTLF) WHERE TLIFE IS THE DROPLET LIFE TIME
	NPRINT	INTEGER	>0	50	1	1	NUMBER OF TIME STEPS BETWEEN OUTPUTS OF THE DROPLET HISTORY FOR FIRST
	NSUMS	INTEGER	1-1E4	3500	1	1	NUMBER OF SUMMATION HISTORIES PER PERIOD
	ISTAND	INTEGER	0-1	0	1	1	MODE TYPE INDICATOR; 0-SPINNING MODE, 1-STANDING MODE
	IVEL	INTEGER	0-1	0	1	1	LINEAR/NON-LINEAR CONTROL; 0-ACOUSTIC VELOCITY EFFECTS NOT INCLUDED, 1-ACOUSTIC VELOCITY EFFECTS (NON-LINEAR) INCLUDED
	PAMPC	REAL	>=0	0.20	1	1	RATIO OF OSCILLATIONS AMPLITUDE TO PC, P'/PC
	NRAD	INTEGER	1-20	3	1	1	NUMBER OF RADIAL INJECTION LOCATIONS
	NCIRC	INTEGER	1-50	5	1	1	NUMBER OF CIRCUMFERENTIAL INJECTION LOCATIONS
	PHIF	REAL	>=0	0.0	1	1	PRESSURE OSCILLATION PHASE ANGLE (DEG.)

MODEL CONTROL VARIABLES (Continued)

Namelist	Variable	Type	Range	Default	Path	Size	Description
$LEINJC							
	IDOMEM	INTEGER	1-2	2	1	1	DOME MODEL FLAG; 1->LUMPED PARAMETER, 2->ACOUSTIC MODE
	PAMPCH	REAL	>=0	0.20	1	1	CHAMBER PEAK-TO-PEAK PRESSURE AMPLITUDE RATIO, P'/PC
	NTINJ	INTEGER	0-50	18	1	1	NUMBER OF TIME STEPS PER CYCLE
	USGF	REAL	0-1	0.020	1	1	UPSTREAM SECTION GRID SIZE FACTOR (NUOR EQUALS XUOR/USGF/(VSOUND/FREQ))
	OGF	REAL	0-1	0.020	1	1	ORIFICE SECTION GRID SIZE FACTOR (NOR EQUALS XOR/OGF/(VSOUND/FREQ))
	DSGF	REAL	0-1	0.020	1	1	DOWNSTREAM SECTION GRID SIZE FACTOR (NDOR EQUALS XDOR/DSGF/(VSOUND /FREQ))
	FCDO	REAL	>0	1.0	1	4	FUEL ORIFICE CD ARRAY (4 ENTRIES - CORE, BAFFLE, BARRIER AND FFC)
	XCDO	REAL	>0	1.0	1	4	OX ORIFICE CD ARRAY (4 ENTRIES - CORE, BAFFLE, BARRIER AND FFC)
$COMBUSTC							
	FALVM	REAL	>=0	1.0	1	4	ARRAY OF MULTIPLIERS FOR FUEL ATOMIZATION LENGTH USED IN VAPORIZATION CALCULATIONS (4 ENTRIES - CORE, BAFFLE, BARRIER AND FFC)
	XALVM	REAL	>=0	1.0	1	4	ARRAY OF MULTIPLIERS FOR OX AUTOMIZATION LENGTH USED IN VAPORIZATION CALCULATIONS (4 ENTRIES - CORE, BAFFLE, BARRIER AND FFC)
	FALTM	REAL	>=0	1.0	1	4	ARRAY OF MULTIPLIERS FOR FUEL ATOMIZATION LENGTH USED IN TOTAL TIMELAG CALCULATIONS (4 ENTRIES - CORE, BAFFLE, BARRIER AND FFC)
	XALTM	REAL	>=0	1.0	1	4	ARRAY OF MULTIPLERS FOR OX ATOMIZATION LENGTH USED IN TOTAL TIMELAG CALCULATIONS (4 ENTRIES - CORE, BAFFLE, BARRIER AND FFC)
	FRMM	REAL	>=0	1.0	1	4	ARRAY OF MULTIPLIERS FOR FUEL DROPSIZES (4 ENTRIES - CORE, BAFFLE, BARRIER AND FFC)

MODEL CONTROL VARIABLES (Continued)

Namelist	Variable	Type	Range	Default	Path	Size	Description
	XRMM	REAL	>0	1.0	1	4	ARRAY OF MULTIPLIERS FOR OX DROPSIZES (4 ENTRIES - CORE, BAFFLE, BARRIER AND FFC)
	EMMULT	REAL	>0	1.0	1	2	ARRAY OF MULTIPLIERS ON CORE (1) AND BARRIER (2) OVERALL MIXING EFFICIENCIES (EM)
	AOMULT	REAL	>0	1.0	1	1	MULTIPLIER ON CALCULATED VALUE OF MEAN CHAMBER SOUND SPEED (AO)
	ENMULT	REAL	>0	1.0	1	1	MULTIPLIER ON CALCULATED VALUE OF PRESSURE INTERACTION INDEX (EN)
	TAUMULT	REAL	>0	1.0	1	1	MULTIPLIER ON CALCULATED VALUES OF SENSITIVE TIMELAG (TAUSEN)
	CCMULT	REAL	>0	1.0	1	1	MULTIPLIER ON CALCULATED VALUES OF CAVITY SOUND SPEEDS (CC1, CC2)
	COMBXB	REAL	0-1.0	0.50	1	1	FRACTION OF C* EFFICIENCY AT WHICH THE COMBUSTION PLANE (XB) IS PLACED.
$FDORCC							
	SHORT	LOGICAL		T/F	F	1	0 TRUE IF SHORT NOZZLE IS ASSUMED, FALSE IF REAL NOZZLE IS USED
	EPSIL	REAL	>0	20	1	1	PEAK-TO-PEAK PRESSURE AMPLITUTE (PERCENT)
	ERROR	REAL	>0	0.1	1	1	MAXIMUM % ERROR BETWEEN SUCCESSIVE ITERATIONS
	LTS	INT	1-10	5	1	1	# OF RADIAL SERIES TERMS
	MTS	INT	1-9	5	1	1	# OF TANGENTIAL SERIES TERMS
	NTS	INT	1-20	10	1	1	# OF LONGITUDINAL SERIES TERMS
	ITMAX	INT	>0	100	1	1	MAXIMUM # OF SUCCESSIVE ITERATIONS
	RELX	REAL	0<RELX <1.0	0.65	1	1	SOLUTION RELAXATION FACTOR
	MTYPE	INT	0-1	0	1	1	TANGENTIAL WAVE TYPE, 0-STANDING, 1-TRAVELING
	NEET	INT	1-10	3	1	1	# OF EIGENFUNCTION EXPANSION TERMS
	NXFST	INT	1-10	3	1	1	# OF FOURIER SERIES TERMS IN THE CAVITY X-DIRECTION
	NYFST	INT	1-10	3	1	1	# OF FOURIER SERIES TERMS IN THE CAVITY Y-DIRECTION
	NAFST	INT	1-10	3	1	1	# OF FOURIER SERIES TERMS IN THE CAVITY APERTURE
	NHAT	INT	>=0	0	1	1	LONGITUDINAL MODE NUMBER
	MORE	LOGICAL		T/F	F	1	0 TRUE FOR ADDITIONAL FDORC OUTPUT TO HISTORY FILE

MORE	LOGICAL	T/F	F	1	0 TRUE FOR ADDITIONAL FDORC OUTPUT TO HISTORY FILE

DEFAULT DESIGN CONTROL VARIABLES

Namelist	Variable	Type	Range	Default	Path	Size	Description
$CONTROL							
	DPPCS	REAL	<0-1	0.15	1	1	RATIO OF INJECTION PRESSURE DROP TO PC AT THROTTLED PC FOR LOW FREQ STABILITY
	RNR	REAL	>0	1.0	1	1	NONDIMENSIONAL NOZZLE ENTRANCE RADIUS OF CURVATURE (RNE/RTHRT)
	RTR	REAL	>0	1.0	1	1	NONDIMENSIONAL THROAT ENTRANCE RADIUS OF CURVATURE (RTE/RTHRT)
	CONVA	REAL	0-90	25.0	1	1	THROAT CONVERGENCE HALF-ANGLE (DEG)
	XMSTAB	REAL	>0	0.20	5	1	MINIMUM MASS FRACTION FOR ELEMENT TO EFFECT STABILITY
$LOLC							
	FCD	REAL	<1	0.78	1	1	FUEL DISCHARGE COEFFICIENT
	XCD	REAL	<1	0.78	1	1	OX DISCHARGE COEFFICIENT
	FIA	REAL	<45	30.0	1	1	FUEL IMPINGEMENT ANGLE (DEG)
	XIA	REAL	<45	30.0	1	1	OX IMPINGEMENT ANGLE (DEG)
	FIHOD	REAL	>0	2.0	1	1	FUEL IMPINGEMENT HEIGHT TO ORIFICE DIAMETER RATIO
	XIHOD	REAL	>0	2.0	1	1	OX IMPINGEMENT HEIGHT TO ORIFICE DIAMETER RATIO
	FCANT	REAL	0-45	16.0	1	1	FUEL CANT ANGLE (DEG)
	XCANT	REAL	0-45	16.0	1	1	OX CANT ANGLE (DEG)
	FLOD	REAL	>0	5.0	1	1	FUEL ORIFICE LENGTH TO DIAMETER RATIO
	XLOD	REAL	>0	5.0	1	1	OX ORIFICE LENGTH TO DIAMETER RATIO
	EMUNI	REAL	<1	0.65	1	1	UNIELEMENT RUPE MIXING EFFICIENCY

DEFAULT DESIGN CONTROL VARIABLES (Continued)

Namelist	Variable	Type	Range	Default	Path	Size	Description
$TRIPC							
	FCD	REAL	<1	0.78	1	1	FUEL DISCHARGE COEFFICIENT
	XCD	REAL	<1	0.78	1	1	OX DISCHARGE COEFFICIENT
	ULIA	REAL	<45	35.0	1	1	UNLIKE IMPINGEMENT HALF-ANGLE (DEG)
	UILOD	REAL	>0	2.0	1	1	TRIPLET IMPINGEMENT HEIGHT TO ORIFICE DIAMETER RATIO; OX L/D FOR OFO'S AND FUEL L/D FOR FOF
	FLOD	REAL	>0	5.0	1	1	FUEL ORIFICE LENGTH TO DIAMETER RATIO
	XLOD	REAL	>0	5.0	1	1	OX ORIFICE LENGTH TO DIAMETER RATIO
	DODF	REAL	>0	1.0	1	1	TRIPLET ORIFICE OX DIAMETER TO FUEL DIAMETER RATIO
	EMUNI	REAL	<1	0.77	1	1	UNIELEMENT RUPE MIXING EFFICIENCY
$SHDC							
	FCD	REAL	<1	0.78	1	1	FUEL DISCHARGE COEFFICIENT
	XCD	REAL	<1	0.78	1	1	OX DISCHARGE COEFFICIENT
	FLOD	REAL	>0	5.0	1	1	FUEL ORIFICE LENGTH TO DIAMETER RATIO
	XLOD	REAL	>0	5.0	1	1	OX ORIFICE LENGTH TO DIAMETER RATIO
	EMUNI	REAL	<1	0.50	1	1	UNIELEMENT RUPE MIXING EFFICIENCY
$SHEARC							
	FCD	REAL	<1	0.93	1	1	FUEL DISCHARGE COEFFICIENT
	VRATMI	REAL	>0	10.0	1	1	MINIMUM GAS TO LIQUID VELOCITY RATIO
	GAPM	REAL	>0	0.010	1	1	MINIMUM FUEL ANNULUS GAP WIDTH
	TPOST	REAL	>0	0.020	1	1	OX POST TIP THICKNESS (IN)
	FLOD	REAL	>0	5.0	1	1	FUEL ANNULUS LENGTH TO ANNULAR GAP RATIO
	DIVANG	REAL	0-7	0.0	1	1	OX POST EXIT DIVERGENCE ANGLE (DEG)
	EMUNI	REAL	<1	0.80	5	1	UNIELEMENT RUPE MIXING EFFICIENCY

DEFAULT DESIGN CONTROL VARIABLES (Continued)

Namelist	Variable	Type	Range	Default	Path	Size	Description
$SWIRLC							
	FCD	REAL	<1	0.93	1	1	FUEL DISCHARGE COEFFICIENT
	VRATMI	REAL	>0	10.0	1	1	MINIMUM GAS TO LIQUID VELOCITY RATIO
	GAPM	REAL	>0	0.010	1	1	MINIMUM FUEL ANNULUS GAP WIDTH (IN)
	TPOST	REAL	>0	0.020	1	1	OX POST TIP THICKNESS (IN)
	FLOD	REAL	>0	5.0	1	1	FUEL ANNULUS LENGTH TO ANNULAR GAP RATIO
	XCA	REAL	<45	24.0	1	1	SWIRL CONE HALF-ANGLE (DEG)
	NINLET	INTEGER	>0	0	1	1	THIS VARIABLE HAS BEEN REMOVED
	DRATIO	REAL	>0	1.20	1	1	SWIRL CHAMBER TO OX POST EXIT DIAMETER RATIO
	CDINLET	REAL	<1	0.90	1	1	SWIRL CHAMBER INLET ORIFICE CD
	EMUNI	REAL	<1	0.80	1	1	UNIELEMENT RUPE MIXING EFFICIENCY
$SAID							
	TBAF	REAL	>0	0.033	1	1	BAFFLE THICKNESS (FT)
	TPART	REAL	>=0	0.0	1	1	CAVITY PARTITION THICKNESS (FT)
	INLET	INTEGER	0-2	0	1	1	1/4 WAVE/HELMHOLTZ CAVITY INLET DESCRIPTOR; 0 - SHARP EDGE, 1 - ROUNDED, 2 - WELL ROUNDED

APPENDIX D

CREATING COMBUSTION GAS TABLES

Creating Combustion Gas Tables

Some of the analysis and design codes of the ROCCID package require combustion gas properties. To keep the user from entering these properties manually, the program interpolates the data, from tables of gas properties versus mixture ratio, temperature and pressure for a given set of propellants. Tables of equilibrium gas temperature as a function of mixture ratio and pressure are also required. The code already provides tables for the following propellant combinations:

LOX/HYDROGEN
LOX/METHANE
LOX/PROPANE
LOX/RP-1

It is likely at some point, that propellant combinations other than those listed above will be needed, or tables with better resolution for the above propellants will be required. For these reasons the ROCCID program has the ability to automatically create new tables using an ODE (one dimensional equilibrium) module.

To make new tables using the ODE module, first enter the utilities menu off the ROCCID base menu. Next enter option 1, the ODE module. The program will now prompt you to enter the mixture ratio, pressure, and temperature arrays and the number of mixture ratio entries. Enter these data using standard IFE syntax. The array sizes are limited to 30, 6, and 10 for mixture ratio, pressure and temperature respectively. Selecting temperature below 600 R is not recommended since ODE may have trouble calculating the gas properties below this temperature. Next the module will ask you if you want to select reactants. Answer Y for yes. The program will then list its propellant library and ask you to pick propellants. For each propellant chosen, the program will display the ODE propellant card. You then have the option of changing the reference temperature, enthalpy, and percent composition of that propellant. Finally before the ODE run begins, you are prompted for omitting species. Simply press RETURN and the ODE will begin.

ODE first uses the TP option to create full tables of viscosity, molecular weight, Prandtl number, thermal conductivity, specific heat ratio, enthalpy, and entropy versus mixture ratio, pressure and temperature. Then ODE uses a very similar run deck using the HP option to create a table of equilibrium temperatures versus pressure and mixture ratio. The input decks are saved for the above to run in files COMTBL.INP and COMTB1.INP respectively.

After ODE has completed the tables, the program asks the user to input a fuel name and an oxidizer name (up to 8 characters each). The module will then create a file based on the propellant names as follows:

<oxidizer name>_<fuel name>.DAT

For example, if the oxidizer is LOX and the fuel is RP-1 the filename created will be LOX_RP-1.DAT.

In order for the ROCCID program to use the generated file, the user must manually enter the filename and a one line propellant descriptor into PROP.FIL, contained in the propellant property library directory. It is important that the filename is appended first, then the one line descriptor. Correct additions to this file will automatically add the new propellant options to the Propellant Menu in both the Point Analysis and Point Design sections of the ROCCID code.

APPENDIX E

FILES NAMING CONVENTIONS

Files Naming Conventions

FILE TYPE	UNIT #	DESCRIPTION
*.DAT	3	Replay files
*.INP	7	Point analysis input
*.HIS	8	History/submodel output
*.DES	9	Point design input
*.OUT	10	Summarized output
*.CNT	12	Analysis model control parameters
*.DEF	13	Point design control parameters
*.DBG	14	Debug output
*.TDK	15	TDK input data
PROPELLANT(1).DAT	20	Combustion gas data
*.PL1	21	Steady state performance plot data
*.PL2	22	Chug stability plot data
*.PL3	23	High frequency stability plot data
*.COF	25	MIPROPS propellant data

(1) Propellant combinaions, i.e., LOX_H2.DAT OR LOX_METHANE.DAT, See Appendix D

APPENDIX F

ROCCID PROGRAM FLOW CHARTS

Part A

Point Analysis Module Flow Charts

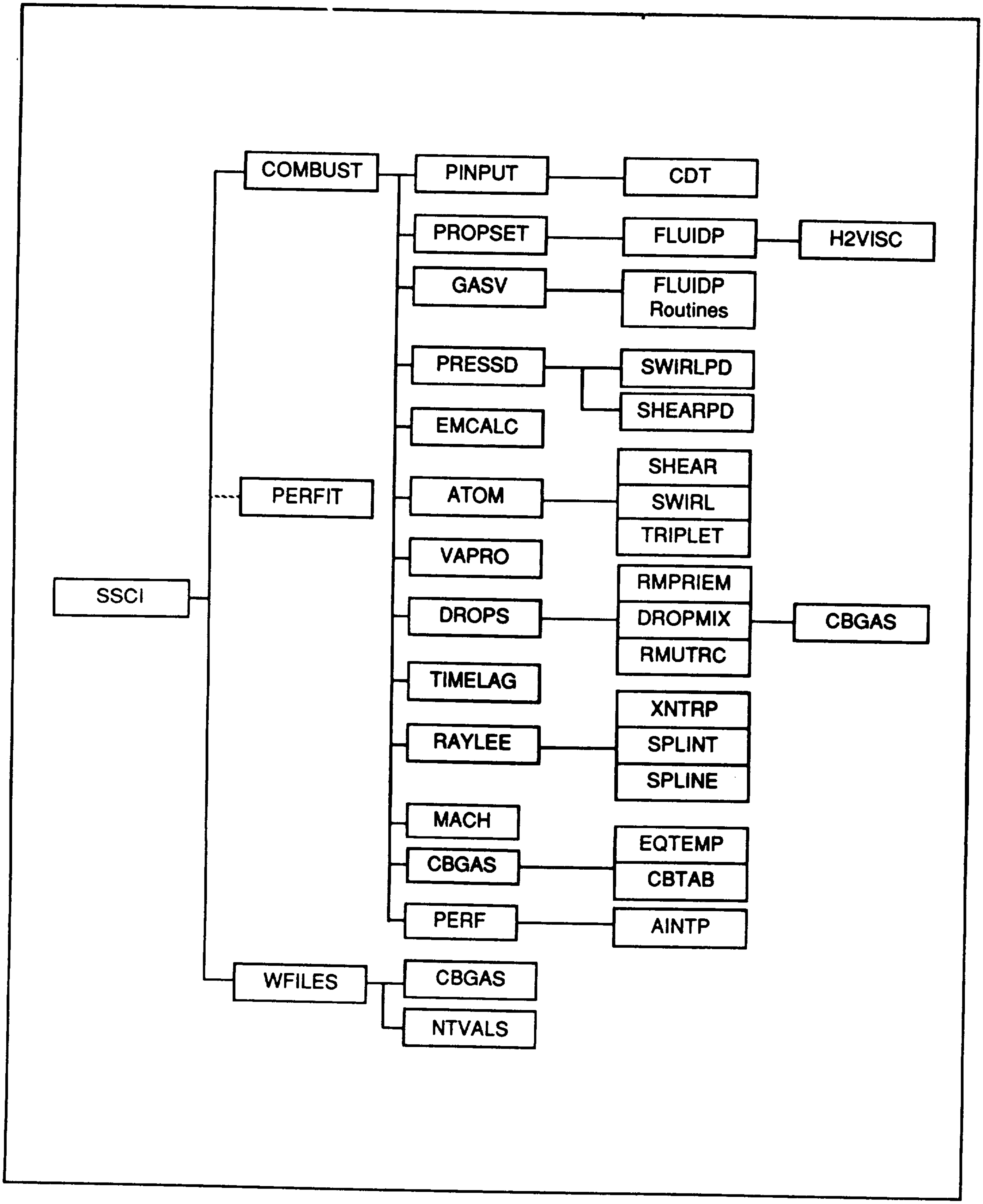


Figure F-1. Flowchart of Module SSCI

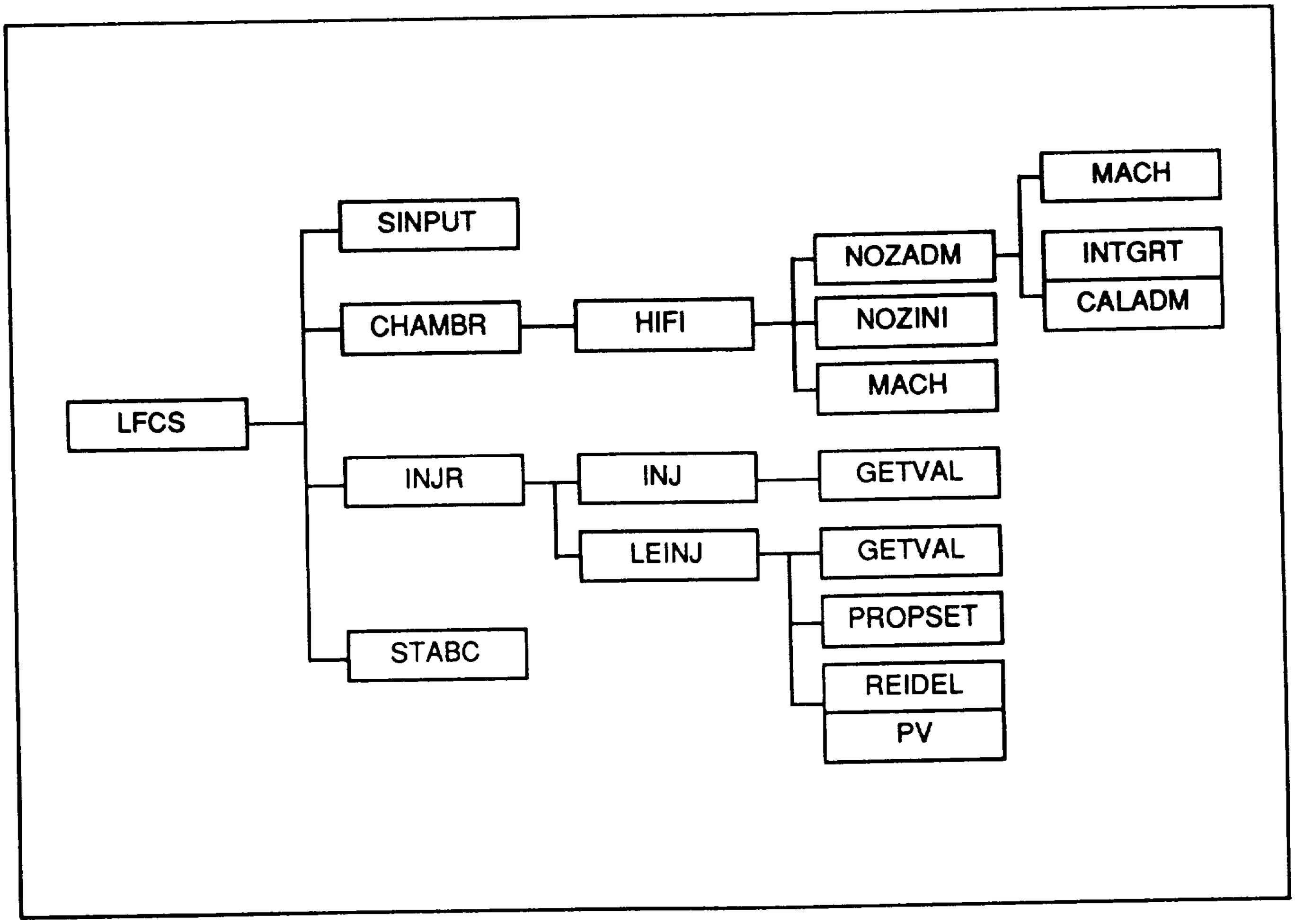


Figure F-2. Flowchart of Module LFCS

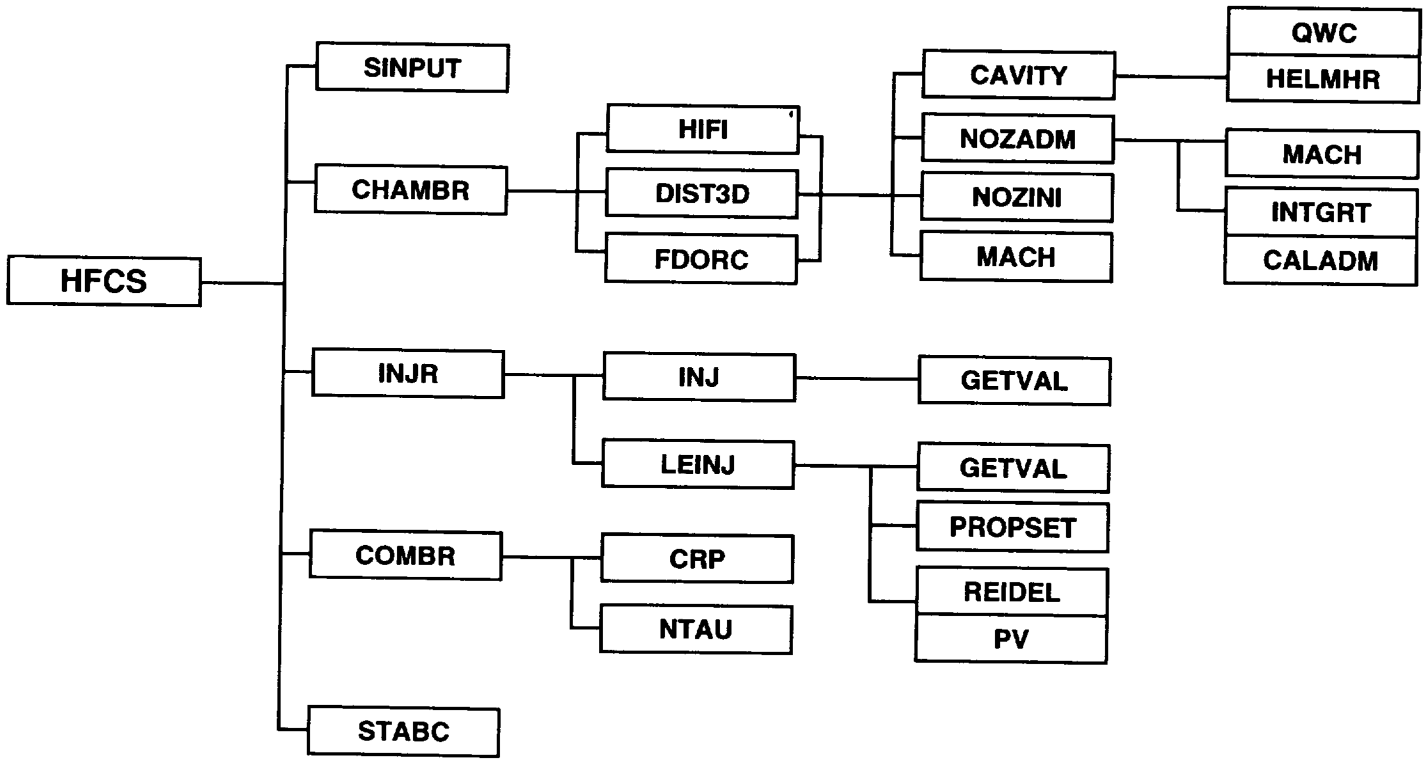


Figure F-3. Flowchart of Module HFCS

Part B

Point Design Module Flow Charts

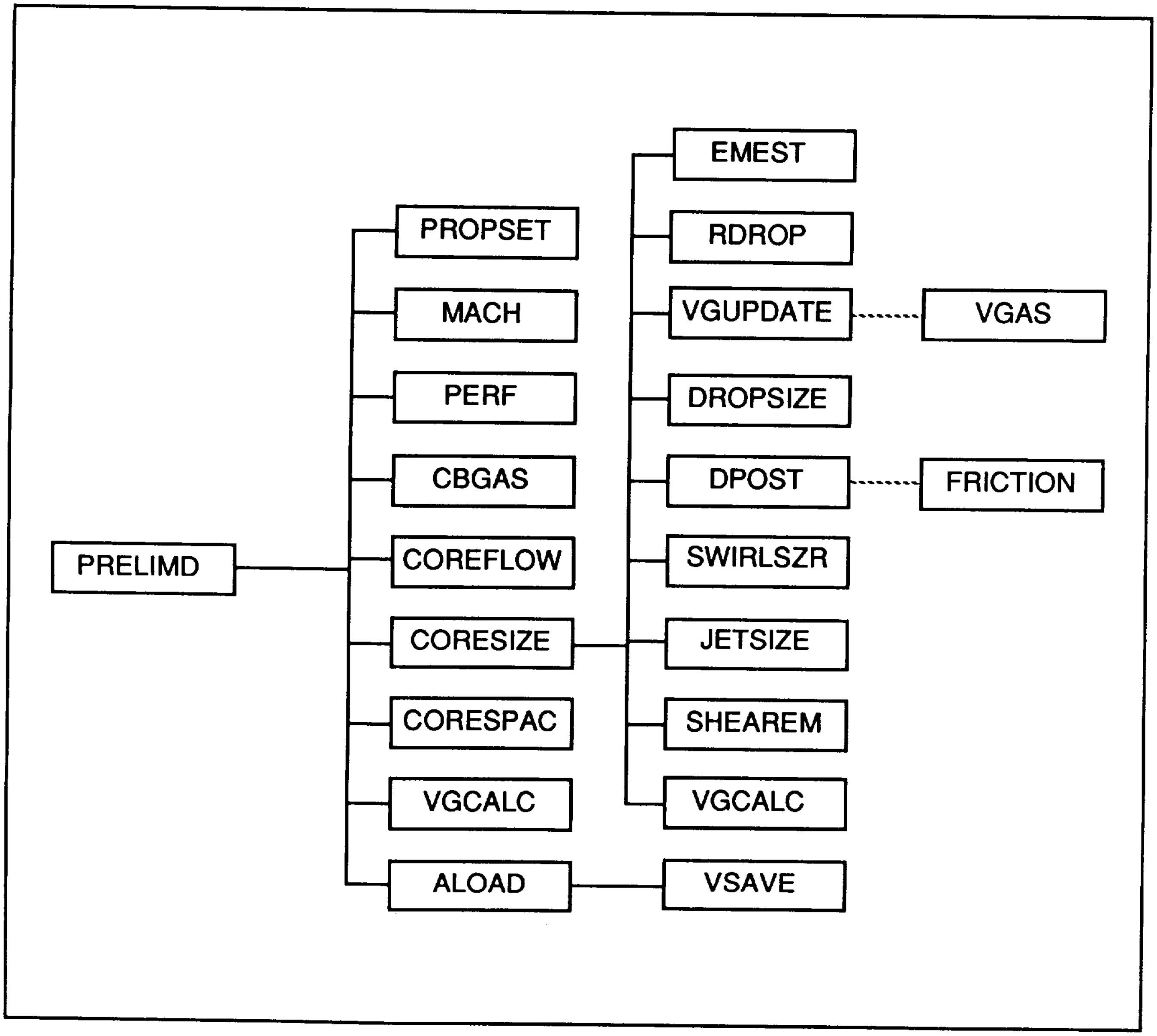


Figure F-4. Flowchart for Module PRELIMD

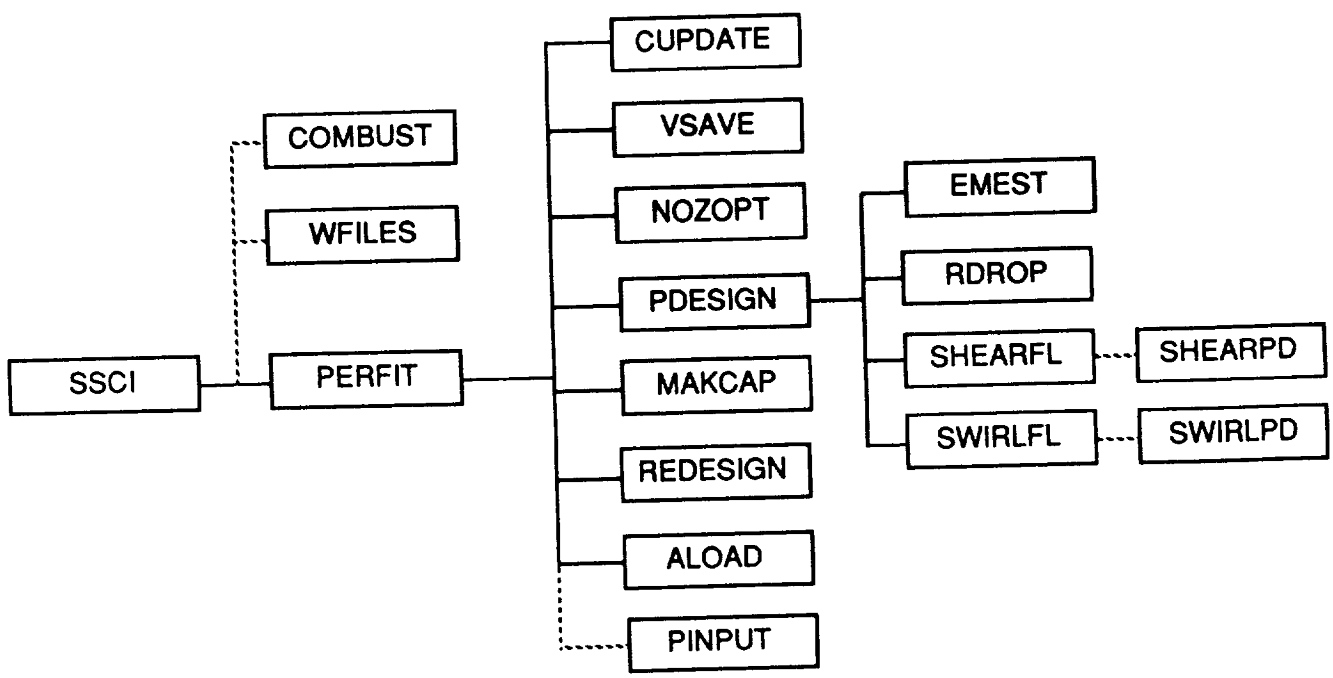


Figure F-5. Flowchart for Module PERFIT

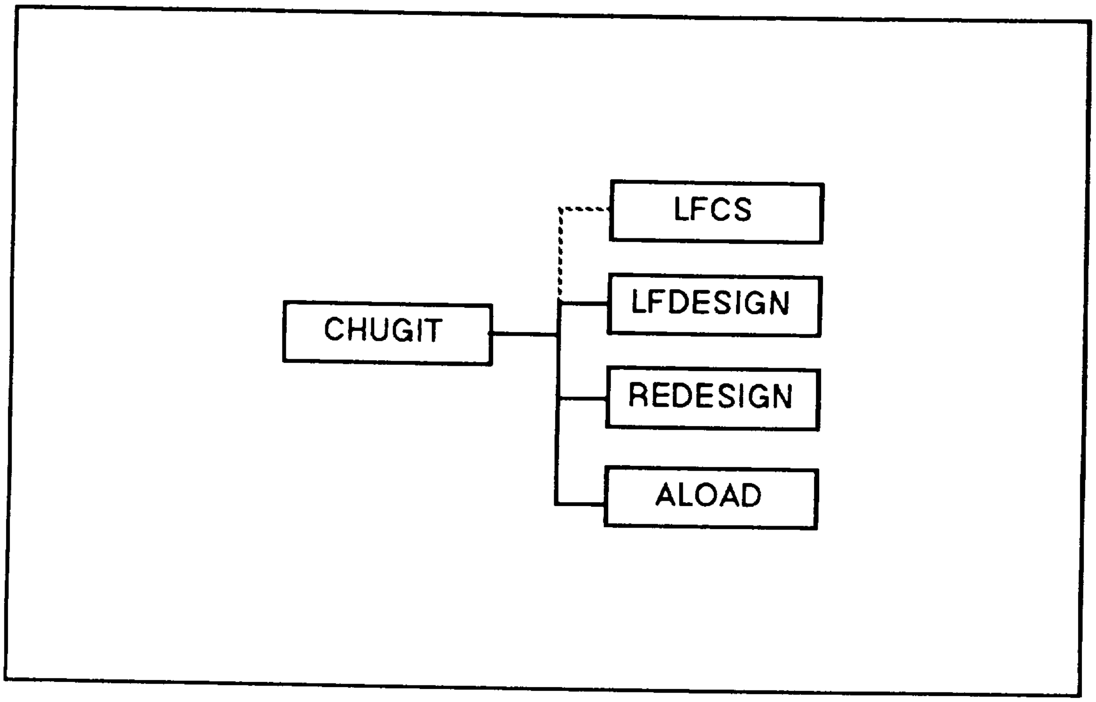


Figure F-6. Flowchart for Module CHUGIT

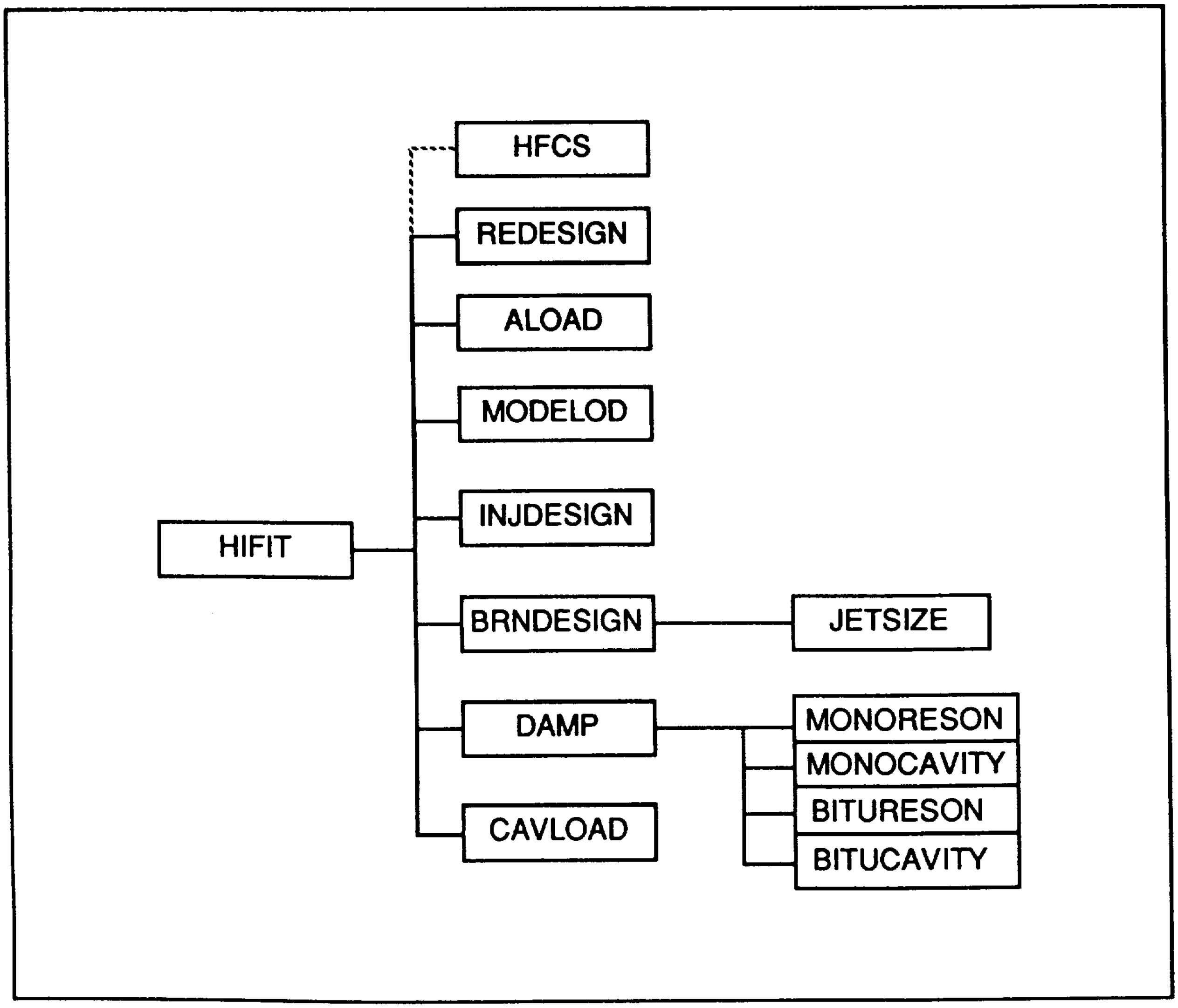


Figure F-7. Flowchart for Module HIFIT

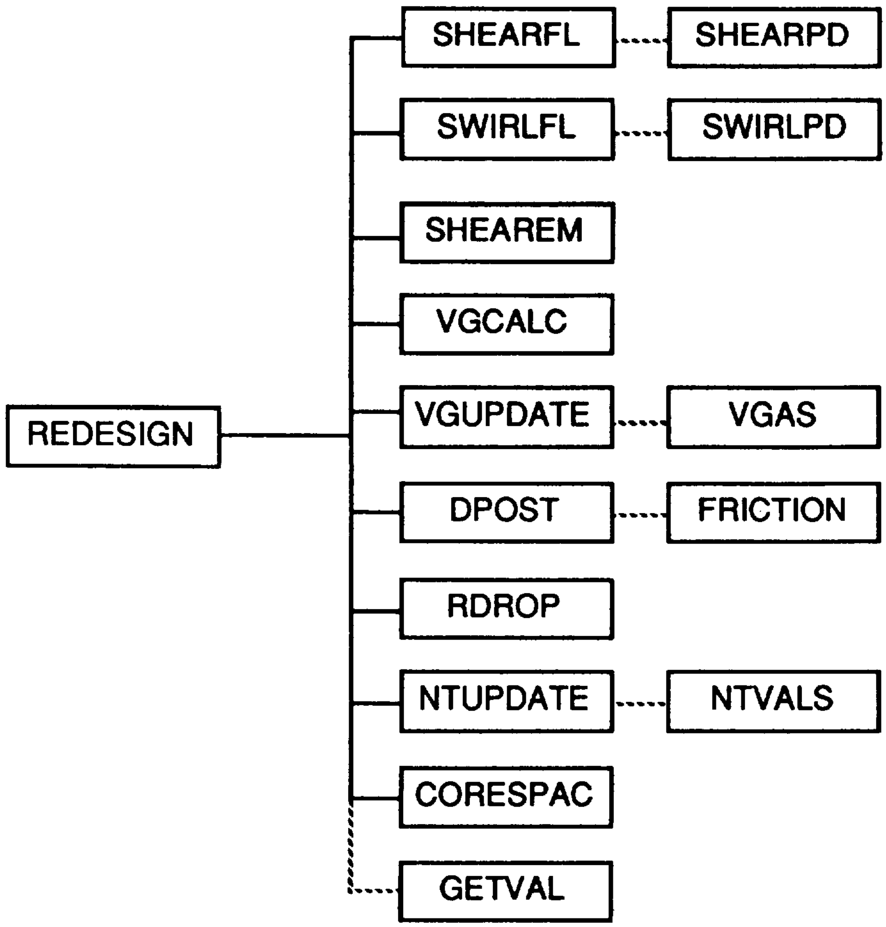


Figure F-8. Flowchart for Module REDESIGN

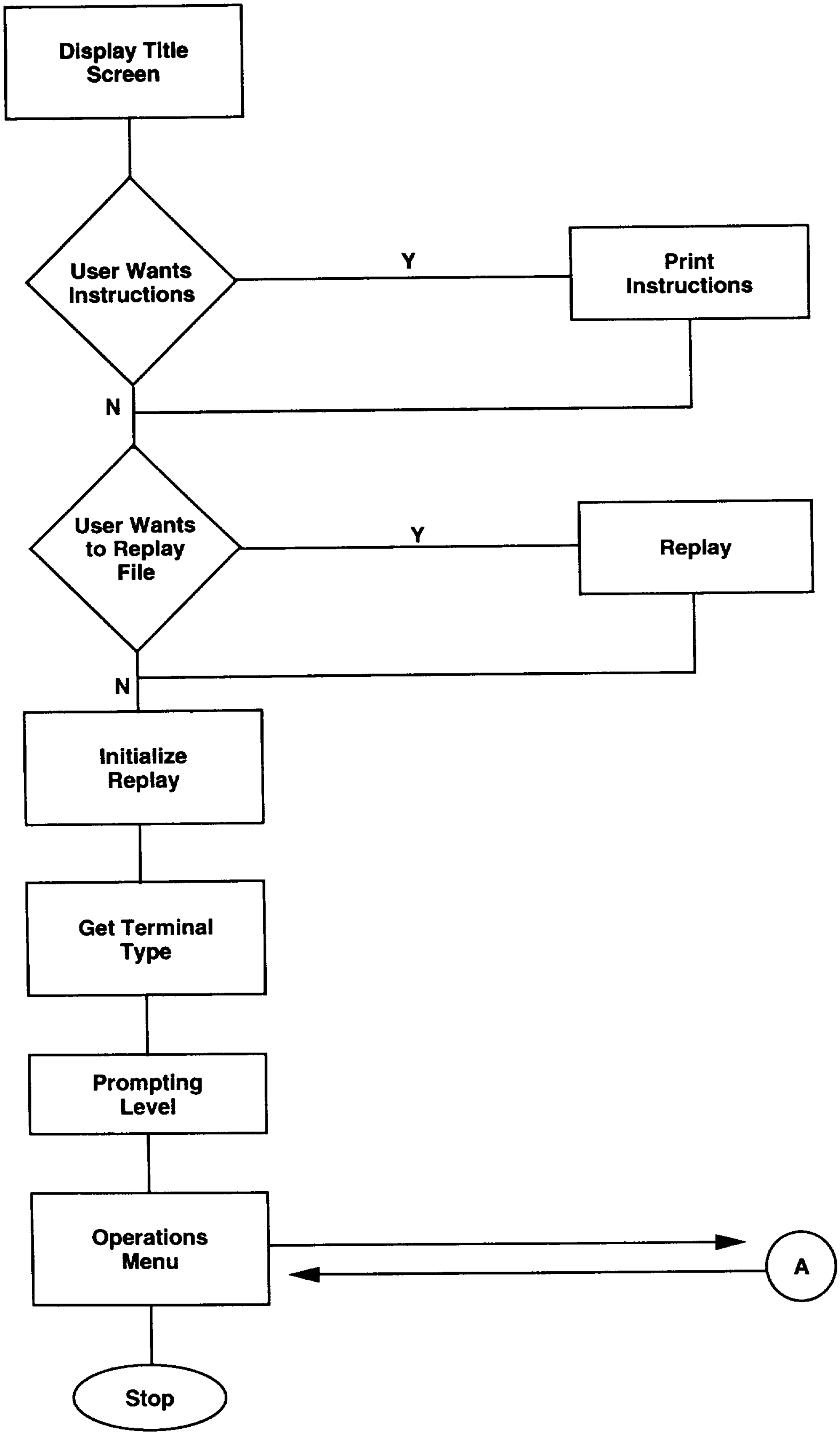
Part C

Main IFE Flow Charts

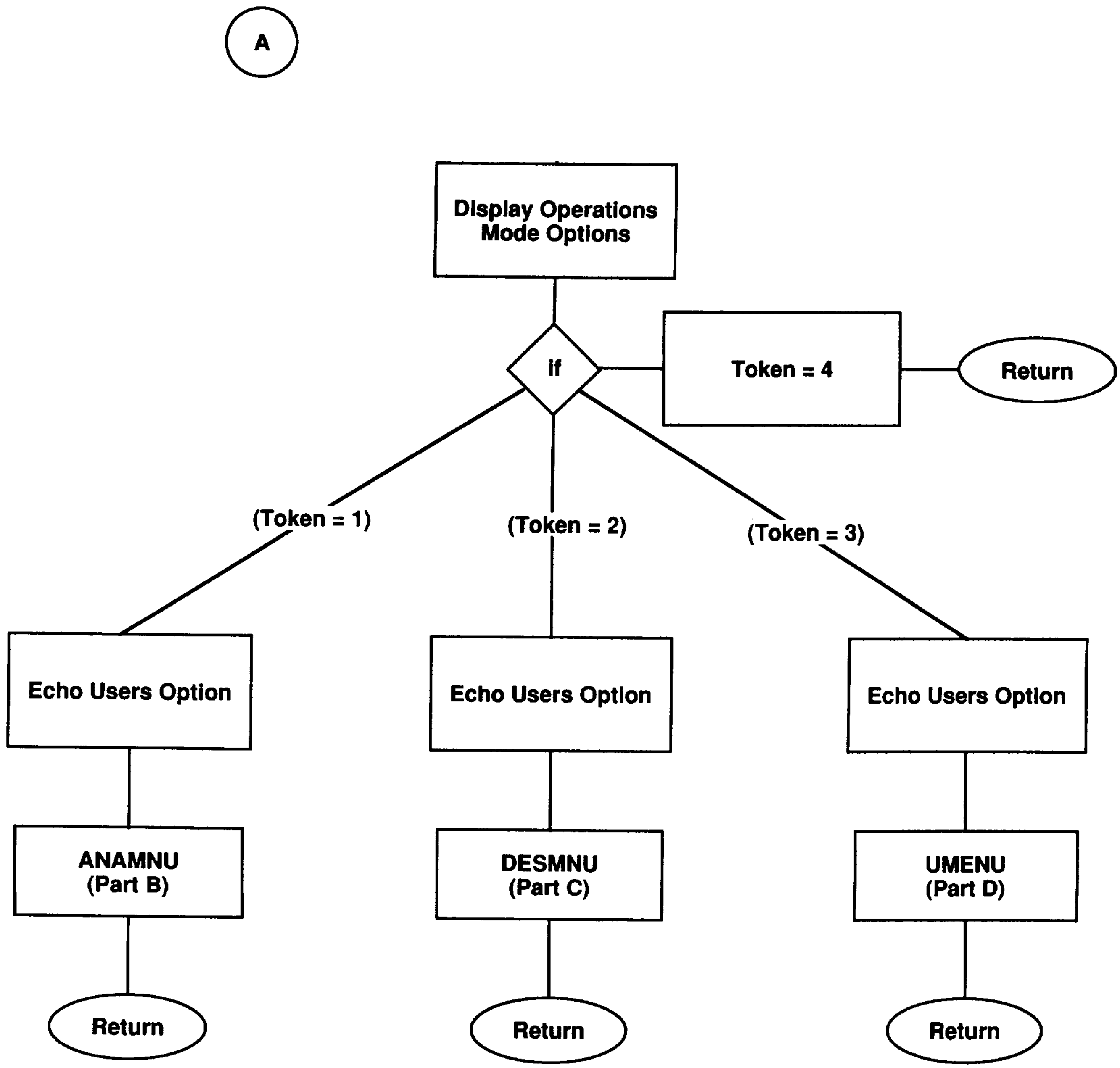
ANALYSIS REQUEST MENU (BMENU)

1. Point Analysis
2. Point Design
3. Utility Routines
4. Stop

ROCCID


Display Title Screen
User Wants Instructions
Y
Print Instructions
N
User Wants to Replay File
Y
Replay
N
Initialize Replay
Get Terminal Type
Prompting Level
Operations Menu
A
Stop

B MENU


A
Display Operations
Mode Options
if
Token = 4
Return
(Token = 1)
(Token = 2)
(Token = 3)
Echo Users Option
Echo Users Option
Echo Users Option
ANAMNU
(Part B)
DESMNU
(Part C)
UMENU
(Part D)
Return
Return
Return

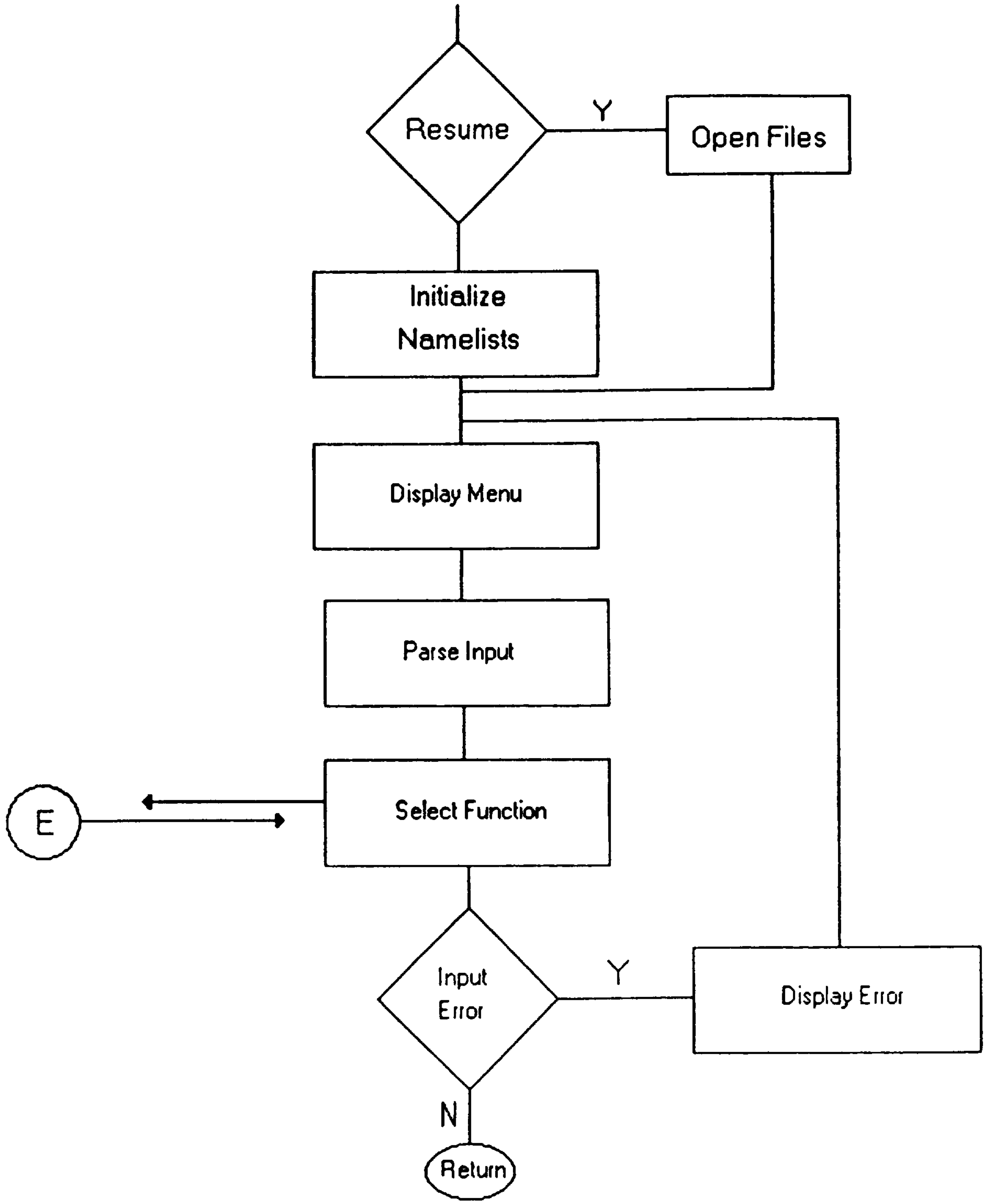
Part D

IFE Point Analysis Section Flow Charts

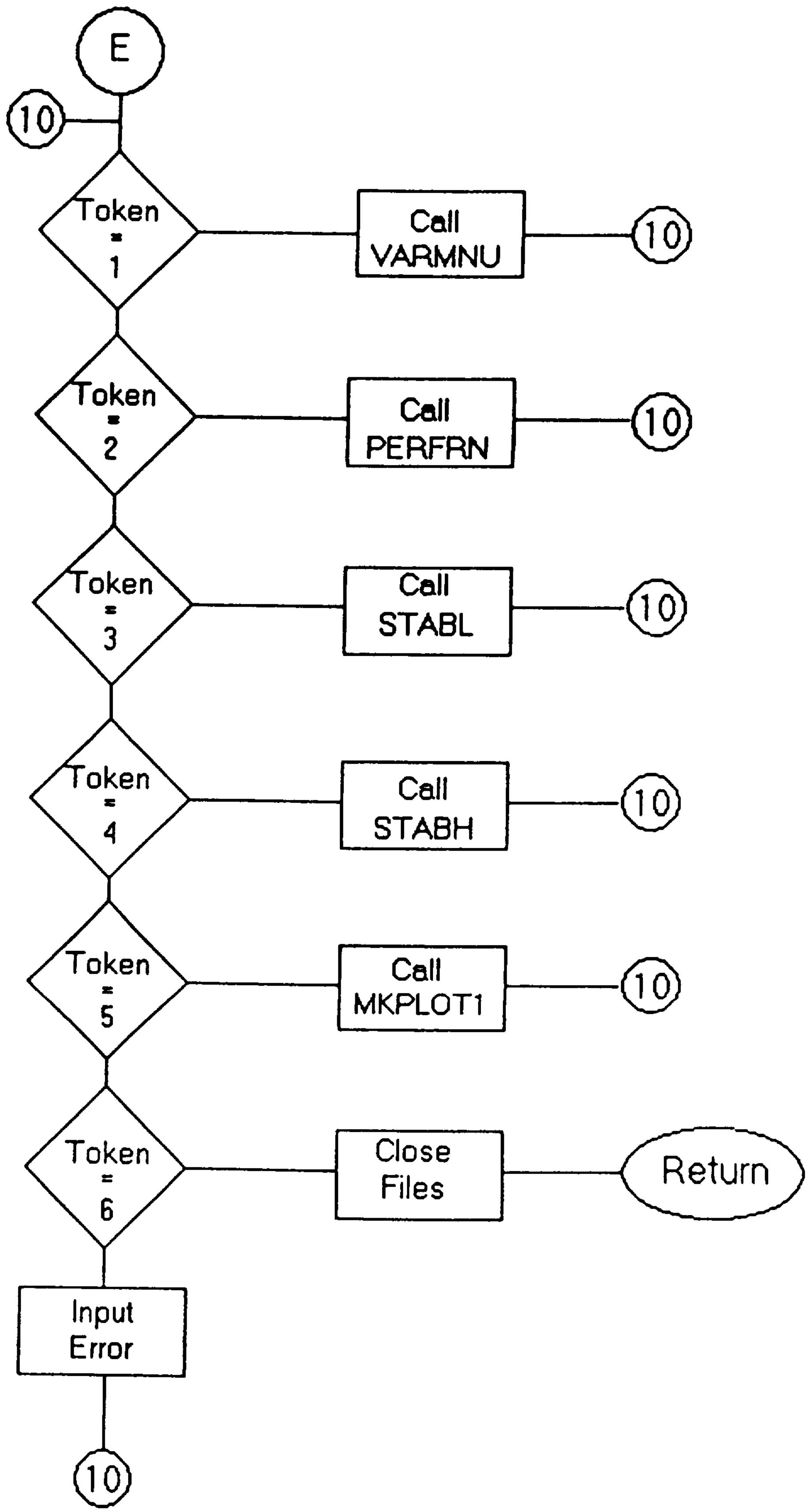
POINT ANALYSIS MENU OPTIONS (ANAMNU)

1. Set Variables
2. Run Steady State Performance
3. Run Low Frequency Stability
4. Run High Frequency Stability
5. Plot Current Data
6. Previous Menu

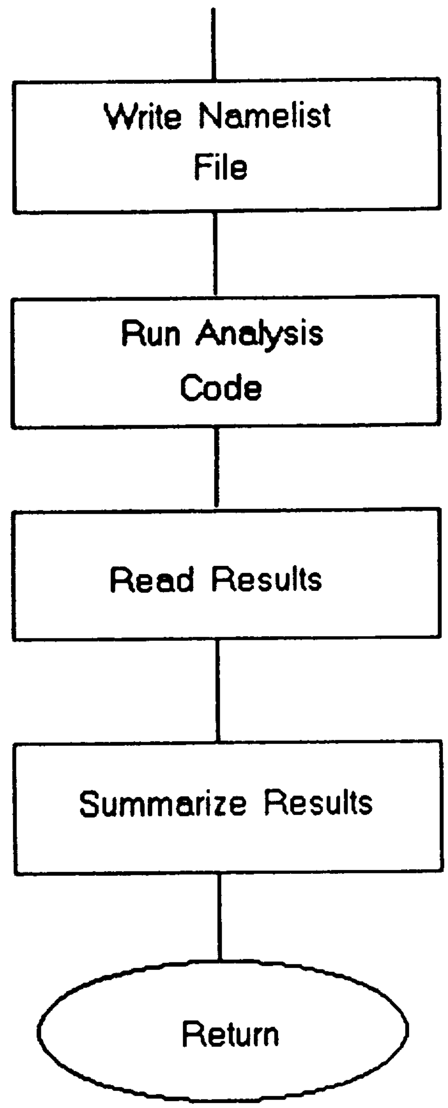
ANALYSIS MENU
(ANAMNU)



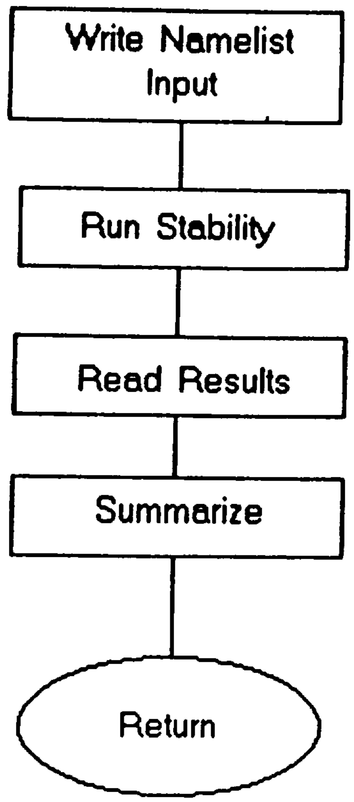
ANAMNU


E
10
Token = 1
Call VARMNU
10
Token = 2
Call PERFRN
10
Token = 3
Call STABL
10
Token = 4
Call STABH
10
Token = 5
Call MKPLOT1
10
Token = 6
Close Files
Return
Input Error
10

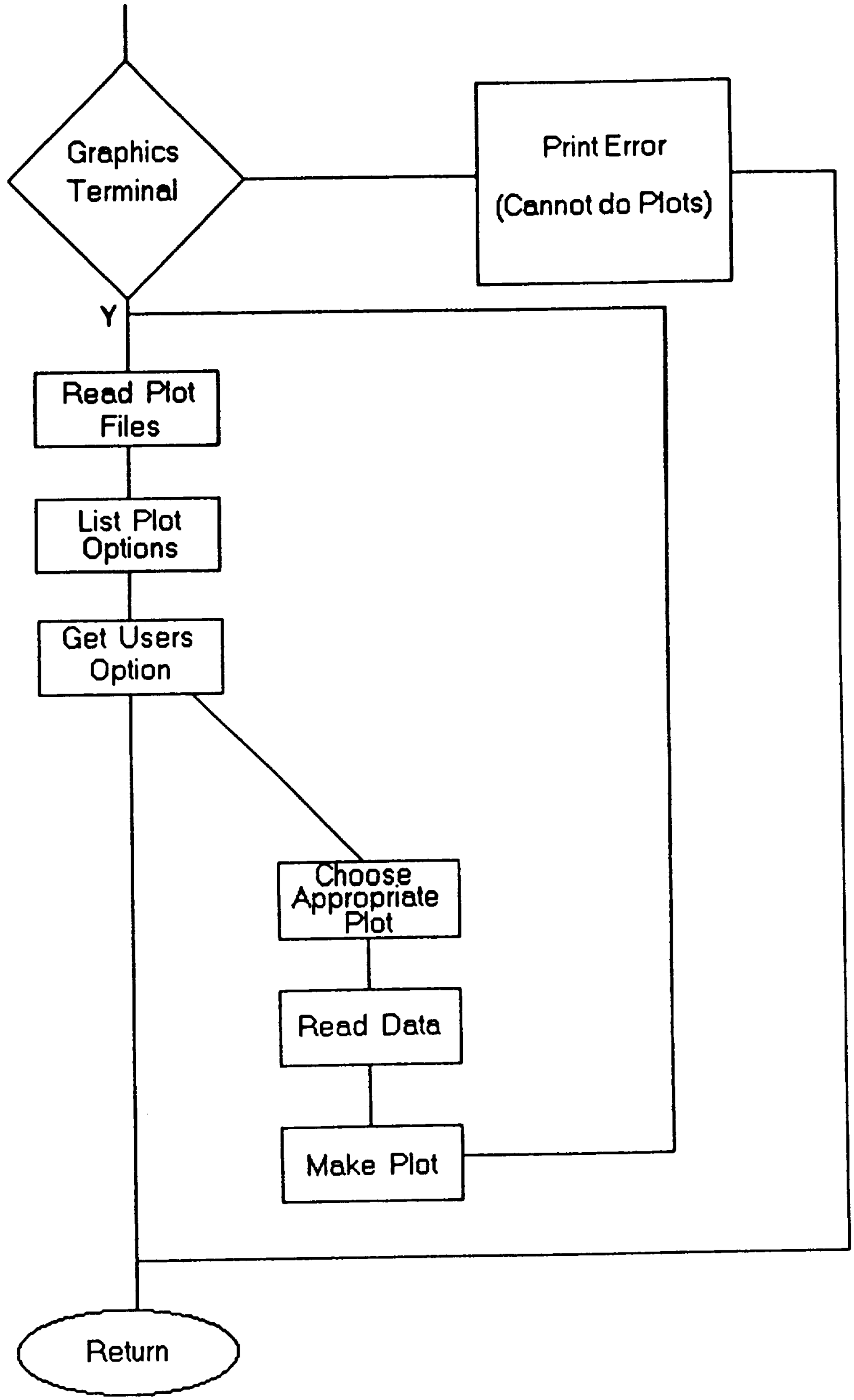
SUBROUTINE PERFRN



SUBROUTINE STAB



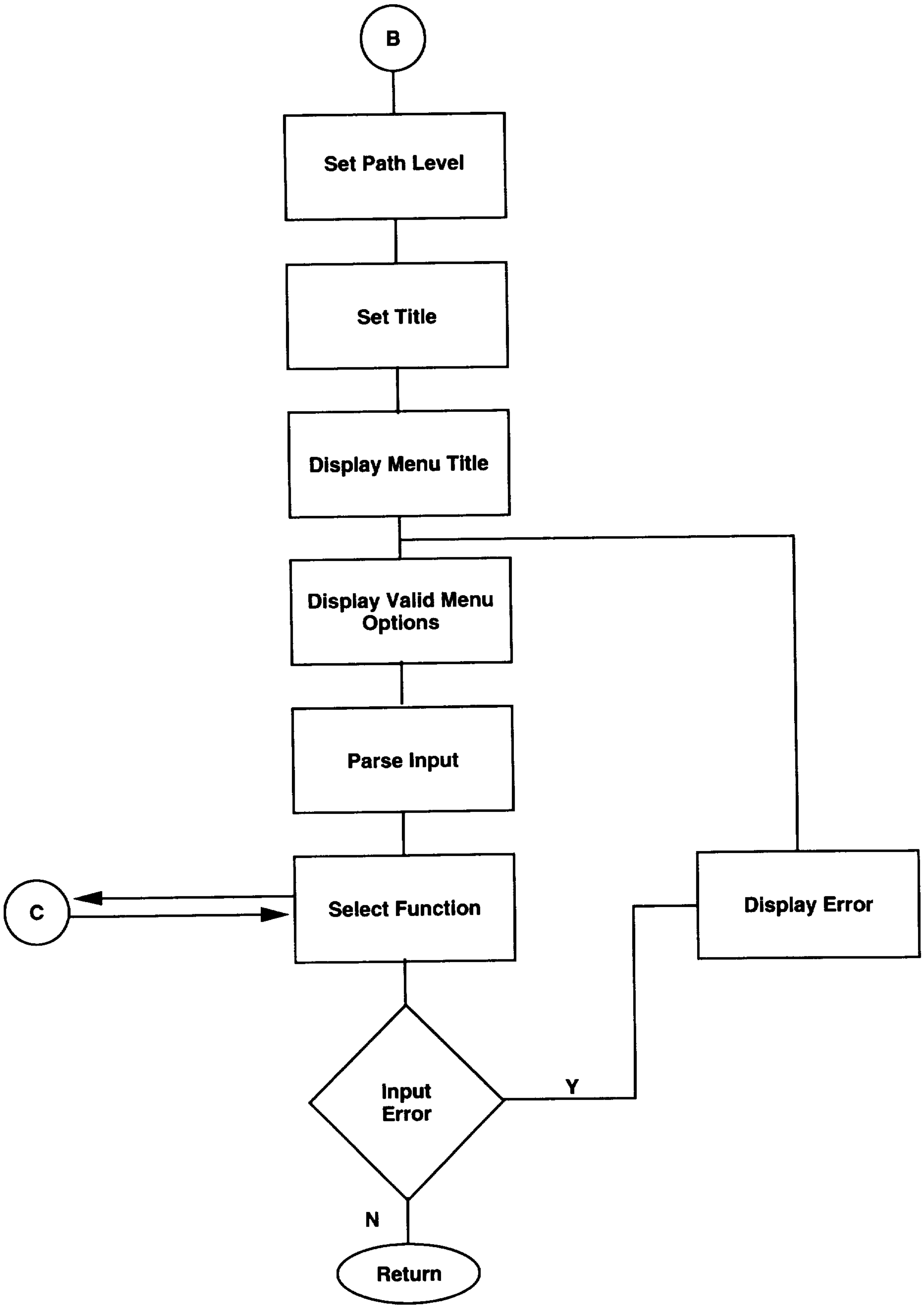
SUBROUTINE DISPLAY



POINT ANALYSIS VARIABLES MENU OPTIONS

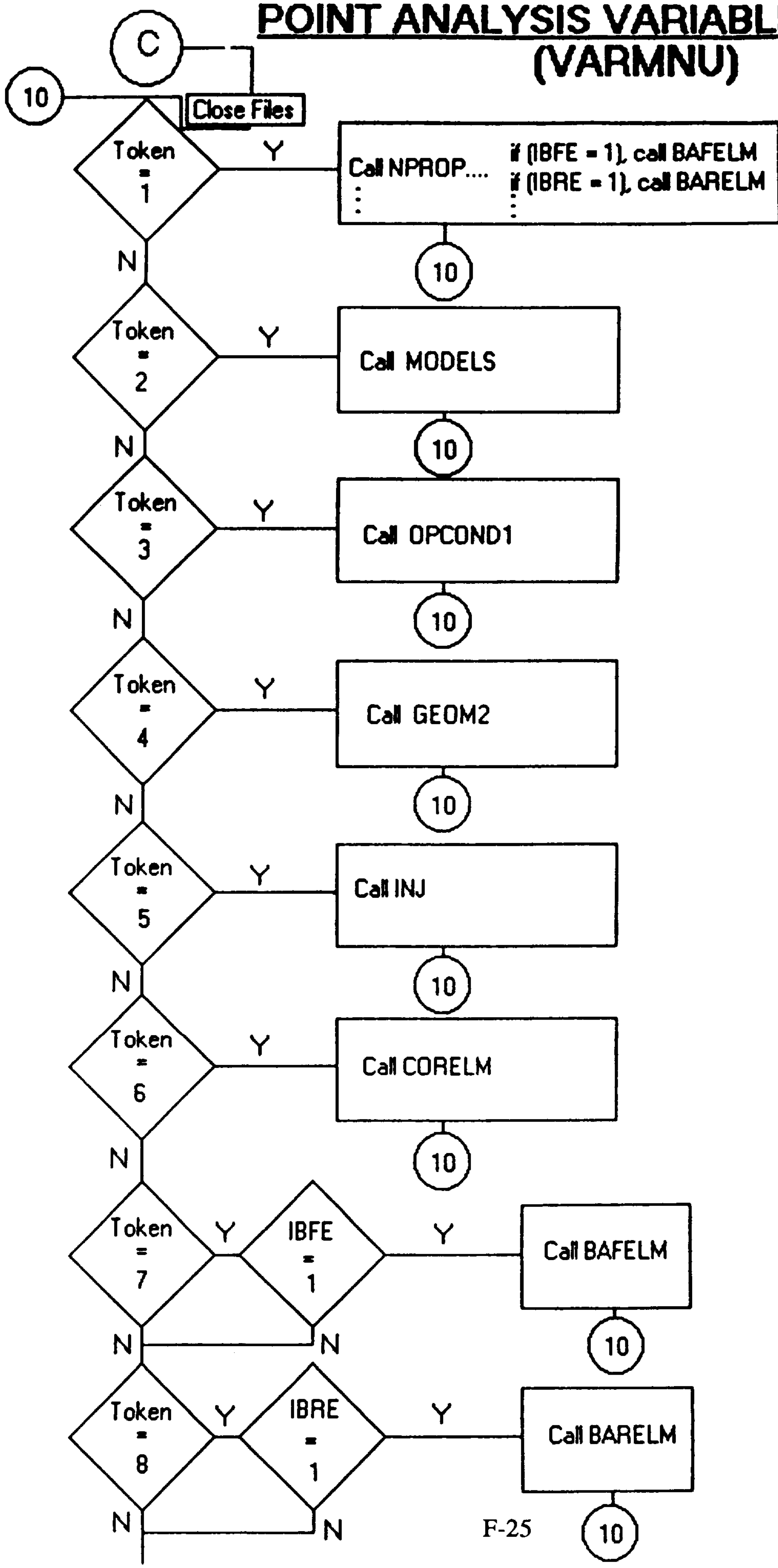
1.	Complete Setup	
2.	Set Model Selection	
3.	Set Operating Conditions	
4.	Set Geometry	
5.	Set Injector Element Types	
6.	Set Core Element	
7.	Set Baffle Element	(if IBFE =1)
8.	Set Barrier Element	(if IBRE =1)
9.	Set Fuel Film/Cavity Cooling Element	(if IFFE =1)
10.	Set Stability Aid Type	(if MCHAM=1 or 2)
11.	Set Manifold Description	
12.	Set Baffle Configuration	(if IBAF =1)
13.	Set 1/4 Wave Cavity Configuration	(if ICAV =1 and MCHAM=1 or 2)
14.	Set Helmholtz Resonator Configuration	(if ICAV =2 and MCHAM=1 pr 2)
15.	Set FDORC Variables	(if MCHAM=3)
16.	Set Model Control Variables	
17.	Previous Menu	

VARMNU

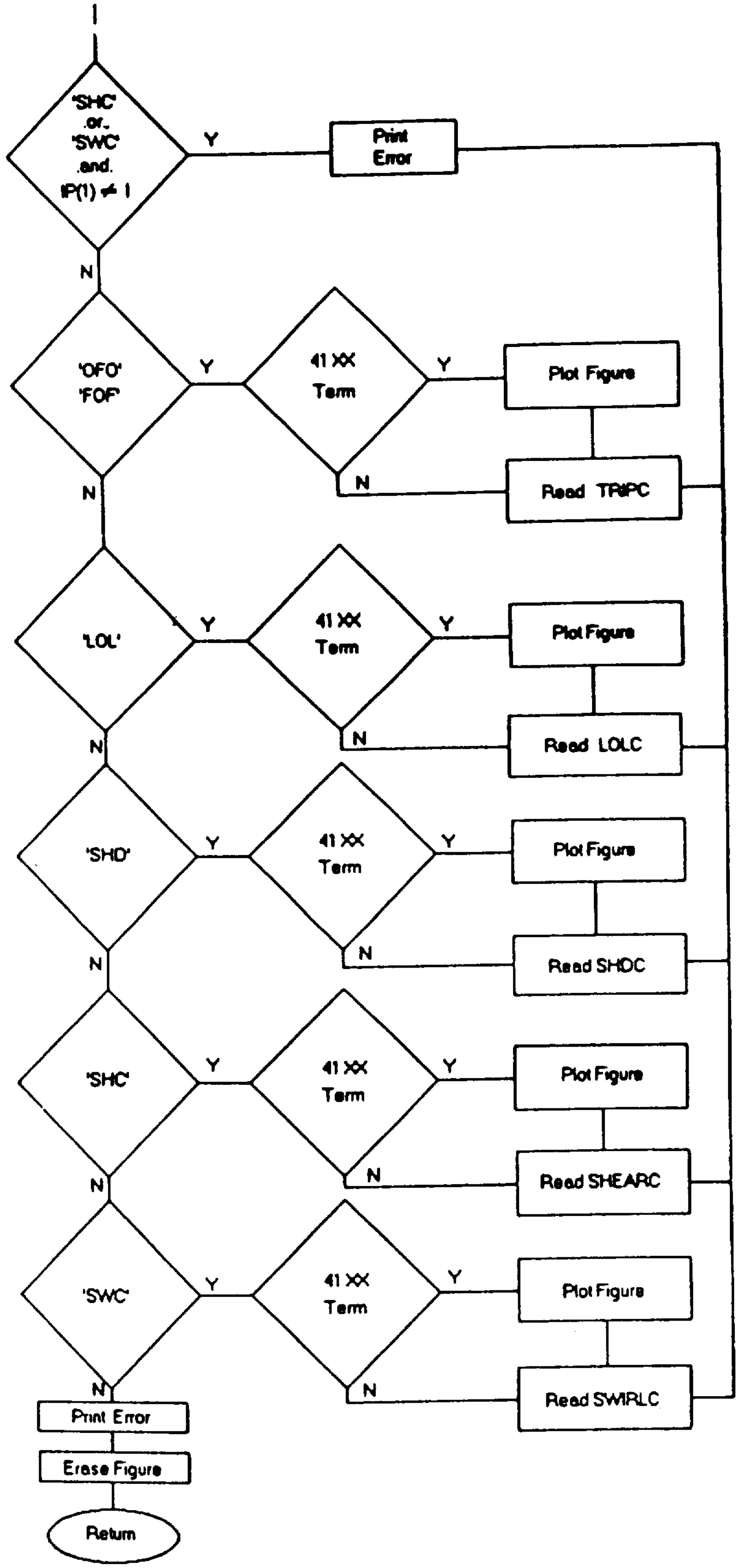


B
Set Path Level
Set Title
Display Menu Title
Display Valid Menu Options
Parse Input
C
Select Function
Display Error
Input Error
Y
N
Return

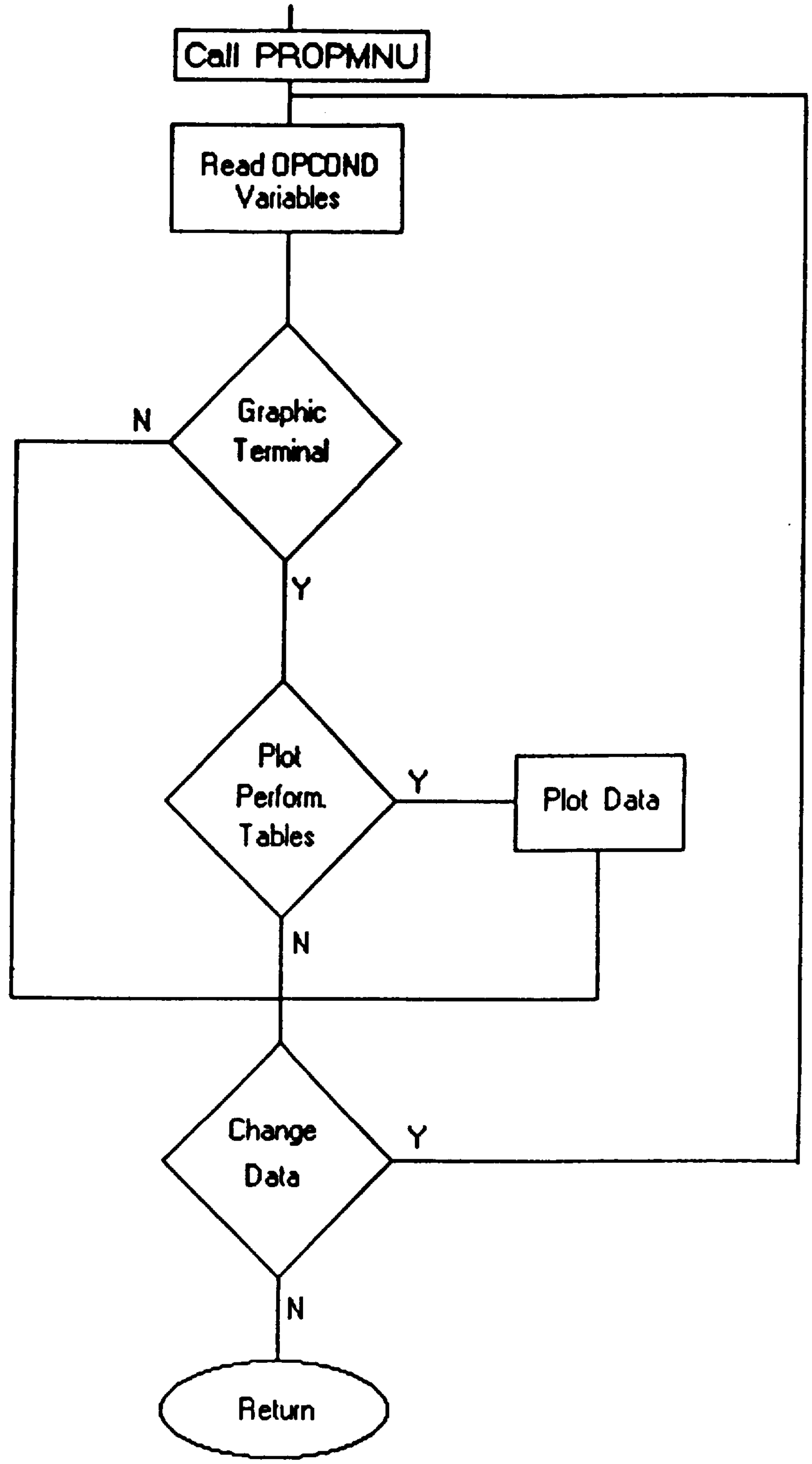
POINT ANALYSIS VARIABLE FUNCTIONS (VARMNU)



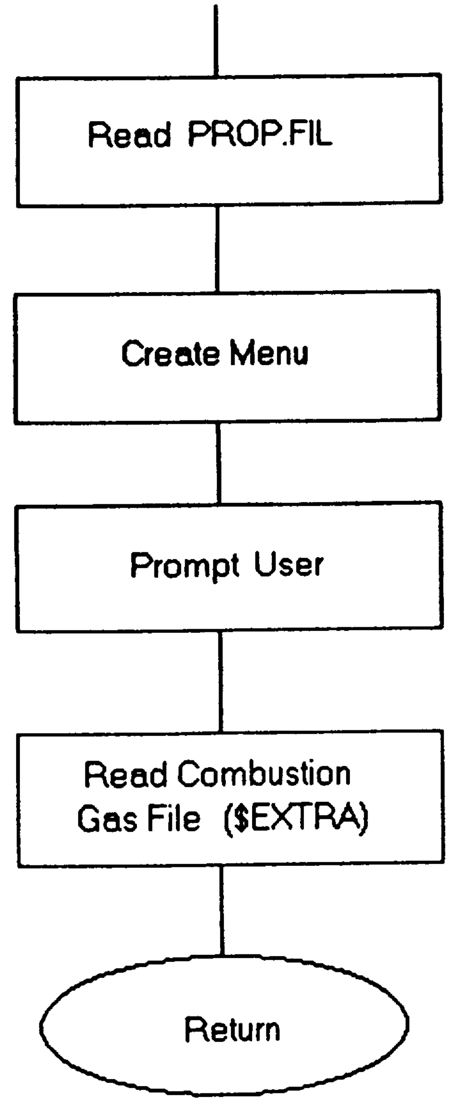
SUBROUTINE ELMDEF



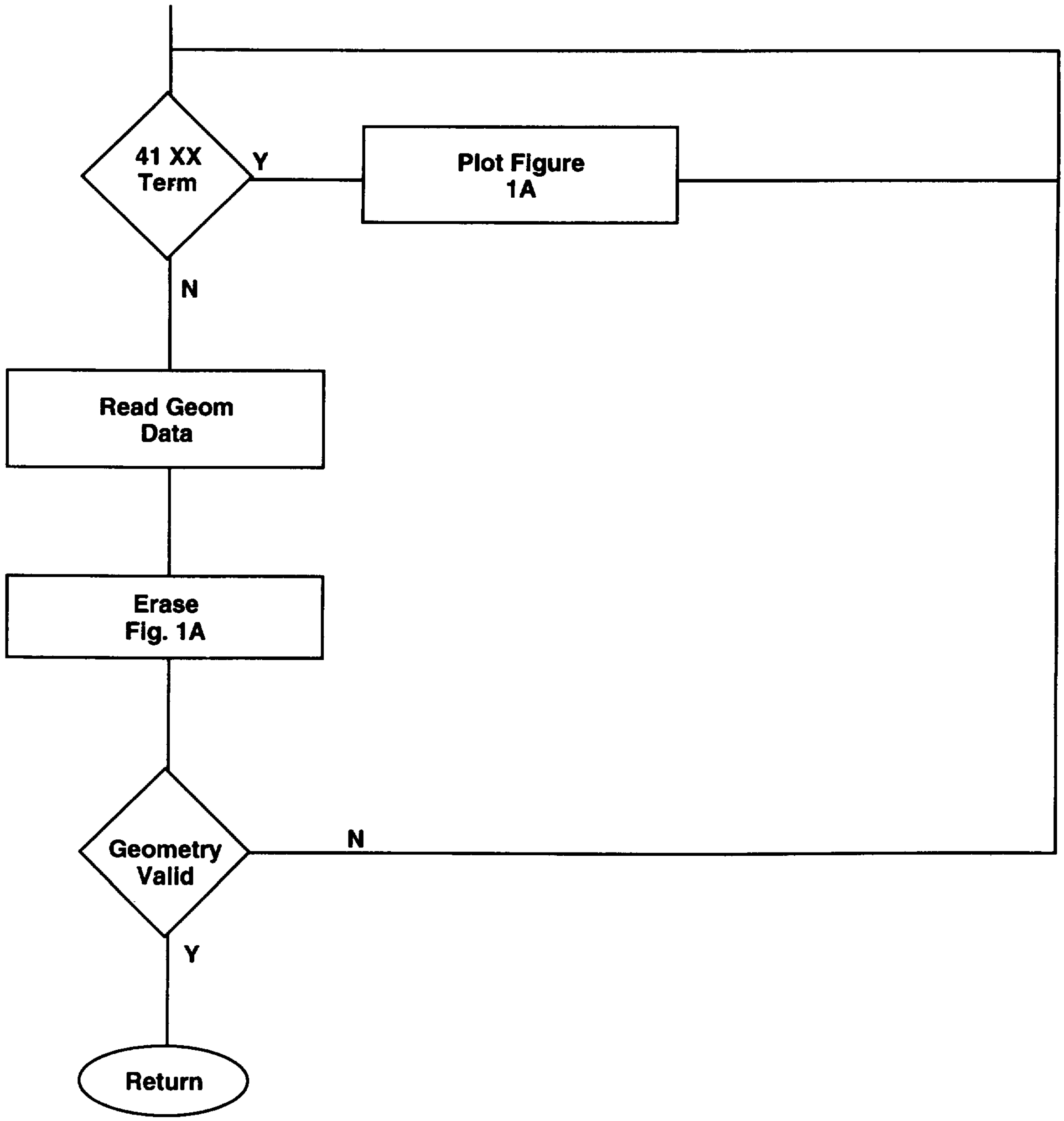
SUBROUTINE OPCOND1



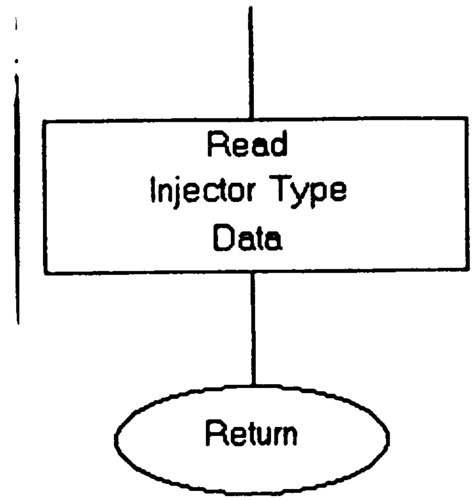
SUBROUTINE PROPMNU



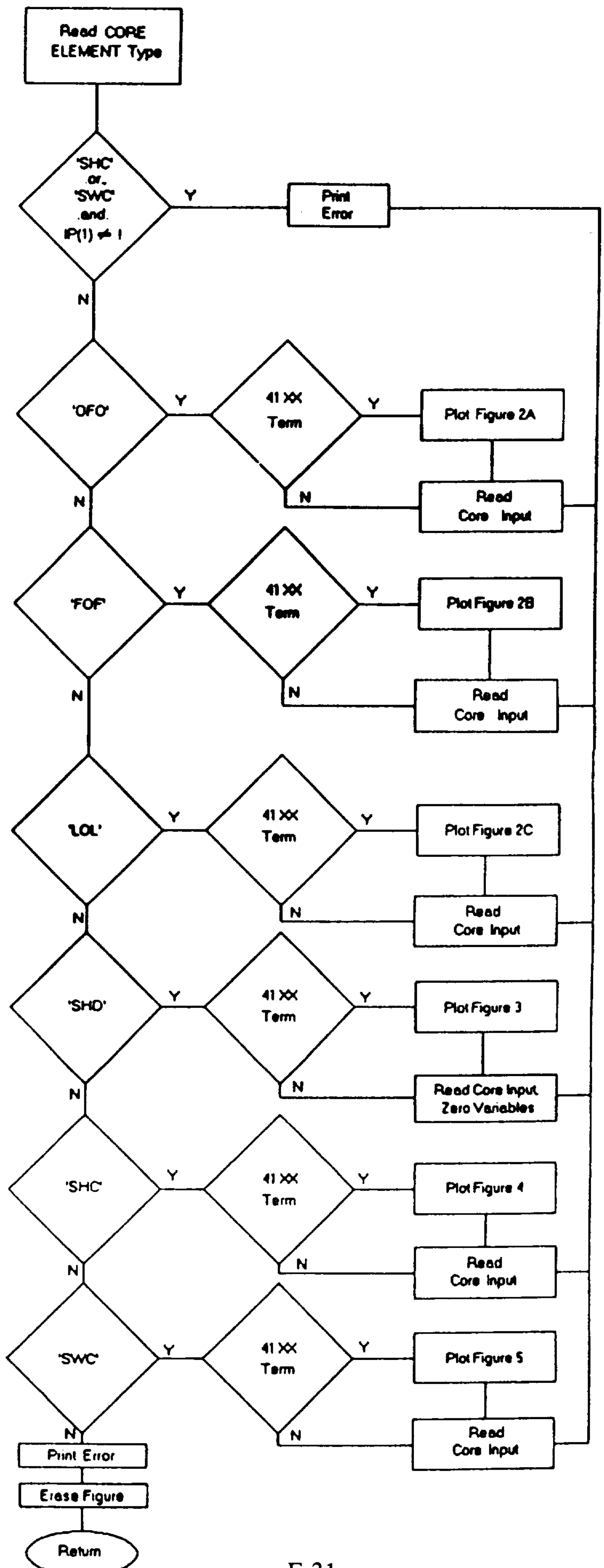
SUBROUTINE GEOM2



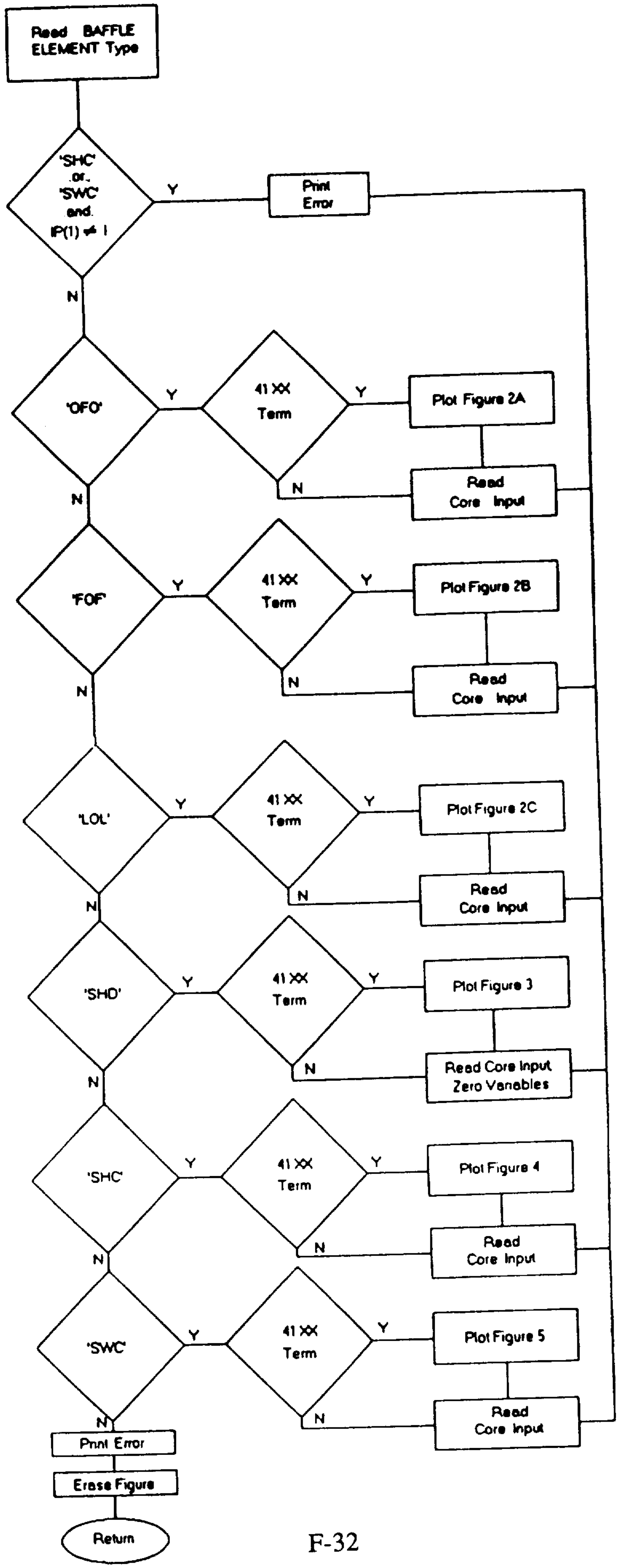
SUBROUTINE INJ



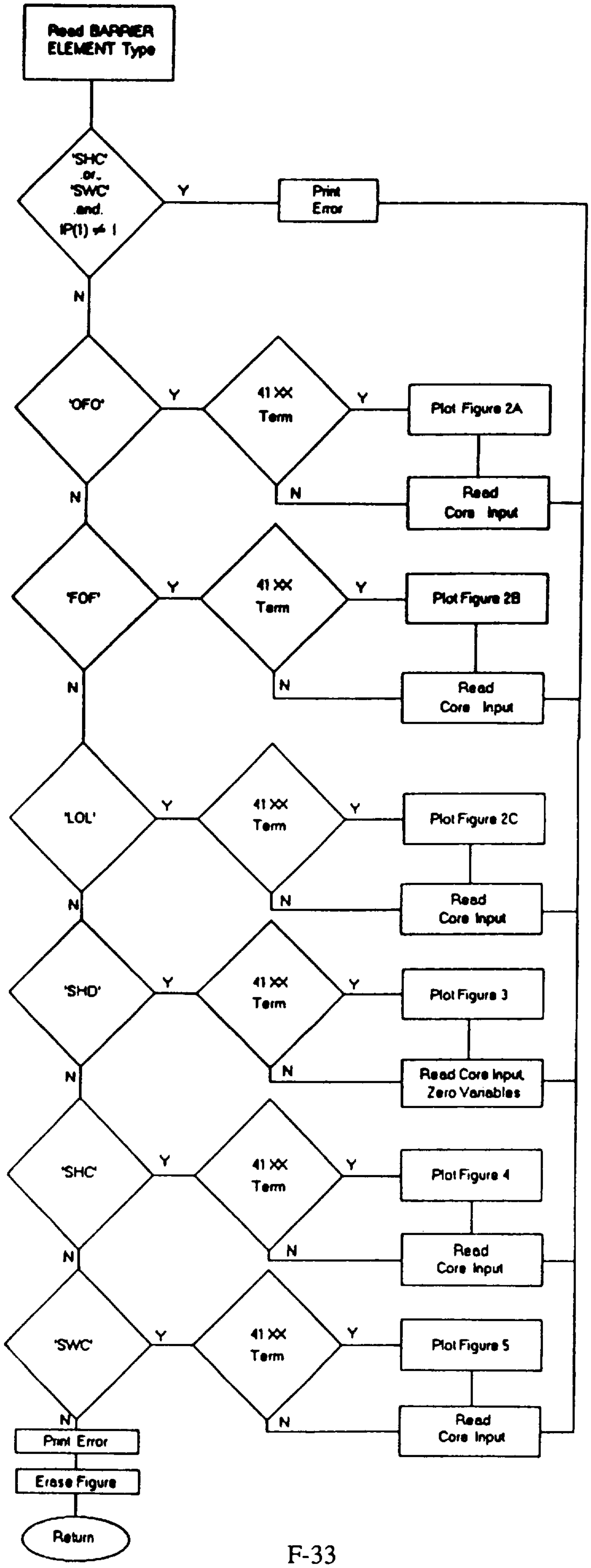
SUBROUTINE CORELM



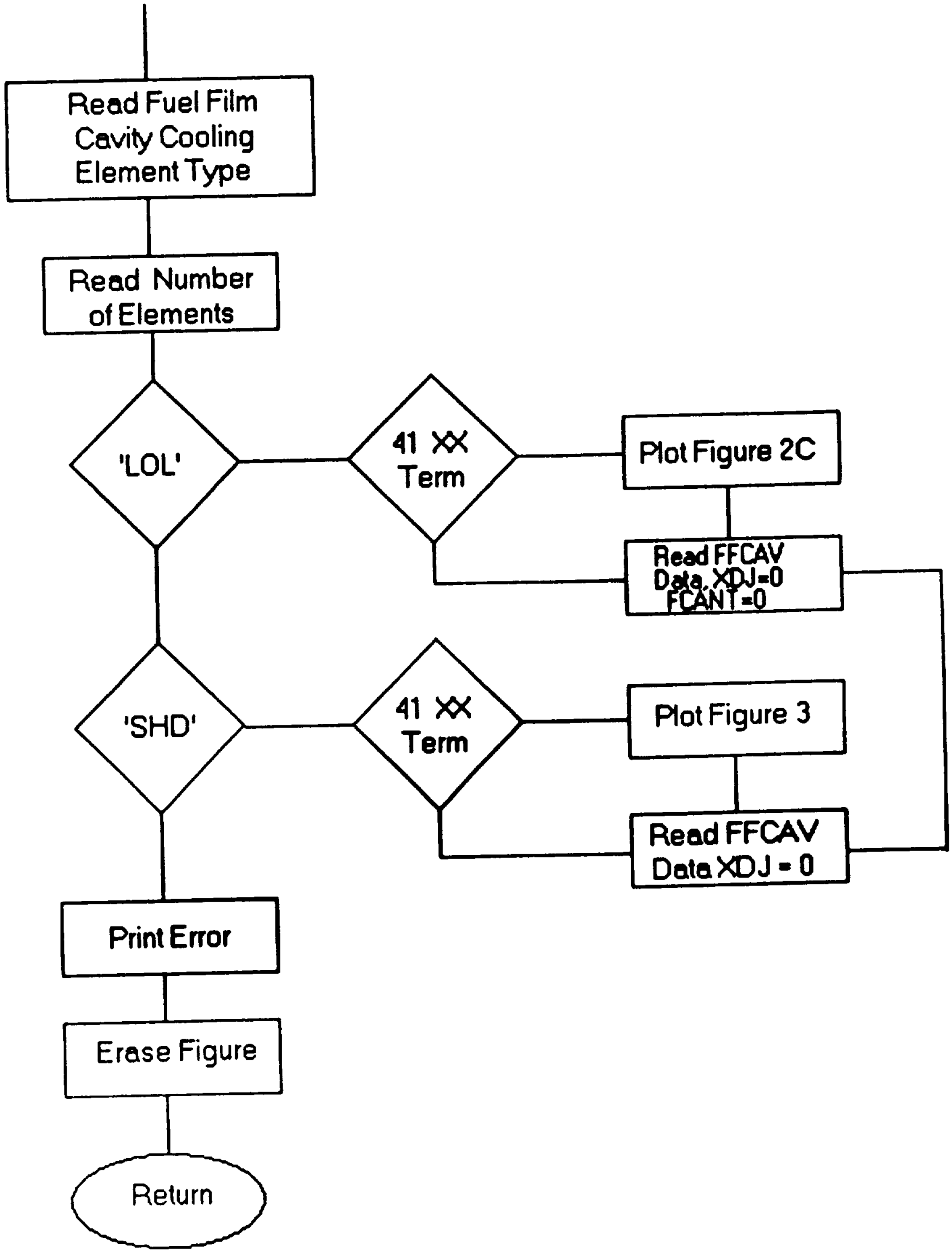
SUBROUTINE BAFELM



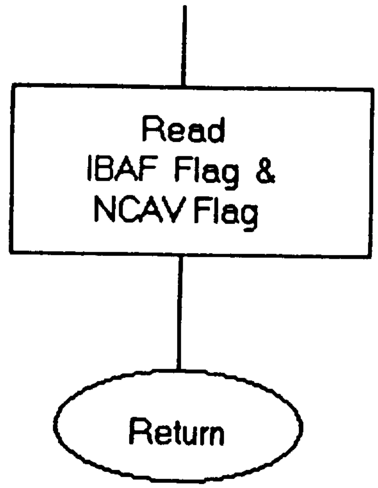
SUBROUTINE BARELM



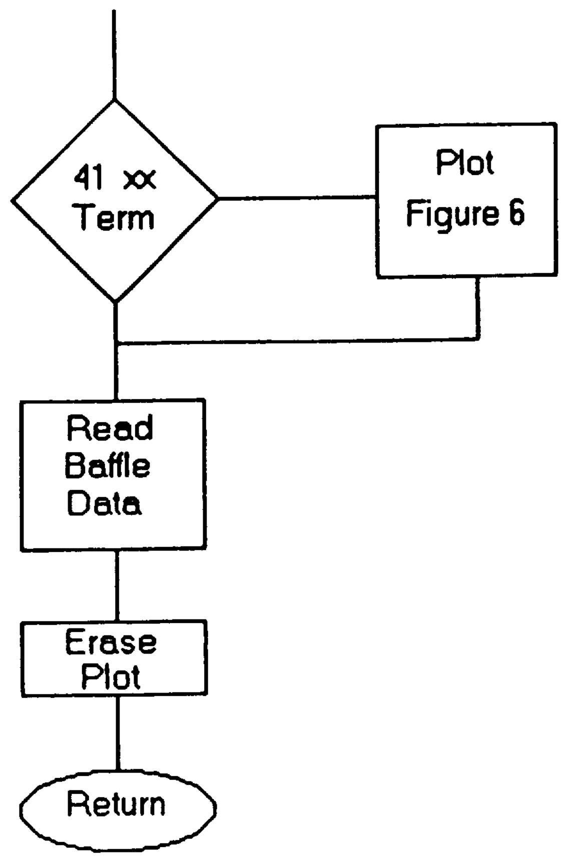
SUBROUTINE FFCAVE



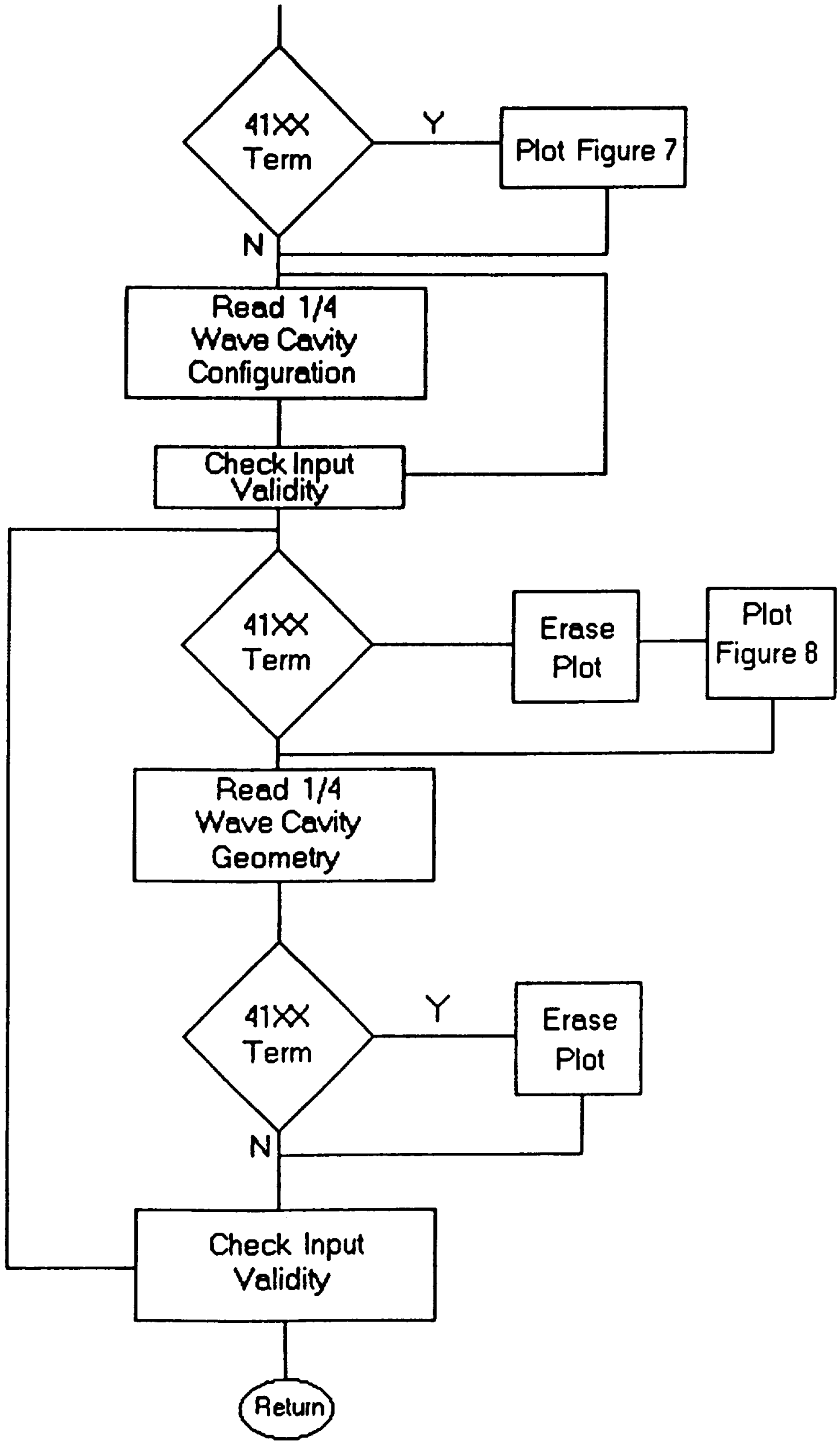
SUBROUTINE STBAID



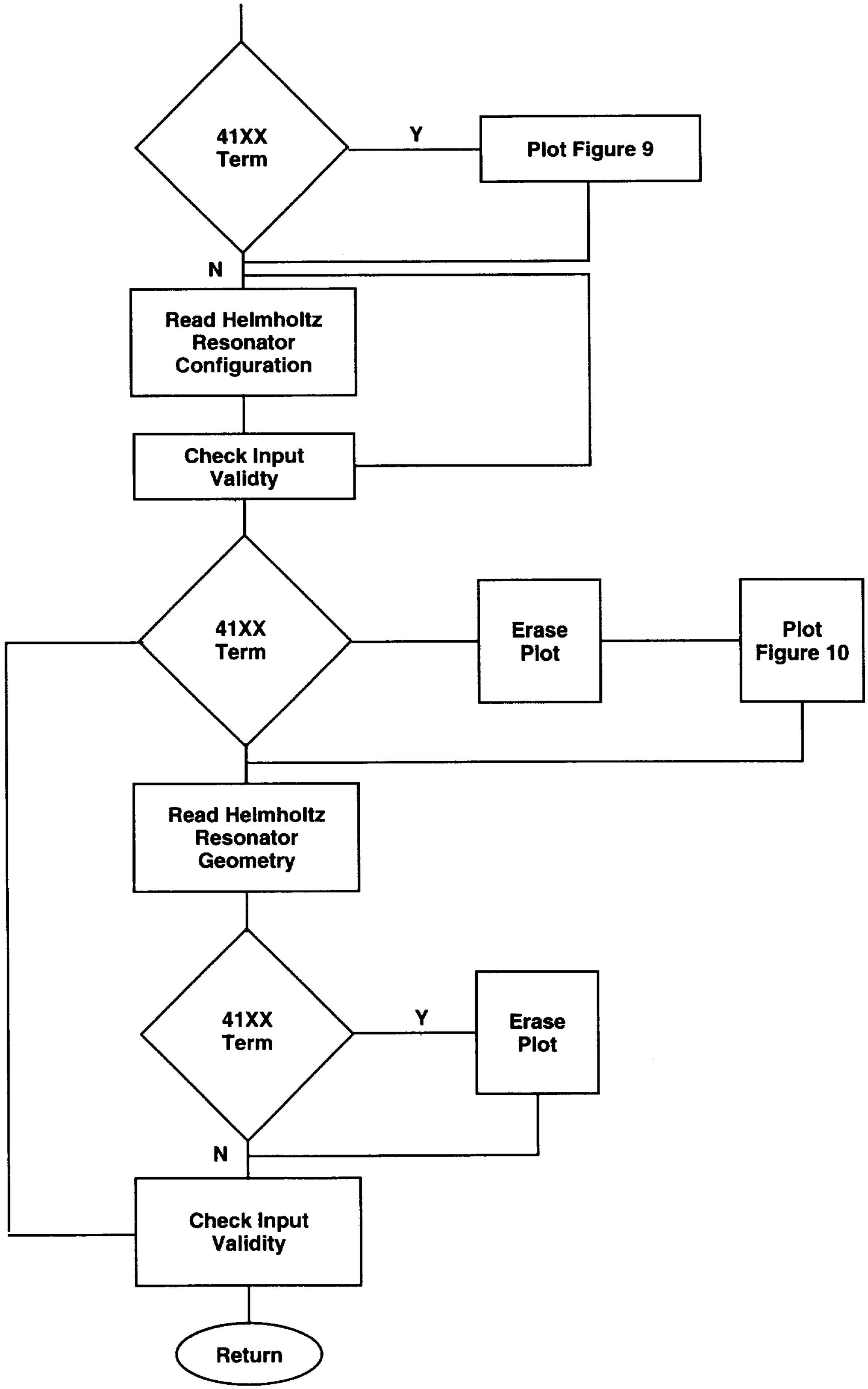
SUBROUTINE RADBAF



SUBROUTINE CAV



SUBROUTINE HELMRS

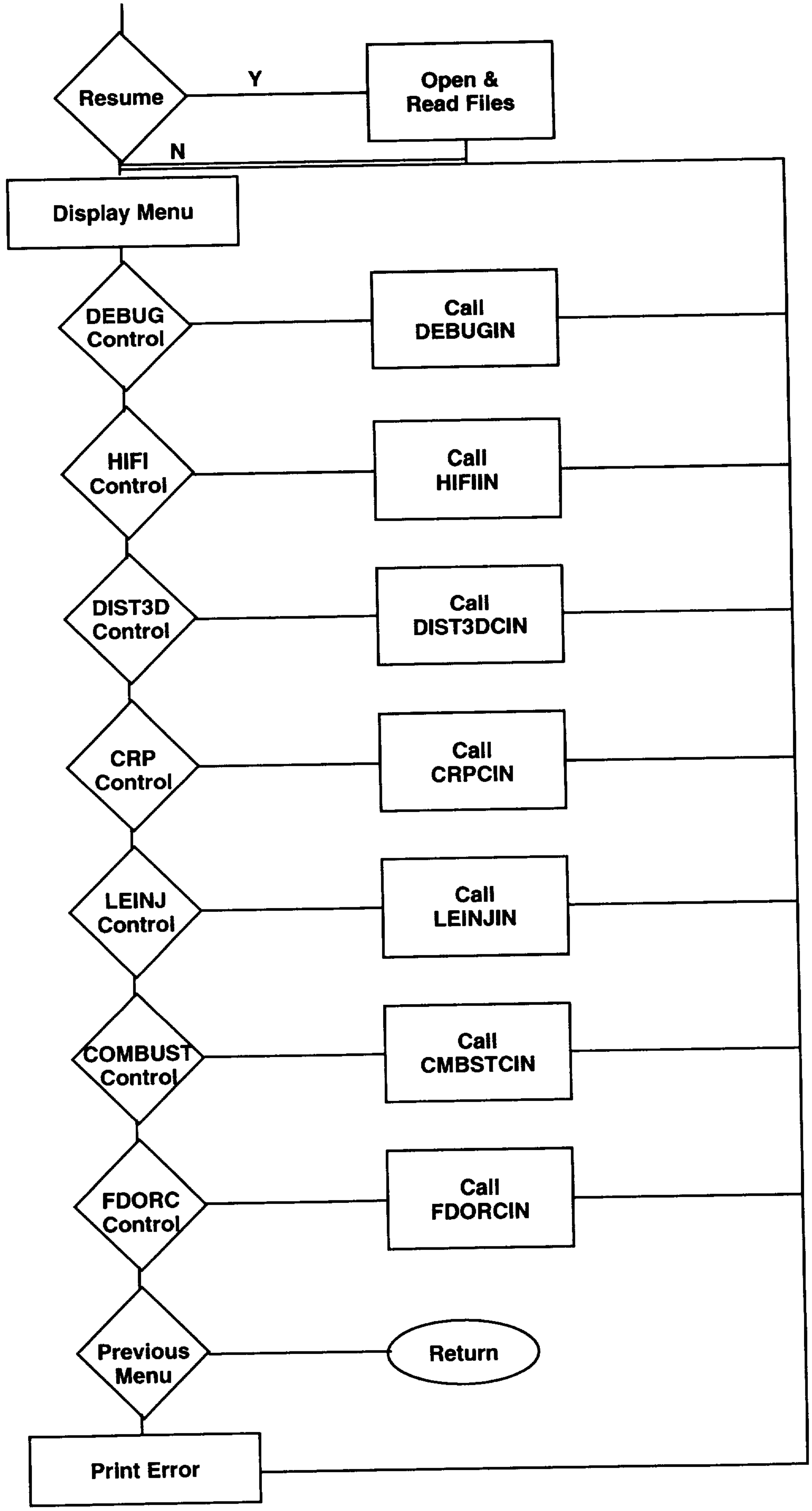


M16/D30/Lox-5

CONTROL VARIABLE OPTIONS (AUXMNU)

1. Set DEBUG Control
2. Set HIFI Control
3. Set DIST3D Control
4. set CRP Control
5. Set LEINJ Control
6. Set COMBUST Control
7. Set FDORC Control
8. Previous Menu

AUXMNU


Resume
Y
Open & Read Files
N
Display Menu
DEBUG Control
Call DEBUGIN
HIFI Control
Call HIFIIN
DIST3D Control
Call DIST3DCIN
CRP Control
Call CRPCIN
LEINJ Control
Call LEINJIN
COMBUST Control
Call CMBSTCIN
FDORC Control
Call FDORCIN
Previous Menu
Return
Print Error

Part E

IFE Point Design Section Flow Charts

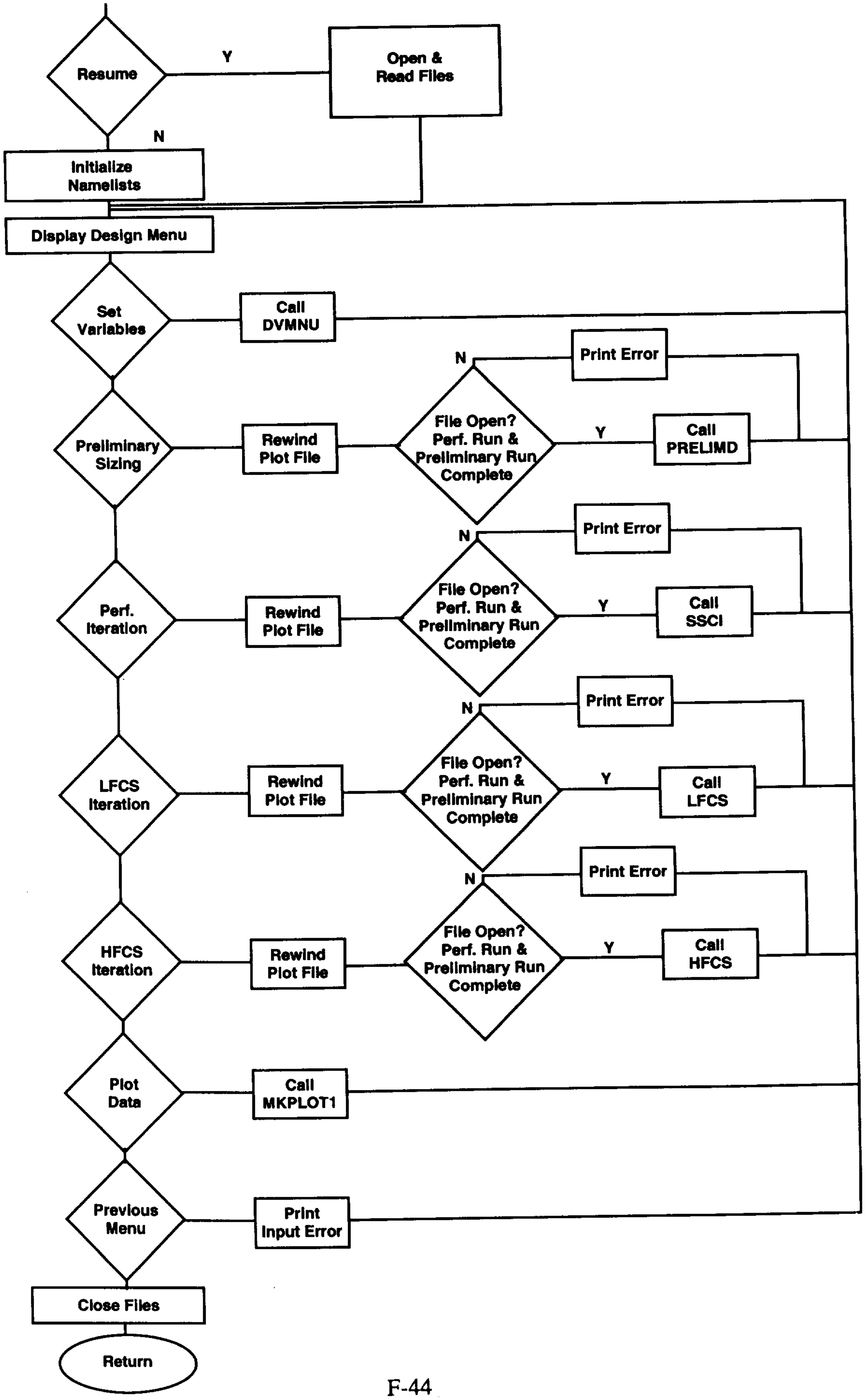
POINT DESIGN MENU OPTIONS (DESMNU)

1 Set Variables
2. Preliminary Sizing
3. Steady State Performance Iteration
4. Chug Stability Iteration
5. High Frequency Stability Iteration
6. Plot Output
7. Previous Menu

POINT DESIGN VARIABLE MENU OPTIONS

1. Complete Setup
2. Set Models
3. Set Design Variables
4. Set Fixed Geometry
5. Set Default Variables
6. Set Control Variables
7. Previous Menu

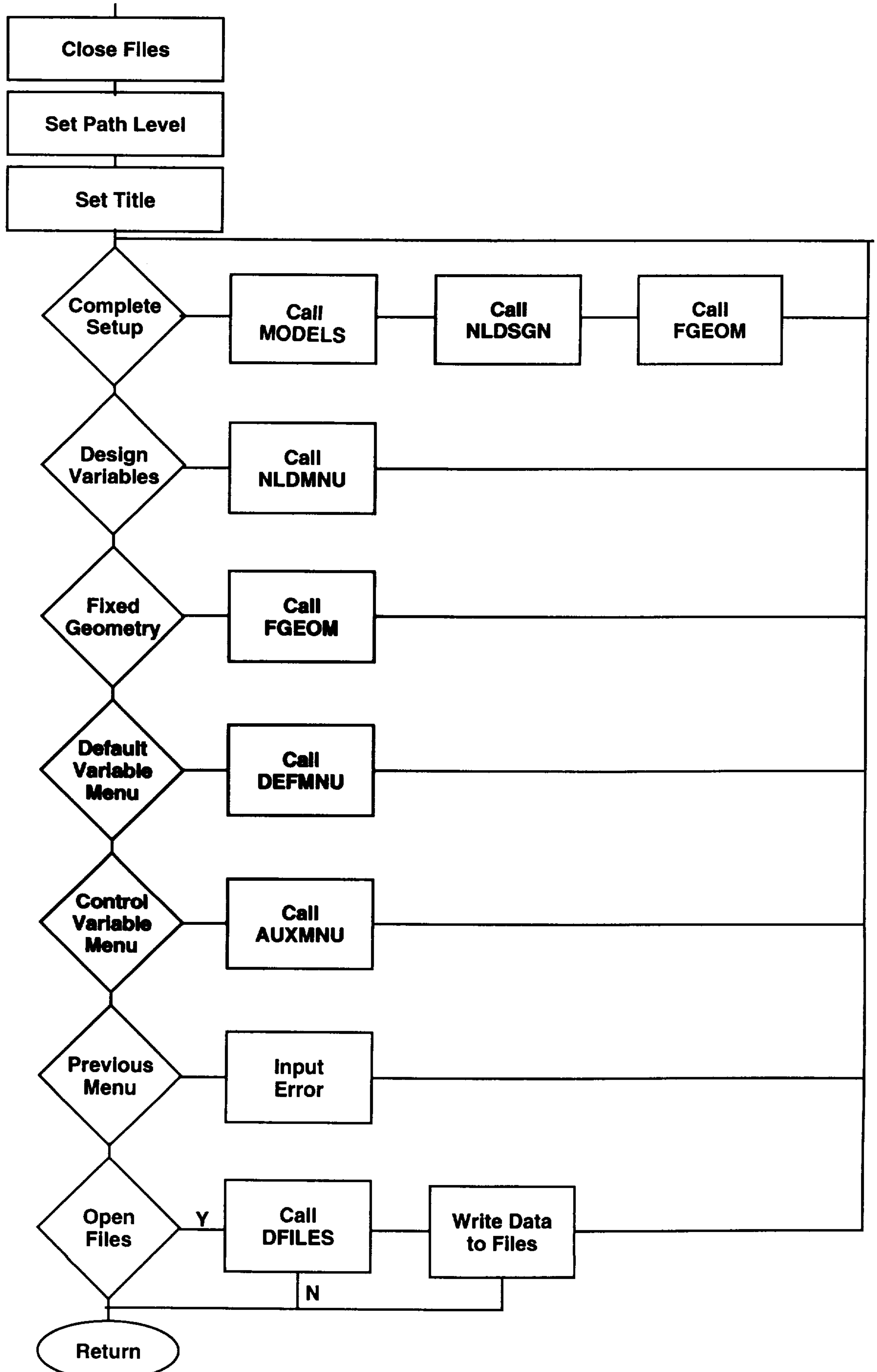
DESMNU MENU



M16/D30/Lox-7

C-2

DVMNU

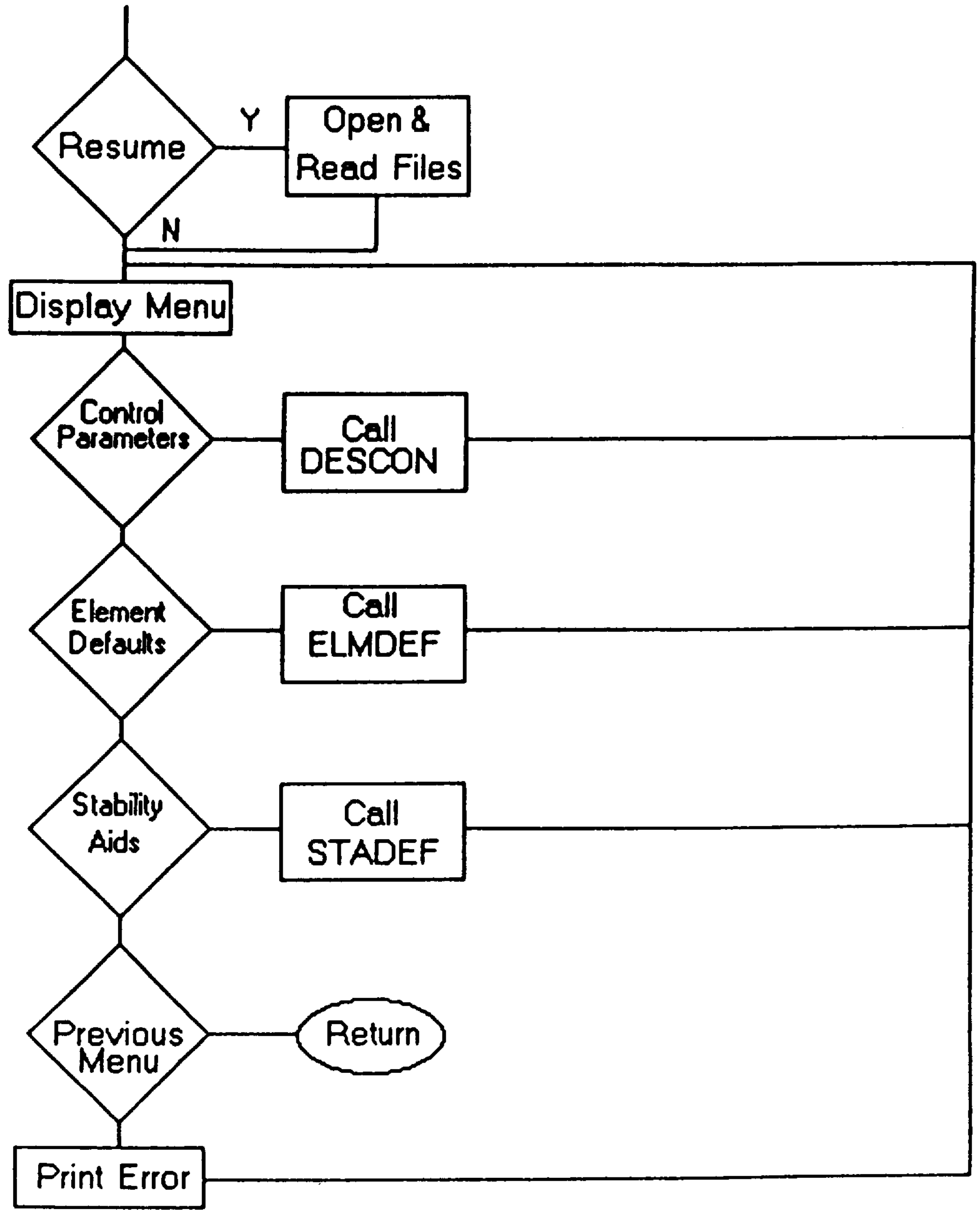


Close Files
Set Path Level
Set Title
Complete Setup
Call MODELS
Call NLDSGN
Call FGEOM
Design Variables
Call NLDMNU
Fixed Geometry
Call FGEOM
Default Variable Menu
Call DEFMNU
Control Variable Menu
Call AUXMNU
Previous Menu
Input Error
Open Files
Y
Call DFILES
Write Data to Files
N
Return

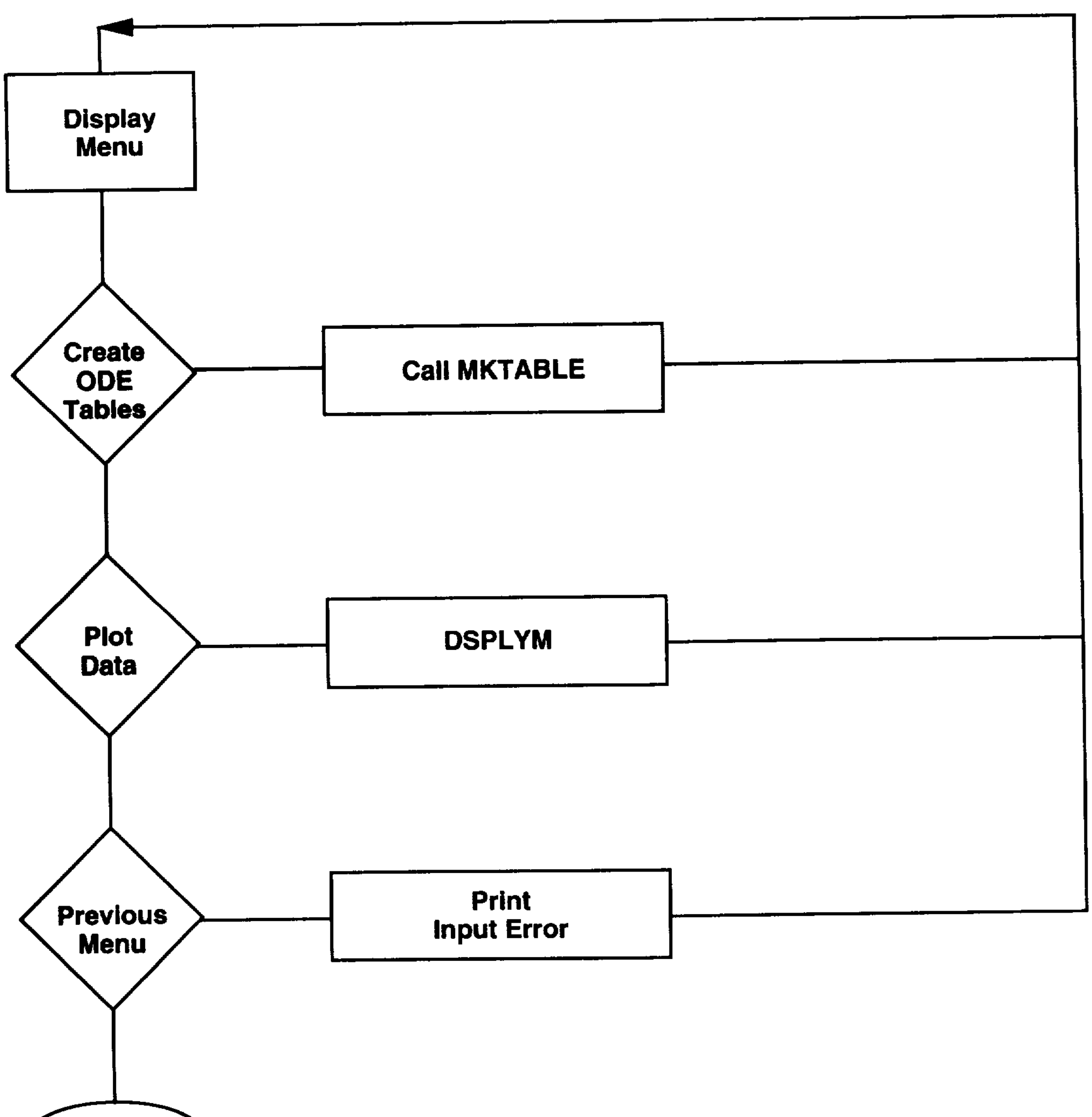
DESIGN DEFAULT MENU OPTIONS (DEFMNU)

1. Set Design Control Inputs
2. Set Element Parameters
3. Set Stability Aid Parameters
4. Return to Previous Menu

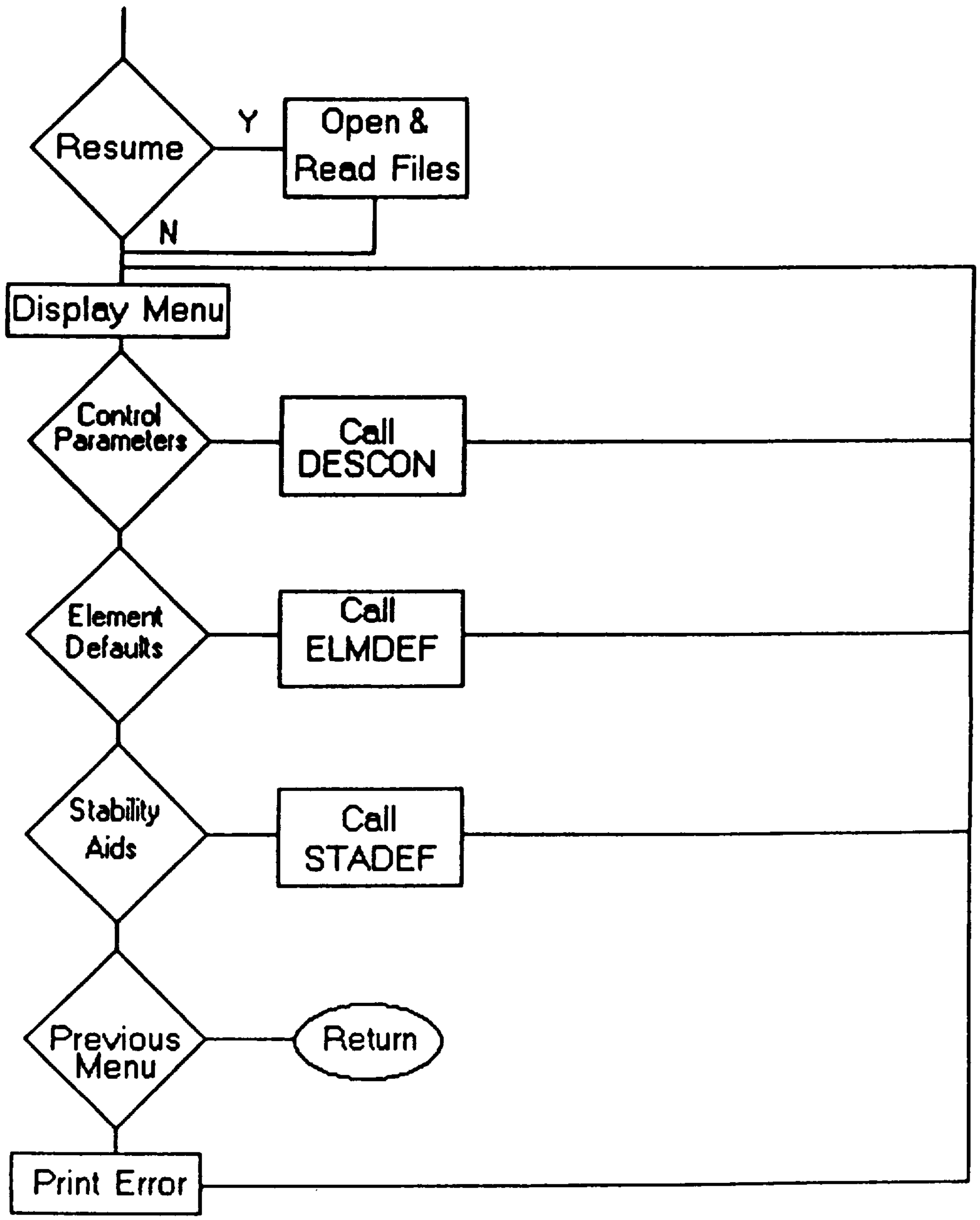
DEFMNU


Resume
Y
Open &
Read Files
N
Display Menu
Control
Parameters
Call
DESCON
Element
Defaults
Call
ELMDEF
Stability
Aids
Call
STADEF
Previous
Menu
Return
Print Error

UMENU


Display Menu
Create ODE Tables
Call MKTABLE
Plot Data
DSPLYM
Previous Menu
Print Input Error

DEF MNU


Resume
Y
Open &
Read Files
N
Display Menu
Control
Parameters
Call
DESCON
Element
Defaults
Call
ELMDEF
Stability
Aids
Call
STADEF
Previous
Menu
Return
Print Error

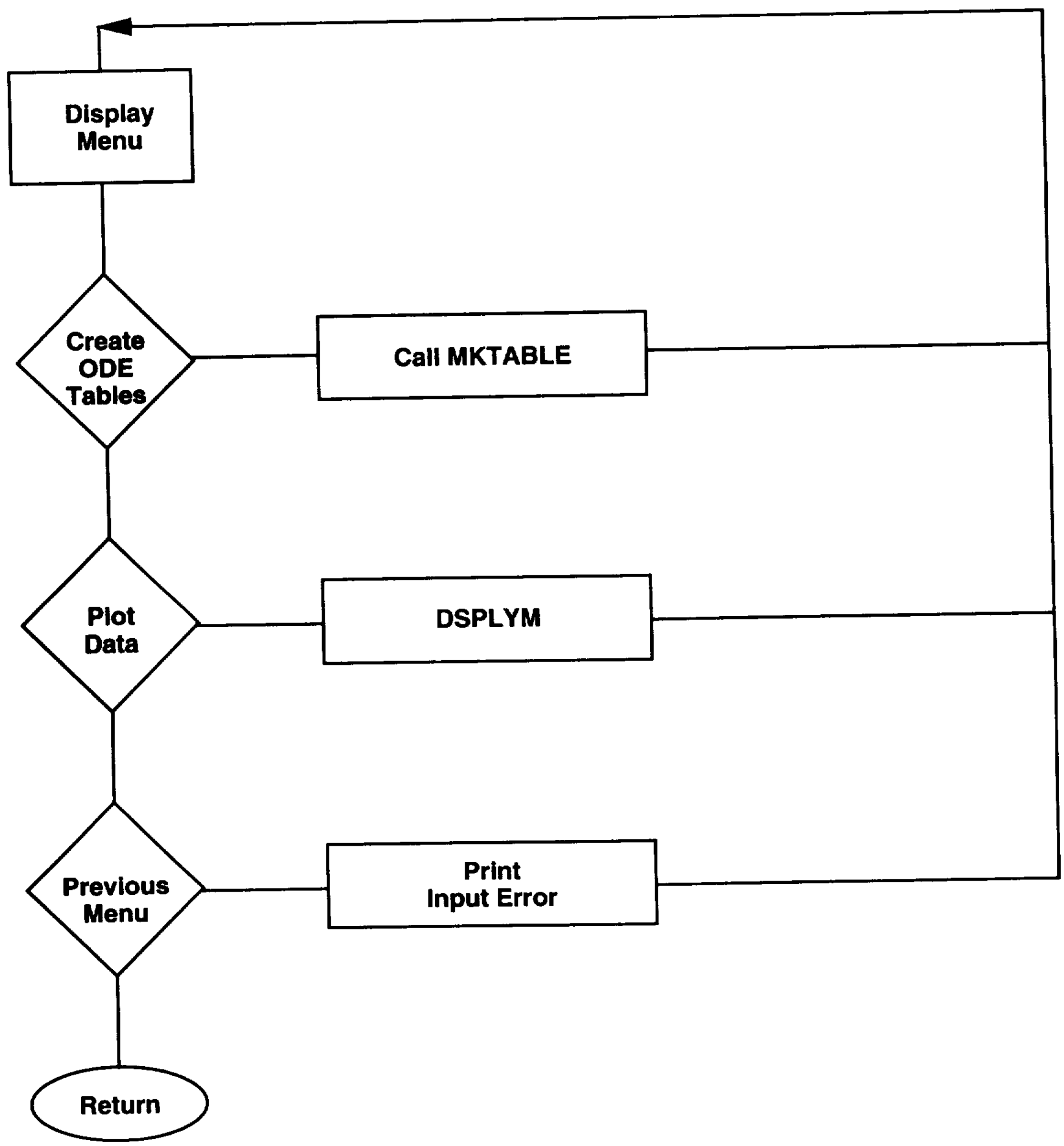
Part F

IFE Utility Programs

UTILITIES MENU (UMENU)

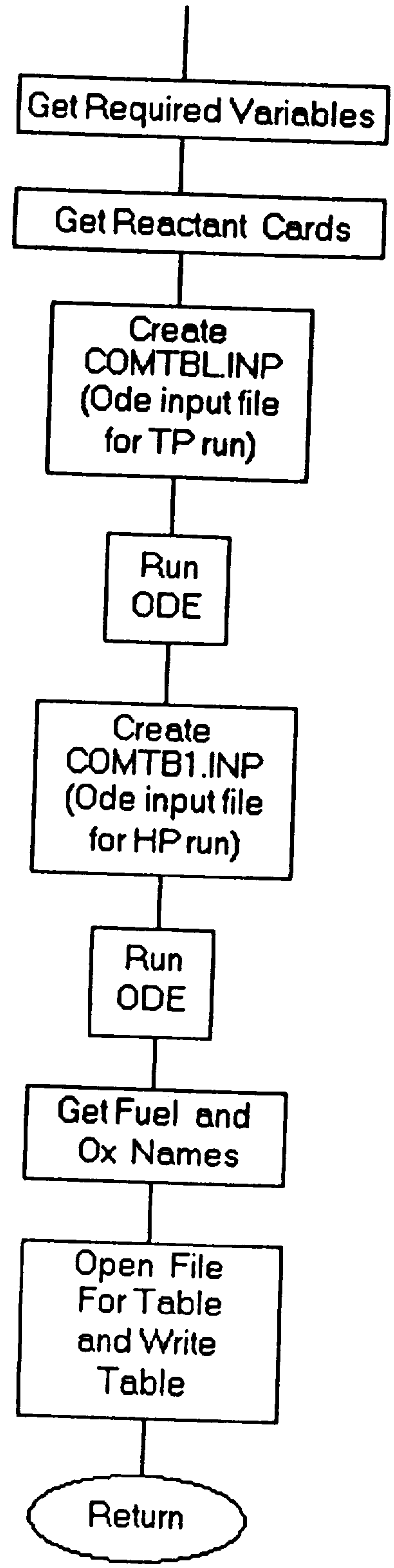
1. Create ODE Combustion Gas Tables
2. Display Results
3. Return to Previous Menu

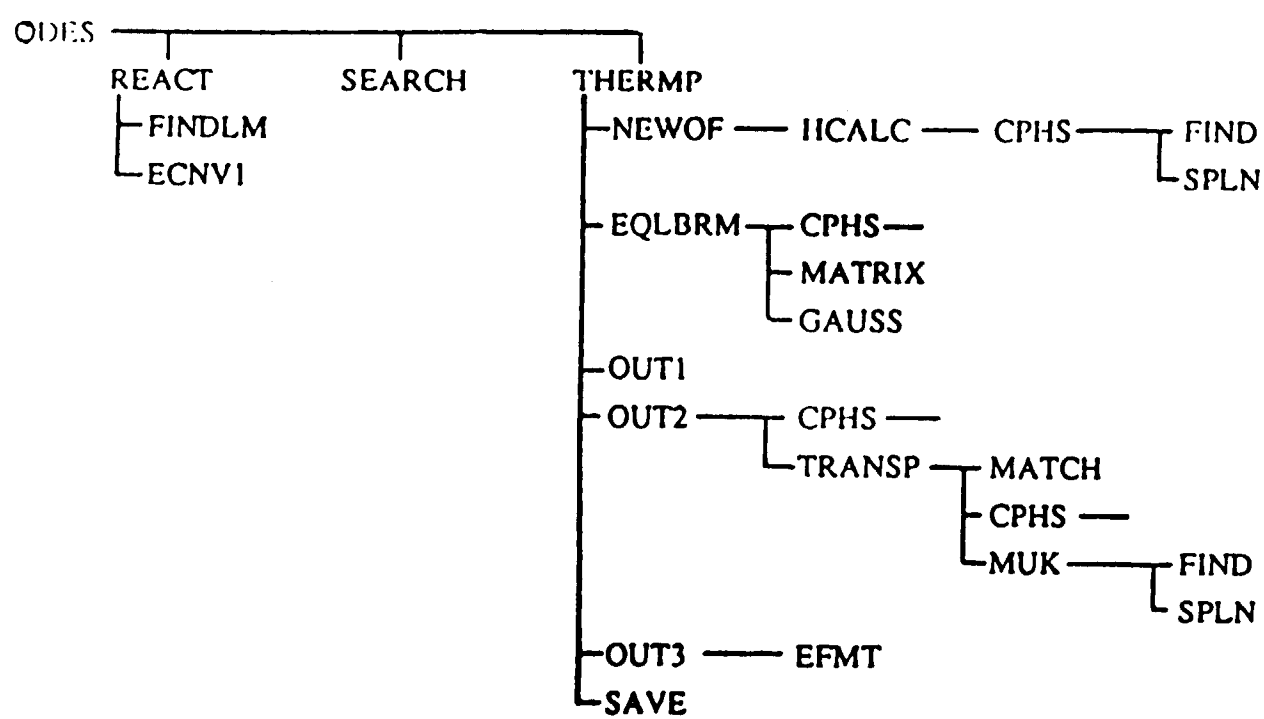
UMENU



Display Menu
Create ODE Tables
Call MKTABLE
Plot Data
DSPLYM
Previous Menu
Print Input Error
Return

SUBROUTINE MKTABL
(Makes Combustion Gas Tables)





ROCCID ODE Module Flowchart

Appendix G

Subroutine Description

Part A

POINTA Routines

Point Analysis Modules

Routine Name	Source Name	Purpose
COMBUSTD	COMBUST	POINTA BLOCK DATA
HFCS	HFCS	HIGH FREQUENCY STABILITY CONTROL PROGRAM
INJR	INJR	INJECTION RESPONSE MODEL SELECTION
LFCS	LFCS	LOW FREQUENCY STABILITY CONTROL PROGRAM
PROPSET	PROPSET	SETS PROPELLANT PROPERTIES
SINPUT	SINPUT	STABILITY MODEL INPUT READ
SSCI	SSCI	STEADY STATE COMBUSTION ITERATION CONTROL
STABC	STABC	DETERMINES STABILITY FROM COMPONENT TRANSFER FUNCTIONS
WFILES	WFILES	WRITES DATA FROM SSCI FOR USE BY STABILITY MODELS AND TDK
CBGAS	CBGAS	DETERMINES COMBUSTION GAS PROPERTIES
CHAMBR	CHAMBR	CHAMBER RESPONSE MODEL SELECTION ROUTINE
COMBR	COMBR	COMBUSTION RESPONSE SELECTION MODULE
COMBUST	COMBUST	STEADY STATE COMBUSTION MAIN PROGRAM
CRP	CRP	COMBUSTION RESPONSE PREDICTION MODEL
DIST3D	DIST3D	DISTRIBUTED COMBUSTION CHAMBER RESPONSE WITH BAFFLES
DROPS	DROPS	PROPELLANT DROPSIZE MODEL SELECTION ROUTINE
EMCALC	EMCALC	STREAMTUBE MASS FRACTION AND MIXTURE RATIO CALCULATION
EQTEMP	EQTEMP	GETS EQUILIBRIUM COMBUSTION GAS TEMPERATURE FROM TABLES
FLUIDP	FLUIDP	MAIN ROUTINE FOR MIPROPS
GASV	GASV	GASEOUS PROPELLANT INJECTION PRESSURE AND VELOCITY CALCULATION
H2VISC	H2VISC	H2 VISCOSITY DATA
HIFI	HIFI	HIGH FREQUENCY CHAMBER RESPONSE MODEL
INJ	INJ	LUMPED PARAMETER INJECTION RESPONSE MODE
LEINJ	LEINJ	NASA/LERC NON-LINEAR INJECTION RESPONSE MODEL
LIMITS	FLUIDP	CHECKS DATA TABLE LIMITS

Point Analysis Modules (Continued)

Routine Name	Source Name	Purpose
MACH	MACH	CALCULATES MACH NUMBER FROM GAMMA AND AREA RATIO
MAKCAP	MAKCAP	CONVERTS STRINGS TO CAPITAL LETTERS
NOZADM	NOZADM	MAIN ROUTINE FOR NOZZLE ADMITTANCE MODEL
NOZINI	NOZADM	INITIALIZES PARAMETERS FOR NOZADM
NTAU	NTAU	CONVERTS N-TAU DATA INTO COMBUSTION RESPONSE
NTAU2	DIST3D	CALCULATES BURNING ADMITTANCE
NTVALS	NTVALS	SMITH-REARDON N-TAU CORRELATION DATA
PERF1	PERF1	INTERPOLATES PERFORMANCE DATA
PINPUT	PINPUT	STEADY STATE COMBUSTION MODEL INPUT
PMELT	FLUIDP	MIPROPS CALCULATION SUBROUTINE
PRESSD	PRESSD	LIQUID PRESSURE DROP CALCULATION ROUTINE
PV	CRP	VAPOR PRESSURE CALCULATION CORRELATION
RAYLEE	RAYLEE	QUASI 1-D GAS DYNAMICS MODEL FOR TOTAL PRESSURE LOSS CALCULATIONS
REIDEL	CRP	DETERMINES PARAMETERS FOR PV CORRELATION
RMPRIEM	DROPS	PREIM DROPSIZE CORRELATION
RMUTRC	DROPS	UTRC DROPSIZE CORRELATION
ROOT	DIST3D	DETERMINES FUNCTION ROOTS
SHEARPD	PRESSD	DETERMINES FLOW CONDITION AND PRESSURE DROP IN SHEAR COAX ELEMENTS
SL	CRP	HEAT OF VAPORIZATION CORRELATION
SOUND	FLUIDP	DETERMINES SOUND SPEED OF PROPELLANT
SPLINE	RAYLEE	SETUP ROUTINE FOR CUBIC SPLINE INTERPOLATION
SPLINT	RAYLEE	CUBIC SPLINE INTERPOLATION ROUTINE
STOIC	ATOM	SETS STOICHIOMETRIC MR FOR DIFFERENT PROPELLANT COMBINTAIONS
SUM	CRP	SUMS OSCILLATORY VAPORIZATION TO DETERMINE RESPONSE
SWIRLPD	PRESSD	SWIRL COAX ELEMENT PRESSURE DROP/FLOWRATE CALCULATION
TIMELAG	TIMELAG	DETERMINES TIMELAGS FROM COMBUST DATA
TMELT	FLUIDP	MIPROPS CALCULATION SUBROUTINE
VAPRO	VAPRO	GENERALIZED LENGTH VAPORIZATION ROUTINE
VDISP	DIST3D	VISCOUS DISIPATION CALCULATIONS
VISC	FLUIDP	VISCOSITY CALCULATION ROUTINE

Point Analysis Modules (Continued)

Routine Name	Source Name	Purpose
XNTRP	RAYLEE	LINEAR INTERPOLATION SUBROUTINE
ACOUSTIC	HIFI	CALCULATES ACOUSTIC BEHAVIOR WITHIN A SECTION
AINTP	AINTP	LINEAR INTERPOLATION FUNCTION
ATOM	ATOM	MAIN ATOMIZATION ROUTINE
BESSCAL	DIST3D	CALCULATES BESSAL FUNCTIONS
BI1	DIST3D	NUMERICAL INTEGRATION FUNCTION
BI2	DIST3D	NUMERICAL INTEGRATION FUNCTION
BI3	DIST3D	NUMERICAL INTEGRATION FUNCTION
BJ	DIST3D	NUMERICAL INTEGRATION FUNCTION
CALADM	NOZADM	COMPUTES NOZZLE ADMITTANCE FROM "CHI"
CAVITY	CAVITY	ACOUSTIC CAVITY CONTROL MODEL
CBTAB	CBTAB	GETS COMBUSTION GAS PROPERTIES FROM TABLES
CCOSH	DIST3D	HYPERBOLIC COSINE
CDT	CDT	THROAT CD CORRELATION
CHI1	DIST3D	NUMERICAL INTEGRATION FUNCTION
CHI2	DIST3D	NUMERICAL INTEGRATION FUNCTION
CHI3	DIST3D	NUMERICAL INTEGRATION FUNCTION
CP	FLUIDP	CONSTANT PRESSURE SPECIFIC HEAT CALCULATION
CRPDBG	CRP	CRP DEBUG OUTPUT GENERATION
CV	FLUIDP	CONSTANT VOLUME SPECIFIC HEAT CALCULATION
DCAVEF	DIST3D	DIST3D CAVITY ORIENTATION EFFECTIVENESS
DILV	FLUIDP	MIPROPS CALCULATION SUBROUTINE
DROPMIX	DROPS	DROPMIX DROPSIZE CORRELATIONS
ENTHAL	FLUIDP	ENTHALPY CALCULATION
ENTROP	FLUIDP	ENTROPY CALCULATION
EXCESV	FLUIDP	EXCESS VISCOSTIY ROUTINE
FDATA	FLUIDP	LOADS PROPELLANT DATA
FDCV	FLUIDP	MIPROPS CALCULATION SUBROUTINE
FINDD	FLUIDP	DENSITY CALCULATION
FRICTION	PRESSD	MOODY FRICTION FACTOR CHART
FWDOT	CRP	OSCILLATORY FLOWRATE CALCULATION
GETVAL	GETVAL	POWER-LAW INTERPOLATION FUNCTION
HCAVEF	HIFI	HIFI CAVITY ORIENTATION EFFECTIVENESS
HELMHR	CAVITY	HELMHOLTZ RESONATOR MODEL
INTGRT	NOZADM	NUMERICAL INTEGRATION ROUTINE

Point Analysis Modules (Continued)

Routine Name	Source Name	Purpose
MAXMIN	RAYLEE	FINDS MAX AND MIN OF DATA SET
PROPS	FLUIDP	MIPROPS CALCULATION SUBROUTINE
QWC	CAVITY	1/4 WAVE CAVITY MODEL
REGULA	FLUIDP	MIPROPS CALCULATION SUBROUTINE
SATL	FLUIDP	MIPROPS CALCULATION SUBROUTINE
SATV	FLUIDP	MIPROPS CALCULATION SUBROUTINE
SHEAR	ATOM	AEROJET SHEAR COAX ATOMIZATION MODEL
SSATL	FLUIDP	MIPROPS CALCULATION SUBROUTINE
SSATV	FLUIDP	MIPROPS CALCULATION SUBROUTINE
SWIRL	ATOM	AREOJET SWIRL COAX ATOMIZATION MODEL
TRIPLET	ATOM	AEROJET TRIPLET ATOMIZATION MODEL
VISCE	FLUIDP	MIPROPS CALCULATION SUBROUTINE
VPN	FLUIDP	MIPROPS CALCULATION SUBROUTINE
VSCTY0	FLUIDP	MIPROPS CALCULATION SUBROUTINE
BJ0	CRP	BESSEL FUNCTION CALCULATION ROUTINE
BJ1	CRP	BESSEL FUNCTION CALCULATION ROUTINE
CPI	FLUIDP	MIPROPS CALCULATION SUBROUTINE
FINDM	FLUIDP	MIPROPS CALCULATION SUBROUTINE
SHI	FLUIDP	MIPROPS CALCULATION SUBROUTINE
HIFI2FD	HIFI2FD	TRANSFER/HIFI/DIST3D CAVITY DATA TO $FDORC
FDORC	FDORC	MAIN ROUTINE FOR FDORC
CAV	FDORC	FDORC ROUTINE FOR VARIABLE TEMPERATURE CAVITIES
FNTAU	FDORC	FDORC ROUTINE TO CALCULATE N AND TAU

Part B

POINTD Routines

Point Design Modules

Routine Name	Source Name	Purpose
CHUGIT	CHUGIT	CHUG STABILITY ITERATION CONTROL
CLOAD	CLOAD	LOADS DESIGN COMMONS WITH POINTA DATA FOR STABILITY MODELS
DINPUT	DINPUT	READS POINT DESIGN INPUT
HIFIT	HIFIT	HIGH FREQUENCY STABILITY ITERATION CONTROL
LFDESIGN	LFDESIGN	LOW FREQUENCY REDESIGN MODULE
MODELOD	MODELOD	LOADS H.F. UNSTABLE MODE TABLE
PERFIT	PERFIT	STEADY STATE PERFORMANCE ITERATION CONTROL
PRELIMD	PRELIMD	MAIN PRELIMINARY DESIGN ROUTINE
REDESIGN	REDESIGN	RESIZES INJECTOR/CHAMBER FOR SELECTED DESIGN CHANGE
VGCALC	VGCALC	GASEOUS INJECTION VELOCITY ROUTINE
VGUPDATE	VGUPDATE	UPDATES GASEOUS VELOCITY AND PRESSURE DROP IN POINTD USING GASV
VSAVE	VSAVE	SAVES "MEMORY" VARIABLES IN $SAVE SO RUNS CAN BE CONTINUED
ALOAD	ALOAD	WRITES DESIGN DATA IN ANALYSIS INPUT FILE FORMAT
BITUCAVITY	BITUCAVITY	BITUNE 1/4 WAVE CAVITY DESIGN MODULE
BITURESON	BITURESON	BITUNE HELMHOLTZ RESONATOR DESIGN MODULE
BRNDESIGN	BRNDESIGN	BURNING-COUPLED H.F. STABILITY REDESIGN MODULE
CAVLOAD	CAVLOAD	LOADS ACOUSTIC CAVITY DESIGN VARIABLES
COREFLOW	COREFLOW	DETERMINES CORE ELEMENT FLOWRATE AND MR
CORESIZE	CORESIZE	SIZES CORE ELEMENTS DURING PRELIMINARY DESIGN
CORESPAC	CORSPACE	CHECKS SPACING AND LAYOUT FOR CORE ELEMENTS
CUPDATE	CUPDATE	UPDATES DESIGN COMMONS WITH POINTA DATA FROM SSCI
DAMP	DAMP	DAMPING DEVICE DESIGN MODULE
DPOST	DPOST	SHEAR COAX LOX POST DESIGN ROUTINE

Point Design Modules (Continued)

Routine Name	Source Name	Purpose
DROPSIZE	DROPSIZE	DETERMINES DROPSIZE TO MEET INPUT RESPONSE
EMEST	EMEST	ESTIMATES OVERALL EM REQUIRED FOR INPUT ETA-MIX
INJDESIGN	INJDESIGN	INJECTION-COUPLED H.F. STABILITY REDESIGN MODULE
JETSIZE	JETSIZE	DETERMINES ORIFICE SIZE TO GENERATE INPUT DROPSIZE
MONOCAVITY	MONOCAVITY	MONOTUNE 1/4 WAVE CAVITY DESIGN MODULE
MONORESON	MONORESON	MONOTUNE HELMHOLTZ RESONATOR DESIGN MODULE
NOZOPT	NOZOPT	NOZZLE-COMBUSTOR LENGTH OPTIMIZATION ROUTINE
NTUPDATE	NTUPDATE	ESTIMATES CHANGES TO N & TAU FROM DESIGN CHANGES W/ NTVALS
PDESIGN	PDESIGN	PERFORMANCE ITERATION REDESIGN MODULE
RDROP	RDROP	DETERMINES DROPSIZE FROM INPUT ORIFICE DIAMETER
SHEAREM	SHEAREM	CALCULATES SHEAR COAX UNI-ELEMENT EM FROM CORRELATION
SHEARFL	SHEARFL	DETERMINES FLOWRATE OF FIXED SHEAR COAX POST W/ SHAERPD
SWIRLFL	SWIRLFL	DETERMINES FLOWRATE OF FIXED SWIRL COAX POST W/ SWIRLPD
SWIRLSZR	SWIRLSZR	SWIRL COAX POST DESIGN ROUTINE

Part C

IFE Routines

IFE Modules

Routine Name	Purpose
Abort	Closes files and stops program
Afiler	Opens files for Point Analysis (asks opening questions)
Afiles	Opens and closes files for Point Analysis
Alfas	Sets alphanumeric letters size on TEK terminal
Allfigs	Draws figures
Anamnu	Point analysis main menu
Ansi	Sets TEK terminal in ANSI mode
Arrow	Draws arrows for figures
Askint	Asks user and gets an Integer
Auxlib	Plotting library
Auxmnu	Control variable menu
Backup	Backs up replay file N lines
Bafelm	Main routine for baffle element data
Bafflein	Computer written code to get baffle element data
Barelm	Main routine for barrier element data
Barrierin	Computer written code to get barrier element data
Bivar	bi-variable interpolation routine
Blanks	Deletes leading blanks
Blink	Starts blinking output on VT100 terminal
Bmenu	Base menu
Bottom	Reads to the bottom of a file
Burnin	Computer written code to get burn data
Caps	Changes everything to capitals
Cav	Main routine for cavity data
Cfdorcin	Reads $FDORC variables
Chambin	Computer written routine to chamber data
Checki	Check limits on an integer
Clear	Clear screen
Clears	Clear graphics screen
Cmbstcin	Reads and checks COMBUSTC variables
Cntrl	Reads and writes title
Controlin	Computer written code to get control variables
Corein	Computer written code to get core element variables
Corelm	Main routine for core element data
Crack	Reads data IFE table
Crpcin	Computer written code to get crp control info.

IFE Modules (Continued)

Routine Name	Purpose
Cursmv	Moves cursor on a VT100 terminal
Cycle	Changes revision number manually (Needed for SUN)
Dasorc	Determine source of nominal namelist data
Debugin	Computer written code to set debug flag
Decodr	Decode character strings to variables
Defmnu	Default menu for Point Design variables
Descon	Gets design control variables
Designin	Computer written code to get design control variables
Desmnu	Point Design main menu
Dfiler	Opens files for Point design (asks opening questions)
Dfiles	Opens and closes files for Point Design
Dgtcomb	Design side routine to get combustion data
Dialog	Asks initial questions
Dispcs	Asks for C* and ISP on the design side
Dist3dcin	Computer written code to get DIST3D control variables
Dnozeff	Prompts user for nozzle efficiency curve
Dopmnu	Design Operating conditions menu
Dpropmnu	Design Propellant selection menu
Dsplay	Displays present variable value
Dsplym	Plotting utility
Dsplymp	Online plotting option
Dvmnu	Design variable menu
Effmnu	Design side efficiency menu
Elmdef	Reads element data for design side
Encode	4107 primative device driver
Erase	erases screen
Errsns	Dummy routine to comply with VAX used in error message
Fcolon	Finds colon when reading plot data files
Fdorcin	Reads $FDORC variables
Ffcave	Main routine for reading Fuel Film/Cavity data
Ffcin	Computer written code to get FFC data
Fgeom1	Reads fixed geometry
Fgeomin	Computer written code to get fixed geometry
Figs	Plots figures
Filler	Interprets input (from replay file)
Find	Finds variable in list
Findsp	Finds space
Finjin	Computer written code to get fixed injector data

IFE Modules (Continued)

Routine Name	Purpose
Geom2	Gets Point Analysis geometry
Geomin	Computer written code to get fixed injector data
Getchr	Gets a character
Getcom	Get a command file
Getdat	Read data
Getfil	Opens a file
Getint	Reads an integer
Getit	Get a variable
Getset1	Reads a set of plot data from a plot file
Getvar	Reads a data input line
Gfdorc	Prompts user and checks $FDORC variables
Gtcomb	Read gas combustion data defaults
Gtcomb1	Read gas combustion data defaults and tables
Gtdata	Searches plot data file for correct data set
Gtdsna	Prompts user for Point Design C*/ISP data
Gtdsne	Prompts user for Point Desing efficiency data
Gtintg	Get an integer
Gtline	Read a Character line
Gtopca	Prompts user for Point Analysis C*/ISP data
Gtreal	Get a real variable
Helmrs	Get Helmholtz resonator data
Hifiin	Computer written code to get HIFI control data
Ifed	Block Data, contained in ROCCID for
Inject1	Routine which reads Injector data
Injin	Computer written code to get injector data
Inperr	Informs of input error
Instr	Displays instructions
Ioerr	Gives VAX status of IO error
Iter	Secant search iteration scheme
Leinjin	Computer written code to get Lewis injector data
Load	Loads variable into array
Lolcin	Computer written code to get LOL data for Design
Ltcphs	Part of ODE
Makfig	Loads the figures at the beginning of a session
Manif	Gets manifold data
Mkplot	Reads plot data 1 file
Mkplot1	Reads plot data 3 files
Mktabl	ODE utility

IFE Modules (Continued)

Routine Name	Purpose
Model	Gets model control variables
Modelsin	Computer written code to read model control data
Nchars	Finds number of non-blank characters (space)
Newfil	Read old replay files
Newfrm	Start new plotting frame
Nldmnu	$Design variable menu
Nldsgn	$Design variable prompts
Not	Yes/No function (reads yes of no and acts)
Nozeff	Nozzle efficiency vs length routine
Nrmvid	Puts VT100 terminal in normal mode
Nulfld	Advances index past null fields
Odecst	Sets up and runs ODE to calculate C* and Isp arrays
Odein	Computer written code to read ODE input data
Odemain	Main calling routine for ODE
Opcoin	Computer written code to read operating conditions
Opcond1	Main routine to get operating conditions
Outcm	Writes character variable out
Outrm	Writes real variable out
Parse	Parse data line
Perfrn	Driver for steady state routines
Perr	Print error
Plotm	Plotting routine
Pltset	Reads plot attributes (size, titles, etc.) from data file
Propmnu	Point Analysis side propellant menu
Putburn	Writes $BURN
Putcham	Writes $CHAMBER
Putgeom	Writes $GEOM
Putinj	Writes $INJ
Putnls	Writes $BURN, $CHAMBER, $GEOM, and $INJ
Radbaf	Routine which gets radial baffle data
Rcheck	Check variable range
Reactc	Prepare reactant cards for an ODE run
Readit	Reads PROCESS.BIN
Resum	Opens and reads one resume file
Retq	Pauses and waits for a return
Retry	Determine if the user wants to RE-TRY resuming data
Rkam	Adams - Moultant integration scheme
Roccid	Main program

IFE Modules (Continued)

Routine Name	Purpose
Roccid_Trace.msg	Vax traceback generators for Roccid (message file)
Rplcat	Replicate the first column of an array into all columns
Saidin	Computer written code to read stability aid data
Search	Search through the replay file to find a "name"
Setit	Set a namelist value
Shdcin	Computer written code to read showerhead control data
Shearcin	Computer written code to read swirl coax control data
Stabh	Driving routine for Point Analysis high freq. stability
Stabl	Driving routine for Point Analysis low freq. stability
Stadef	Gets $SAID data
Stbaid	Gets stability aid data (Point Analysis)
String	Read a character string
Stuffin	Computer written code to read baffle flags
Swirlcin	Computer written code to read swirl coax flags
Tekdfl	Sets TEK screen dialog area
Tekdia	Turns TEK dialog on
Tekdof	Turns TEK dialog off
Tekmod	Puts TEK terminal in graphics mode
Title	Gets run title
Tripcin	Computer written code to read triplet control
Trivar	Tri-variable interpolation routine
Trmtyp	Ask user for terminal type
Umenu	Utility menu
Varmnu	Point Analysis variable menu
Vax1_auxlib	SEA modified Calcomp library
Vax1_clean	File deletion routine
Vax1_getfil	Reads replay file entries
Vax1_newfil	Adds entries to replay file list
Vax1_seapltlib	SEA vax-tektronics plotting drivers

Part D

ODE Routines

ODE Routines

The utilities module of ROCCID contains an ODE option which allows calculation of thermodynamic and transport gas properties for various rocket engine propellants. Complete documentation of the ODE subroutines have been published in "Two Dimensional Kinetics (TDK) Nozzle Performance Computer Program, Volumes I - III" by Nickerson, Dang, and Coats of Software and Engineering Associates, under NASA contract NAS 8-36863 (March 1989). The following describes only subroutines that are used directly with ROCCID.

Routine Name	Purpose
ODEMAIN	Drives the ODE routines used to calculate ISP and C*
ODES	Reads input for calculating ISP and C* and runs the rocket chemical equilibrium analysis
OUT1	ODE output routine (used only in the ODE utility)
RKTOUT	Stores ISP and C* arrays
ROCKET	Calculates ISP and C* using equilibrium gas properties
THERMP	Calculates thermochemical properties of equilibrium gases

APPENDIX H

ROCCID INSTALLATION INSTRUCTIONS

ROCCID Installation Instructions for VAX/VMS Computer Systems

ROCCID is currently configured with a multiple directory structure (Fig. H.1). The main directory contains the executable code (ROCCID.EXE), a linker map (ROCCID.MAP), a command file to link the code (LINK_ROCCID.COM), object code for the main program (ROCCID.OBJ), the IFE binary control data file (PROCESS.BIN) and four object libraries, (POINTA.OLB, POINTD.OLB, IFE.OLB and ODE.OLB) and the date stamp (VDATE.BIN). It also has 6 subdirectories. The POINTA, POINTD, IFE and ODE subdirectories contain the source code modules for those respective segments of the code, and the object libraries contain the compiled code in the respective subdirectories. The PROPDAT subdirectory contains propellant property and combustion gas data used by all modules of the program. The SAMPLES subdirectory contains sample case input and output files, and the UPDATE directory contains utility code used to generate/update the defaults in the IFE control file, PROCESS.BIN.

Several modifications must be made to the files to ensure that the code will look in the correct place for files. Table H.1 contains a list of routines and files which must be changed. Data files only need to be changed, but FORTRAN files (file type **.FOR**) must be changed, compiled and replaced in the appropriate libraries prior to running the command file to link ROCCID, LINK_ROCCID.COM. In order to minimize potential problems during the initial installation, it is recommended that the contents of the all object libraries be deleted and replaced with object code generated under your machine's operating system. The object code for main calling program, ROCCID, which is contained in the IFE subdirectory, should be copied to the main directory and must <u>not</u> be included in the IFE object library (IFE.OLB).

The VAX/VMS message file ROCCID_TRACE. MSG is contained in the IFE subdirectory. It has been included to facilitate error handling, and it generates a traceback message for controlled aborts in ROCCID. To compile it, use the VAX/VMS message compiles:

Message ROCCID_Traceback. msg

Then insert the object code (**.OBJ**) into the IFE object library. If you are not running on a VAX/VMS System, you must either A) write a similar routine for your operating system or B) comment - out all references to ROCCID-TRACEB in ABORT. FOR.

Accompanying the ROCCID code in another program called FILGEN (located in subdirectory [**.UPDATE**]), which creates a binary file of variable definitions for the interactive front end. This binary file, named PROCESS.BIN must be read by ROCCID before any analyses can be executed, therefore <u>FILGEN must be run whenever ROCCID is transported to a new computer</u>.

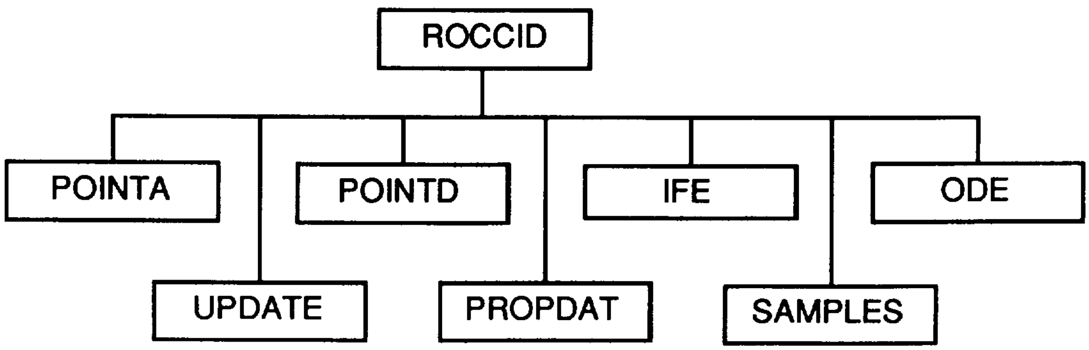


Figure H-1. ROCCID Directory Structure

FILGEN reads an ASCII file of variable definitions (**VARIABLES.DAT**) which provides the information contained in PROCESS.BIN. This input file can be modified to add new variable names or definitions, or to modify the attributes of current variables. The number of variables and the order of the variables must not change. The list below describes the parameters used to define each variable in **VARIABLES.DAT**:

01.NAME: Entry for the variable name (upper case only)

02.DESCR: A brief 1 to 2 line variable description. For each additional line use the end-of-line character @, as the line continuation character. The description may not contain the equal symbol (=).

03.IND-VAR: The independent variable entry. Indicate if the variable is an independent variable (enter FLAG, COUNTER, or dependent variable name) or is not (enter NO). Typically, this entry is used to describe variable arrays used to enter tables of data, e.g. gas property tables, wall table data, initial condition profiles, etc.

FLAG indicates that the variable is a flag

COUNTER indicates that this variable is a COUNTER for arrays (tables) input.

YES indicates that other variables are required inputs in conjunction with this variable.

NO indicates that there are no other variables required in addition to this variable.

Ø4.TYPE: Defines the variable type; INTEGER, REAL, OR LOGICAL.

05.DIM: The length of array variables or **NONE** for scalar quantities.

06.RANGE: This sets the variable limits of applicability. General form of this expression is (lower limit:upper limit). The upper and lower values must be integers. Examples of acceptable forms include **(1:2)**, **(T:F)**, **>0**, **<0**, **MONOTONIC INCREASING**, and **MONOTONIC DECREASING**.

07.APPLIC: Describes the general application of variable. Application must match one of the applications listed in Table 1.

08.DESTIN: Name of $NAMELIST to which this variable belongs.

09.DEFAULT: Default value for this variable. Use .FALSE. or .TRUE. to indicate set defaults for logical type variables.

10.SUBSET: The name of variable(s) which makes this variable a required input. If this condition does not exist enter NONE. See SUPERSET for more details on usage.

11.SUPERSET: Sets condition and variable(s) which are required. Multiple conditions and/or options are specified using the () to enclose condition and required variable(s); and commas to separate multiple sets of conditions and variable requirements. Conditional statements are separated by colons and variable lists are separated by commas. If these conditions do not exist, enter NONE. Typically, the SUPERSET/SUBSET combination is used to describe a variable which flags a variety of options, which require different sets of variable value and corresponding variables to be used in conjunction with the option value; the SUBSET entry describes the backward tract to the option variable. Two examples are given below.

1) A variable array, ID, is read in and is only used if the number of array elements, NID, is specified. For the variable NID, its SUPERSET is the variable ID. For the variable ID, its SUPERSET and SUBSET entries are NONE.

2) An option to specify different wall contours to a nozzle performance program is set by the variable IWALL. IWALL has possible values of 1,3, and 4. The associated variables for IWALL=1 are RWTD, THETA, EPS, RZNORM. For IWALL=3, the required variables to be used are RWTD, THETA, RMAX...

SUPERSET:(IWALL=1:RWTD, THETA, EPS, ZNORM),

(IWALL=3:RWTD, THETA, RMAX, ZMAX,RZNORM),

(IWALL=4:RWTD, THETA, THE, RS, ZS, NWS, RZNORN)

12.LEVEL: Defines the usage or path level. Enter 1 for commonly used, 2 for sometimes used, and 3 for rarely usage only.

The FILGEN executable is created by ,compile and link all the FORTRAN files (file type **.FOR**) in the **[.UPDATE]** subdirectory. If necessary, modify the VARIABLES.DAT file to reflect any changes to the variable names or definitions. The sucessful execution of FILGEN requires a driver file **MASTER.DAT**, which must reside in the same subdirectory as FILGEN. After running FILGEN, copy the new PROCESS.BIN file into the **[ROCCID]** directory, where ROCCID will read it.

If you have any questions about this installation procedure, please contact Jeff Muss at (916) 355-3663.

TABLE H.1

ROCCID Files Which Contain Path Statements

File Name: [ROCCID.IFE]AFILER.FOR

```
      OPEN(UNIT=12,FILE='DISK$3:[UTILITY.ROCCID]DEFAULT.CNT',
 9100 WRITE(6,*) '"DISK$3:[UTILITY.ROCCID]DEFAULT.CNT" NOT FOUND, ',
```

File Name: [ROCCID.IFE]DASORC.FOR

```
      DATA LIBNAM /'DISK$3:[UTILITY.ROCCID.PROPDAT]REACTLIB.DAT'/
```

File Name: [ROCCID.IFE]DFILER.FOR

```
         OPEN(UNIT=13,FILE='DISK$3:[UTILITY.ROCCID]DEFAULT.DEF',
      30 OPEN(UNIT=12,FILE='DISK$3:[UTILITY.ROCCID]DEFAULT.CNT',

 9100 WRITE(6,*) '"DISK$3:[UTILITY.ROCCID]DEFAULT.CNT" NOT FOUND, ',
 9200 Write (6,*)' "DISK$3:[UTILITY.ROCCID]DEFAULF.DEF" NOT FOUND,',
```

File Name: [ROCCID.IFE]DFILES.FOR

```
   30 OPEN(UNIT=12,FILE='DISK$3:[UTILITY.ROCCID]DEFAULT.CNT',
 9100 WRITE(6,*) '"DISK$3:[UTILITY.ROCCID]DEFAULT.CNT" NOT FOUND, ',
```

File Name: [ROCCID.IFE]DPROPMNU.FOR

```
      OPEN(UNIT=45, FILE='DISK$3:[UTILITY.ROCCID.PROPDAT]PROP.FIL',
```

File Name: [ROCCID.IFE]GETCOM.FOR

```
      DATA DIRECT /'DISK$3:[UTILITY.ROCCID]COMFIL.DAT'/
```

File Name: [ROCCID.IFE]PROPMNU.FOR

```
       OPEN(UNIT=45, FILE='DISK$3:[UTILITY.ROCCID.PROPDAT]PROP.FIL',
```

File Name: [ROCCID.IFE]REACTC.FOR

```
      DATA FILNAM /'DISK$3:[UTILITY.ROCCID.PROPDAT]REACTLIB.DAT'/
```

File Name: [ROCCID.IFE]READIT.FOR

```
      DATA FILNAM /'DISK$3:[UTILITY.ROCCID]PROCESS.BIN'/
```

TABLE H.1 (continued)

ROCCID Files Which Contain Path Statements

File Name: [ROCCID.IFE]TITLE.FOR

```
OPEN(UNIT=91, FILE='DISK$3:[UTILITY.ROCCID]VDATE.BIN',
```

File Name: [ROCCID.ODE]ODEMAIN.FOR

```
OPEN(UNIT = 25,FILE='DISK$3:[UTILITY.ROCCID.PROPDAT]JANNAF.DAT',
```

File Name: [ROCCID.POINTA]FLUIDP.FOR

```
3 OPEN(UNIT=25,FILE='DISK$3:[UTILITY.ROCCID.PROPDAT]PH2.COF',
4 OPEN(UNIT=25,FILE='DISK$3:[UTILITY.ROCCID.PROPDAT]METH.COF',
7 OPEN(UNIT=25,FILE='DISK$3:[UTILITY.ROCCID.PROPDAT]O2.COF',
9 OPEN(UNIT=25,FILE='DISK$3:[UTILITY.ROCCID.PROPDAT]C3H8.COF',
```

File Name: [ROCCID.POINTA]PINPUT.FOR

```
OPEN(UNIT=57,FILE='DISK$3:[UTILITY.ROCCID]DEFAULT.CNT',
```

File Name: [ROCCID.POINTA]PROPSET.FOR

```
PROPFILE='DISK$3:[UTILITY.ROCCID.PROPDAT]'//OX(:IOEND)//'_'//
```

File Name: [ROCCID.PROPDAT]PROP.FIL

```
DISK$3:[UTILITY.ROCCID.PROPDAT]LOX_RP-1.DAT
DISK$3:[UTILITY.ROCCID.PROPDAT]LOX_H2.DAT
DISK$3:[UTILITY.ROCCID.PROPDAT]LOX_METHANE.DAT
DISK$3:[UTILITY.ROCCID.PROPDAT]LOX_PROPANE.DAT
```

Transporting ROCCID to a UNIX Computer

ROCCID is available for the VAX computer only. If you wish to use ROCCID on any other computer you must transport the code. Although transporting codes typically is not difficult, it requires a strong understanding of both FORTRAN and the FORTRAN compiler on your computer in order to do it efficiently. A short discussion of FORTRAN statements which are likely to cause problems follows.

OPEN Statements

The VAX/VMS compiler's OPEN statement arguments are often incompatible with UNIX OPENs. For example, to make a VAX/VMS OPEN statement so the file can only be read (to prevent overwriting the file) the command is

```
OPEN(....STATUS='OLD',READONLY....)
```

The same statement on a SUN/UNIX is

```
OPEN(....STATUS='READONLY'....).
```

Another likely syntax problem on the OPEN statements is the VAX/VMS CARRIAGE CONTROL statement which will probably have to be deleted.

To ensure the OPEN statements are compatible with your compiler, first consult your FORTRAN manual to find the correct formatting, then "grep" through the ROCCID source code and check each OPEN statement in the source.

Along with the OPEN statements the file paths (sub-directory tree) must also be changed to a UNIX format. An improper path is the most likely cause if the code cannot open a file.

REAL*16 Declarations

One subroutine in ROCCID uses two REAL*16 variables, which will not be supported on most UNIX computers. The existing SUN version of ROCCID runs fine with the variables declared as REAL*8, so that fix will probably work on other UNIX machines. These variables are found in the function CPI in the FLUIDP.FOR file.

DATA Statements

Another common transporting problem is the setting of hollerith variables in DATA statements. For example, a VAX/VMS DATA statement of

```
DATA   BS/'08'X/
```

reverses to

```
DATA   BS/X'08'/
```

on the SUN computer.

READ and WRITE Statements

READ and WRITE statements can also require modification to work on different computers. For example, a SGI computer requires a NAMELIST read to be formatted

```
READ(10,NML=CRPC)
```

ROCCID currently is written as

```
READ(10, CRPC).
```

GRAPHICS

Another problem in transporting the ROCCID code is the graphics. Since transporting the graphics to different computers is a BIG problem, it is best to comment out all graphics subroutines and just run the code without graphics. The following is a list of subroutines which should be commented out:

PLOTM
TEKMOD
TEKDIA
FIG*
ERASE
ANSI

The interactive front end of ROCCID was developed on a SUN computer, therefore, most of the source should transport to most UNIX computers relatively easily. An expert programmer should be able to transport the code within one man-week.

APPENDIX I

SAMPLE CASE OUTPUT

Part A

POINTA Sample Case ACASE1

```
                              ROCCID
            ROCket Combustor Interactive Design Methodology
                        Version 23-FEB-91



    DIRECT INPUT ECHO FROM SUBROUTINE DINPUT,

ROCCID POINT DESIGN TEST CASE 1
LOX/RP-1 LIKE DOUBLET PAIR WITH FIXED PC
APPROXIMATES -0100 SUBSCALE DOUBLET
 $MODELS
 MCHAM=        1
 MBURN=        2
 MINJ=         1
 $END
 $DESIGN
 PISPA=     8.9600E+01,  1.0940E+02,  1.3940E+02,  1.5880E+02,  1.7780E+02,
            2.0970E+02,  2.3550E+02,  2.5470E+02,  2.6700E+02,  2.7040E+02,
            2.7180E+02,  2.7190E+02,  2.7130E+02,  2.6980E+02,  2.6820E+02,
            2.6660E+02,  2.6500E+02,  2.6210E+02,  2.5920E+02,  2.5630E+02,
            2.5060E+02,  2.3840E+02,  2.2750E+02,  2.1100E+02,  2.0140E+02,
            1.5560E+02,  1.0970E+02,  6.0000E+01,
 PCSA=      1.7760E+03,  2.4560E+03,  3.4670E+03,  4.0740E+03,  4.5800E+03,
            5.0700E+03,  5.4540E+03,  5.7340E+03,  5.9080E+03,  5.9610E+03,
            5.9690E+03,  5.9540E+03,  5.9340E+03,  5.9090E+03,  5.8820E+03,
            5.8550E+03,  5.8260E+03,  5.7590E+03,  5.7000E+03,  5.6430E+03,
            5.5320E+03,  5.2750E+03,  5.0470E+03,  4.6760E+03,  4.4200E+03,
            3.4570E+03,  2.4940E+03,  1.4650E+03,
 ETANOZ=    3.9200E-01,  5.3000E-01,  6.6900E-01,  7.5000E-01,  8.1200E-01,
            8.6300E-01,  8.9800E-01,  9.2200E-01,  9.3900E-01,  9.5200E-01,
            9.6200E-01,  9.7000E-01,  9.7700E-01,  9.8100E-01,
 TYPE=    'LOL'
 FUEL=    'RP-1     '
 OX=      'LOX      '
 XMR=       2.8800E+00
 FTMAN=     7.1000E+01
 XTMAN=    -2.7900E+02
 PCNOM=     2.1160E+03
 WDNOM=     1.7933E+02
 WDMIN=     1.2994E+02
 ETACSG=    9.5860E-01
 XLEMAX=    4.0000E+00
 DCMAX=     7.5000E-01
 NPERFP=        28
 PMRA=      1.0000E-01,  3.0000E-01,  6.0000E-01,  8.0000E-01,  1.0000E+00,
            1.2500E+00,  1.5000E+00,  1.7500E+00,  2.0000E+00,  2.2000E+00,
            2.4000E+00,  2.5000E+00,  2.6000E+00,  2.7000E+00,  2.8000E+00,
            2.9000E+00,  3.0000E+00,  3.2000E+00,  3.4000E+00,  3.6000E+00,
            4.0000E+00,  5.0000E+00,  6.0000E+00,  8.0000E+00,  1.0000E+01,
            1.5000E+01,  2.0000E+01,  5.0000E+01,
 NNOZ=          14
 XNOZ=      3.6300E-01,  7.2700E-01,  1.4530E+00,  2.1800E+00,  2.9070E+00,
            3.6330E+00,  4.3600E+00,  5.0870E+00,  5.8130E+00,  6.5770E+00,
            7.2670E+00,  7.9930E+00,  8.7170E+00,  9.0830E+00,
 $END
 $FGEOM
 RNE=       1.1100E-01
 RTE=       1.1100E-01
 ALPHA=     3.0000E+01
```

```
$END
$FDORC
NZON=          5
FTER=     20*1.0000E+00
$END
$CONTROL
DPPCS=     2.3000E-01
RNR=       1.0000E+00
RTR=       1.0000E+00
CONVA=     2.6000E+01
XMSTAB=    2.0000E-01
$END
$LOLC
FCD=       9.1000E-01
XCD=       9.4000E-01
FIA=       3.0000E+01
XIA=       3.0000E+01
FIHOD=     2.0000E+00
XIHOD=     2.0000E+00
FCANT=     1.6000E+01
XCANT=     1.6000E+01
FLOD=      5.0000E+00
XLOD=      5.0000E+00
EMUNI=     6.5000E-01
$END
$SAID
TBAF=      3.3000E-02
$END

    END OF INPUT ECHO
```

POINTD DESIGN MODEL INPUTS

RUN DESCRIPTORS

ROCCID POINT DESIGN TEST CASE 1
LOX/RP-1 LIKE DOUBLET PAIR WITH FIXED PC
APPROXIMATES -0100 SUBSCALE DOUBLET

SELECTED STABILITY MODELS

BURNING MODEL=N-TAU   INJECTION MODEL=INJ   CHAMBER MODEL=HIFI
DEBUG OUTPUT=F

PROPELLENT DESCRIPTION

FUEL=RP-1   Tman., F= 71.00
OX=LOX   Tman., F=-279.00

OPERATING CONSTRAINTS

CORE ELEMENT TYPE=LOL   INJECTED MR= 2.6800
NOMINAL PC=2116.00 PSIA
NOMINAL FLOWRATE= 1.793E+02 LBm/S   THROTTLED FLOWRATE= 1.299E+02 LBm/S
MAXIMUM CHAMBER DIAMETER= 0.7500 FT   MAXIMUM ENGINE LENGTH= 4.0000 FT
C* EFFICIENCY GOAL= 95.66 %

STABILITY AID PREFERENCE

NO BAFFLES   NO CAVITIES

FIXED CHAMBER GEOMETRY

NOZZLE ENTRANCE RADIUS OF CURVATURE = 0.1110 FT
THROAT ENTRANCE RADIUS OF CURVATURE = 0.1110 FT
CONVERGENCE HALF-ANGLE =30.0000 DEGREES

DESIGN CONTROL PARAMETERS

DELTA-P/PC AT PCMIN= 0.2300
NON-DIMENSIONAL NOZZLE ENTRANCE RADIUS OF CURVATURE (RNE/RTHRT)= 1.0000
NON-DIMENSIONAL THROAT ENTRANCE RADIUS OF CURVATURE (RTE/RTHRT)= 1.0000
NOZZLE CONVERGENCE HALF-ANGLE=25.0000 DEGREES

LIKE DOUBLET PAIR DESIGN VARIABLES

FUEL Cd= 0.9100   OX Cd= 0.9400   UNIELEMENT Em= 0.6500
FUEL IMPINGEMENT HALF-ANGLE=30.0000 DEG
OX IMPINGEMENT HALF-ANGLE=30.0000 DEG
FUEL IMPINGEMENT POINT HEIGHT TO ORIFICE DIAMETER RATIO= 2.0000
OX IMPINGEMENT POINT HEIGHT TO ORIFICE DIAMETER RATIO= 2.0000
FUEL UNLIKE CANT ANGLE=16.0000 DEG
OX UNLIKE CANT ANGLE=16.0000 DEG
FUEL ORIFICE LENGTH TO ORIFICE DIAMETER RATIO= 5.0000

OX ORIFICE LENGTH TO ORIFICE DIAMETER RATIO= 5.0000

STABILITY AID DESIGN VARIABLES

BAFFLE BLADE THICKNESS= 0.0330 IN
1/4 WAVE CAVITY PARTITION THICKNESS= 0.0000 FT
ACOUSTIC CAVITY TYPE 1 INLET=SHARP EDGED
ACOUSTIC CAVITY TYPE 2 INLET=SHARP EDGED

PRELIMINARY DESIGN CHAMBER SIZING RESULTS

```
NOMINAL CHAMBER PRESSURE                    =  2.118E+03 PSIA
THROTTLED CHAMBER PRESSURE                  =  1.535E+03 PSIA
FUEL MANIFOLD PRESSURE                      =  2.790E+03 PSIA
OXIDIZER MANIFOLD PRESSURE                  =  2.790E+03 PSIA
CHAMBER RADIUS                              =  2.795E-01 FT
THROAT RADIUS                               =  1.852E-01 FT
NOZZLE ENTRANCE RADIUS OF CURVATURE         =  1.110E-01 FT
THROAT ENTRANCE RADIUS OF CURVATURE         =  1.110E-01 FT
NOZZLE CONVERGENCE HALF-ANGLE               =  3.000E+01 DEG
INJECTOR-TO-THROAT CHAMBER LENGTH           =  1.183E+00 FT
BARREL SECTION LENGTH                       =  9.601E-01 FT
```

IMPINGING ELEMENT SIZING RESULTS

```
ELEMENT TYPE                     =LOL
NO. OF ELEMENTS                  =     93
FUEL 20% VAPORIZATION LENGTH     =  6.360E-01 IN
OX 20% VAPORIZATION LENGTH       =  5.363E-01 IN
FUEL ORIFICE DIAMETER            =  5.329E-02 IN
OX   ORIFICE DIAMETER            =  8.171E-02 IN
```

CORE ELEMENT SPACING RESULTS

```
ELEMENT TYPE                     = LOL
NUMBER OF ELEMENTS               =     93
FUEL ORIFICE/ANNULUS DIAMETER    =  5.329E-02 IN
OXIDIZER ORIFICE DIAMETER        =  6.171E-02 IN
FUEL INJECTION VELOCITY          =  3.533E+02 FT/S
OXIDIZER INJECTION VELOCITY      =  2.979E+02 FT/S
```

ROW	# ELEMENTS	MID-ROW RADIUS (IN)
1	6	8.316E-01
2	12	1.392E+00
3	18	1.953E+00
4	24	2.513E+00
5	33	3.074E+00

```
DIRECT INPUT ECHO FROM SUBROUTINE PINPUT

                                   ROCCID
                ROCket Combustor Interactive Design Methodology
                             Version 23-FEB-91

ROCCID POINT DESIGN TEST CASE 1
LOX/RP-1 LIKE DOUBLET PAIR WITH FIXED PC
APPROXIMATES -0100 SUBSCALE DOUBLET
 $MODELS
 MCHAM=          1
 MBURN=          2
 MINJ=           1
 $END
 $OPCOND
 PISPA=     8.9600E+01,  1.0940E+02,  1.3940E+02,  1.5880E+02,  1.7780E+02,
            2.0970E+02,  2.3550E+02,  2.5470E+02,  2.6700E+02,  2.7040E+02,
            2.7180E+02,  2.7190E+02,  2.7130E+02,  2.6980E+02,  2.6820E+02,
            2.6660E+02,  2.6500E+02,  2.6210E+02,  2.5920E+02,  2.5630E+02,
            2.5080E+02,  2.3840E+02,  2.2750E+02,  2.1100E+02,  2.0140E+02,
            1.5560E+02,  1.0970E+02,  6.0000E+01,
 PCSA=      1.7760E+03,  2.4560E+03,  3.4870E+03,  4.0740E+03,  4.5800E+03,
            5.0700E+03,  5.4540E+03,  5.7340E+03,  5.9080E+03,  5.9610E+03,
            5.9690E+03,  5.9540E+03,  5.9340E+03,  5.9090E+03,  5.8820E+03,
            5.8550E+03,  5.8260E+03,  5.7590E+03,  5.7000E+03,  5.6430E+03,
            5.5320E+03,  5.2750E+03,  5.0470E+03,  4.8760E+03,  4.4200E+03,
            3.4570E+03,  2.4940E+03,  1.4650E+03,
 FUEL=     'RP-1      '
 OX=       'LOX       '
 PC=        2.1180E+03
 XMR=       2.8800E+00
 FTMAN=     7.1000E+01
 XTMAN=    -2.7900E+02
 EMMAN=     1.0000E+00
 NPERFP=        28
 PMRA=      1.0000E-01,  3.0000E-01,  6.0000E-01,  8.0000E-01,  1.0000E+00,
            1.2500E+00,  1.5000E+00,  1.7500E+00,  2.0000E+00,  2.2000E+00,
            2.4000E+00,  2.5000E+00,  2.6000E+00,  2.7000E+00,  2.8000E+00,
            2.9000E+00,  3.0000E+00,  3.2000E+00,  3.4000E+00,  3.6000E+00,
            4.0000E+00,  5.0000E+00,  6.0000E+00,  8.0000E+00,  1.0000E+01,
            1.5000E+01,  2.0000E+01,  5.0000E+01,
 $END
 $GEOM
 RCHAMB=    2.7949E-01
 RTHRT=     1.6523E-01
 RNE=       1.1100E-01
 RTE=       1.1100E-01
 ALPHA=     3.0000E+01
 CHAMBL=    1.1626E+00
 XC=        9.6009E-01
 $END
 $CORE
 TYPE=     'LOL'
 NEL=           93
 FDJ=       5.3289E-02
 FCD=       9.1000E-01
 FIH=       9.2300E-02
 FIA=       3.0000E+01
 FCANT=     1.6000E+01
 FFACET=    2.3075E-01
 XDJ=       6.1706E-02
 XCD=       9.4000E-01
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XIH=      1.4152E-01
XIA=      3.0000E+01
XCANT=    1.6000E+01
XFACET=   3.5380E-01
EMUNI=    6.5000E-01
$END
$BAFFLE
$END
$BARRIER
$END
$FFC
$END
$BURN
$END
$INJ
FMAND=    6.7076E+00
XMAND=    6.7076E+00
FMANL=    3.3538E+00
XMANL=    3.3538E+00
PCA=      2.1180E+03,  1.5347E+03,  7.6734E+02
$END
$CHAMBER
MUB=              3
T=        3.3000E-02
$END
$FDORC
NZON=             5
FTER=    20*1.0000E+00
$END
$MIX
 EM(1)= 9.160E-01,  1.000E+00
$END
$DEBUGC
DEBUG=   F
$END
$HIFIC
SHORT=   F
POC=      2.0000E-01,  2.0000E-01
$END
$DISTSDC
SHORT=   F
POC=      2.0000E-01,  2.0000E-01
PAMP=     2.0000E-01
MC=              11
LC=               8
MB=              11
LB=               8
IDMAX=           10
$END
$CRPC
NDPC=            16
NDTFQ=           16
NDTLF=         1000
NPRINT=          50
NSUMB=         3500
PAMPC=    2.0000E-01
NRAD=             3
NCIRC=            6
$END
$LEINJC
IDOMEM=           2
PAMPCH=   2.0000E-01
NTINJ=           16
USGF=     2.0000E-02
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OGF=      2.0000E-02
DSGF=     2.0000E-02
FCDO=     1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XCDO=     1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
$END
$COMBUSTC
FALVM=    1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XALVM=    1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
FALTM=    1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XALTM=    1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
FRMM=     1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XRMM=     1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
EMMULT=   1.0000E+00,  1.0000E+00
COMBXB=   5.0000E-01
ACMULT=   1.0000E+00
CCMULT=   1.0000E+00
ENMULT=   1.0000E+00
TAUMULT=  1.0000E+00
$END
$FDORCC
SHORT=   F
EPSIL=    2.0000E+01
ERROR=    1.0000E-01
LTS=          5
MTS=          5
NTS=         10
ITMAX=      100
RELX=     6.5000E-01
NEET=         3
NXFST=        3
NYFST=        3
NAFST=        3
MORE=    F
$END

   END OF INPUT ECHO
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                    STEADY STATE COMBUSTION ANALYSIS PROGRAM

                              RUN DESCRIPTORS

ROCCID POINT DESIGN TEST CASE 1
LOX/RP-1 LIKE DOUBLET PAIR WITH FIXED PC
APPROXIMATES -0100 SUBSCALE DOUBLET

                              PROPELLENT DESCRIPTION

            FUEL=RP-1         Tman., F=  71.00
              OX=LOX          Tman., F=-279.00

                              CHAMBER GEOMETRY

CHAMBER RADIUS = 3.3539 IN.                              THROAT RADIUS = 2.2228 IN.
CYLINDRICAL SECTION =11.5206 IN.                         CONVERGENT SECTION LENGTH = 2.6730 IN.
NOZZLE ENTRANCE RADIUS OF CURVATURE = 1.3320 IN.         THROAT ENTRANCE RADIUS OF CURVATURE = 1.3320 IN.
CONVERGENCE HALF-ANGLE =30.0000 DEG.                     CONTRACTION RATIO =  2.28

                              INJECTOR DATA

INJECTOR CORE CONTAINS    93 LOL ELEMENTS

FUEL SIDE:   Orifice Diam. =5.329E-02 In.       Cd =0.9100                      Impingement Height =0.092 In.
             Impingement Half-angle =30.00 Deg. Unlike Cant Angle =16.00 Deg.   Faceplate Thickness = 0.2307 In.
  OX SIDE:   Orifice Diam. =6.170E-02 In.       Cd =0.9400                      Impingement Height =0.142 In.
             Impingement Half-angle =30.00 Deg. Unlike Cant Angle =16.00 Deg.   Faceplate Thickness = 0.3538 In.

                              MIXING EFFICIENCIES

CORE MIXING EFFICIENCY=0.9160     BARRIER MIXING EFFICIENCY=1.0000

                              COMBUST CONTROL PARAMETERS

MULTIPLIERS:                                    CORE     BAFFLE    BARRIER    FFC
FUEL ATOMIZATION LENGTH FOR VAPORIZATION:      1.000     1.000     1.000     1.000
  OX ATOMIZATION LENGTH FOR VAPORIZATION:      1.000     1.000     1.000     1.000
FUEL ATOMIZATION LENGTH FOR TIMELAGS:          1.000     1.000     1.000     1.000
  OX ATOMIZATION LENGTH FOR TIMELAGS:          1.000     1.000     1.000     1.000
FUEL DROPSIZE:                                 1.000     1.000     1.000     1.000
  OX DROPSIZE:                                 1.000     1.000     1.000     1.000
MIXING (Em):                                   1.000               1.000

   AO-Multiplier=1.000     CC-Multiplier=1.000     N-Multiplier=1.000     Tau-Multiplier=1.000
   Eta-C* for XB=0.500
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          BEGIN STEADY STATE COMBUSTION ANALYSIS
                PC=2116.00 PSIA


                         PROPELLANT PROPERTIES

FUEL=RP-1       Phase=Liquid                          Tman., F=  71.00
                Injected Density= 49.69 Lbm/Cu. Ft    Viscosity=1.380E-03 Lbm/Ft-S    Surface Tension=1.867E-03 Lbf/Ft

  OX=LOX        Phase=Liquid                          Tman., F=-279.00
                Injected Density= 70.18 Lbm/Cu. Ft    Viscosity=1.186E-04 Lbm/Ft-S    Surface Tension=7.326E-04 Lbf/Ft

                         OPERATING CONDITIONS

PC FACE=2116.00 PSIA     PC THROAT=2034.15      MIXTURE RATIO= 2.880
FUEL INJECTION PRESSURE DROP= 633.67 Psia       FUEL INJECTION VELOCITY= 343.06 Ft/S
  OX INJECTION PRESSURE DROP= 633.67 Psia         OX INJECTION VELOCITY= 289.25 Ft/S

    FUEL FLOWRATE=  44.894     OX FLOWRATE= 129.296

                         ATOMIZATION OUTPUT


          DROPSIZE MODEL=AEROJET

ELEMENT TYPE 1 IS LOL
FUEL:      ATOMIZATION LENGTH, In.=0.84239     ATOMIZATION LENGTH FOR VAPORIZATION, In.=0.84239     DROPLET RADIUS, Microns=  61.99
  OX:      ATOMIZATION LENGTH, In.=1.84611     ATOMIZATION LENGTH FOR VAPORIZATION, In.=1.84611     DROPLET RADIUS, Microns=  68.69
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VAPORIZATION CALCULATIONS

X (In.)	CORE=LOL %FUEL VAP	CORE=LOL %OX VAP	BAFFLE= %FUEL VAP	BAFFLE= %OX VAP	BARRIER= %FUEL VAP	BARRIER= %OX VAP	FFC= %FUEL VAP	FFC= %OX VAP
0.0000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.2839	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.5677	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.8516	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.1355	10.421	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.4194	22.348	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.7032	31.303	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.9871	38.902	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2.2710	44.860	31.536	0.000	0.000	0.000	0.000	0.000	0.000
2.5548	49.928	48.762	0.000	0.000	0.000	0.000	0.000	0.000
2.8387	54.297	60.033	0.000	0.000	0.000	0.000	0.000	0.000
3.1226	58.099	67.571	0.000	0.000	0.000	0.000	0.000	0.000
3.4065	61.462	73.310	0.000	0.000	0.000	0.000	0.000	0.000
3.6903	64.386	77.933	0.000	0.000	0.000	0.000	0.000	0.000
3.9742	67.004	81.238	0.000	0.000	0.000	0.000	0.000	0.000
4.2581	69.246	83.965	0.000	0.000	0.000	0.000	0.000	0.000
4.5420	71.372	86.236	0.000	0.000	0.000	0.000	0.000	0.000
4.8258	73.322	88.311	0.000	0.000	0.000	0.000	0.000	0.000
5.1097	75.154	89.847	0.000	0.000	0.000	0.000	0.000	0.000
5.3936	76.762	91.126	0.000	0.000	0.000	0.000	0.000	0.000
5.6774	78.256	92.243	0.000	0.000	0.000	0.000	0.000	0.000
5.9613	79.475	93.134	0.000	0.000	0.000	0.000	0.000	0.000
6.2452	80.661	94.019	0.000	0.000	0.000	0.000	0.000	0.000
6.5291	81.851	94.687	0.000	0.000	0.000	0.000	0.000	0.000
6.8129	82.956	95.355	0.000	0.000	0.000	0.000	0.000	0.000
7.0968	83.785	95.918	0.000	0.000	0.000	0.000	0.000	0.000
7.3807	84.613	96.414	0.000	0.000	0.000	0.000	0.000	0.000
7.6645	85.442	96.815	0.000	0.000	0.000	0.000	0.000	0.000
7.9484	86.270	97.211	0.000	0.000	0.000	0.000	0.000	0.000
8.2323	87.099	97.478	0.000	0.000	0.000	0.000	0.000	0.000
8.5162	87.919	97.745	0.000	0.000	0.000	0.000	0.000	0.000
8.8000	88.479	98.012	0.000	0.000	0.000	0.000	0.000	0.000
9.0839	89.040	98.260	0.000	0.000	0.000	0.000	0.000	0.000
9.3678	89.600	98.460	0.000	0.000	0.000	0.000	0.000	0.000
9.6516	90.160	98.625	0.000	0.000	0.000	0.000	0.000	0.000
9.9355	90.606	98.781	0.000	0.000	0.000	0.000	0.000	0.000
10.2194	91.046	98.924	0.000	0.000	0.000	0.000	0.000	0.000
10.5033	91.485	99.065	0.000	0.000	0.000	0.000	0.000	0.000
10.7871	91.924	99.149	0.000	0.000	0.000	0.000	0.000	0.000
11.0710	92.268	99.242	0.000	0.000	0.000	0.000	0.000	0.000
11.3549	92.593	99.336	0.000	0.000	0.000	0.000	0.000	0.000
11.6388	92.934	99.419	0.000	0.000	0.000	0.000	0.000	0.000
11.9226	93.298	99.479	0.000	0.000	0.000	0.000	0.000	0.000
12.2065	93.661	99.539	0.000	0.000	0.000	0.000	0.000	0.000
12.4904	94.018	99.599	0.000	0.000	0.000	0.000	0.000	0.000
12.7742	94.291	99.636	0.000	0.000	0.000	0.000	0.000	0.000
13.0581	94.563	99.677	0.000	0.000	0.000	0.000	0.000	0.000
13.3420	94.836	99.716	0.000	0.000	0.000	0.000	0.000	0.000
13.6259	95.109	99.747	0.000	0.000	0.000	0.000	0.000	0.000
13.9097	95.381	99.774	0.000	0.000	0.000	0.000	0.000	0.000
14.1936	95.623	99.801	0.000	0.000	0.000	0.000	0.000	0.000

OVERALL VAPORIZATION EFFICIENCIES
FUEL= 95.62%   OX= 99.80%

MASS DISTRIBUTION PROFILE

X (IN)	CORE (lbm/s) FUEL	CORE (lbm/s) OX	BARRIER (lbm/s) FUEL	BARRIER (lbm/s) OX	LOCAL VAPOR MIXTURE RATIO	ETA-C*
0.0000	0.000	0.000	0.000	0.000	0.00	0.0000
0.2839	0.000	0.000	0.000	0.000	0.00	0.0000
0.5677	0.000	0.000	0.000	0.000	0.00	0.0000
0.8516	0.000	0.000	0.000	0.000	0.00	0.0000
1.1355	4.676	0.000	0.000	0.000	0.00	0.0066
1.4194	10.033	0.000	0.000	0.000	0.00	0.0141
1.7032	14.053	0.000	0.000	0.000	0.00	0.0198
1.9871	17.465	0.000	0.000	0.000	0.00	0.0246
2.2710	20.139	40.775	0.000	0.000	2.02	0.3497
2.5548	22.415	63.048	0.000	0.000	2.81	0.4901
2.8387	24.377	77.620	0.000	0.000	3.18	0.5750
3.1226	26.083	87.366	0.000	0.000	3.35	0.6344
3.4065	27.593	94.786	0.000	0.000	3.44	0.6614
3.6903	28.906	100.765	0.000	0.000	3.49	0.7200
3.9742	30.081	105.036	0.000	0.000	3.49	0.7500
4.2581	31.088	108.563	0.000	0.000	3.49	0.7752
4.5420	32.042	111.500	0.000	0.000	3.48	0.7973
4.8258	32.917	114.182	0.000	0.000	3.47	0.8176
5.1097	33.740	116.169	0.000	0.000	3.44	0.8343
5.3936	34.462	117.823	0.000	0.000	3.42	0.8486
5.6774	35.133	119.267	0.000	0.000	3.39	0.8615
5.9613	35.680	120.419	0.000	0.000	3.37	0.8716
6.2452	36.221	121.562	0.000	0.000	3.36	0.8821
6.5291	36.747	122.428	0.000	0.000	3.33	0.8909
6.8129	37.243	123.290	0.000	0.000	3.31	0.8995
7.0968	37.615	124.018	0.000	0.000	3.30	0.9062
7.3807	37.987	124.660	0.000	0.000	3.28	0.9126
7.6645	38.359	125.178	0.000	0.000	3.26	0.9184
7.9484	38.731	125.669	0.000	0.000	3.25	0.9242
8.2323	39.103	126.035	0.000	0.000	3.22	0.9292
8.5162	39.471	126.380	0.000	0.000	3.20	0.9342
8.8000	39.722	126.726	0.000	0.000	3.19	0.9381
9.0839	39.974	127.046	0.000	0.000	3.18	0.9418
9.3678	40.225	127.305	0.000	0.000	3.16	0.9453
9.6516	40.477	127.518	0.000	0.000	3.15	0.9486
9.9355	40.678	127.719	0.000	0.000	3.14	0.9514
10.2194	40.875	127.905	0.000	0.000	3.13	0.9540
10.5033	41.072	128.075	0.000	0.000	3.12	0.9566
10.7871	41.269	128.195	0.000	0.000	3.11	0.9590
11.0710	41.423	128.316	0.000	0.000	3.10	0.9609
11.3549	41.569	128.437	0.000	0.000	3.09	0.9628
11.6388	41.722	128.545	0.000	0.000	3.08	0.9647
11.9226	41.885	128.623	0.000	0.000	3.07	0.9665
12.2065	42.049	128.700	0.000	0.000	3.06	0.9684
12.4904	42.209	128.777	0.000	0.000	3.05	0.9702
12.7742	42.331	128.828	0.000	0.000	3.04	0.9715
13.0581	42.454	128.878	0.000	0.000	3.04	0.9728
13.3420	42.576	128.928	0.000	0.000	3.03	0.9741
13.6259	42.698	128.969	0.000	0.000	3.02	0.9754
13.9097	42.821	129.004	0.000	0.000	3.01	0.9767
14.1936	42.929	129.038	0.000	0.000	3.01	0.9778

AXIAL PRESSURE PROFILE

X (in)	MACH #	Ptotal (psia)	Pstatic (psia)	Ttotal (R)	Tstatic (R)	Wdot (Lbm/s)	Local Radius (in)
0.91	0.000	2118.74	2119.69	1695.15	1689.71	0.58	3.354
1.21	0.004	2118.72	2119.65	1691.89	1686.48	6.00	3.354
1.51	0.009	2118.66	2119.51	1770.23	1764.55	12.10	3.354
1.81	0.009	2118.65	2119.51	1691.89	1686.46	12.49	3.354
2.11	0.036	2117.17	2116.54	3559.19	3547.55	34.80	3.354
2.42	0.113	2103.63	2089.35	6861.31	6835.43	76.31	3.354
2.72	0.142	2095.15	2072.25	6817.73	6790.31	95.34	3.354
3.02	0.165	2087.07	2055.88	6861.31	6832.01	109.80	3.354
3.32	0.181	2080.97	2043.48	6835.68	6805.42	119.88	3.354
3.62	0.194	2075.45	2032.23	6829.70	6798.10	128.14	3.354
3.93	0.205	2071.07	2023.28	6826.95	6794.41	134.28	3.354
4.23	0.213	2067.37	2015.71	6826.97	6793.63	139.20	3.354
4.53	0.220	2064.09	2008.99	6828.61	6794.74	143.38	3.354
4.83	0.226	2061.03	2002.70	6830.60	6795.63	147.17	3.354
5.13	0.232	2058.54	1997.58	6834.73	6799.38	150.12	3.354
5.44	0.236	2056.39	1993.15	6838.55	6802.69	152.62	3.354
5.74	0.240	2054.49	1989.23	6841.91	6805.59	154.78	3.354
6.04	0.243	2052.90	1985.95	6843.83	6807.14	156.57	3.354
6.34	0.246	2051.36	1982.76	6846.05	6808.98	158.28	3.354
6.64	0.249	2050.02	1980.00	6848.64	6811.25	159.73	3.354
6.95	0.251	2048.78	1977.44	6850.48	6812.79	161.07	3.354
7.25	0.253	2047.75	1975.29	6851.91	6813.97	162.18	3.354
7.55	0.255	2046.80	1973.33	6853.77	6815.60	163.18	3.354
7.85	0.257	2045.89	1971.45	6855.70	6817.30	164.13	3.354
8.15	0.258	2045.10	1969.81	6857.87	6819.27	164.94	3.354
8.46	0.260	2044.35	1968.25	6860.35	6821.55	165.71	3.354
8.76	0.261	2043.72	1966.94	6860.90	6821.95	166.36	3.354
9.06	0.262	2043.14	1965.73	6860.90	6821.81	166.97	3.354
9.36	0.263	2042.61	1964.64	6860.94	6821.73	167.52	3.354
9.66	0.264	2042.13	1963.65	6860.97	6821.65	168.01	3.354
9.97	0.265	2041.72	1962.79	6861.00	6821.58	168.44	3.354
10.27	0.266	2041.33	1961.97	6861.03	6821.52	168.84	3.354
10.57	0.266	2040.98	1961.20	6861.06	6821.46	169.23	3.354
10.87	0.267	2040.64	1960.54	6861.08	6821.41	169.55	3.354
11.17	0.268	2040.36	1959.93	6861.10	6821.35	169.84	3.354
11.48	0.268	2040.08	1959.38	6861.12	6821.32	170.12	3.354
11.78	0.273	2039.81	1958.27	6861.15	6820.20	170.39	3.330
12.08	0.292	2039.54	1943.78	6861.17	6815.11	170.64	3.228
12.38	0.329	2039.20	1918.54	6861.20	6804.57	170.90	3.064
12.68	0.378	2038.85	1881.29	6861.22	6788.68	171.11	2.888
12.99	0.440	2038.45	1827.89	6861.24	6765.25	171.29	2.714
13.29	0.526	2037.86	1744.80	6861.26	6727.67	171.47	2.540
13.59	0.657	2037.05	1599.18	6861.28	6657.81	171.65	2.368
13.89	0.821	2035.80	1399.45	6861.30	6552.51	171.81	2.257
14.19	0.998	2034.15	1174.65	6861.31	6419.73	171.97	2.223

```
                PERFORMANCE SUMMARY

               C* EFFICIENCY CALCULATIONS (ODK)

                                           CORE Em=0.9169      BARRIER Em=1.0000
INJECTED MR= 2.8800     CSTAR=5860.40                      CSTAR-MIX=5804.37     MASS FRACTION= 1.0000
CORE:          OVERALL MR= 2.8800     VAPOR MR= 3.0058     CSTAR-MIX=   0.00     MASS FRACTION= 0.0000
BARRIER:       OVERALL MR= 0.0000     VAPOR MR=99.9900     CSTAR-DEL=5730.31
ENGINE:        OVERALL MR= 2.8800     VAPOR MR= 3.0058
C* EFFICIENCY = 9.778E-01

               ISP EFFICIENCY CALCULATIONS

ISP-ODK, INJ = 2.669E+02 SEC.
ISP-ODK, M.Z. INJ = 2.661E+02 SEC.           ISP-ODK, M.Z. VAPOR = 2.646E+02 SEC.
VAPORIZATION EFFICIENCY = 9.816E-01          MIXING EFFICIENCY = 9.969E-01
ENERGY RELEASE EFFICIENCY = 9.786E-01

NOTE: ISP-DEL = ISP-ODK, INJ. * ERE * ETADIV - DELISP-BL
```

```
                    TIME-LAG CALCULATIONS, Milliseconds

Coham, In.=9.164E-03     FUEL Cohem, In.=2.293E+02     OX Cohem, In.=8.194E+01


ELEMENT 1 IS TYPE=LOL
FUEL:     Cinj, In.=1.165E-02     Lvap, In.= 0.422     ATOMIZATION LENGTH USED, In.= 8.424E-01
          Timp=2.589E-02     Tatom=2.046E-01     Tvap=1.025E-01     Total=3.330E-01

  OX:     Cinj, In.=1.190E-02     Lvap, In.= 0.154     ATOMIZATION LENGTH USED, In.= 1.846E+00
          Timp=4.708E-02     Tatom=5.319E-01     Tvap=4.433E-02     Total=6.233E-01


                    EFFECTIVE TIMELAGS, Milliseconds

FUEL:     Cinj, In.=1.165E-02     Lvap, In.= 0.422
          Timp=2.589E-02     Tatom=2.046E-01     Tvap=1.025E-01     Total=3.330E-01

  OX:     Cinj, In.=1.190E-02     Lvap, In.= 0.154
          Timp=4.708E-02     Tatom=5.319E-01     Tvap=4.433E-02     Total=6.233E-01
```

CHAMBER-NOZZLE OPTIMIZATION RESULTS

CHAMBER LENGTH (FEET)	ETA-C*	ETA-NOZ	OVERALL EFFICIENCY
0.0000	0.0000	0.8807	0.0000
0.1667	0.0393	0.8726	0.0343
0.3333	0.7523	0.8646	0.6505
0.5000	0.8732	0.8537	0.7454
0.6667	0.9251	0.8419	0.7789
0.8333	0.9520	0.8302	0.7904
1.0000	0.9670	0.8185	0.7915
1.1667	0.9770	0.8057	0.7872
1.3333	0.9850	0.7915	0.7796
1.5000	0.9929	0.7773	0.7718
1.6667	1.0000	0.7631	0.7631
1.8333	1.0000	0.7485	0.7485
2.0000	1.0000	0.7299	0.7299
2.1667	1.0000	0.7114	0.7114
2.3333	1.0000	0.6928	0.6928
2.5000	1.0000	0.6742	0.6742
2.6667	1.0000	0.6461	0.6461
2.8333	1.0000	0.6142	0.6142
3.0000	1.0000	0.5823	0.5823
3.1667	1.0000	0.5504	0.5504
3.3333	1.0000	0.5071	0.5071
3.5000	1.0000	0.4439	0.4439
3.6667	1.0000	0.3808	0.3808
3.8333	1.0000	0.3176	0.3176
4.0000	1.0000	0.2544	0.2544

OPTIMUM CHAMBER LENGTH= 1.0000 FT
MAXIMUM OVERALL EFFICIENCY= 0.7915

REDESIGNED CHAMBER RESULTS

```
NOMINAL CHAMBER PRESSURE              =  2.118E+03 PSIA
THROTTLED CHAMBER PRESSURE            =  1.535E+03 PSIA
FUEL INJECTION PRESSURE DROP          =  6.337E+02 PSI
OX INJECTION PRESSURE DROP            =  6.337E+02 PSI
CHAMBER RADIUS                        =  2.795E-01 FT
THROAT RADIUS                         =  1.852E-01 FT
NOZZLE ENTRANCE RADIUS OF CURVATURE   =  1.110E-01 FT
THROAT ENTRANCE RADIUS OF CURVATURE   =  1.110E-01 FT
NOZZLE CONVERGENCE HALF-ANGLE         =  3.000E+01 DEG
INJECTOR-TO-THROAT CHAMBER LENGTH     =  1.183E+00 FT
BARREL SECTION LENGTH                 =  9.601E-01 FT
```

IMPINGING ELEMENT SIZING RESULTS

```
ELEMENT TYPE                =LOL
NO. OF ELEMENTS             =    60
FUEL ORIFICE DIAMETER       =  6.634E-02 IN
OX ORIFICE DIAMETER         =  1.017E-01 IN
```

CORE ELEMENT SPACING RESULTS

```
ELEMENT TYPE                    = LOL
NUMBER OF ELEMENTS              =    60
FUEL ORIFICE/ANNULUS DIAMETER   =  6.634E-02 IN
OXIDIZER ORIFICE DIAMETER       =  1.017E-01 IN
FUEL INJECTION VELOCITY         =  3.430E+02 FT/S
OXIDIZER INJECTION VELOCITY     =  2.892E+02 FT/S
```

ROW	# ELEMENTS	MID-ROW RADIUS (IN)
1	6	9.115E-01
2	12	1.609E+00
3	18	2.307E+00
4	24	3.005E+00

```
DIRECT INPUT ECHO FROM SUBROUTINE PINPUT

                              ROCCID
              ROCket Combustor Interactive Design Methodology
                         Version 23-FEB-91

ROCCID POINT DESIGN TEST CASE 1
LOX/RP-1 LIKE DOUBLET PAIR WITH FIXED PC
APPROXIMATES .0100 SUBSCALE DOUBLET
 $MODELS
 MCHAM=        1
 MBURN=        2
 MINJ=         1
 $END
 $OPCOND
 PISPA=    8.9600E+01,  1.0940E+02,  1.3940E+02,  1.5880E+02,  1.7780E+02,
           2.0970E+02,  2.3550E+02,  2.5470E+02,  2.6700E+02,  2.7040E+02,
           2.7180E+02,  2.7190E+02,  2.7130E+02,  2.6980E+02,  2.6820E+02,
           2.6660E+02,  2.6500E+02,  2.6210E+02,  2.5920E+02,  2.5630E+02,
           2.5080E+02,  2.3840E+02,  2.2750E+02,  2.1100E+02,  2.0140E+02,
           1.5560E+02,  1.0970E+02,  8.0000E+01,
 PCSA=     1.7760E+03,  2.4560E+03,  3.4870E+03,  4.0740E+03,  4.5800E+03,
           5.0700E+03,  5.4540E+03,  5.7340E+03,  5.9080E+03,  5.9610E+03,
           5.9690E+03,  5.9540E+03,  5.9340E+03,  5.9090E+03,  5.8820E+03,
           5.8550E+03,  5.8260E+03,  5.7590E+03,  5.7000E+03,  5.6430E+03,
           5.5320E+03,  5.2750E+03,  5.0470E+03,  4.8760E+03,  4.4200E+03,
           3.4570E+03,  2.4940E+03,  1.4850E+03,
 FUEL=    'RP-1       '
 OX=      'LOX        '
 PC=       2.1160E+03
 XMR=      2.6800E+00
 FTMAN=    7.1000E+01
 XTMAN=   -2.7900E+02
 EMMAN=    1.0000E+00
 NPERFP=       28
 PMRA=     1.0000E-01,  3.0000E-01,  6.0000E-01,  8.0000E-01,  1.0000E+00,
           1.2500E+00,  1.5000E+00,  1.7500E+00,  2.0000E+00,  2.2000E+00,
           2.4000E+00,  2.5000E+00,  2.6000E+00,  2.7000E+00,  2.8000E+00,
           2.9000E+00,  3.0000E+00,  3.2000E+00,  3.4000E+00,  3.6000E+00,
           4.0000E+00,  5.0000E+00,  6.0000E+00,  8.0000E+00,  1.0000E+01,
           1.5000E+01,  2.0000E+01,  5.0000E+01,
 $END
 $GEOM
 RCHAMB=   2.7949E-01
 RTHRT=    1.8523E-01
 RNE=      1.1100E-01
 RTE=      1.1100E-01
 ALPHA=    3.0000E+01
 CHAMBL=   1.1828E+00
 XC=       9.6009E-01
 $END
 $CORE
 TYPE=    'LOL'
 NEL=          60
 FDJ=      6.6345E-02
 FCD=      9.1000E-01
 FIH=      1.1491E-01
 FIA=      3.0000E+01
 FCANT=    1.6000E+01
 FFACET=   2.8728E-01
 XDJ=      1.0172E-01
 XCD=      9.4000E-01
```

```
XIH=      1.7619E-01
XIA=      3.0000E+01
XCANT=    1.6000E+01
XFACET=   4.4047E-01
EMUNI=    6.5000E-01
$END
$BAFFLE
$END
$BARRIER
$END
$FFC
$END
$BURN
$END
$INJ
FMAND=    6.7076E+00
XMAND=    6.7076E+00
FMANL=    3.3538E+00
XMANL=    3.3538E+00
PCA=      2.1160E+03,  1.5347E+03,  7.6734E+02
$END
$CHAMBER
MUB=            3
T=        3.3000E-02
$END
$FDORC
NZON=           5
FTER=     20*1.0000E+00
$END
$MIX
 EM(1)= 6.930E-01,  1.000E+00
$END
$DEBUGC
DEBUG=    F
$END
$HIFIC
SHORT=    F
POC=      2.0000E-01,  2.0000E-01
$END
$DISTSDC
SHORT=    F
POC=      2.0000E-01,  2.0000E-01
PAMP=     2.0000E-01
MC=            11
LC=             6
MB=            11
LB=             6
IDMAX=         10
$END
$CRPC
NDPC=          16
NDTFQ=         16
NDTLF=       1000
NPRINT=        50
NSUMS=       3500
PAMPC=    2.0000E-01
NRAD=           3
NCIRC=          5
$END
$LEINJC
IDOMEM=         2
PAMPCH=   2.0000E-01
NTINJ=         16
USGF=     2.0000E-02
```

```
OGF=        2.0000E-02
DSGF=       2.0000E-02
FCDO=       1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XCDO=       1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
$END
$COMBUSTC
FALVM=      1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XALVM=      1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
FALTM=      1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XALTM=      1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
FRMM=       1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XRMM=       1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
EMMULT=     1.0000E+00,  1.0000E+00
COMBXB=     5.0000E-01
AOMULT=     1.0000E+00
CCMULT=     1.0000E+00
ENMULT=     1.0000E+00
TAUMULT=    1.0000E+00
$END
$FDORCC
SHORT=     F
EPSIL=      2.0000E+01
ERROR=      1.0000E-01
LTS=                 5
MTS=                 5
NTS=                10
ITMAX=             100
RELX=       6.5000E-01
NEET=                3
NXFST=               3
NYFST=               3
NAFST=               3
MORE=      F
$END

     END OF INPUT ECHO
```

STEADY STATE COMBUSTION ANALYSIS PROGRAM

RUN DESCRIPTORS

ROCCID POINT DESIGN TEST CASE 1
LOX/RP-1 LIKE DOUBLET PAIR WITH FIXED PC
APPROXIMATES .0100 SUBSCALE DOUBLET

PROPELLENT DESCRIPTION

FUEL=RP-1 Tman., F= 71.00
OX=LOX Tman., F=-279.00

CHAMBER GEOMETRY

CHAMBER RADIUS = 3.3539 IN.	THROAT RADIUS = 2.2228 IN.
CYLINDRICAL SECTION =11.5206 IN.	CONVERGENT SECTION LENGTH = 2.6730 IN.
NOZZLE ENTRANCE RADIUS OF CURVATURE = 1.3320 IN.	THROAT ENTRANCE RADIUS OF CURVATURE = 1.3320 IN.
CONVERGENCE HALF-ANGLE =30.0000 DEG.	CONTRACTION RATIO = 2.28

INJECTOR DATA

INJECTOR CORE CONTAINS 60 LOL ELEMENTS

FUEL SIDE:	Orifice Diam. =6.834E-02 In.	Cd =0.9100	Impingement Height =0.115 In.
	Impingement Half-angle =30.00 Deg.	Unlike Cant Angle =16.00 Deg.	Faceplate Thickness = 0.2873 In.
OX SIDE:	Orifice Diam. =1.017E-01 In.	Cd =0.9400	Impingement Height =0.176 In.
	Impingement Half-angle =30.00 Deg.	Unlike Cant Angle =16.00 Deg.	Faceplate Thickness = 0.4405 In.

MIXING EFFICIENCIES

CORE MIXING EFFICIENCY=0.8930 BARRIER MIXING EFFICIENCY=1.0000

COMBUST CONTROL PARAMETERS

MULTIPLIERS:	CORE	BAFFLE	BARRIER	FFC
FUEL ATOMIZATION LENGTH FOR VAPORIZATION:	1.000	1.000	1.000	1.000
OX ATOMIZATION LENGTH FOR VAPORIZATION:	1.000	1.000	1.000	1.000
FUEL ATOMIZATION LENGTH FOR TIMELAGS:	1.000	1.000	1.000	1.000
OX ATOMIZATION LENGTH FOR TIMELAGS:	1.000	1.000	1.000	1.000
FUEL DROPSIZE:	1.000	1.000	1.000	1.000
OX DROPSIZE:	1.000	1.000	1.000	1.000
MIXING (Em):	1.000		1.000	

AO-Multiplier=1.000 CC-Multiplier=1.000 N-Multiplier=1.000 Tau-Multiplier=1.000
Eta-C* for XB=0.500

```
BEGIN STEADY STATE COMBUSTION ANALYSIS
     PC=2118.00 PSIA


                    PROPELLANT PROPERTIES

FUEL=RP-1      Phase=Liquid                           Tman., F=  71.00
               Injected Density= 49.89 Lbm/Cu. Ft     Viscosity=1.380E-03 Lbm/Ft-S    Surface Tension=1.857E-03 Lbf/Ft

  OX=LOX       Phase=Liquid                           Tman., F=-279.00
               Injected Density= 70.18 Lbm/Cu. Ft     Viscosity=1.186E-04 Lbm/Ft-S    Surface Tension=7.328E-04 Lbf/Ft

                    OPERATING CONDITIONS

PC FACE=2118.00 PSIA     PC THROAT=2030.94     MIXTURE RATIO= 2.880
FUEL INJECTION PRESSURE DROP= 656.62 Psia      FUEL INJECTION VELOCITY= 349.73 Ft/S
  OX INJECTION PRESSURE DROP= 658.62 Psia        OX INJECTION VELOCITY= 294.66 Ft/S

   FUEL FLOWRATE=  45.732     OX FLOWRATE= 131.707

                    ATOMIZATION OUTPUT


      DROPSIZE MODEL=AEROJET

ELEMENT TYPE 1 IS LOL
FUEL:    ATOMIZATION LENGTH, In.=1.07694    ATOMIZATION LENGTH FOR VAPORIZATION, In.=1.07694    DROPLET RADIUS, Microns=  75.16
  OX:    ATOMIZATION LENGTH, In.=2.36005    ATOMIZATION LENGTH FOR VAPORIZATION, In.=2.36005    DROPLET RADIUS, Microns=  83.28
```

VAPORIZATION CALCULATIONS

X (in.)	CORE=LOL %FUEL VAP	CORE=LOL %OX VAP	BAFFLE= %FUEL VAP	BAFFLE= %OX VAP	BARRIER= %FUEL VAP	BARRIER= %OX VAP	FFC= %FUEL VAP	FFC= %OX VAP
0.0000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.2839	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.5677	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.8516	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.1355	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.4194	6.599	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.7032	16.464	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.9871	26.294	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2.2710	32.325	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2.5548	37.965	1.798	0.000	0.000	0.000	0.000	0.000	0.000
2.8387	42.919	27.016	0.000	0.000	0.000	0.000	0.000	0.000
3.1226	46.697	42.394	0.000	0.000	0.000	0.000	0.000	0.000
3.4065	50.475	52.613	0.000	0.000	0.000	0.000	0.000	0.000
3.6903	53.740	60.293	0.000	0.000	0.000	0.000	0.000	0.000
3.9742	56.574	66.206	0.000	0.000	0.000	0.000	0.000	0.000
4.2581	59.407	70.763	0.000	0.000	0.000	0.000	0.000	0.000
4.5420	61.724	74.721	0.000	0.000	0.000	0.000	0.000	0.000
4.8258	63.904	77.981	0.000	0.000	0.000	0.000	0.000	0.000
5.1097	66.064	80.468	0.000	0.000	0.000	0.000	0.000	0.000
5.3936	67.735	82.841	0.000	0.000	0.000	0.000	0.000	0.000
5.6774	69.406	84.534	0.000	0.000	0.000	0.000	0.000	0.000
5.9613	71.016	86.227	0.000	0.000	0.000	0.000	0.000	0.000
6.2452	72.468	87.914	0.000	0.000	0.000	0.000	0.000	0.000
6.5291	73.921	89.059	0.000	0.000	0.000	0.000	0.000	0.000
6.8129	75.239	90.203	0.000	0.000	0.000	0.000	0.000	0.000
7.0968	76.438	91.100	0.000	0.000	0.000	0.000	0.000	0.000
7.3807	77.637	91.996	0.000	0.000	0.000	0.000	0.000	0.000
7.6645	78.609	92.661	0.000	0.000	0.000	0.000	0.000	0.000
7.9484	79.517	93.325	0.000	0.000	0.000	0.000	0.000	0.000
8.2323	80.424	93.969	0.000	0.000	0.000	0.000	0.000	0.000
8.5162	81.296	94.490	0.000	0.000	0.000	0.000	0.000	0.000
8.8000	82.168	94.988	0.000	0.000	0.000	0.000	0.000	0.000
9.0839	82.970	95.486	0.000	0.000	0.000	0.000	0.000	0.000
9.3678	83.587	95.887	0.000	0.000	0.000	0.000	0.000	0.000
9.6516	84.205	96.285	0.000	0.000	0.000	0.000	0.000	0.000
9.9355	84.823	96.586	0.000	0.000	0.000	0.000	0.000	0.000
10.2194	85.440	96.886	0.000	0.000	0.000	0.000	0.000	0.000
10.5033	86.058	97.186	0.000	0.000	0.000	0.000	0.000	0.000
10.7871	86.675	97.389	0.000	0.000	0.000	0.000	0.000	0.000
11.0710	87.293	97.588	0.000	0.000	0.000	0.000	0.000	0.000
11.3549	87.907	97.788	0.000	0.000	0.000	0.000	0.000	0.000
11.6388	88.346	97.997	0.000	0.000	0.000	0.000	0.000	0.000
11.9226	88.813	98.215	0.000	0.000	0.000	0.000	0.000	0.000
12.2065	89.280	98.382	0.000	0.000	0.000	0.000	0.000	0.000
12.4904	89.748	98.538	0.000	0.000	0.000	0.000	0.000	0.000
12.7742	90.212	98.668	0.000	0.000	0.000	0.000	0.000	0.000
13.0581	90.577	98.798	0.000	0.000	0.000	0.000	0.000	0.000
13.3420	90.943	98.917	0.000	0.000	0.000	0.000	0.000	0.000
13.6259	91.309	99.028	0.000	0.000	0.000	0.000	0.000	0.000
13.9097	91.675	99.113	0.000	0.000	0.000	0.000	0.000	0.000
14.1936	92.030	99.191	0.000	0.000	0.000	0.000	0.000	0.000

OVERALL VAPORIZATION EFFICIENCIES

FUEL= 92.03%   OX= 99.19%

MASS DISTRIBUTION PROFILE

X (IN)	CORE (lbm/s) FUEL	CORE (lbm/s) OX	BARRIER (lbm/s) FUEL	BARRIER (lbm/s) OX	LOCAL VAPOR MIXTURE RATIO	ETA-C*
0.0000	0.000	0.000	0.000	0.000	0.00	0.0000
0.2839	0.000	0.000	0.000	0.000	0.00	0.0000
0.5677	0.000	0.000	0.000	0.000	0.00	0.0000
0.8516	0.000	0.000	0.000	0.000	0.00	0.0000
1.1355	0.000	0.000	0.000	0.000	0.00	0.0000
1.4194	3.933	0.000	0.000	0.000	0.00	0.0054
1.7032	8.453	0.000	0.000	0.000	0.00	0.0117
1.9871	12.025	0.000	0.000	0.000	0.00	0.0166
2.2710	14.783	0.000	0.000	0.000	0.00	0.0204
2.5548	17.362	2.369	0.000	0.000	0.14	0.0362
2.8387	19.628	35.582	0.000	0.000	1.81	0.3041
3.1226	21.355	55.835	0.000	0.000	2.61	0.4361
3.4065	23.083	69.296	0.000	0.000	3.00	0.5149
3.6903	24.576	79.410	0.000	0.000	3.23	0.5734
3.9742	25.872	87.198	0.000	0.000	3.37	0.6193
4.2581	27.168	93.199	0.000	0.000	3.43	0.6574
4.5420	28.227	98.412	0.000	0.000	3.49	0.6897
4.8258	29.224	102.707	0.000	0.000	3.51	0.7176
5.1097	30.212	105.982	0.000	0.000	3.51	0.7410
5.3936	30.976	109.108	0.000	0.000	3.52	0.7616
5.6774	31.741	111.338	0.000	0.000	3.51	0.7795
5.9613	32.476	113.567	0.000	0.000	3.50	0.7950
6.2452	33.141	115.789	0.000	0.000	3.49	0.8109
6.5291	33.805	117.297	0.000	0.000	3.47	0.8237
6.8129	34.408	118.804	0.000	0.000	3.45	0.8358
7.0968	34.956	119.985	0.000	0.000	3.43	0.8461
7.3807	35.504	121.165	0.000	0.000	3.41	0.8563
7.6645	35.949	122.041	0.000	0.000	3.39	0.8643
7.9484	36.364	122.915	0.000	0.000	3.38	0.8719
8.2323	36.779	123.790	0.000	0.000	3.37	0.8796
8.5162	37.178	124.449	0.000	0.000	3.35	0.8862
8.8000	37.577	125.105	0.000	0.000	3.33	0.8928
9.0839	37.943	125.761	0.000	0.000	3.31	0.8991
9.3678	38.226	126.290	0.000	0.000	3.30	0.9040
9.6516	38.508	126.814	0.000	0.000	3.29	0.9089
9.9355	38.791	127.213	0.000	0.000	3.28	0.9133
10.2194	39.073	127.608	0.000	0.000	3.27	0.9176
10.5033	39.356	128.000	0.000	0.000	3.25	0.9219
10.7871	39.638	128.269	0.000	0.000	3.24	0.9257
11.0710	39.920	128.531	0.000	0.000	3.22	0.9294
11.3549	40.201	128.793	0.000	0.000	3.20	0.9332
11.6388	40.402	129.068	0.000	0.000	3.19	0.9362
11.9226	40.616	129.356	0.000	0.000	3.18	0.9394
12.2065	40.829	129.578	0.000	0.000	3.17	0.9423
12.4904	41.043	129.781	0.000	0.000	3.16	0.9451
12.7742	41.255	129.953	0.000	0.000	3.15	0.9478
13.0581	41.422	130.124	0.000	0.000	3.14	0.9501
13.3420	41.590	130.280	0.000	0.000	3.13	0.9523
13.6259	41.757	130.427	0.000	0.000	3.12	0.9544
13.9097	41.924	130.538	0.000	0.000	3.11	0.9564
14.1936	42.087	130.641	0.000	0.000	3.10	0.9583

AXIAL PRESSURE PROFILE

X (in)	MACH #	Ptotal (psia)	Pstatic (psia)	Ttotal (R)	Tstatic (R)	Wdot (Lbm/s)	Local Radius (in)
1.21	0.000	2118.69	2118.66	1691.89	1685.35	0.66	3.354
1.51	0.004	2118.68	2118.63	1696.04	1689.48	5.49	3.354
1.81	0.007	2118.64	2118.56	1691.89	1685.34	9.62	3.354
2.11	0.010	2118.58	2118.49	1769.84	1762.99	13.61	3.354
2.42	0.010	2118.57	2118.42	1691.89	1685.34	14.42	3.354
2.72	0.042	2116.54	2115.96	3878.22	3860.90	38.99	3.354
3.02	0.103	2106.14	2094.46	6861.55	6832.61	71.07	3.354
3.32	0.130	2098.70	2079.49	6858.99	6827.60	88.15	3.354
3.62	0.151	2092.03	2066.00	6859.75	6826.98	101.56	3.354
3.93	0.167	2086.39	2054.86	6846.01	6812.13	111.67	3.354
4.23	0.179	2081.52	2044.67	6837.01	6802.17	119.65	3.354
4.53	0.190	2077.14	2035.75	6828.22	6792.50	126.39	3.354
4.83	0.199	2073.25	2027.61	6823.88	6787.16	132.03	3.354
5.13	0.207	2069.97	2021.10	6824.59	6787.33	136.64	3.354
5.44	0.214	2066.95	2014.01	6822.59	6784.64	140.58	3.354
5.74	0.219	2064.51	2009.02	6825.20	6786.61	143.69	3.354
6.04	0.224	2061.96	2004.00	6826.33	6787.31	146.69	3.354
6.34	0.229	2059.64	1999.01	6827.80	6789.28	149.72	3.354
6.64	0.233	2057.73	1995.98	6831.88	6791.55	151.97	3.354
6.95	0.237	2055.95	1992.31	6834.28	6793.86	154.05	3.354
7.25	0.240	2054.34	1988.88	6837.82	6796.81	155.86	3.354
7.55	0.243	2052.91	1986.04	6840.60	6799.34	157.49	3.354
7.85	0.245	2051.71	1983.55	6842.40	6800.95	158.83	3.354
8.15	0.248	2050.44	1980.94	6843.64	6802.09	160.23	3.354
8.46	0.250	2049.36	1978.70	6845.71	6803.69	161.41	3.354
8.76	0.252	2048.33	1976.96	6847.67	6805.39	162.52	3.354
9.06	0.254	2047.30	1974.43	6849.30	6806.78	163.63	3.354
9.36	0.256	2046.48	1972.73	6850.46	6807.73	164.50	3.354
9.66	0.257	2045.67	1971.06	6851.59	6808.67	165.35	3.354
9.97	0.259	2044.98	1969.69	6853.06	6809.96	166.07	3.354
10.27	0.260	2044.28	1968.16	6854.49	6811.22	166.80	3.354
10.57	0.261	2043.61	1966.77	6855.98	6812.64	167.49	3.354
10.87	0.262	2043.04	1965.60	6857.74	6814.15	168.07	3.354
11.17	0.264	2042.46	1964.37	6859.54	6815.78	168.65	3.354
11.48	0.264	2041.92	1963.27	6860.78	6816.90	169.20	3.354
11.78	0.270	2041.41	1959.73	6860.88	6815.89	169.72	3.330
12.08	0.289	2040.88	1946.95	6860.91	6810.80	170.22	3.228
12.38	0.326	2040.31	1921.69	6860.94	6800.49	170.67	3.064
12.68	0.375	2039.60	1884.29	6860.97	6784.70	171.09	2.889
12.99	0.437	2038.78	1830.58	6860.99	6761.62	171.46	2.714
13.29	0.523	2037.70	1747.48	6861.01	6724.48	171.81	2.540
13.59	0.654	2036.14	1602.15	6861.03	6655.42	172.15	2.368
13.89	0.817	2033.96	1402.87	6861.06	6551.66	172.45	2.257
14.19	0.999	2030.94	1172.79	6861.08	6419.51	172.73	2.223

PERFORMANCE SUMMARY

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              C* EFFICIENCY CALCULATIONS (ODK)

INJECTED MR= 2.8800     CSTAR=5860.40     CORE Em=0.8930     BARRIER Em=1.0000
CORE:          OVERALL MR= 2.8800     VAPOR MR= 3.1041     CSTAR-MIX=5769.16     MASS FRACTION= 1.0000
BARRIER:       OVERALL MR= 0.0000     VAPOR MR=99.9000     CSTAR-MIX=    0.00    MASS FRACTION= 0.0000
ENGINE:        OVERALL MR= 2.8800     VAPOR MR= 3.1041     CSTAR-DEL=5615.99
C* EFFICIENCY = 9.583E-01

              ISP EFFICIENCY CALCULATIONS

ISP-ODK, INJ = 2.669E+02 SEC.
ISP-ODK, M.Z. INJ = 2.652E+02 SEC.          ISP-ODK, M.Z. VAPOR = 2.628E+02 SEC.
VAPORIZATION EFFICIENCY = 9.647E-01         MIXING EFFICIENCY = 9.935E-01
ENERGY RELEASE EFFICIENCY = 9.584E-01

NOTE: ISP-DEL = ISP-ODK, INJ. * ERE * ETADIV - DELISP-BL
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                    TIME-LAG CALCULATIONS, Milliseconds

Coham, In.=9.164E-03     FUEL Cohem, In.=2.293E+02     OX Cohem, In.=8.194E+01


ELEMENT 1 IS TYPE=LOL
FUEL:     Cinj, In.=1.564E-02     Lvap, In.= 0.566     ATOMIZATION LENGTH USED, In.= 1.077E+00
          Timp=3.162E-02     Tatom=2.566E-01     Tvap=1.348E-01     Total=4.230E-01

  OX:     Cinj, In.=1.596E-02     Lvap, In.= 0.206     ATOMIZATION LENGTH USED, In.= 2.360E+00
          Timp=5.749E-02     Tatom=6.669E-01     Tvap=5.833E-02     Total=7.828E-01

                    EFFECTIVE TIMELAGS, Milliseconds

FUEL:     Cinj, In.=1.564E-02     Lvap, In.= 0.566
          Timp=3.162E-02     Tatom=2.566E-01     Tvap=1.348E-01     Total=4.230E-01

  OX:     Cinj, In.=1.596E-02     Lvap, In.= 0.206
          Timp=5.749E-02     Tatom=6.669E-01     Tvap=5.833E-02     Total=7.828E-01
```

CHAMBER-NOZZLE OPTIMIZATION RESULTS

CHAMBER LENGTH (FEET)	ETA-C*	ETA-NOZ	OVERALL EFFICIENCY
0.0000	0.0000	0.8807	0.0000
0.1667	0.0168	0.8726	0.0146
0.3333	0.6227	0.8646	0.5384
0.5000	0.7972	0.8537	0.6805
0.6667	0.8733	0.8419	0.7353
0.8333	0.9142	0.8302	0.7590
1.0000	0.9402	0.8185	0.7696
1.1667	0.9570	0.8057	0.7711
1.3333	0.9704	0.7915	0.7681
1.5000	0.9838	0.7773	0.7647
1.6667	0.9972	0.7631	0.7610
1.8333	1.0000	0.7465	0.7465
2.0000	1.0000	0.7299	0.7299
2.1667	1.0000	0.7114	0.7114
2.3333	1.0000	0.6928	0.6928
2.5000	1.0000	0.6742	0.6742
2.6667	1.0000	0.6461	0.6461
2.8333	1.0000	0.6142	0.6142
3.0000	1.0000	0.5823	0.5823
3.1667	1.0000	0.5504	0.5504
3.3333	1.0000	0.5071	0.5071
3.5000	1.0000	0.4439	0.4439
3.6667	1.0000	0.3808	0.3808
3.8333	1.0000	0.3176	0.3176
4.0000	1.0000	0.2544	0.2544

OPTIMUM CHAMBER LENGTH= 1.1667 FT
MAXIMUM OVERALL EFFICIENCY= 0.7711

REDESIGNED CHAMBER RESULTS

NOMINAL CHAMBER PRESSURE	=	2.116E+03 PSIA
THROTTLED CHAMBER PRESSURE	=	1.535E+03 PSIA
FUEL INJECTION PRESSURE DROP	=	6.586E+02 PSI
OX INJECTION PRESSURE DROP	=	6.586E+02 PSI
CHAMBER RADIUS	=	2.796E-01 FT
THROAT RADIUS	=	1.852E-01 FT
NOZZLE ENTRANCE RADIUS OF CURVATURE	=	1.110E-01 FT
THROAT ENTRANCE RADIUS OF CURVATURE	=	1.110E-01 FT
NOZZLE CONVERGENCE HALF-ANGLE	=	3.000E+01 DEG
INJECTOR-TO-THROAT CHAMBER LENGTH	=	1.166E+00 FT
BARREL SECTION LENGTH	=	9.646E-01 FT

IMPINGING ELEMENT SIZING RESULTS

ELEMENT TYPE	=	LOL
NO. OF ELEMENTS	=	60
FUEL ORIFICE DIAMETER	=	6.634E-02 IN
OX ORIFICE DIAMETER	=	1.017E-01 IN

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DIRECT INPUT ECHO FROM SUBROUTINE PINPUT

                              ROCCID
          ROCket Combustor Interactive Design Methodology
                         Version 23-FEB-91

ROCCID POINT DESIGN TEST CASE 1
LOX/RP-1 LIKE DOUBLET PAIR WITH FIXED PC
APPROXIMATES -0100 SUBSCALE DOUBLET
 $MODELS
 MCHAM=        1
 MBURN=        2
 MINJ=         1
 $END
 $OPCOND
 PISPA=     8.9600E+01,  1.0940E+02,  1.3940E+02,  1.5880E+02,  1.7780E+02,
            2.0970E+02,  2.3550E+02,  2.5470E+02,  2.6700E+02,  2.7040E+02,
            2.7160E+02,  2.7190E+02,  2.7130E+02,  2.6980E+02,  2.6820E+02,
            2.6660E+02,  2.6500E+02,  2.6210E+02,  2.5920E+02,  2.5630E+02,
            2.5060E+02,  2.3840E+02,  2.2750E+02,  2.1100E+02,  2.0140E+02,
            1.5560E+02,  1.0970E+02,  8.0000E+01,
 PCSA=      1.7760E+03,  2.4560E+03,  3.4870E+03,  4.0740E+03,  4.5800E+03,
            5.0700E+03,  5.4540E+03,  5.7340E+03,  5.9060E+03,  5.9810E+03,
            5.9690E+03,  5.9540E+03,  5.9340E+03,  5.9090E+03,  5.8820E+03,
            5.8550E+03,  5.8260E+03,  5.7590E+03,  5.7000E+03,  5.6430E+03,
            5.5320E+03,  5.2750E+03,  5.0470E+03,  4.6760E+03,  4.4200E+03,
            3.4570E+03,  2.4940E+03,  1.4650E+03,
 FUEL=    'RP-1     '
 OX=      'LOX      '
 PC=        2.1160E+03
 XMR=       2.8800E+00
 FTMAN=     7.1000E+01
 XTMAN=    -2.7900E+02
 EMMAN=     1.0000E+00
 NPERFP=        28
 PMRA=      1.0000E-01,  3.0000E-01,  5.0000E-01,  8.0000E-01,  1.0000E+00,
            1.2500E+00,  1.5000E+00,  1.7500E+00,  2.0000E+00,  2.2000E+00,
            2.4000E+00,  2.5000E+00,  2.6000E+00,  2.7000E+00,  2.8000E+00,
            2.9000E+00,  3.0000E+00,  3.2000E+00,  3.4000E+00,  3.6000E+00,
            4.0000E+00,  5.0000E+00,  6.0000E+00,  8.0000E+00,  1.0000E+01,
            1.5000E+01,  2.0000E+01,  5.0000E+01,
 $END
 $GEOM
 RCHAMB=    2.7949E-01
 RTHRT=     1.8523E-01
 RNE=       1.1100E-01
 RTE=       1.1100E-01
 ALPHA=     3.0000E+01
 CHAMBL=    1.1875E+00
 XC=        9.6477E-01
 $END
 $CORE
 TYPE=    'LOL'
 NEL=           60
 FDJ=       5.6345E-02
 FCD=       9.1000E-01
 FIH=       1.1491E-01
 FIA=       3.0000E+01
 FCANT=     1.6000E+01
 FFACET=    2.8728E-01
 XDJ=       1.0172E-01
 XCD=       9.4000E-01
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 XIH=       1.7619E-01
 XIA=       3.0000E+01
 XCANT=     1.6000E+01
 XFACET=    4.4047E-01
 EMUNI=     6.5000E-01
 $END
 $BAFFLE
 $END
 $BARRIER
 $END
 $FFC
 $END
 $BURN
 $END
 $INJ
 FMAND=     6.7076E+00
 XMAND=     6.7076E+00
 FMANL=     3.3538E+00
 XMANL=     3.3538E+00
 PCA=       2.1160E+03,  1.5347E+03,  7.6734E+02
 $END
 $CHAMBER
 MUB=             3
 T=         3.3000E-02
 $END
 $FDORC
 NZON=            5
 FTER=    20*1.0000E+00
 $END
 $MIX
  EM(1)= 6.930E-01,  1.000E+00
 $END
 $DEBUGC
 DEBUG=    F
 $END
 $HIFIC
 SHORT=    F
 POC=       2.0000E-01,  2.0000E-01
 $END
 $DIST3DC
 SHORT=    F
 POC=       2.0000E-01,  2.0000E-01
 PAMP=      2.0000E-01
 MC=             11
 LC=              6
 MB=             11
 LB=              6
 IDMAX=          10
 $END
 $CRPC
 NDPC=           16
 NDTFQ=          16
 NDTLF=        1000
 NPRINT=         50
 NSUMS=        3500
 PAMPC=     2.0000E-01
 NRAD=            3
 NCIRC=           5
 $END
 $LEINJC
 IDOMEM=          2
 PAMPCH=    2.0000E-01
 NTINJ=          16
 USGF=      2.0000E-02
```

```
OGF=       2.0000E-02
DSGF=      2.0000E-02
FCDO=      1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XCDO=      1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
$END
$COMBUSTC
FALVM=     1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XALVM=     1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
FALTM=     1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XALTM=     1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
FRMM=      1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XRMM=      1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
EMMULT=    1.0000E+00,  1.0000E+00
COMBXB=    5.0000E-01
AOMULT=    1.0000E+00
CCMULT=    1.0000E+00
ENMULT=    1.0000E+00
TAUMULT=   1.0000E+00
$END
$FDORCC
SHORT=    F
EPSIL=     2.0000E+01
ERROR=     1.0000E-01
LTS=             5
MTS=             5
NTS=            10
ITMAX=         100
RELX=      6.5000E-01
NEET=            3
NXFST=           3
NYFST=           3
NAFST=           3
MORE=     F
$END

    END OF INPUT ECHO
```

STEADY STATE COMBUSTION ANALYSIS PROGRAM

RUN DESCRIPTORS

ROCCID POINT DESIGN TEST CASE 1
LOX/RP-1 LIKE DOUBLET PAIR WITH FIXED PC
APPROXIMATES -0100 SUBSCALE DOUBLET

PROPELLENT DESCRIPTION

FUEL=RP-1	Tman., F= 71.00
OX=LOX	Tman., F=-279.00

CHAMBER GEOMETRY

CHAMBER RADIUS = 3.3539 IN.	THROAT RADIUS = 2.2228 IN.
CYLINDRICAL SECTION =11.5770 IN.	CONVERGENT SECTION LENGTH = 2.6730 IN.
NOZZLE ENTRANCE RADIUS OF CURVATURE = 1.3320 IN.	THROAT ENTRANCE RADIUS OF CURVATURE = 1.3320 IN.
CONVERGENCE HALF-ANGLE =30.0000 DEG.	CONTRACTION RATIO = 2.28

INJECTOR DATA

INJECTOR CORE CONTAINS 60 LOL ELEMENTS

FUEL SIDE:	Orifice Diam. =6.634E-02 In.	Cd =0.9100	Impingement Height =0.115 In.
	Impingement Half-angle =30.00 Deg.	Unlike Cant Angle =16.00 Deg.	Faceplate Thickness = 0.2873 In.
OX SIDE:	Orifice Diam. =1.017E-01 In.	Cd =0.9400	Impingement Height =0.176 In.
	Impingement Half-angle =30.00 Deg.	Unlike Cant Angle =16.00 Deg.	Faceplate Thickness = 0.4405 In.

MIXING EFFICIENCIES

CORE MIXING EFFICIENCY=0.8930 BARRIER MIXING EFFICIENCY=1.0000

COMBUST CONTROL PARAMETERS

MULTIPLIERS:	CORE	BAFFLE	BARRIER	FFC
FUEL ATOMIZATION LENGTH FOR VAPORIZATION:	1.000	1.000	1.000	1.000
OX ATOMIZATION LENGTH FOR VAPORIZATION:	1.000	1.000	1.000	1.000
FUEL ATOMIZATION LENGTH FOR TIMELAGS:	1.000	1.000	1.000	1.000
OX ATOMIZATION LENGTH FOR TIMELAGS:	1.000	1.000	1.000	1.000
FUEL DROPSIZE:	1.000	1.000	1.000	1.000
OX DROPSIZE:	1.000	1.000	1.000	1.000
MIXING (Em):	1.000		1.000	

AO-Multiplier=1.000 CC-Multiplier=1.000 N-Multiplier=1.000 Tau-Multiplier=1.000
Eta-C* for XB=0.500

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           BEGIN STEADY STATE COMBUSTION ANALYSIS
                PC=2116.00 PSIA


                         PROPELLANT PROPERTIES

FUEL=RP-1      Phase=Liquid                             Tman., F=  71.00
               Injected Density= 49.89 Lbm/Cu. Ft       Viscosity=1.380E-03 Lbm/Ft-S     Surface Tension=1.657E-03 Lbf/Ft

  OX=LOX       Phase=Liquid                             Tman., F=-279.00
               Injected Density= 70.18 Lbm/Cu. Ft       Viscosity=1.166E-04 Lbm/Ft-S     Surface Tension=7.326E-04 Lbf/Ft

                         OPERATING CONDITIONS

PC FACE=2116.00 PSIA     PC THROAT=2031.07      MIXTURE RATIO= 2.880
FUEL INJECTION PRESSURE DROP= 658.47 Psia       FUEL INJECTION VELOCITY= 349.70 Ft/S
  OX INJECTION PRESSURE DROP= 658.47 Psia         OX INJECTION VELOCITY= 294.85 Ft/S

    FUEL FLOWRATE=  45.721      OX FLOWRATE= 131.677

                         ATOMIZATION OUTPUT


         DROPSIZE MODEL=AEROJET

ELEMENT TYPE 1 IS LOL
FUEL:     ATOMIZATION LENGTH, In.=1.07692     ATOMIZATION LENGTH FOR VAPORIZATION, In.=1.07692     DROPLET RADIUS, Microns=  75.16
  OX:     ATOMIZATION LENGTH, In.=2.36002     ATOMIZATION LENGTH FOR VAPORIZATION, In.=2.36002     DROPLET RADIUS, Microns=  83.28
```

VAPORIZATION CALCULATIONS

X (In.)	CORE=LOL %FUEL VAP	CORE=LOL %OX VAP	BAFFLE= %FUEL VAP	BAFFLE= %OX VAP	BARRIER= %FUEL VAP	BARRIER= %OX VAP	FFC= %FUEL VAP	FFC= %OX VAP
0.0000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.2850	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.5700	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.8550	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.1400	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.4250	6.846	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.7100	16.674	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.9950	26.464	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2.2800	32.518	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2.5650	38.161	3.124	0.000	0.000	0.000	0.000	0.000	0.000
2.8500	43.071	27.675	0.000	0.000	0.000	0.000	0.000	0.000
3.1350	46.864	42.849	0.000	0.000	0.000	0.000	0.000	0.000
3.4200	50.658	52.986	0.000	0.000	0.000	0.000	0.000	0.000
3.7050	53.888	60.604	0.000	0.000	0.000	0.000	0.000	0.000
3.9900	56.733	66.463	0.000	0.000	0.000	0.000	0.000	0.000
4.2750	59.578	71.002	0.000	0.000	0.000	0.000	0.000	0.000
4.5600	61.864	74.931	0.000	0.000	0.000	0.000	0.000	0.000
4.8450	64.053	78.151	0.000	0.000	0.000	0.000	0.000	0.000
5.1300	66.165	80.641	0.000	0.000	0.000	0.000	0.000	0.000
5.4150	67.863	82.970	0.000	0.000	0.000	0.000	0.000	0.000
5.7000	69.541	84.670	0.000	0.000	0.000	0.000	0.000	0.000
5.9850	71.138	86.370	0.000	0.000	0.000	0.000	0.000	0.000
6.2700	72.597	88.015	0.000	0.000	0.000	0.000	0.000	0.000
6.5550	74.056	89.165	0.000	0.000	0.000	0.000	0.000	0.000
6.8400	75.355	90.290	0.000	0.000	0.000	0.000	0.000	0.000
7.1250	76.559	91.190	0.000	0.000	0.000	0.000	0.000	0.000
7.4100	77.762	92.066	0.000	0.000	0.000	0.000	0.000	0.000
7.6950	78.708	92.733	0.000	0.000	0.000	0.000	0.000	0.000
7.9800	79.619	93.400	0.000	0.000	0.000	0.000	0.000	0.000
8.2650	80.526	94.050	0.000	0.000	0.000	0.000	0.000	0.000
8.5500	81.401	94.550	0.000	0.000	0.000	0.000	0.000	0.000
8.8350	82.277	95.050	0.000	0.000	0.000	0.000	0.000	0.000
9.1200	83.050	95.540	0.000	0.000	0.000	0.000	0.000	0.000
9.4050	83.670	95.940	0.000	0.000	0.000	0.000	0.000	0.000
9.6900	84.290	96.330	0.000	0.000	0.000	0.000	0.000	0.000
9.9750	84.910	96.630	0.000	0.000	0.000	0.000	0.000	0.000
10.2600	85.530	96.930	0.000	0.000	0.000	0.000	0.000	0.000
10.5450	86.150	97.220	0.000	0.000	0.000	0.000	0.000	0.000
10.8300	86.770	97.420	0.000	0.000	0.000	0.000	0.000	0.000
11.1150	87.390	97.620	0.000	0.000	0.000	0.000	0.000	0.000
11.4000	87.975	97.820	0.000	0.000	0.000	0.000	0.000	0.000
11.6850	88.413	98.029	0.000	0.000	0.000	0.000	0.000	0.000
11.9700	88.882	98.239	0.000	0.000	0.000	0.000	0.000	0.000
12.2550	89.351	98.407	0.000	0.000	0.000	0.000	0.000	0.000
12.5400	89.820	98.558	0.000	0.000	0.000	0.000	0.000	0.000
12.8250	90.270	98.689	0.000	0.000	0.000	0.000	0.000	0.000
13.1100	90.637	98.819	0.000	0.000	0.000	0.000	0.000	0.000
13.3950	91.005	98.935	0.000	0.000	0.000	0.000	0.000	0.000
13.6800	91.372	99.047	0.000	0.000	0.000	0.000	0.000	0.000
13.9650	91.739	99.126	0.000	0.000	0.000	0.000	0.000	0.000
14.2500	92.079	99.205	0.000	0.000	0.000	0.000	0.000	0.000

OVERALL VAPORIZATION EFFICIENCIES
FUEL= 92.08% OX= 99.20%

MASS DISTRIBUTION PROFILE

X (IN)	CORE (lbm/s) FUEL	CORE (lbm/s) OX	BARRIER (lbm/s) FUEL	BARRIER (lbm/s) OX	LOCAL VAPOR MIXTURE RATIO	ETA-C*
0.0000	0.000	0.000	0.000	0.000	0.00	0.0000
0.2850	0.000	0.000	0.000	0.000	0.00	0.0000
0.5700	0.000	0.000	0.000	0.000	0.00	0.0000
0.8550	0.000	0.000	0.000	0.000	0.00	0.0000
1.1400	0.000	0.000	0.000	0.000	0.00	0.0000
1.4250	4.045	0.000	0.000	0.000	0.00	0.0056
1.7100	8.538	0.000	0.000	0.000	0.00	0.0118
1.9950	12.099	0.000	0.000	0.000	0.00	0.0167
2.2800	14.866	0.000	0.000	0.000	0.00	0.0205
2.5650	17.446	4.114	0.000	0.000	0.24	0.0468
2.8500	19.692	36.442	0.000	0.000	1.85	0.3105
3.1350	21.427	56.422	0.000	0.000	2.63	0.4396
3.4200	23.161	69.770	0.000	0.000	3.01	0.5178
3.7050	24.636	79.602	0.000	0.000	3.24	0.5756
3.9900	25.939	87.516	0.000	0.000	3.37	0.6214
4.2750	27.240	93.493	0.000	0.000	3.43	0.6595
4.5600	28.285	98.667	0.000	0.000	3.49	0.6915
4.8450	29.286	102.907	0.000	0.000	3.51	0.7192
5.1300	30.260	106.185	0.000	0.000	3.51	0.7425
5.4150	31.026	109.253	0.000	0.000	3.52	0.7629
5.7000	31.795	111.491	0.000	0.000	3.51	0.7798
5.9850	32.525	113.729	0.000	0.000	3.50	0.7964
6.2700	33.192	115.695	0.000	0.000	3.49	0.8120
6.5550	33.859	117.409	0.000	0.000	3.47	0.8248
6.8400	34.463	118.691	0.000	0.000	3.45	0.8368
7.1250	35.003	120.076	0.000	0.000	3.43	0.8471
7.4100	35.554	121.230	0.000	0.000	3.41	0.8573
7.6950	35.986	122.108	0.000	0.000	3.39	0.8651
7.9800	36.403	122.986	0.000	0.000	3.38	0.8728
8.2650	36.817	123.642	0.000	0.000	3.36	0.8804
8.5500	37.216	124.500	0.000	0.000	3.35	0.8870
8.8350	37.616	125.158	0.000	0.000	3.33	0.8936
9.1200	37.971	125.803	0.000	0.000	3.31	0.8997
9.4050	38.255	126.330	0.000	0.000	3.30	0.9046
9.6900	38.536	126.844	0.000	0.000	3.29	0.9095
9.9750	38.822	127.239	0.000	0.000	3.28	0.9139
10.2600	39.105	127.634	0.000	0.000	3.26	0.9182
10.5450	39.389	128.016	0.000	0.000	3.25	0.9225
10.8300	39.672	128.279	0.000	0.000	3.23	0.9263
11.1150	39.956	128.542	0.000	0.000	3.22	0.9300
11.4000	40.223	128.806	0.000	0.000	3.20	0.9336
11.6850	40.423	129.081	0.000	0.000	3.19	0.9367
11.9700	40.636	129.358	0.000	0.000	3.18	0.9398
12.2550	40.852	129.579	0.000	0.000	3.17	0.9427
12.5400	41.067	129.778	0.000	0.000	3.16	0.9456
12.8250	41.272	129.950	0.000	0.000	3.15	0.9482
13.1100	41.440	130.122	0.000	0.000	3.14	0.9504
13.3950	41.608	130.275	0.000	0.000	3.13	0.9526
13.6800	41.776	130.422	0.000	0.000	3.12	0.9548
13.9650	41.944	130.526	0.000	0.000	3.11	0.9567
14.2500	42.099	130.629	0.000	0.000	3.10	0.9586

AXIAL PRESSURE PROFILE

X (in)	MACH #	Ptotal (psia)	Pstatic (psia)	Ttotal (R)	Tstatic (R)	Wdot (Lbm/s)	Local Radius (in)
1.20	0.000	2118.69	2119.65	1691.89	1685.41	0.59	3.354
1.30	0.001	2118.69	2119.64	1691.89	1685.41	1.99	3.354
1.61	0.005	2118.66	2119.59	1696.27	1689.78	7.02	3.354
1.91	0.008	2118.62	2119.51	1691.89	1685.41	11.01	3.354
2.21	0.010	2118.56	2119.39	1747.29	1740.60	14.53	3.354
2.51	0.013	2118.49	2119.26	1691.89	1685.40	18.01	3.354
2.81	0.065	2113.63	2109.53	5194.34	5173.41	51.27	3.354
3.11	0.112	2103.85	2089.87	6788.26	6758.52	76.48	3.354
3.41	0.137	2096.60	2075.26	6861.19	6829.62	92.55	3.354
3.71	0.156	2090.31	2062.52	6856.63	6823.79	104.72	3.354
4.01	0.171	2084.92	2051.58	6842.59	6808.69	114.13	3.354
4.32	0.183	2080.22	2042.04	6834.93	6800.09	121.66	3.354
4.62	0.193	2075.99	2033.41	6826.31	6790.82	128.07	3.354
4.92	0.202	2072.30	2025.87	6823.87	6787.40	133.34	3.354
5.22	0.209	2069.10	2019.33	6824.00	6786.64	137.69	3.354
5.52	0.215	2066.26	2013.51	6823.08	6785.30	141.45	3.354
5.82	0.220	2063.84	2008.54	6825.78	6787.45	144.52	3.354
6.12	0.226	2061.31	2003.35	6826.49	6787.59	147.68	3.354
6.42	0.230	2059.13	1998.88	6828.92	6789.52	150.30	3.354
6.72	0.234	2057.25	1994.99	6832.30	6792.44	152.52	3.354
7.02	0.238	2055.55	1991.50	6835.13	6794.88	154.48	3.354
7.33	0.241	2053.94	1988.18	6838.55	6797.90	156.31	3.354
7.63	0.244	2052.61	1985.43	6841.10	6800.13	157.80	3.354
7.93	0.246	2051.40	1982.94	6842.76	6801.50	159.15	3.354
8.23	0.249	2050.17	1980.38	6844.28	6802.73	160.51	3.354
8.53	0.251	2049.12	1978.22	6846.20	6804.39	161.64	3.354
8.83	0.253	2048.09	1976.07	6848.12	6806.06	162.76	3.354
9.13	0.255	2047.10	1974.04	6849.59	6807.28	163.81	3.354
9.43	0.256	2046.30	1972.38	6850.72	6808.22	164.66	3.354
9.73	0.258	2045.52	1970.75	6851.92	6809.22	165.49	3.354
10.04	0.259	2044.84	1969.34	6853.40	6810.53	166.20	3.354
10.34	0.260	2044.14	1967.89	6854.82	6811.78	166.92	3.354
10.64	0.261	2043.49	1966.54	6856.37	6813.16	167.59	3.354
10.94	0.263	2042.93	1965.38	6858.13	6814.77	168.16	3.354
11.24	0.264	2042.36	1964.15	6859.89	6816.37	168.74	3.354
11.54	0.265	2041.84	1963.11	6860.86	6817.23	169.26	3.354
11.84	0.270	2041.34	1959.41	6860.88	6816.00	169.78	3.328
12.14	0.290	2040.82	1946.44	6860.91	6810.89	170.27	3.225
12.44	0.327	2040.25	1920.98	6860.94	6800.44	170.71	3.061
12.74	0.376	2039.56	1883.50	6860.97	6784.71	171.12	2.886
13.05	0.438	2038.73	1829.82	6860.99	6761.49	171.49	2.712
13.35	0.524	2037.68	1746.33	6861.02	6724.23	171.83	2.539
13.65	0.655	2036.12	1600.73	6861.04	6654.99	172.16	2.367
13.95	0.818	2033.99	1402.09	6861.06	6551.43	172.46	2.257
14.25	0.999	2031.07	1172.87	6861.09	6419.51	172.73	2.223

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                PERFORMANCE SUMMARY

               C* EFFICIENCY CALCULATIONS (ODK)

INJECTED MR= 2.8800    CSTAR=5860.40     CORE Em=0.8930     BARRIER Em=1.0000
CORE:        OVERALL MR= 2.8800     VAPOR MR= 3.1029     CSTAR-MIX=5769.49     MASS FRACTION= 1.0000
BARRIER:     OVERALL MR= 0.0000     VAPOR MR=99.9000     CSTAR-MIX=    0.00    MASS FRACTION= 0.0000
ENGINE:      OVERALL MR= 2.8800     VAPOR MR= 3.1029     CSTAR-DEL=5617.84
C* EFFICIENCY = 9.586E-01

               ISP EFFICIENCY CALCULATIONS

ISP-ODK, INJ = 2.669E+02 SEC.
ISP-ODK, M.Z. INJ = 2.652E+02 SEC.          ISP-ODK, M.Z. VAPOR = 2.628E+02 SEC.
VAPORIZATION EFFICIENCY = 9.650E-01         MIXING EFFICIENCY = 9.935E-01
ENERGY RELEASE EFFICIENCY = 9.587E-01

NOTE: ISP-DEL = ISP-ODK, INJ. * ERE * ETADIV - DELISP-BL
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                         TIME-LAG CALCULATIONS, Milliseconds

Cohem, In.=9.164E-03     FUEL Cohem, In.=2.293E+02     OX Cohem, In.=6.194E+01

ELEMENT 1 IS TYPE=LOL
FUEL:      Cinj, In.=1.563E-02     Lvap, In.= 0.566     ATOMIZATION LENGTH USED, In.= 1.077E+00
           Timp=3.162E-02     Tatom=2.566E-01     Tvap=1.348E-01     Total=4.231E-01

  OX:      Cinj, In.=1.596E-02     Lvap, In.= 0.206     ATOMIZATION LENGTH USED, In.= 2.360E+00
           Timp=5.750E-02     Tatom=6.670E-01     Tvap=5.833E-02     Total=7.828E-01

                         EFFECTIVE TIMELAGS, Milliseconds

FUEL:      Cinj, In.=1.563E-02     Lvap, In.= 0.566
           Timp=3.162E-02     Tatom=2.566E-01     Tvap=1.348E-01     Total=4.231E-01

  OX:      Cinj, In.=1.596E-02     Lvap, In.= 0.206
           Timp=5.750E-02     Tatom=6.670E-01     Tvap=5.833E-02     Total=7.828E-01
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CHAMBER-NOZZLE OPTIMIZATION RESULTS

CHAMBER LENGTH (FEET)	ETA-C*	ETA-NOZ	OVERALL EFFICIENCY
0.0000	0.0000	0.8807	0.0000
0.1667	0.0168	0.8726	0.0146
0.3333	0.6228	0.8646	0.5384
0.5000	0.7972	0.8537	0.6805
0.6667	0.8733	0.8419	0.7353
0.8333	0.9143	0.8302	0.7590
1.0000	0.9401	0.8185	0.7695
1.1667	0.9570	0.8057	0.7710
1.3333	0.9699	0.7915	0.7677
1.5000	0.9828	0.7773	0.7639
1.6667	0.9957	0.7631	0.7598
1.8333	1.0000	0.7485	0.7485
2.0000	1.0000	0.7299	0.7299
2.1667	1.0000	0.7114	0.7114
2.3333	1.0000	0.6928	0.6928
2.5000	1.0000	0.6742	0.6742
2.6667	1.0000	0.6461	0.6461
2.8333	1.0000	0.6142	0.6142
3.0000	1.0000	0.5823	0.5823
3.1667	1.0000	0.5504	0.5504
3.3333	1.0000	0.5071	0.5071
3.5000	1.0000	0.4439	0.4439
3.6667	1.0000	0.3808	0.3808
3.8333	1.0000	0.3176	0.3176
4.0000	1.0000	0.2544	0.2544

OPTIMUM CHAMBER LENGTH= 1.1667 FT
MAXIMUM OVERALL EFFICIENCY= 0.7710

REDESIGNED CHAMBER RESULTS

NOMINAL CHAMBER PRESSURE	=	2.141E+03 PSIA
THROTTLED CHAMBER PRESSURE	=	1.535E+03 PSIA
FUEL INJECTION PRESSURE DROP	=	6.729E+02 PSI
OX INJECTION PRESSURE DROP	=	6.729E+02 PSI
CHAMBER RADIUS	=	2.795E-01 FT
THROAT RADIUS	=	1.652E-01 FT
NOZZLE ENTRANCE RADIUS OF CURVATURE	=	1.110E-01 FT
THROAT ENTRANCE RADIUS OF CURVATURE	=	1.110E-01 FT
NOZZLE CONVERGENCE HALF-ANGLE	=	3.000E+01 DEG
INJECTOR-TO-THROAT CHAMBER LENGTH	=	1.166E+00 FT
BARREL SECTION LENGTH	=	9.646E-01 FT

IMPINGING ELEMENT SIZING RESULTS

ELEMENT TYPE	=	LOL
NO. OF ELEMENTS	=	60
FUEL ORIFICE DIAMETER	=	6.634E-02 IN
OX ORIFICE DIAMETER	=	1.017E-01 IN

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DIRECT INPUT ECHO FROM SUBROUTINE PINPUT

                                        ROCCID
                  ROCket Combustor Interactive Design Methodology
                                  Version 23-FEB-91


ROCCID POINT DESIGN TEST CASE 1
LOX/RP-1 LIKE DOUBLET PAIR WITH FIXED PC
APPROXIMATES -0100 SUBSCALE DOUBLET
 $MODELS
 MCHAM=         1
 MBURN=         2
 MINJ=          1
 $END
 $OPCOND
 PISPA=     8.0000E+01,  1.0940E+02,  1.3940E+02,  1.5880E+02,  1.7780E+02,
            2.0970E+02,  2.3550E+02,  2.5470E+02,  2.6700E+02,  2.7040E+02,
            2.7180E+02,  2.7190E+02,  2.7130E+02,  2.6960E+02,  2.6820E+02,
            2.6660E+02,  2.6500E+02,  2.6210E+02,  2.5920E+02,  2.5630E+02,
            2.5080E+02,  2.3840E+02,  2.2750E+02,  2.1100E+02,  2.0140E+02,
            1.5560E+02,  1.0970E+02,  8.0000E+01,
 PCSA=      1.7760E+03,  2.4560E+03,  3.4870E+03,  4.0740E+03,  4.5800E+03,
            5.0700E+03,  5.4540E+03,  5.7340E+03,  5.9080E+03,  5.9610E+03,
            5.9690E+03,  5.9540E+03,  5.9340E+03,  5.8990E+03,  5.8620E+03,
            5.8550E+03,  5.8260E+03,  5.7590E+03,  5.7000E+03,  5.6430E+03,
            5.5320E+03,  5.2750E+03,  5.0470E+03,  4.6780E+03,  4.4200E+03,
            3.4570E+03,  2.4940E+03,  1.4650E+03,
 FUEL=     'RP-1      '
 OX=       'LOX       '
 PC=        2.1411E+03
 XMR=       2.8800E+00
 FTMAN=     7.1000E+01
 XTMAN=    -2.7900E+02
 EMMAN=     1.0000E+00
 NPERFP=        28
 PMRA=      1.0000E-01,  3.0000E-01,  6.0000E-01,  8.0000E-01,  1.0000E+00,
            1.2500E+00,  1.5000E+00,  1.7500E+00,  2.0000E+00,  2.2000E+00,
            2.4000E+00,  2.5000E+00,  2.6000E+00,  2.7000E+00,  2.8000E+00,
            2.9000E+00,  3.0000E+00,  3.2000E+00,  3.4000E+00,  3.6000E+00,
            4.0000E+00,  5.0000E+00,  6.0000E+00,  8.0000E+00,  1.0000E+01,
            1.5000E+01,  2.0000E+01,  5.0000E+01,
 $END
 $GEOM
 RCHAMB=    2.7949E-01
 RTHRT=     1.8523E-01
 RNE=       1.1100E-01
 RTE=       1.1100E-01
 ALPHA=     3.0000E+01
 CHAMBL=    1.1875E+00
 XC=        9.6477E-01
 $END
 $CORE
 TYPE=     'LOL'
 NEL=           60
 FDJ=       6.6345E-02
 FCD=       9.1000E-01
 FIH=       1.1491E-01
 FIA=       3.0000E+01
 FCANT=     1.6000E+01
 FFACET=    2.8728E-01
 XDJ=       1.0172E-01
 XCD=       9.4000E-01
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 XIH=      1.7619E-01
 XIA=      3.0000E+01
 XCANT=    1.6000E+01
 XFACET=   4.4047E-01
 EMUNI=    6.5000E-01
 $END
 $BAFFLE
 $END
 $BARRIER
 $END
 $FFC
 $END
 $BURN
 $END
 $INJ
 FMAND=    6.7076E+00
 XMAND=    6.7076E+00
 FMANL=    3.3538E+00
 XMANL=    3.3538E+00
 PCA=      2.1411E+03,  1.5514E+03,  7.6734E+02
 $END
 $CHAMBER
 MUB=           3
 T=        3.3000E-02
 $END
 $FDORC
 NZON=          5
 FTER=    20*1.0000E+00
 $END
 $MIX
  EM(1)= 6.930E-01,  1.000E+00
 $END
 $DEBUGC
 DEBUG=   F
 $END
 $HIFIC
 SHORT=   F
 POC=      2.0000E-01,  2.0000E-01
 $END
 $DIST3DC
 SHORT=   F
 POC=      2.0000E-01,  2.0000E-01
 PAMP=     2.0000E-01
 MC=           11
 LC=            6
 MB=           11
 LB=            6
 IDMAX=        10
 $END
 $CRPC
 NDPC=         16
 NDTFQ=        16
 NDTLF=      1000
 NPRINT=       50
 NSUMS=      3500
 PAMPC=    2.0000E-01
 NRAD=          3
 NCIRC=         5
 $END
 $LEINJC
 IDOMEM=        2
 PAMPCH=   2.0000E-01
 NTINJ=        16
 USGF=     2.0000E-02
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OGF=       2.0000E-02
DSGF=      2.0000E-02
FCDO=      1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XCDO=      1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
$END
$COMBUSTC
FALVM=     1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XALVM=     1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
FALTM=     1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XALTM=     1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
FRMM=      1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XRMM=      1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
EMMULT=    1.0000E+00,  1.0000E+00
COMBXB=    5.0000E-01
ACMULT=    1.0000E+00
CCMULT=    1.0000E+00
ENMULT=    1.0000E+00
TAUMULT=   1.0000E+00
$END
$FDORCC
SHORT=    F
EPSIL=     2.0000E+01
ERROR=     1.0000E-01
LTS=            5
MTS=            5
NTS=           10
ITMAX=        100
RELX=      6.5000E-01
NEET=           3
NXFST=          3
NYFST=          3
NAFST=          3
MORE=     F
$END

   END OF INPUT ECHO
```

STEADY STATE COMBUSTION ANALYSIS PROGRAM

RUN DESCRIPTORS

ROCCID POINT DESIGN TEST CASE 1
LOX/RP-1 LIKE DOUBLET PAIR WITH FIXED PC
APPROXIMATES -0100 SUBSCALE DOUBLET

PROPELLENT DESCRIPTION

FUEL=RP-1	Tman., F= 71.00
OX=LOX	Tman., F=-279.00

CHAMBER GEOMETRY

CHAMBER RADIUS = 3.3539 IN.
CYLINDRICAL SECTION =11.5770 IN.
NOZZLE ENTRANCE RADIUS OF CURVATURE = 1.3320 IN.
CONVERGENCE HALF-ANGLE =30.0000 DEG.

THROAT RADIUS = 2.2228 IN.
CONVERGENT SECTION LENGTH = 2.6730 IN.
THROAT ENTRANCE RADIUS OF CURVATURE = 1.3320 IN.
CONTRACTION RATIO = 2.28

INJECTOR DATA

INJECTOR CORE CONTAINS 60 LOL ELEMENTS

FUEL SIDE:	Orifice Diam. =6.634E-02 In.	Cd =0.9100	Impingement Height =0.115 In.
	Impingement Half-angle =30.00 Deg.	Unlike Cant Angle =16.00 Deg.	Faceplate Thickness = 0.2673 In.
OX SIDE:	Orifice Diam. =1.017E-01 In.	Cd =0.9400	Impingement Height =0.176 In.
	Impingement Half-angle =30.00 Deg.	Unlike Cant Angle =16.00 Deg.	Faceplate Thickness = 0.4405 In.

MIXING EFFICIENCIES

CORE MIXING EFFICIENCY=0.8930 BARRIER MIXING EFFICIENCY=1.0000

COMBUST CONTROL PARAMETERS

MULTIPLIERS:	CORE	BAFFLE	BARRIER	FFC
FUEL ATOMIZATION LENGTH FOR VAPORIZATION:	1.000	1.000	1.000	1.000
OX ATOMIZATION LENGTH FOR VAPORIZATION:	1.000	1.000	1.000	1.000
FUEL ATOMIZATION LENGTH FOR TIMELAGS:	1.000	1.000	1.000	1.000
OX ATOMIZATION LENGTH FOR TIMELAGS:	1.000	1.000	1.000	1.000
FUEL DROPSIZE:	1.000	1.000	1.000	1.000
OX DROPSIZE:	1.000	1.000	1.000	1.000
MIXING (Em):	1.000		1.000	

AO-Multiplier=1.000 CC-Multiplier=1.000 N-Multiplier=1.000 Tau-Multiplier=1.000
Eta-C* for XB=0.500

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BEGIN STEADY STATE COMBUSTION ANALYSIS
      PC=2141.10 PSIA


                 PROPELLANT PROPERTIES

FUEL=RP-1      Phase=Liquid                              Tman., F=  71.00
               Injected Density= 49.89 Lbm/Cu. Ft        Viscosity=1.380E-03 Lbm/Ft-S     Surface Tension=1.557E-03 Lbf/Ft

  OX=LOX       Phase=Liquid                              Tman., F=-279.00
               Injected Density= 70.20 Lbm/Cu. Ft        Viscosity=1.187E-04 Lbm/Ft-S     Surface Tension=7.326E-04 Lbf/Ft

                 OPERATING CONDITIONS

PC FACE=2141.10 PSIA     PC THROAT=2063.29     MIXTURE RATIO= 2.880
FUEL INJECTION PRESSURE DROP= 673.18 Psia      FUEL INJECTION VELOCITY= 353.58 Ft/S
  OX INJECTION PRESSURE DROP= 673.18 Psia        OX INJECTION VELOCITY= 288.08 Ft/S

    FUEL FLOWRATE=  46.218     OX FLOWRATE= 133.109

                 ATOMIZATION OUTPUT


         DROPSIZE MODEL=AEROJET

ELEMENT TYPE 1 IS LOL
FUEL:     ATOMIZATION LENGTH, In.=1.07825    ATOMIZATION LENGTH FOR VAPORIZATION, In.=1.07825    DROPLET RADIUS, Microns=  75.07
  OX:     ATOMIZATION LENGTH, In.=2.36258    ATOMIZATION LENGTH FOR VAPORIZATION, In.=2.36258    DROPLET RADIUS, Microns=  63.19
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VAPORIZATION CALCULATIONS

X (In.)	CORE=LOL %FUEL VAP	CORE=LOL %OX VAP	BAFFLE= %FUEL VAP	BAFFLE= %OX VAP	BARRIER= %FUEL VAP	BARRIER= %OX VAP	FFC= %FUEL VAP	FFC= %OX VAP
0.0000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.2850	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.5700	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.8550	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.1400	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.4250	8.795	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.7100	18.647	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.9950	26.447	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2.2800	32.505	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2.5650	38.153	2.803	0.000	0.000	0.000	0.000	0.000	0.000
2.8500	43.068	27.537	0.000	0.000	0.000	0.000	0.000	0.000
3.1350	46.864	42.768	0.000	0.000	0.000	0.000	0.000	0.000
3.4200	50.659	52.930	0.000	0.000	0.000	0.000	0.000	0.000
3.7050	53.892	60.564	0.000	0.000	0.000	0.000	0.000	0.000
3.9900	56.736	66.435	0.000	0.000	0.000	0.000	0.000	0.000
4.2750	59.585	70.980	0.000	0.000	0.000	0.000	0.000	0.000
4.5600	61.871	74.915	0.000	0.000	0.000	0.000	0.000	0.000
4.8450	64.061	78.140	0.000	0.000	0.000	0.000	0.000	0.000
5.1300	66.192	80.632	0.000	0.000	0.000	0.000	0.000	0.000
5.4150	67.871	82.965	0.000	0.000	0.000	0.000	0.000	0.000
5.7000	69.550	84.866	0.000	0.000	0.000	0.000	0.000	0.000
5.9850	71.147	86.366	0.000	0.000	0.000	0.000	0.000	0.000
6.2700	72.607	88.013	0.000	0.000	0.000	0.000	0.000	0.000
6.5550	74.067	89.164	0.000	0.000	0.000	0.000	0.000	0.000
6.8400	75.365	90.289	0.000	0.000	0.000	0.000	0.000	0.000
7.1250	76.569	91.190	0.000	0.000	0.000	0.000	0.000	0.000
7.4100	77.774	92.067	0.000	0.000	0.000	0.000	0.000	0.000
7.6950	78.717	92.734	0.000	0.000	0.000	0.000	0.000	0.000
7.9800	79.629	93.401	0.000	0.000	0.000	0.000	0.000	0.000
8.2650	80.536	94.051	0.000	0.000	0.000	0.000	0.000	0.000
8.5500	81.412	94.551	0.000	0.000	0.000	0.000	0.000	0.000
8.8350	82.288	95.051	0.000	0.000	0.000	0.000	0.000	0.000
9.1200	83.058	95.541	0.000	0.000	0.000	0.000	0.000	0.000
9.4050	83.678	95.941	0.000	0.000	0.000	0.000	0.000	0.000
9.6900	84.299	96.331	0.000	0.000	0.000	0.000	0.000	0.000
9.9750	84.919	96.631	0.000	0.000	0.000	0.000	0.000	0.000
10.2600	85.540	96.932	0.000	0.000	0.000	0.000	0.000	0.000
10.5450	86.160	97.221	0.000	0.000	0.000	0.000	0.000	0.000
10.8300	86.781	97.421	0.000	0.000	0.000	0.000	0.000	0.000
11.1150	87.401	97.621	0.000	0.000	0.000	0.000	0.000	0.000
11.4000	87.982	97.821	0.000	0.000	0.000	0.000	0.000	0.000
11.6850	88.421	98.031	0.000	0.000	0.000	0.000	0.000	0.000
11.9700	88.891	98.241	0.000	0.000	0.000	0.000	0.000	0.000
12.2550	89.360	98.409	0.000	0.000	0.000	0.000	0.000	0.000
12.5400	89.830	98.559	0.000	0.000	0.000	0.000	0.000	0.000
12.8250	90.278	98.690	0.000	0.000	0.000	0.000	0.000	0.000
13.1100	90.646	98.821	0.000	0.000	0.000	0.000	0.000	0.000
13.3950	91.012	98.937	0.000	0.000	0.000	0.000	0.000	0.000
13.6800	91.380	99.049	0.000	0.000	0.000	0.000	0.000	0.000
13.9650	91.747	99.127	0.000	0.000	0.000	0.000	0.000	0.000
14.2500	92.085	99.206	0.000	0.000	0.000	0.000	0.000	0.000

OVERALL VAPORIZATION EFFICIENCIES
FUEL= 92.08% OX= 99.21%

MASS DISTRIBUTION PROFILE

X (IN)	CORE (lbm/s) FUEL	CORE (lbm/s) OX	BARRIER (lbm/s) FUEL	BARRIER (lbm/s) OX	LOCAL VAPOR MIXTURE RATIO	ETA-C*
0.0000	0.000	0.000	0.000	0.000	0.00	0.0000
0.2850	0.000	0.000	0.000	0.000	0.00	0.0000
0.5700	0.000	0.000	0.000	0.000	0.00	0.0000
0.8550	0.000	0.000	0.000	0.000	0.00	0.0000
1.1400	0.000	0.000	0.000	0.000	0.00	0.0000
1.4250	4.065	0.000	0.000	0.000	0.00	0.0056
1.7100	8.618	0.000	0.000	0.000	0.00	0.0118
1.9950	12.223	0.000	0.000	0.000	0.00	0.0167
2.2800	15.023	0.000	0.000	0.000	0.00	0.0205
2.5650	17.634	3.732	0.000	0.000	0.21	0.0441
2.8500	19.905	38.654	0.000	0.000	1.64	0.3092
3.1350	21.660	56.928	0.000	0.000	2.63	0.4391
3.4200	23.414	70.454	0.000	0.000	3.01	0.5175
3.7050	24.908	80.616	0.000	0.000	3.24	0.5756
3.9900	26.224	88.430	0.000	0.000	3.37	0.6213
4.2750	27.539	94.480	0.000	0.000	3.43	0.6594
4.5600	28.596	99.718	0.000	0.000	3.49	0.6915
4.8450	29.608	104.011	0.000	0.000	3.51	0.7192
5.1300	30.593	107.327	0.000	0.000	3.51	0.7425
5.4150	31.369	110.433	0.000	0.000	3.52	0.7629
5.7000	32.146	112.897	0.000	0.000	3.51	0.7798
5.9850	32.883	114.961	0.000	0.000	3.50	0.7964
6.2700	33.558	117.153	0.000	0.000	3.49	0.8120
6.5550	34.233	118.865	0.000	0.000	3.47	0.8249
6.8400	34.832	120.183	0.000	0.000	3.45	0.8369
7.1250	35.369	121.382	0.000	0.000	3.43	0.8472
7.4100	35.946	122.549	0.000	0.000	3.41	0.8573
7.6950	36.362	123.437	0.000	0.000	3.39	0.8652
7.9800	36.803	124.325	0.000	0.000	3.38	0.8729
8.2650	37.222	125.190	0.000	0.000	3.36	0.8805
8.5500	37.627	125.858	0.000	0.000	3.34	0.8871
8.8350	38.032	126.522	0.000	0.000	3.33	0.8937
9.1200	38.388	127.174	0.000	0.000	3.31	0.8998
9.4050	38.675	127.706	0.000	0.000	3.30	0.9047
9.6900	38.961	128.225	0.000	0.000	3.29	0.9096
9.9750	39.248	128.625	0.000	0.000	3.28	0.9139
10.2600	39.535	129.024	0.000	0.000	3.26	0.9183
10.5450	39.822	129.410	0.000	0.000	3.25	0.9226
10.8300	40.109	129.676	0.000	0.000	3.23	0.9263
11.1150	40.395	129.942	0.000	0.000	3.22	0.9301
11.4000	40.664	130.209	0.000	0.000	3.20	0.9337
11.6850	40.867	130.487	0.000	0.000	3.19	0.9367
11.9700	41.084	130.767	0.000	0.000	3.18	0.9399
12.2550	41.301	130.990	0.000	0.000	3.17	0.9428
12.5400	41.518	131.191	0.000	0.000	3.16	0.9456
12.8250	41.725	131.365	0.000	0.000	3.15	0.9482
13.1100	41.895	131.539	0.000	0.000	3.14	0.9505
13.3950	42.064	131.693	0.000	0.000	3.13	0.9527
13.6800	42.234	131.842	0.000	0.000	3.12	0.9548
13.9650	42.404	131.947	0.000	0.000	3.11	0.9568
14.2500	42.560	132.051	0.000	0.000	3.10	0.9586

AXIAL PRESSURE PROFILE

X (in)	MACH #	Ptotal (psia)	Pstatic (psia)	Ttotal (R)	Tstatic (R)	Wdot (Lbm/s)	Local Radius (in)
1.20	0.000	2141.79	2142.76	1692.26	1685.78	0.59	3.354
1.30	0.001	2141.79	2142.76	1692.26	1685.78	2.00	3.354
1.61	0.005	2141.76	2142.71	1697.15	1690.65	7.06	3.354
1.91	0.008	2141.72	2142.62	1692.26	1685.78	11.10	3.354
2.21	0.010	2141.66	2142.50	1754.02	1747.31	14.73	3.354
2.51	0.012	2141.61	2142.39	1692.26	1685.77	17.83	3.354
2.81	0.064	2136.76	2132.69	5162.56	5141.79	51.60	3.354
3.11	0.112	2126.84	2112.76	6787.36	6757.66	77.20	3.354
3.41	0.137	2119.51	2097.96	6863.43	6831.87	93.46	3.354
3.71	0.156	2113.13	2085.07	6859.00	6826.16	105.81	3.354
4.01	0.171	2107.67	2074.00	6844.66	6811.00	115.34	3.354
4.32	0.183	2102.92	2064.34	6837.28	6802.45	122.96	3.354
4.62	0.193	2098.64	2055.61	6828.59	6792.91	129.44	3.354
4.92	0.202	2094.90	2047.98	6826.13	6789.67	134.76	3.354
5.22	0.209	2091.67	2041.36	6826.24	6789.06	139.16	3.354
5.52	0.215	2088.79	2035.47	6825.31	6787.54	142.99	3.354
5.82	0.220	2086.35	2030.45	6828.00	6789.67	146.09	3.354
6.12	0.226	2083.79	2025.20	6828.70	6789.80	149.28	3.354
6.42	0.230	2081.59	2020.67	6831.13	6791.73	151.94	3.354
6.72	0.234	2079.66	2016.74	6834.50	6794.65	154.19	3.354
7.02	0.238	2077.97	2013.21	6837.33	6797.08	156.17	3.354
7.33	0.241	2076.34	2009.85	6840.75	6800.11	158.01	3.354
7.63	0.244	2075.00	2007.06	6843.26	6802.31	159.52	3.354
7.93	0.246	2073.77	2004.55	6844.92	6803.66	160.88	3.354
8.23	0.249	2072.52	2001.97	6846.44	6804.69	162.26	3.354
8.53	0.251	2071.46	1999.76	6848.37	6806.55	163.41	3.354
8.83	0.253	2070.41	1997.61	6850.29	6808.22	164.54	3.354
9.13	0.255	2069.42	1995.56	6851.75	6809.44	165.60	3.354
9.43	0.256	2068.61	1993.88	6852.86	6810.37	166.46	3.354
9.73	0.258	2067.82	1992.23	6854.07	6811.38	167.30	3.354
10.04	0.259	2067.13	1990.81	6855.56	6812.69	168.01	3.354
10.34	0.260	2066.43	1989.34	6856.98	6813.94	168.75	3.354
10.64	0.261	2065.77	1987.98	6858.53	6815.32	169.42	3.354
10.94	0.263	2065.20	1986.80	6860.29	6816.94	169.99	3.354
11.24	0.264	2064.62	1985.56	6862.04	6818.53	170.58	3.354
11.54	0.265	2064.10	1984.51	6863.00	6819.36	171.11	3.354
11.84	0.270	2063.59	1980.77	6863.01	6818.13	171.63	3.328
12.14	0.290	2063.07	1967.66	6863.05	6813.03	172.12	3.225
12.44	0.327	2062.49	1941.92	6863.08	6802.57	172.57	3.061
12.74	0.376	2061.79	1904.03	6863.12	6786.84	172.99	2.886
13.05	0.438	2060.96	1849.56	6863.15	6763.60	173.36	2.712
13.35	0.524	2059.89	1765.36	6863.17	6728.31	173.70	2.539
13.65	0.655	2058.32	1618.15	6863.20	6657.03	174.04	2.387
13.95	0.818	2056.17	1417.33	6863.23	6553.39	174.34	2.257
14.25	0.999	2053.23	1185.64	6863.26	6421.39	174.61	2.223

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                 PERFORMANCE SUMMARY

                C* EFFICIENCY CALCULATIONS (ODK)

                                                          BARRIER Em=1.0000
INJECTED MR= 2.8800     CSTAR=5660.40     CORE Em=0.8930
CORE:          OVERALL MR= 2.8800     VAPOR MR= 3.1027      CSTAR-MIX=5769.54      MASS FRACTION= 1.0000
BARRIER:       OVERALL MR= 0.0000     VAPOR MR=99.9000      CSTAR-MIX=    0.00     MASS FRACTION= 0.0000
ENGINE:        OVERALL MR= 2.8800     VAPOR MR= 3.1027      CSTAR-DEL=5617.83
C* EFFICIENCY = 9.566E-01


                ISP EFFICIENCY CALCULATIONS

ISP-ODK, INJ = 2.669E+02 SEC.
ISP-ODK, M.Z. INJ = 2.652E+02 SEC.            ISP-ODK, M.Z. VAPOR = 2.628E+02 SEC.
VAPORIZATION EFFICIENCY = 9.650E-01           MIXING EFFICIENCY = 9.935E-01
ENERGY RELEASE EFFICIENCY = 9.568E-01

NOTE: ISP-DEL = ISP-ODK, INJ. * ERE * ETADIV - DELISP-BL
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                    TIME-LAG CALCULATIONS, Milliseconds

Coham, In.=9.099E-03     FUEL Cohem, In.=2.293E+02     OX Cohem, In.=8.194E+01


ELEMENT 1 IS TYPE=LOL
FUEL:     Cinj, In.=1.574E-02     Lvap, In.= 0.565     ATOMIZATION LENGTH USED, In.= 1.076E+00
          Timp=3.127E-02     Tatom=2.541E-01     Tvap=1.333E-01     Total=4.187E-01

  OX:     Cinj, In.=1.607E-02     Lvap, In.= 0.206     ATOMIZATION LENGTH USED, In.= 2.363E+00
          Timp=5.688E-02     Tatom=6.605E-01     Tvap=5.787E-02     Total=7.750E-01

                    EFFECTIVE TIMELAGS, Milliseconds

FUEL:     Cinj, In.=1.574E-02     Lvap, In.= 0.565
          Timp=3.127E-02     Tatom=2.541E-01     Tvap=1.333E-01     Total=4.187E-01

  OX:     Cinj, In.=1.607E-02     Lvap, In.= 0.206
          Timp=5.688E-02     Tatom=6.605E-01     Tvap=5.787E-02     Total=7.750E-01
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CHAMBER-NOZZLE OPTIMIZATION RESULTS

CHAMBER LENGTH (FEET)	ETA-C*	ETA-NOZ	OVERALL EFFICIENCY
0.0000	0.0000	0.8807	0.0000
0.1667	0.0168	0.8726	0.0146
0.3333	0.6226	0.8646	0.5383
0.5000	0.7972	0.8537	0.6805
0.6667	0.8734	0.8419	0.7354
0.8333	0.9143	0.8302	0.7591
1.0000	0.9402	0.8185	0.7696
1.1667	0.9570	0.8057	0.7711
1.3333	0.9699	0.7915	0.7677
1.5000	0.9827	0.7773	0.7639
1.6667	0.9956	0.7631	0.7597
1.8333	1.0000	0.7485	0.7485
2.0000	1.0000	0.7299	0.7299
2.1667	1.0000	0.7114	0.7114
2.3333	1.0000	0.6928	0.6928
2.5000	1.0000	0.6742	0.6742
2.6667	1.0000	0.6461	0.6461
2.8333	1.0000	0.6142	0.6142
3.0000	1.0000	0.5823	0.5823
3.1667	1.0000	0.5504	0.5504
3.3333	1.0000	0.5071	0.5071
3.5000	1.0000	0.4439	0.4439
3.6667	1.0000	0.3808	0.3808
3.8333	1.0000	0.3176	0.3176
4.0000	1.0000	0.2544	0.2544

OPTIMUM CHAMBER LENGTH= 1.1667 FT
MAXIMUM OVERALL EFFICIENCY= 0.7711

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BEGIN STEADY STATE COMBUSTION ANALYSIS
     PC=1551.40 PSIA


              PROPELLANT PROPERTIES

FUEL=RP-1      Phase=Liquid                        Tman., F=  71.00
               Injected Density= 49.89 Lbm/Cu. Ft  Viscosity=1.380E-03 Lbm/Ft-S   Surface Tension=1.857E-03 Lbf/Ft

  OX=LOX       Phase=Liquid                        Tman., F=-279.00
               Injected Density= 69.62 Lbm/Cu. Ft  Viscosity=1.143E-04 Lbm/Ft-S   Surface Tension=7.326E-04 Lbf/Ft

              OPERATING CONDITIONS

PC FACE=1551.40 PSIA    PC THROAT=1487.56    MIXTURE RATIO= 2.880
FUEL INJECTION PRESSURE DROP= 353.97 Psia    FUEL INJECTION VELOCITY= 256.39 Ft/S
  OX INJECTION PRESSURE DROP= 356.79 Psia      OX INJECTION VELOCITY= 217.92 Ft/S

   FUEL FLOWRATE=  33.533    OX FLOWRATE=  96.576

              ATOMIZATION OUTPUT


       DROPSIZE MODEL=AEROJET

ELEMENT TYPE 1 IS LOL
FUEL:    ATOMIZATION LENGTH, In.=1.04042    ATOMIZATION LENGTH FOR VAPORIZATION, In.=1.04042    DROPLET RADIUS, Microns=  77.80
  OX:    ATOMIZATION LENGTH, In.=2.28933    ATOMIZATION LENGTH FOR VAPORIZATION, In.=2.28933    DROPLET RADIUS, Microns=  85.85
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VAPORIZATION CALCULATIONS

X (In.)	CORE=LOL %FUEL VAP	CORE=LOL %OX VAP	BAFFLE= %FUEL VAP	BAFFLE= %OX VAP	BARRIER= %FUEL VAP	BARRIER= %OX VAP	FFC= %FUEL VAP	FFC= %OX VAP
0.0000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.2850	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.5700	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.8550	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.1400	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.4250	10.171	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.7100	19.343	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.9950	26.839	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2.2800	32.758	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2.5650	38.255	10.299	0.000	0.000	0.000	0.000	0.000	0.000
2.8500	43.050	31.288	0.000	0.000	0.000	0.000	0.000	0.000
3.1350	46.758	44.877	0.000	0.000	0.000	0.000	0.000	0.000
3.4200	50.467	54.332	0.000	0.000	0.000	0.000	0.000	0.000
3.7050	53.681	61.504	0.000	0.000	0.000	0.000	0.000	0.000
3.9900	56.462	67.049	0.000	0.000	0.000	0.000	0.000	0.000
4.2750	59.244	71.422	0.000	0.000	0.000	0.000	0.000	0.000
4.5600	61.558	75.203	0.000	0.000	0.000	0.000	0.000	0.000
4.8450	63.697	78.300	0.000	0.000	0.000	0.000	0.000	0.000
5.1300	65.836	80.730	0.000	0.000	0.000	0.000	0.000	0.000
5.4150	67.515	82.995	0.000	0.000	0.000	0.000	0.000	0.000
5.7000	69.155	84.657	0.000	0.000	0.000	0.000	0.000	0.000
5.9850	70.770	86.316	0.000	0.000	0.000	0.000	0.000	0.000
6.2700	72.196	87.954	0.000	0.000	0.000	0.000	0.000	0.000
6.5550	73.622	89.078	0.000	0.000	0.000	0.000	0.000	0.000
6.8400	74.970	90.202	0.000	0.000	0.000	0.000	0.000	0.000
7.1250	76.147	91.081	0.000	0.000	0.000	0.000	0.000	0.000
7.4100	77.323	91.961	0.000	0.000	0.000	0.000	0.000	0.000
7.6950	78.355	92.623	0.000	0.000	0.000	0.000	0.000	0.000
7.9800	79.246	93.274	0.000	0.000	0.000	0.000	0.000	0.000
8.2650	80.137	93.926	0.000	0.000	0.000	0.000	0.000	0.000
8.5500	81.004	94.433	0.000	0.000	0.000	0.000	0.000	0.000
8.8350	81.859	94.922	0.000	0.000	0.000	0.000	0.000	0.000
9.1200	82.715	95.410	0.000	0.000	0.000	0.000	0.000	0.000
9.4050	83.346	95.819	0.000	0.000	0.000	0.000	0.000	0.000
9.6900	83.952	96.210	0.000	0.000	0.000	0.000	0.000	0.000
9.9750	84.558	96.526	0.000	0.000	0.000	0.000	0.000	0.000
10.2600	85.165	96.819	0.000	0.000	0.000	0.000	0.000	0.000
10.5450	85.771	97.112	0.000	0.000	0.000	0.000	0.000	0.000
10.8300	86.377	97.337	0.000	0.000	0.000	0.000	0.000	0.000
11.1150	86.983	97.533	0.000	0.000	0.000	0.000	0.000	0.000
11.4000	87.589	97.728	0.000	0.000	0.000	0.000	0.000	0.000
11.6850	88.118	97.932	0.000	0.000	0.000	0.000	0.000	0.000
11.9700	88.577	98.151	0.000	0.000	0.000	0.000	0.000	0.000
12.2550	89.036	98.327	0.000	0.000	0.000	0.000	0.000	0.000
12.5400	89.494	98.491	0.000	0.000	0.000	0.000	0.000	0.000
12.8250	89.953	98.621	0.000	0.000	0.000	0.000	0.000	0.000
13.1100	90.366	98.748	0.000	0.000	0.000	0.000	0.000	0.000
13.3950	90.725	98.872	0.000	0.000	0.000	0.000	0.000	0.000
13.6800	91.084	98.981	0.000	0.000	0.000	0.000	0.000	0.000
13.9650	91.442	99.079	0.000	0.000	0.000	0.000	0.000	0.000
14.2500	91.801	99.155	0.000	0.000	0.000	0.000	0.000	0.000

OVERALL VAPORIZATION EFFICIENCIES
FUEL= 91.80% OX= 99.16%

MASS DISTRIBUTION PROFILE

X (IN)	CORE (lbm/s) FUEL	CORE (lbm/s) OX	BARRIER (lbm/s) FUEL	BARRIER (lbm/s) OX	LOCAL VAPOR MIXTURE RATIO	ETA-C*
0.0000	0.000	0.000	0.000	0.000	0.00	0.0000
0.2850	0.000	0.000	0.000	0.000	0.00	0.0000
0.5700	0.000	0.000	0.000	0.000	0.00	0.0000
0.8550	0.000	0.000	0.000	0.000	0.00	0.0000
1.1400	0.000	0.000	0.000	0.000	0.00	0.0000
1.4250	3.411	0.000	0.000	0.000	0.00	0.0064
1.7100	6.487	0.000	0.000	0.000	0.00	0.0122
1.9950	9.000	0.000	0.000	0.000	0.00	0.0169
2.2800	10.985	0.000	0.000	0.000	0.00	0.0207
2.5650	12.828	9.946	0.000	0.000	0.78	0.1202
2.8500	14.438	30.216	0.000	0.000	2.09	0.3430
3.1350	15.680	43.341	0.000	0.000	2.76	0.4526
3.4200	16.923	52.471	0.000	0.000	3.10	0.5251
3.7050	18.001	59.396	0.000	0.000	3.30	0.5801
3.9900	18.934	64.753	0.000	0.000	3.42	0.6236
4.2750	19.866	68.976	0.000	0.000	3.47	0.6604
4.5600	20.642	72.628	0.000	0.000	3.52	0.6917
4.8450	21.360	75.620	0.000	0.000	3.54	0.7185
5.1300	22.077	77.966	0.000	0.000	3.53	0.7415
5.4150	22.640	80.154	0.000	0.000	3.54	0.7615
5.7000	23.190	81.759	0.000	0.000	3.53	0.7780
5.9850	23.732	83.363	0.000	0.000	3.51	0.7945
6.2700	24.210	84.943	0.000	0.000	3.51	0.8099
6.5550	24.688	86.026	0.000	0.000	3.48	0.8224
6.8400	25.140	87.113	0.000	0.000	3.47	0.8347
7.1250	25.535	87.963	0.000	0.000	3.44	0.8447
7.4100	25.929	88.812	0.000	0.000	3.43	0.8546
7.6950	26.275	89.452	0.000	0.000	3.40	0.8630
7.9800	26.574	90.061	0.000	0.000	3.39	0.8705
8.2650	26.873	90.710	0.000	0.000	3.38	0.8780
8.5500	27.169	91.200	0.000	0.000	3.36	0.8846
8.8350	27.450	91.672	0.000	0.000	3.34	0.8911
9.1200	27.737	92.144	0.000	0.000	3.32	0.8976
9.4050	27.949	92.539	0.000	0.000	3.31	0.9028
9.6900	28.152	92.916	0.000	0.000	3.30	0.9074
9.9750	28.355	93.221	0.000	0.000	3.29	0.9118
10.2600	28.559	93.504	0.000	0.000	3.27	0.9160
10.5450	28.762	93.787	0.000	0.000	3.26	0.9203
10.8300	28.965	94.004	0.000	0.000	3.25	0.9241
11.1150	29.168	94.193	0.000	0.000	3.23	0.9278
11.4000	29.372	94.382	0.000	0.000	3.21	0.9315
11.6850	29.549	94.579	0.000	0.000	3.20	0.9349
11.9700	29.703	94.790	0.000	0.000	3.19	0.9381
12.2550	29.857	94.961	0.000	0.000	3.18	0.9410
12.5400	30.010	95.119	0.000	0.000	3.17	0.9438
12.8250	30.164	95.244	0.000	0.000	3.16	0.9465
13.1100	30.309	95.367	0.000	0.000	3.15	0.9489
13.3950	30.423	95.487	0.000	0.000	3.14	0.9511
13.6800	30.543	95.593	0.000	0.000	3.13	0.9532
13.9650	30.664	95.686	0.000	0.000	3.12	0.9552
14.2500	30.784	95.760	0.000	0.000	3.11	0.9572

AXIAL PRESSURE PROFILE

X (in)	MACH #	Ptotal (psia)	Pstatic (psia)	Ttotal (R)	Tstatic (R)	Wdot (Lbm/s)	Local Radius (in)
1.20	0.001	1551.85	1552.56	1677.21	1670.62	0.53	3.354
1.30	0.002	1551.85	1552.56	1677.24	1670.65	1.76	3.354
1.61	0.005	1551.83	1552.51	1677.18	1670.79	5.43	3.354
1.91	0.008	1551.80	1552.44	1677.83	1671.53	8.42	3.354
2.21	0.010	1551.77	1552.40	1677.18	1670.79	9.99	3.354
2.51	0.021	1551.45	1551.75	2174.94	2166.62	19.32	3.354
2.81	0.077	1546.67	1542.17	5799.97	5776.25	41.76	3.354
3.11	0.117	1540.07	1528.90	6769.88	6740.14	58.05	3.354
3.41	0.140	1535.06	1518.79	6766.10	6737.01	69.13	3.354
3.71	0.158	1530.64	1509.85	6755.82	6723.58	77.60	3.354
4.01	0.172	1526.85	1502.16	6743.97	6710.75	84.16	3.354
4.32	0.183	1523.51	1495.38	6737.29	6703.17	89.51	3.354
4.62	0.193	1520.48	1489.19	6731.91	6698.96	94.06	3.354
4.92	0.202	1517.86	1483.83	6730.29	6694.61	97.80	3.354
5.22	0.209	1515.55	1479.12	6730.94	6694.59	100.94	3.354
5.52	0.215	1513.52	1474.96	6730.45	6693.51	103.63	3.354
5.82	0.220	1511.79	1471.40	6732.73	6695.27	105.84	3.354
6.12	0.226	1509.95	1467.63	6733.49	6695.48	108.13	3.354
6.42	0.230	1508.40	1464.43	6736.26	6696.77	110.02	3.354
6.72	0.234	1507.02	1461.60	6738.14	6699.22	111.85	3.354
7.02	0.237	1505.79	1459.07	6740.54	6701.24	113.07	3.354
7.33	0.241	1504.66	1456.70	6743.01	6703.36	114.39	3.354
7.63	0.243	1503.65	1454.65	6745.64	6705.65	115.51	3.354
7.93	0.246	1502.78	1452.85	6747.47	6707.20	116.48	3.354
8.23	0.248	1501.69	1451.00	6748.93	6708.38	117.47	3.354
8.53	0.250	1501.12	1449.41	6750.61	6710.01	118.31	3.354
8.83	0.252	1500.37	1447.87	6752.71	6711.66	119.11	3.354
9.13	0.254	1499.63	1446.33	6754.55	6713.26	119.91	3.354
9.43	0.256	1499.03	1445.09	6755.68	6714.20	120.55	3.354
9.73	0.257	1498.46	1443.91	6756.82	6715.18	121.15	3.354
10.04	0.259	1497.96	1442.86	6758.22	6716.38	121.68	3.354
10.34	0.260	1497.46	1441.83	6759.62	6717.62	122.20	3.354
10.64	0.261	1496.98	1440.83	6761.08	6718.92	122.69	3.354
10.94	0.262	1496.56	1439.96	6762.76	6720.45	123.12	3.354
11.24	0.263	1496.16	1439.08	6764.46	6722.00	123.53	3.354
11.54	0.264	1495.75	1438.27	6766.07	6723.48	123.94	3.354
11.84	0.270	1495.36	1435.52	6766.87	6723.06	124.33	3.328
12.14	0.290	1494.97	1426.04	6767.16	6718.36	124.69	3.225
12.44	0.327	1494.54	1407.41	6767.54	6708.56	125.03	3.061
12.74	0.378	1494.02	1380.00	6767.94	6693.65	125.33	2.886
13.05	0.438	1493.39	1340.56	6768.31	6671.44	125.61	2.712
13.35	0.524	1492.58	1279.81	6768.61	6635.50	125.87	2.539
13.65	0.655	1491.46	1173.26	6768.91	6568.56	126.11	2.367
13.95	0.816	1489.78	1027.76	6769.22	6468.21	126.34	2.257
14.25	0.999	1487.56	859.65	6769.55	6340.07	126.54	2.223

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                    PERFORMANCE SUMMARY

                  C* EFFICIENCY CALCULATIONS (ODK)

INJECTED MR= 2.6800     CSTAR=5860.40     CORE Em=0.9930     BARRIER Em=1.0000
CORE:        OVERALL MR= 2.6800     VAPOR MR= 3.1107     CSTAR-MIX=5767.36     MASS FRACTION= 1.0000
BARRIER:     OVERALL MR= 0.0000     VAPOR MR=99.9000     CSTAR-MIX=    0.00     MASS FRACTION= 0.0000
ENGINE:      OVERALL MR= 2.6800     VAPOR MR= 3.1107     CSTAR-DEL=5609.32
C* EFFICIENCY = 9.572E-01

                  ISP EFFICIENCY CALCULATIONS

ISP-ODK, INJ = 2.669E+02 SEC.
ISP-ODK, M.Z. INJ = 2.652E+02 SEC.         ISP-ODK, M.Z. VAPOR = 2.627E+02 SEC.
VAPORIZATION EFFICIENCY = 9.695E-01        MIXING EFFICIENCY = 9.935E-01
ENERGY RELEASE EFFICIENCY = 9.572E-01

NOTE: ISP-DEL = ISP-ODK, INJ. * ERE * ETADIV - DELISP-BL
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TIME-LAG CALCULATIONS, Milliseconds

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Ceham, In.=1.125E-02      FUEL Cohem, In.=2.293E+02      OX Cohem, In.=8.194E+01

ELEMENT 1 IS TYPE=LOL
FUEL:     Cinj, In.=1.302E-02      Lvap, In.= 0.579      ATOMIZATION LENGTH USED, In.= 1.040E+00
          Timp=4.313E-02      Tatom=3.382E-01      Tvap=1.881E-01      Total=5.694E-01

  OX:     Cinj, In.=1.330E-02      Lvap, In.= 0.211      ATOMIZATION LENGTH USED, In.= 2.289E+00
          Timp=7.780E-02      Tatom=8.755E-01      Tvap=8.074E-02      Total=1.034E+00
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EFFECTIVE TIMELAGS, Milliseconds

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FUEL:     Cinj, In.=1.302E-02      Lvap, In.= 0.579
          Timp=4.313E-02      Tatom=3.382E-01      Tvap=1.881E-01      Total=5.694E-01

  OX:     Cinj, In.=1.330E-02      Lvap, In.= 0.211
          Timp=7.780E-02      Tatom=8.755E-01      Tvap=8.074E-02      Total=1.034E+00
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BEGIN STEADY STATE COMBUSTION ANALYSIS
     PC= 767.34 PSIA


                    PROPELLANT PROPERTIES

FUEL=RP-1      Phase=Liquid                          Tman., F=  71.00
               Injected Density= 49.89 Lbm/Cu. Ft    Viscosity=1.380E-03 Lbm/Ft-S    Surface Tension=1.657E-03 Lbf/Ft

  OX=LOX       Phase=Liquid                          Tman., F=-279.00
               Injected Density= 68.77 Lbm/Cu. Ft    Viscosity=1.082E-04 Lbm/Ft-S    Surface Tension=7.326E-04 Lbf/Ft

                    OPERATING CONDITIONS

PC FACE= 767.34 PSIA    PC THROAT= 735.66    MIXTURE RATIO= 2.880
FUEL INJECTION PRESSURE DROP=  87.21 Psia    FUEL INJECTION VELOCITY= 127.27 Ft/S
  OX INJECTION PRESSURE DROP=  89.07 Psia      OX INJECTION VELOCITY= 109.55 Ft/S

    FUEL FLOWRATE=  16.644    OX FLOWRATE=  47.935

                    ATOMIZATION OUTPUT


         DROPSIZE MODEL=AEROJET

ELEMENT TYPE 1 IS LOL
FUEL:    ATOMIZATION LENGTH, In.=0.96252    ATOMIZATION LENGTH FOR VAPORIZATION, In.=0.96252    DROPLET RADIUS, Microns=  64.09
  OX:    ATOMIZATION LENGTH, In.=2.13095    ATOMIZATION LENGTH FOR VAPORIZATION, In.=2.13095    DROPLET RADIUS, Microns=  92.23
```

VAPORIZATION CALCULATIONS

X (in.)	CORE=LOL %FUEL VAP	CORE=LOL %OX VAP	BAFFLE= %FUEL VAP	BAFFLE= %OX VAP	BARRIER= %FUEL VAP	BARRIER= %OX VAP	FFC= %FUEL VAP	FFC= %OX VAP
0.0000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.2850	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.5700	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.8550	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.1400	2.136	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.4250	12.619	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.7100	20.569	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.9950	27.466	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2.2800	33.106	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2.5650	38.298	22.495	0.000	0.000	0.000	0.000	0.000	0.000
2.8500	42.892	38.290	0.000	0.000	0.000	0.000	0.000	0.000
3.1350	46.412	49.009	0.000	0.000	0.000	0.000	0.000	0.000
3.4200	49.931	57.039	0.000	0.000	0.000	0.000	0.000	0.000
3.7050	53.138	63.286	0.000	0.000	0.000	0.000	0.000	0.000
3.9900	55.776	68.183	0.000	0.000	0.000	0.000	0.000	0.000
4 2750	58.418	72.207	0.000	0.000	0.000	0.000	0.000	0.000
4.5600	60.614	75.686	0.000	0.000	0.000	0.000	0.000	0.000
4.8450	62.845	78.540	0.000	0.000	0.000	0.000	0.000	0.000
5.1300	64.875	80.840	0.000	0.000	0.000	0.000	0.000	0.000
5.4150	66.695	82.968	0.000	0.000	0.000	0.000	0.000	0.000
5.7000	68.251	84.564	0.000	0.000	0.000	0.000	0.000	0.000
5.9850	69.808	86.140	0.000	0.000	0.000	0.000	0.000	0.000
6.2700	71.265	87.716	0.000	0.000	0.000	0.000	0.000	0.000
6.5550	72.619	88.842	0.000	0.000	0.000	0.000	0.000	0.000
6.8400	73.973	89.908	0.000	0.000	0.000	0.000	0.000	0.000
7.1250	75.200	90.806	0.000	0.000	0.000	0.000	0.000	0.000
7.4100	76.318	91.641	0.000	0.000	0.000	0.000	0.000	0.000
7.6950	77.433	92.352	0.000	0.000	0.000	0.000	0.000	0.000
7.9800	78.393	92.970	0.000	0.000	0.000	0.000	0.000	0.000
8.2650	79.239	93.588	0.000	0.000	0.000	0.000	0.000	0.000
8.5500	80.085	94.155	0.000	0.000	0.000	0.000	0.000	0.000
8.8350	80.910	94.618	0.000	0.000	0.000	0.000	0.000	0.000
9.1200	81.722	95.082	0.000	0.000	0.000	0.000	0.000	0.000
9.4050	82.534	95.536	0.000	0.000	0.000	0.000	0.000	0.000
9.6900	83.187	95.907	0.000	0.000	0.000	0.000	0.000	0.000
9 9750	83.762	96.278	0.000	0.000	0.000	0.000	0.000	0.000
10.2600	84.338	96.562	0.000	0.000	0.000	0.000	0.000	0.000
10.5450	84.913	96.840	0.000	0.000	0.000	0.000	0.000	0.000
10.8300	85.489	97.118	0.000	0.000	0.000	0.000	0.000	0.000
11.1150	86.064	97.331	0.000	0.000	0.000	0.000	0.000	0.000
11.4000	86.639	97.516	0.000	0.000	0.000	0.000	0.000	0.000
11.6850	87.240	97.710	0.000	0.000	0.000	0.000	0.000	0.000
11.9700	87.884	97.917	0.000	0.000	0.000	0.000	0.000	0.000
12.2550	88.325	98.125	0.000	0.000	0.000	0.000	0.000	0.000
12.5400	88.760	98.299	0.000	0.000	0.000	0.000	0.000	0.000
12.8250	89.195	98.465	0.000	0.000	0.000	0.000	0.000	0.000
13.1100	89.631	98.586	0.000	0.000	0.000	0.000	0.000	0.000
13.3950	90.066	98.707	0.000	0.000	0.000	0.000	0.000	0.000
13.6800	90.436	98.828	0.000	0.000	0.000	0.000	0.000	0.000
13.9650	90.777	98.935	0.000	0.000	0.000	0.000	0.000	0.000
14.2500	91.117	99.038	0.000	0.000	0.000	0.000	0.000	0.000

OVERALL VAPORIZATION EFFICIENCIES

FUEL= 91.12%   OX= 99.04%

MASS DISTRIBUTION PROFILE

X (IN)	CORE (lbm/s) FUEL	CORE (lbm/s) OX	BARRIER (lbm/s) FUEL	BARRIER (lbm/s) OX	LOCAL VAPOR MIXTURE RATIO	ETA-C*
0.0000	0.000	0.000	0.000	0.000	0.00	0.0000
0.2850	0.000	0.000	0.000	0.000	0.00	0.0000
0.5700	0.000	0.000	0.000	0.000	0.00	0.0000
0.8550	0.000	0.000	0.000	0.000	0.00	0.0000
1.1400	0.356	0.000	0.000	0.000	0.00	0.0013
1.4250	2.100	0.000	0.000	0.000	0.00	0.0080
1.7100	3.427	0.000	0.000	0.000	0.00	0.0130
1.9950	4.575	0.000	0.000	0.000	0.00	0.0174
2.2800	5.510	0.000	0.000	0.000	0.00	0.0209
2.5650	6.374	10.783	0.000	0.000	1.69	0.2556
2.8500	7.139	18.355	0.000	0.000	2.57	0.3961
3.1350	7.725	23.493	0.000	0.000	3.04	0.4772
3.4200	8.311	27.342	0.000	0.000	3.29	0.5366
3.7050	8.844	30.336	0.000	0.000	3.43	0.5879
3.9900	9.284	32.684	0.000	0.000	3.52	0.6270
4.2750	9.723	34.613	0.000	0.000	3.56	0.6611
4.5600	10.122	36.280	0.000	0.000	3.58	0.6910
4.8450	10.460	37.649	0.000	0.000	3.60	0.7159
5.1300	10.798	38.751	0.000	0.000	3.59	0.7377
5.4150	11.101	39.780	0.000	0.000	3.58	0.7576
5.7000	11.360	40.596	0.000	0.000	3.57	0.7735
5.9850	11.619	41.291	0.000	0.000	3.55	0.7892
6.2700	11.862	42.047	0.000	0.000	3.54	0.8044
6.5550	12.087	42.587	0.000	0.000	3.52	0.8167
6.8400	12.312	43.098	0.000	0.000	3.50	0.8286
7.1250	12.516	43.528	0.000	0.000	3.48	0.8391
7.4100	12.702	43.928	0.000	0.000	3.46	0.8486
7.6950	12.888	44.269	0.000	0.000	3.43	0.8575
7.9800	13.046	44.565	0.000	0.000	3.42	0.8651
8.2650	13.189	44.862	0.000	0.000	3.40	0.8723
8.5500	13.329	45.133	0.000	0.000	3.39	0.8791
8.8350	13.467	45.365	0.000	0.000	3.37	0.8853
9.1200	13.602	45.578	0.000	0.000	3.35	0.8914
9.4050	13.737	45.796	0.000	0.000	3.33	0.8975
9.6900	13.846	45.973	0.000	0.000	3.32	0.9024
9.9750	13.942	46.151	0.000	0.000	3.31	0.9070
10.2600	14.037	46.287	0.000	0.000	3.30	0.9110
10.5450	14.133	46.420	0.000	0.000	3.28	0.9151
10.8300	14.229	46.554	0.000	0.000	3.27	0.9191
11.1150	14.325	46.656	0.000	0.000	3.26	0.9228
11.4000	14.420	46.745	0.000	0.000	3.24	0.9263
11.6850	14.520	46.837	0.000	0.000	3.23	0.9299
11.9700	14.628	46.937	0.000	0.000	3.21	0.9338
12.2550	14.701	47.036	0.000	0.000	3.20	0.9369
12.5400	14.773	47.120	0.000	0.000	3.19	0.9397
12.8250	14.846	47.194	0.000	0.000	3.18	0.9424
13.1100	14.918	47.257	0.000	0.000	3.17	0.9449
13.3950	14.991	47.315	0.000	0.000	3.16	0.9474
13.6800	15.052	47.373	0.000	0.000	3.15	0.9497
13.9650	15.109	47.425	0.000	0.000	3.14	0.9517
14.2500	15.166	47.474	0.000	0.000	3.13	0.9537

AXIAL PRESSURE PROFILE

X (in)	MACH #	Ptotal (psia)	Pstatic (psia)	Ttotal (R)	Tstatic (R)	Wdot (Lbm/s)	Local Radius (in)
1.00	0.000	767.58	767.91	1636.08	1629.81	0.03	3.354
1.30	0.003	767.56	767.91	1642.51	1636.21	1.32	3.354
1.61	0.006	767.55	767.89	1636.08	1629.81	2.93	3.354
1.91	0.009	767.53	767.86	1723.90	1717.29	4.49	3.354
2.21	0.008	767.53	767.86	1636.08	1629.81	4.40	3.354
2.51	0.048	766.55	765.89	4445.27	4427.77	14.69	3.354
2.81	0.099	763.40	759.56	6458.54	6431.16	24.58	3.354
3.11	0.125	760.88	754.48	6560.30	6551.07	30.79	3.354
3.41	0.145	758.63	749.95	6563.62	6533.30	35.54	3.354
3.71	0.161	756.65	745.93	6547.50	6516.23	39.27	3.354
4.01	0.174	754.95	742.48	6533.95	6501.65	42.18	3.354
4.32	0.185	753.40	739.33	6528.37	6495.48	44.65	3.354
4.62	0.194	751.99	736.45	6524.67	6491.04	46.77	3.354
4.92	0.202	750.79	733.89	6523.30	6489.02	48.49	3.354
5.22	0.209	749.69	731.76	6524.97	6490.06	49.98	3.354
5.52	0.215	748.71	729.75	6526.07	6490.63	51.28	3.354
5.82	0.220	747.90	728.00	6528.71	6492.80	52.31	3.354
6.12	0.225	747.03	726.30	6530.34	6493.93	53.41	3.354
6.42	0.229	746.27	724.74	6532.63	6495.78	54.34	3.354
6.72	0.233	745.62	723.39	6536.26	6499.01	55.11	3.354
7.02	0.237	745.00	722.12	6539.84	6502.21	55.83	3.354
7.33	0.240	744.46	720.89	6542.94	6504.97	56.46	3.354
7.63	0.243	743.94	719.94	6546.43	6508.14	57.04	3.354
7.93	0.245	743.50	719.02	6549.63	6511.06	57.53	3.354
8.23	0.247	743.08	718.15	6551.91	6513.08	58.00	3.354
8.53	0.250	742.68	717.33	6553.65	6514.57	58.44	3.354
8.83	0.251	742.33	716.60	6555.54	6516.24	58.82	3.354
9.13	0.253	741.98	715.87	6557.35	6517.84	59.20	3.354
9.43	0.255	741.63	715.16	6559.15	6519.41	59.56	3.354
9.73	0.257	741.36	714.58	6560.49	6520.57	59.86	3.354
10.04	0.258	741.09	714.02	6561.58	6521.50	60.14	3.354
10.34	0.259	740.86	713.55	6562.98	6522.75	60.38	3.354
10.64	0.261	740.62	713.08	6564.31	6523.94	60.63	3.354
10.94	0.262	740.40	712.58	6565.72	6525.20	60.86	3.354
11.24	0.263	740.20	712.17	6567.34	6526.67	61.06	3.354
11.54	0.264	740.00	711.78	6568.97	6528.19	61.26	3.354
11.84	0.270	739.79	710.37	6570.78	6528.83	61.47	3.328
12.14	0.290	739.57	706.65	6572.12	6526.45	61.67	3.225
12.44	0.327	739.36	698.47	6572.73	6516.50	61.84	3.061
12.74	0.375	739.08	682.98	6573.26	6502.65	62.00	2.886
13.05	0.438	738.76	663.51	6573.85	6482.01	62.15	2.712
13.35	0.523	738.32	633.41	6574.48	6448.54	62.28	2.539
13.65	0.655	737.72	580.91	6574.95	6385.77	62.41	2.387
13.95	0.817	736.87	509.26	6575.40	6291.66	62.53	2.257
14.25	0.999	735.66	425.78	6575.85	6171.04	62.64	2.223

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                 PERFORMANCE SUMMARY

                C* EFFICIENCY CALCULATIONS (ODK)

INJECTED MR= 2.8800     CSTAR=5860.40     CORE Em=0.8930     BARRIER Em=1.0000
CORE:          OVERALL MR= 2.8800     VAPOR MR= 3.1304     CSTAR-MIX=5762.01     MASS FRACTION= 1.0000
BARRIER:       OVERALL MR= 0.0000     VAPOR MR=99.9000     CSTAR-MIX=    0.00     MASS FRACTION= 0.0000
ENGINE:        OVERALL MR= 2.8800     VAPOR MR= 3.1304     CSTAR-DEL=5588.96
C* EFFICIENCY = 9.537E-01

                ISP EFFICIENCY CALCULATIONS

ISP-ODK, INJ = 2.869E+02 SEC.
ISP-ODK, M.Z. INJ = 2.652E+02 SEC.          ISP-ODK, M.Z. VAPOR = 2.624E+02 SEC.
VAPORIZATION EFFICIENCY = 9.598E-01         MIXING EFFICIENCY = 9.935E-01
ENERGY RELEASE EFFICIENCY = 9.536E-01

NOTE: ISP-DEL = ISP-ODK, INJ. * ERE * ETADIV - DELISP-BL
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                    TIME-LAG CALCULATIONS, Milliseconds

Coham, In.=1.791E-02     FUEL Cohem, In.=2.293E+02     OX Cohem, In.=6.194E+01


ELEMENT 1 IS TYPE=LOL
FUEL:     Cinj, In.=6.621E-03     Lvap, In.= 0.610     ATOMIZATION LENGTH USED, In.= 9.625E-01
          Timp=8.686E-02     Tatom=6.303E-01     Tvap=3.993E-01     Total=1.116E+00

  OX:     Cinj, In.=6.809E-03     Lvap, In.= 0.223     ATOMIZATION LENGTH USED, In.= 2.131E+00
          Timp=1.548E-01     Tatom=1.621E+00     Tvap=1.693E-01     Total=1.945E+00

                    EFFECTIVE TIMELAGS, Milliseconds

FUEL:     Cinj, In.=6.621E-03     Lvap, In.= 0.610
          Timp=8.686E-02     Tatom=6.303E-01     Tvap=3.993E-01     Total=1.116E+00

  OX:     Cinj, In.=6.809E-03     Lvap, In.= 0.223
          Timp=1.548E-01     Tatom=1.621E+00     Tvap=1.693E-01     Total=1.945E+00
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LOW FREQUENCY COMBUSTION STABILITY CALCULATIONS

                    ROCCID
ROCket Combustor Interactive Design Methodology
            Version 23-FEB-91



 DIRECT INPUT ECHO FROM SUBROUTINE SINPUT

ROCCID POINT DESIGN TEST CASE 1
LOX/RP-1 LIKE DOUBLET PAIR WITH FIXED PC
APPROXIMATES -0100 SUBSCALE DOUBLET
 $MODELS
 MCHAM=        1
 MBURN=        2
 MINJ=         1
 $END
 $OPCOND
 PISPA=     8.9600E+01,  1.0940E+02,  1.3940E+02,  1.5880E+02,  1.7780E+02,
            2.0970E+02,  2.3550E+02,  2.5470E+02,  2.6700E+02,  2.7040E+02,
            2.7180E+02,  2.7190E+02,  2.7130E+02,  2.6980E+02,  2.6820E+02,
            2.6660E+02,  2.6500E+02,  2.6210E+02,  2.5920E+02,  2.5630E+02,
            2.5060E+02,  2.3840E+02,  2.2750E+02,  2.1100E+02,  2.0140E+02,
            1.5560E+02,  1.0970E+02,  8.0000E+01,
 PCSA=      1.7760E+03,  2.4560E+03,  3.4870E+03,  4.0740E+03,  4.5800E+03,
            5.0700E+03,  5.4540E+03,  5.7340E+03,  5.9080E+03,  5.9610E+03,
            5.9690E+03,  5.9540E+03,  5.9340E+03,  5.9090E+03,  5.8820E+03,
            5.8550E+03,  5.8260E+03,  5.7590E+03,  5.7000E+03,  5.6430E+03,
            5.5320E+03,  5.2750E+03,  5.0470E+03,  4.6760E+03,  4.4200E+03,
            3.4570E+03,  2.4940E+03,  1.4650E+03,
FUEL=    'RP-1     '
OX=      'LOX      '
PC=        2.1411E+03
XMR=       2.8800E+00
FTMAN=     7.1000E+01
XTMAN=    -2.7900E+02
EMMAN=     1.0000E+00
NPERFP=       28
PMRA=      1.0000E-01,  3.0000E-01,  6.0000E-01,  8.0000E-01,  1.0000E+00,
           1.2500E+00,  1.5000E+00,  1.7500E+00,  2.0000E+00,  2.2000E+00,
           2.4000E+00,  2.5000E+00,  2.6000E+00,  2.7000E+00,  2.8000E+00,
           2.9000E+00,  3.0000E+00,  3.2000E+00,  3.4000E+00,  3.6000E+00,
           4.0000E+00,  5.0000E+00,  6.0000E+00,  8.0000E+00,  1.0000E+01,
           1.5000E+01,  2.0000E+01,  5.0000E+01,
$END
$GEOM
RCHAMB=    2.7949E-01
RTHRT=     1.6523E-01
RNE=       1.1100E-01
RTE=       1.1100E-01
ALPHA=     3.0000E+01
CHAMBL=    1.1875E+00
XC=        9.6475E-01
$END
$CORE
TYPE=    'LOL'
NEL=          60
FDJ=       6.6345E-02
FCD=       9.1000E-01
FIH=       1.1491E-01
FIA=       3.0000E+01
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FCANT=     1.6000E+01
FFACET=    2.8728E-01
XDJ=       1.0172E-01
XCD=       9.4000E-01
XIH=       1.7619E-01
XIA=       3.0000E+01
XCANT=     1.6000E+01
XFACET=    4.4047E-01
EMUNI=     6.5000E-01
$END
$BAFFLE
$END
$BARRIER
$END
$FFC
$END
$BURN
GAMMA=     1.1462E+00
AO=        4.0656E+03
GMW=       2.3218E+01
GPR=       5.9752E-01
GK=        5.4180E-05
GMU=       6.6324E-06
RML=       7.5067E+01
VJL=       3.5358E+02
TJL=       5.3100E+02
RHOL=      4.9895E+01
CPL=       4.7321E-01
PCRITL=    3.1500E+02
TCRITL=    1.2180E+03
TBOILL=    5.8200E+02
XMWL=      1.7200E+02
HVAPL=     1.2500E+02
EN=        8.6793E-01
TAUSEN=    1.3326E-04
ISEN=           1
$END
$INJ
FMAND=     6.7076E+00
XMAND=     6.7076E+00
FMANL=     3.3538E+00
XMANL=     3.3538E+00
PCA=       2.1411E+03,  1.5514E+03,  7.6734E+02
FRA=       6.2881E-01,  4.6633E-01,  2.2731E-01
FCAPA=     7.8914E-04,  8.1791E-04,  8.6053E-04
NFE=            4
FTLA=      4.1866E-04,  5.6940E-04,  1.1164E-03,
FINA=      4.4707E-05,  4.4767E-05,  4.4924E-05,
FFA=       1.0000E+00,  1.0000E+00,  1.0000E+00,
NXE=            4
XRA=       6.2881E-01,  4.5996E-01,  2.3215E-01
XCAPA=     5.9163E-04,  6.1747E-04,  6.5615E-04
XTLA=      7.7504E-04,  1.0340E-03,  1.9451E-03,
XINA=      8.3982E-05,  8.4094E-05,  8.4389E-05,
XFA=       1.0000E+00,  1.0000E+00,  1.0000E+00,
XUOR=      6.2931E-02,  1.0000E-01,
AUOR=      3.4571E-03,  8.1266E-03,
RUOR=      3.3172E-02,  5.0860E-02,
XOR=       6.2931E-02,  1.0000E-01,
AOR=       3.4571E-03,  8.1266E-03,
ROR=       3.3172E-02,  5.0860E-02,
XDOR=      1.6586E-01,  3.0861E-01,
ADOR=      3.4571E-03,  8.1266E-03,
RDOR=      3.3172E-02,  5.0860E-02,
```

```
 WDOT=      4.6216E+01,  1.3311E+02,  3.3533E+01,  9.6576E+01,  1.6644E+01,
            4.7935E+01
 $END
 $CHAMBER
 XB=        2.6125E-01
 ZS=        1.1875E-01
 ZE=        4.9875E-01
 MUB=            3
 T=         3.3000E-02
 CC1=       5*2.5000E+03
 GAMC1=     5*1.2000E+00
 CC2=       5*2.5000E+03
 GAMC2=     5*1.2000E+00
 $END
 $FDORC
 ZCOMB=     9.5000E-01
 NZON=           5
 FTER=      2.1986E-02,  7.4060E-01,  8.9632E-01,  9.6366E-01,  1.0000E+00,

        15*1.0000E+00
 CCAV1=   20*2.5000E+03
 CGAM1=   20*1.2000E+00
 XMMC1=   20*1.7314E+01
 RHOAP1=  20*1.9046E+00
 CCAV2=   20*2.5000E+03
 CGAM2=   20*1.2000E+00
 XMMC2=   20*1.7314E+01
 RHOAP2=  20*1.9046E+00
 $END
 $MIX
  EM(1)= 8.930E-01,  1.000E+00
 $END
 $DEBUGC
 DEBUG=    F
 $END
 $HIFIC
 SHORT=    F
 POC=       2.0000E-01,  2.0000E-01
 $END
 $DIST3DC
 SHORT=    F
 POC=       2.0000E-01,  2.0000E-01
 PAMP=      2.0000E-01
 MC=            11
 LC=             8
 MB=            11
 LB=             8
 IDMAX=         10
 $END
 $CRPC
 NDPC=          16
 NDTFQ=         16
 NDTLF=       1000
 NPRINT=        50
 NSUMS=       3500
 PAMPC=     2.0000E-01
 NRAD=           3
 NCIRC=          5
 $END
 $LEINJC
 IDOMEM=         2
 PAMPCH=    2.0000E-01
 NTINJ=         16
 USGF=      2.0000E-02
```

```
OGF=       2.0000E-02
DSGF=      2.0000E-02
FCDO=      1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XCDO=      1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
$END
$COMBUSTC
FALVM=     1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XALVM=     1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
FALTM=     1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XALTM=     1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
FRMM=      1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XRMM=      1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
EMMULT=    1.0000E+00,  1.0000E+00
COMBXB=    5.0000E-01
ACMULT=    1.0000E+00
CCMULT=    1.0000E+00
ENMULT=    1.0000E+00
TAUMULT=   1.0000E+00
$END
$FDORCC
SHORT=    F
EPSIL=     2.0000E+01
ERROR=     1.0000E-01
LTS=             5
MTS=             5
NTS=            10
ITMAX=         100
RELX=      6.5000E-01
NEET=            3
NXFST=           3
NYFST=           3
NAFST=           3
MORE=     F
$END

    END OF INPUT ECHO
```

STABILITY MODEL INPUTS

RUN DESCRIPTOR

ROCCID POINT DESIGN TEST CASE 1
LOX/RP-1 LIKE DOUBLET PAIR WITH FIXED PC
APPROXIMATES -0100 SUBSCALE DOUBLET

SELECTED MODELS

BURNING MODEL=N-TAU   INJECTION MODEL=INJ   CHAMBER MODEL=HIFI

AXISYMETRIC=T   DEBUG OUTPUT=F

CHAMBER GEOMETRY AND OPERATING CONDITIONS

CHAMBER RADIUS, FT= 0.2795   THROAT RADIUS, FT= 0.1652
CYLINDRICAL SECTION, FT= 0.9647   CONVERGENCE HALF-ANGLE, DEG=30.0000
NOZZLE ENTRANCE RADIUS OF CURVATURE, FT= 0.1110   THROAT ENTRANCE RADIUS OF CURVATURE, FT= 0.1110

CHAMBER PRESSURE, PSIA=2141.10   MIXTURE RATIO= 2.8800
SOUND SPEED, FT/SEC=4085.80   GAMMA=1.1462

N-TAU BURNING MODEL INPUTS

PRESSURE INTERACTION INDEX, EN= 0.8679   SENSITIVE TIMELAG, TAU, SEC= 1.333E-04   SENSITIVE CIRCUIT=FUEL

LUMPED INJECTION MODEL INPUTS

PC, PSIA=2141.10

	% TOTAL FLOW	RESISTANCE	INERTANCE (SEC)	CAPACITANCE (SEC)	TIMELAG (SEC)
FUEL:	100.000	6.288E-01	4.471E-05	7.891E-04	4.187E-04
	0.000	6.288E-01	0.000E+00	7.891E-04	0.000E+00
	0.000	6.288E-01	0.000E+00	7.891E-04	0.000E+00
	0.000	6.288E-01	0.000E+00	7.891E-04	0.000E+00
OX:	100.000	6.288E-01	8.398E-05	5.916E-04	7.750E-04
	0.000	6.288E-01	0.000E+00	5.916E-04	0.000E+00
	0.000	6.288E-01	0.000E+00	5.916E-04	0.000E+00
	0.000	6.288E-01	0.000E+00	5.916E-04	0.000E+00

PC, PSIA=1551.40

% TOTAL FLOW	RESISTANCE	INERTANCE	CAPACITANCE	TIMELAG

			(SEC)	(SEC)	(SEC)
FUEL:	100.000	4.563E-01	4.477E-05	6.179E-04	5.694E-04
	0.000	4.563E-01	0.000E+00	6.179E-04	0.000E+00
	0.000	4.563E-01	0.000E+00	6.179E-04	0.000E+00
	0.000	4.563E-01	0.000E+00	6.179E-04	0.000E+00
OX:	100.000	4.600E-01	6.409E-05	6.175E-04	1.034E-03
	0.000	4.600E-01	0.000E+00	6.175E-04	0.000E+00
	0.000	4.600E-01	0.000E+00	6.175E-04	0.000E+00
	0.000	4.600E-01	0.000E+00	6.175E-04	0.000E+00

PC, PSIA= 767.34

	% TOTAL FLOW	RESISTANCE	INERTANCE (SEC)	CAPACITANCE (SEC)	TIMELAG (SEC)
FUEL:	100.000	2.273E-01	4.492E-05	6.605E-04	1.116E-03
	0.000	2.273E-01	0.000E+00	6.605E-04	0.000E+00
	0.000	2.273E-01	0.000E+00	6.605E-04	0.000E+00
	0.000	2.273E-01	0.000E+00	6.605E-04	0.000E+00
OX:	100.000	2.322E-01	6.439E-05	6.561E-04	1.945E-03
	0.000	2.322E-01	0.000E+00	6.561E-04	0.000E+00
	0.000	2.322E-01	0.000E+00	6.561E-04	0.000E+00
	0.000	2.322E-01	0.000E+00	6.561E-04	0.000E+00

HIFI CHAMBER MODEL INPUTS

COMBUSTION PLANE, FT= 2.612E-01   SHORT NOZZLE ASSUMED=F

ACOUSTIC CAVITY INPUTS

CAVITY TYPE=NONE
CAVITY TYPE 1:   NUMBER OF CAVITIES= 0   NUMBER OF PROPERTY SECTIONS= 1
CAVITY TYPE 2:   NUMBER OF CAVITIES= 0   NUMBER OF PROPERTY SECTIONS= 1
PARTITION THICKNESS, FT= 0.0000

PC (PSIA)	MAX. AMPLITUDE	FREQUENCY (HZ)	PHASE MARGIN (DEG)
2.141E+03	2.974E-01	5.450E+02	180.00
2.091E+03	3.076E-01	5.378E+02	180.00
2.041E+03	3.166E-01	5.315E+02	180.00
1.991E+03	3.257E-01	5.252E+02	180.00
1.941E+03	3.351E-01	5.189E+02	180.00
1.891E+03	3.446E-01	5.125E+02	180.00
1.841E+03	3.542E-01	5.060E+02	180.00
1.791E+03	3.640E-01	4.994E+02	180.00
1.741E+03	3.739E-01	4.928E+02	180.00
1.691E+03	3.837E-01	4.861E+02	180.00
1.641E+03	3.936E-01	4.793E+02	180.00
1.591E+03	4.034E-01	4.724E+02	180.00
1.541E+03	4.130E-01	4.653E+02	180.00
1.491E+03	4.224E-01	4.581E+02	180.00
1.441E+03	4.315E-01	4.508E+02	180.00
1.391E+03	4.400E-01	4.433E+02	180.00
1.341E+03	4.480E-01	4.355E+02	180.00
1.291E+03	4.553E-01	4.276E+02	180.00
1.241E+03	4.617E-01	4.194E+02	180.00
1.191E+03	4.671E-01	4.109E+02	180.00
1.141E+03	4.711E-01	4.021E+02	180.00
1.091E+03	4.739E-01	3.929E+02	180.00
1.041E+03	4.750E-01	3.833E+02	180.00
9.911E+02	4.744E-01	3.733E+02	180.00
9.411E+02	4.720E-01	3.627E+02	180.00
8.911E+02	4.676E-01	3.516E+02	180.00
8.411E+02	4.611E-01	3.399E+02	180.00
7.911E+02	4.524E-01	3.276E+02	180.00
7.411E+02	4.525E-01	6.456E+02	180.00
6.911E+02	5.050E-01	6.186E+02	180.00
6.411E+02	5.482E-01	5.909E+02	180.00
5.911E+02	5.741E-01	5.616E+02	180.00
5.411E+02	5.767E-01	5.306E+02	180.00
4.911E+02	7.858E-01	7.626E+02	-75.41
4.411E+02	1.087E+00	7.068E+02	24.25
4.578E+02	9.794E-01	7.252E+02	-5.97
4.522E+02	1.015E+00	7.190E+02	4.28
4.541E+02	1.003E+00	7.211E+02	0.89

MARGINAL CHUG POINT FOUND:
PC= 454.06 PSIA FREQUENCY= 721.07 HZ

CHUG STABILITY ITERATION SUMMARY

THE CURRENT CONFIGURATION IS CHUG STABLE

DESIRED MARGINAL PC = 800.00 PSIA
CURRENT MARGINAL PC = 454.06 PSIA
CURRENT CHUG MARGIN = 345.94 PSI
CHUG FREQUENCY = 721.07 HZ

REDESIGNED CHAMBER RESULTS

NOMINAL CHAMBER PRESSURE	= 2.141E+03	PSIA
THROTTLED CHAMBER PRESSURE	= 1.535E+03	PSIA
FUEL INJECTION PRESSURE DROP	= 5.090E+02	PSI
OX INJECTION PRESSURE DROP	= 5.090E+02	PSI
CHAMBER RADIUS	= 2.795E-01	FT
THROAT RADIUS	= 1.852E-01	FT
NOZZLE ENTRANCE RADIUS OF CURVATURE	= 1.110E-01	FT
THROAT ENTRANCE RADIUS OF CURVATURE	= 1.110E-01	FT
NOZZLE CONVERGENCE HALF-ANGLE	= 3.000E+01	DEG
INJECTOR-TO-THROAT CHAMBER LENGTH	= 1.186E+00	FT
BARREL SECTION LENGTH	= 9.648E-01	FT

IMPINGING ELEMENT SIZING RESULTS

ELEMENT TYPE	=LOL	
NO. OF ELEMENTS	= 69	
FUEL ORIFICE DIAMETER	= 6.634E-02	IN
OX ORIFICE DIAMETER	= 1.017E-01	IN

CORE ELEMENT SPACING RESULTS

ELEMENT TYPE	= LOL	
NUMBER OF ELEMENTS	= 69	
FUEL ORIFICE/ANNULUS DIAMETER	= 6.634E-02	IN
OX'DIZER ORIFICE DIAMETER	= 1.017E-01	IN
FUEL INJECTION VELOCITY	= 3.075E+02	FT/S
OXIDIZER INJECTION VELOCITY	= 2.592E+02	FT/S

ROW	# ELEMENTS	MID-ROW RADIUS (IN)
1	6	9.115E-01
2	12	1.609E+00
3	21	2.307E+00
4	30	3.005E+00

LOW FREQUENCY COMBUSTION STABILITY CALCULATIONS

ROCCID
ROCket Combustor Interactive Design Methodology
Version 23-FEB-91

```
   DIRECT INPUT ECHO FROM SUBROUTINE SINPUT

ROCCID POINT DESIGN TEST CASE 1
LOX/RP-1 LIKE DOUBLET PAIR WITH FIXED PC
APPROXIMATES -0100 SUBSCALE DOUBLET
 $MODELS
 MCHAM=        1
 MBURN=        2
 MINJ=         1
 $END
 $OPCOND
 PISPA=     8.9600E+01,  1.0940E+02,  1.3940E+02,  1.5880E+02,  1.7780E+02,
            2.0970E+02,  2.3550E+02,  2.5470E+02,  2.6700E+02,  2.7040E+02,
            2.7180E+02,  2.7190E+02,  2.7130E+02,  2.6980E+02,  2.6820E+02,
            2.6660E+02,  2.6500E+02,  2.6210E+02,  2.5920E+02,  2.5630E+02,
            2.5080E+02,  2.3640E+02,  2.2760E+02,  2.1100E+02,  2.0140E+02,
            1.5560E+02,  1.0970E+02,  6.0000E+01,
 PCSA=      1.7760E+03,  2.4560E+03,  3.4870E+03,  4.0740E+03,  4.5800E+03,
            5.0700E+03,  5.4540E+03,  5.7340E+03,  5.9060E+03,  5.9610E+03,
            5.9690E+03,  5.9540E+03,  5.9340E+03,  5.9090E+03,  5.8820E+03,
            5.8550E+03,  5.8260E+03,  5.7590E+03,  5.7000E+03,  5.6430E+03,
            5.5320E+03,  5.2750E+03,  5.0470E+03,  4.6760E+03,  4.4200E+03,
            3.4570E+03,  2.4940E+03,  1.4650E+03,
 FUEL=    'RP-1     '
 OX=      'LOX      '
 PC=        2.1411E+03
 XMR=       2.6800E+00
 FTMAN=     7.1000E+01
 XTMAN=    -2.7900E+02
 EMMAN=     1.0000E+00
 NPERFP=        28
 PMRA=      1.0000E-01,  3.0000E-01,  6.0000E-01,  8.0000E-01,  1.0000E+00,
            1.2500E+00,  1.5000E+00,  1.7500E+00,  2.0000E+00,  2.2000E+00,
            2.4000E+00,  2.5000E+00,  2.6000E+00,  2.7000E+00,  2.8000E+00,
            2.9000E+00,  3.0000E+00,  3.2000E+00,  3.4000E+00,  3.6000E+00,
            4.0000E+00,  5.0000E+00,  6.0000E+00,  8.0000E+00,  1.0000E+01,
            1.5000E+01,  2.0000E+01,  5.0000E+01,
 $END
 $GEOM
 RCHAMB=    2.7949E-01
 RTHRT=     1.6523E-01
 RNE=       1.1100E-01
 RTE=       1.1100E-01
 ALPHA=     3.0000E+01
 CHAMBL=    1.1675E+00
 XC=        9.6477E-01
 $END
 $CORE
 TYPE=    'LOL'
 NEL=           60
 FDJ=       6.6345E-02
 FCD=       9.1000E-01
 FIH=       1.1491E-01
 FIA=       3.0000E+01
```

```
FCANT=     1.6000E+01
FFACET=    2.8728E-01
XDJ=       1.0172E-01
XCD=       9.4000E-01
XIH=       1.7619E-01
XIA=       3.0000E+01
XCANT=     1.6000E+01
XFACET=    4.4047E-01
EMUNI=     6.5000E-01
$END
$BAFFLE
$END
$BARRIER
$END
$FFC
$END
$BURN
GAMMA=     1.1462E+00
AO=        4.0666E+03
GMW=       2.3216E+01
GPR=       5.9752E-01
GK=        5.4180E-05
GMU=       6.6324E-05
RML=       7.6242E+01
VJL=       3.0746E+02
TJL=       5.3100E+02
RHOL=      4.9695E+01
CPL=       4.7321E-01
PCRITL=    3.1500E+02
TCRITL=    1.2180E+03
TBOILL=    8.8200E+02
XMWL=      1.7200E+02
HVAPL=     1.2500E+02
EN=        8.6793E-01
TAUSEN=    1.4114E-04
ISEN=          1
$END
$INJ
FMAND=     6.7076E+00
XMAND=     6.7076E+00
FMANL=     3.3538E+00
XMANL=     3.3538E+00
PCA=       2.1411E+03,  1.5514E+03,  7.6734E+02
FRA=       4.7547E-01,  3.4643E-01,  1.7206E-01
FCAPA=     7.6914E-04,  6.1791E-04,  8.6053E-04
NFE=           4
FTLA=      4.6146E-04,  6.5481E-04,  1.2839E-03,
FINA=      3.8876E-05,  3.8928E-05,  3.9064E-05,
FFA=       1.0000E+00,  1.0000E+00,  1.0000E+00,
NXE=           4
XRA=       4.7547E-01,  3.4643E-01,  1.7205E-01
XCAPA=     5.9163E-04,  6.1747E-04,  6.5615E-04
XTLA=      8.9130E-04,  1.1891E-03,  2.2369E-03,
XINA=      7.3028E-05,  7.3125E-05,  7.3382E-05,
XFA=       1.0000E+00,  1.0000E+00,  1.0000E+00,
XUOR=      4.7880E-02,  7.3412E-02,
AUOR=      3.4570E-03,  8.1269E-03,
RUOR=      3.3172E-02,  5.0861E-02,
XOR=       4.7880E-02,  7.3412E-02,
AOR=       3.4570E-03,  8.1269E-03,
ROR=       3.3172E-02,  5.0861E-02,
XDOR=      9.5761E-02,  1.4682E-01,
ADOR=      3.4570E-03,  8.1269E-03,
RDOR=      3.3172E-02,  5.0861E-02,
```

```
WDOT=       4.6216E+01,  1.3311E+02,  3.3533E+01,  9.6576E+01,  1.6644E+01,
            4.7935E+01
$END
$CHAMBER
XB=         2.6125E-01
ZS=         1.1875E-01
ZE=         4.9875E-01
MUB=             3
T=          3.3000E-02
CC1=        5*2.5000E+03
GAMC1=      5*1.2000E+00
CC2=        5*2.5000E+03
GAMC2=      5*1.2000E+00
$END
$FDORC
NZON=            5
FTER=      20*1.0000E+00
$END
$MIX
 EM(1)= 9.003E-01,  1.000E+00
$END
$DEBUGC
DEBUG=     F
$END
$HIFIC
SHORT=     F
POC=        2.0000E-01,  2.0000E-01
$END
$DIST3DC
SHORT=     F
POC=        2.0000E-01,  2.0000E-01
PAMP=       2.0000E-01
MC=             11
LC=              6
MB=             11
LB=              6
IDMAX=          10
$END
$CRPC
NDPC=           16
NDTFQ=          16
NDTLF=        1000
NPRINT=         50
NSUMS=        3500
PAMPC=      2.0000E-01
NRAD=            3
NCIRC=           5
$END
$LEINJC
IDOMEM=          2
PAMPCH=     2.0000E-01
NTINJ=          16
USGF=       2.0000E-02
OGF=        2.0000E-02
DSGF=       2.0000E-02
FCDO=       1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XCDO=       1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
$END
$COMBUSTC
FALVM=      1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XALVM=      1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
FALTM=      1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XALTM=      1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
FRMM=       1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
```

```
XRMM=      1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
EMMULT=    1.0000E+00,  1.0000E+00
COMBXB=    5.0000E-01
AOMULT=    1.0000E+00
CCMULT=    1.0000E+00
ENMULT=    1.0000E+00
TAUMULT=   1.0000E+00
$END
$FDORCC
SHORT=    F
EPSIL=     2.0000E+01
ERROR=     1.0000E-01
LTS=            5
MTS=            5
NTS=           10
ITMAX=        100
RELX=      6.5000E-01
NEET=           3
NXFST=          3
NYFST=          3
NAFST=          3
MORE=     F
$END

   END OF INPUT ECHO
```

STABILITY MODEL INPUTS

RUN DESCRIPTOR

ROCCID POINT DESIGN TEST CASE 1
LOX/RP-1 LIKE DOUBLET PAIR WITH FIXED PC
APPROXIMATES -0100 SUBSCALE DOUBLET

SELECTED MODELS

BURNING MODEL=N-TAU   INJECTION MODEL=INJ   CHAMBER MODEL=HIFI

AXISYMETRIC=T   DEBUG OUTPUT=F

CHAMBER GEOMETRY AND OPERATING CONDITIONS

CHAMBER RADIUS, FT= 0.2795   THROAT RADIUS, FT= 0.1652
CYLINDRICAL SECTION, FT= 0.9648   CONVERGENCE HALF-ANGLE, DEG=30.0000
NOZZLE ENTRANCE RADIUS OF CURVATURE, FT= 0.1110   THROAT ENTRANCE RADIUS OF CURVATURE, FT= 0.1110

CHAMBER PRESSURE, PSIA=2141.10   MIXTURE RATIO= 2.8800
SOUND SPEED, FT/SEC=4065.80   GAMMA=1.1462

N-TAU BURNING MODEL INPUTS

PRESSURE INTERACTION INDEX, EN= 0.8679   SENSITIVE TIMELAG, TAU, SEC= 1.411E-04   SENSITIVE CIRCUIT=FUEL

LUMPED INJECTION MODEL INPUTS

PC, PSIA=2141.10

	% TOTAL FLOW	RESISTANCE	INERTANCE (SEC)	CAPACITANCE (SEC)	TIMELAG (SEC)
FUEL:	100.000	4.755E-01	3.888E-05	7.891E-04	4.815E-04
	0.000	4.755E-01	0.000E+00	7.891E-04	0.000E+00
	0.000	4.755E-01	0.000E+00	7.891E-04	0.000E+00
	0.000	4.755E-01	0.000E+00	7.891E-04	0.000E+00
OX:	100.000	4.755E-01	7.303E-05	5.916E-04	5.913E-04
	0.000	4.755E-01	0.000E+00	5.916E-04	0.000E+00
	0.000	4.755E-01	0.000E+00	5.916E-04	0.000E+00
	0.000	4.755E-01	0.000E+00	5.916E-04	0.000E+00

PC, PSIA=1551.40

% TOTAL FLOW	RESISTANCE	INERTANCE	CAPACITANCE	TIMELAG

			(SEC)	(SEC)	(SEC)
FUEL:	100.000	3.454E-01	3.693E-05	8.179E-04	6.546E-04
	0.000	3.454E-01	0.000E+00	8.179E-04	0.000E+00
	0.000	3.454E-01	0.000E+00	8.179E-04	0.000E+00
	0.000	3.454E-01	0.000E+00	8.179E-04	0.000E+00
OX:	100.000	3.454E-01	7.312E-05	6.175E-04	1.169E-03
	0.000	3.454E-01	0.000E+00	6.175E-04	0.000E+00
	0.000	3.454E-01	0.000E+00	6.175E-04	0.000E+00
	0.000	3.454E-01	0.000E+00	6.175E-04	0.000E+00

PC, PSIA= 767.34

	% TOTAL FLOW	RESISTANCE	INERTANCE (SEC)	CAPACITANCE (SEC)	TIMELAG (SEC)
FUEL:	100.000	1.721E-01	3.906E-05	8.605E-04	1.264E-03
	0.000	1.721E-01	0.000E+00	8.605E-04	0.000E+00
	0.000	1.721E-01	0.000E+00	8.605E-04	0.000E+00
	0.000	1.721E-01	0.000E+00	8.605E-04	0.000E+00
OX:	100.000	1.720E-01	7.338E-05	6.561E-04	2.237E-03
	0.000	1.720E-01	0.000E+00	6.561E-04	0.000E+00
	0.000	1.720E-01	0.000E+00	6.561E-04	0.000E+00
	0.000	1.720E-01	0.000E+00	6.561E-04	0.000E+00

HIFI CHAMBER MODEL INPUTS

COMBUSTION PLANE, FT= 2.612E-01 SHORT NOZZLE ASSUMED=F

ACOUSTIC CAVITY INPUTS

CAVITY TYPE=NONE
CAVITY TYPE 1: NUMBER OF CAVITIES= 0 NUMBER OF PROPERTY SECTIONS= 1
CAVITY TYPE 2: NUMBER OF CAVITIES= 0 NUMBER OF PROPERTY SECTIONS= 1
PARTITION THICKNESS, FT= 0.0000

PC (PSIA)	MAX. AMPLITUDE	FREQUENCY (HZ)	PHASE MARGIN (DEG)
2.141E+03	3.710E-01	5.199E+02	180.00
2.091E+03	3.819E-01	5.131E+02	180.00
2.041E+03	3.898E-01	5.073E+02	180.00
1.991E+03	3.977E-01	5.014E+02	180.00
1.941E+03	4.054E-01	4.955E+02	180.00
1.891E+03	4.130E-01	4.894E+02	180.00
1.841E+03	4.204E-01	4.833E+02	180.00
1.791E+03	4.276E-01	4.770E+02	180.00
1.741E+03	4.345E-01	4.707E+02	180.00
1.691E+03	4.409E-01	4.641E+02	180.00
1.641E+03	4.469E-01	4.574E+02	180.00
1.591E+03	4.524E-01	4.506E+02	180.00
1.541E+03	4.573E-01	4.435E+02	180.00
1.491E+03	4.615E-01	4.363E+02	180.00
1.441E+03	4.650E-01	4.288E+02	180.00
1.391E+03	4.676E-01	4.211E+02	180.00
1.341E+03	4.693E-01	4.131E+02	180.00
1.291E+03	4.699E-01	4.048E+02	180.00
1.241E+03	4.695E-01	3.963E+02	180.00
1.191E+03	4.679E-01	3.873E+02	180.00
1.141E+03	4.651E-01	3.780E+02	180.00
1.091E+03	4.611E-01	3.683E+02	180.00
1.041E+03	4.558E-01	3.582E+02	180.00
9.911E+02	4.491E-01	3.476E+02	180.00
9.411E+02	4.412E-01	3.366E+02	180.00
8.911E+02	4.754E-01	6.716E+02	180.00
8.411E+02	5.128E-01	6.483E+02	180.00
7.911E+02	5.419E-01	6.243E+02	180.00
7.411E+02	5.590E-01	5.991E+02	180.00
6.911E+02	5.619E-01	5.725E+02	180.00
6.411E+02	6.223E-01	6.394E+02	180.00
5.911E+02	6.399E-01	7.913E+02	-49.13
5.411E+02	1.089E+00	7.444E+02	26.49
5.578E+02	1.009E+00	7.599E+02	2.58

MARGINAL CHUG POINT FOUND:
PC= 557.77 PSIA FREQUENCY= 759.90 HZ

CHUG STABILITY ITERATION SUMMARY

THE CURRENT CONFIGURATION IS CHUG STABLE

DESIRED MARGINAL PC	=	800.00 PSIA
CURRENT MARGINAL PC	=	557.77 PSIA
CURRENT CHUG MARGIN	=	242.23 PSI
CHUG FREQUENCY	=	759.90 HZ

LOW FREQUENCY COMBUSTION STABILITY CALCULATIONS

ROCCID
ROCket Combustor Interactive Design Methodology
Version 23-FEB-91

```
   DIRECT INPUT ECHO FROM SUBROUTINE SINPUT

ROCCID POINT DESIGN TEST CASE 1
LOX/RP-1 LIKE DOUBLET PAIR WITH FIXED PC
APPROXIMATES -0100 SUBSCALE DOUBLET
 $MODELS
 MCHAM=         1
 MBURN=         2
 MINJ=          1
 $END
 $OPCOND
 PISPA=     8.9600E+01,  1.0940E+02,  1.3940E+02,  1.5880E+02,  1.7780E+02,
            2.0970E+02,  2.3550E+02,  2.5470E+02,  2.6700E+02,  2.7040E+02,
            2.7180E+02,  2.7190E+02,  2.7130E+02,  2.6980E+02,  2.6820E+02,
            2.6660E+02,  2.6500E+02,  2.6210E+02,  2.5920E+02,  2.5630E+02,
            2.5080E+02,  2.3840E+02,  2.2750E+02,  2.1100E+02,  2.0140E+02,
            1.5560E+02,  1.0970E+02,  8.0000E+01,
 PCSA=      1.7760E+03,  2.4660E+03,  3.4870E+03,  4.0740E+03,  4.5800E+03,
            5.0700E+03,  5.4540E+03,  5.7340E+03,  5.9080E+03,  5.9610E+03,
            5.9690E+03,  5.9540E+03,  5.9340E+03,  5.9090E+03,  5.8820E+03,
            5.8550E+03,  5.8260E+03,  5.7590E+03,  5.7000E+03,  5.6430E+03,
            5.5320E+03,  5.2750E+03,  5.0470E+03,  4.6760E+03,  4.4200E+03,
            3.4570E+03,  2.4940E+03,  1.4650E+03,
 FUEL=     'RP-1     '
 OX=       'LOX      '
 PC=        2.1411E+03
 XMR=       2.8800E+00
 FTMAN=     7.1000E+01
 XTMAN=    -2.7900E+02
 EMMAN=     1.0000E+00
 NPERFP=        28
 PMRA=      1.0000E-01,  3.0000E-01,  6.0000E-01,  8.0000E-01,  1.0000E+00,
            1.2500E+00,  1.5000E+00,  1.7500E+00,  2.0000E+00,  2.2000E+00,
            2.4000E+00,  2.5000E+00,  2.6000E+00,  2.7000E+00,  2.8000E+00,
            2.9000E+00,  3.0000E+00,  3.2000E+00,  3.4000E+00,  3.6000E+00,
            4.0000E+00,  5.0000E+00,  6.0000E+00,  8.0000E+00,  1.0000E+01,
            1.5000E+01,  2.0000E+01,  5.0000E+01,
 $END
 $GEOM
 RCHAMB=    2.7949E-01
 RTHRT=     1.8623E-01
 RNE=       1.1100E-01
 RTE=       1.1100E-01
 ALPHA=     3.0000E+01
 CHAMBL=    1.1875E+00
 XC=        9.6477E-01
 $END
 $CORE
 TYPE=     'LOL'
 NEL=           69
 FDJ=       6.6345E-02
 FCD=       9.1000E-01
 FIH=       1.1491E-01
 FIA=       3.0000E+01
```

```
FCANT=     1.6000E+01
FFACET=    2.6728E-01
XDJ=       1.0172E-01
XCD=       9.4000E-01
XIH=       1.7619E-01
XIA=       3.0000E+01
XCANT=     1.6000E+01
XFACET=    4.4047E-01
EMUNI=     6.5000E-01
$END
$BAFFLE
$END
$BARRIER
$END
$FFC
$END
$BURN
GAMMA=     1.1462E+00
AO=        4.0658E+03
GMW=       2.3216E+01
GPR=       5.9752E-01
GK=        5.4180E-05
GMU=       6.6324E-05
RML=       7.6242E+01
VJL=       3.0746E+02
TJL=       5.3100E+02
RHOL=      4.9895E+01
CPL=       4.7321E-01
PCRITL=    3.1500E+02
TCRITL=    1.2180E+03
TBOILL=    8.8200E+02
XMWL=      1.7200E+02
HVAPL=     1.2500E+02
EN=        8.6793E-01
TAUSEN=    1.4114E-04
ISEN=          1
$END
$INJ
FMAND=     6.7076E+00
XMAND=     6.7076E+00
FMANL=     3.3538E+00
XMANL=     3.3538E+00
PCA=       2.1411E+03,  1.5514E+03,  7.6734E+02
FRA=       4.7547E-01,  3.4549E-01,  1.7206E-01
FCAPA=     7.6914E-04,  6.1791E-04,  6.6053E-04
NFE=           4
FTLA=      5.0142E-04,  6.8196E-04,  1.3371E-03,
FINA=      3.8876E-05,  3.8928E-05,  3.9064E-05,
FFA=       1.0000E+00,  1.0000E+00,  1.0000E+00,
NXE=           4
XRA=       4.7547E-01,  3.4549E-01,  1.7206E-01
XCAPA=     5.9163E-04,  6.1747E-04,  6.5615E-04
XTLA=      9.3236E-04,  1.2439E-03,  2.3399E-03,
XINA=      7.3028E-05,  7.3125E-05,  7.3382E-05,
XFA=       1.0000E+00,  1.0000E+00,  1.0000E+00,
XUOR=      4.7860E-02,  7.3412E-02,
AUOR=      3.4570E-03,  8.1269E-03,
RUOR=      3.3172E-02,  5.0861E-02,
XOR=       4.7860E-02,  7.3412E-02,
AOR=       3.4570E-03,  8.1269E-03,
ROR=       3.3172E-02,  5.0861E-02,
XDOR=      9.5761E-02,  1.4682E-01,
ADOR=      3.4570E-03,  8.1269E-03,
RDOR=      3.3172E-02,  5.0861E-02,
```

```
WDOT=      4.6216E+01,  1.3311E+02,  3.3533E+01,  9.6576E+01,  1.6644E+01,
           4.7935E+01
$END
$CHAMBER
XB=        2.6125E-01
ZS=        1.1875E-01
ZE=        4.9875E-01
MUS=           3
T=         3.3000E-02
CC1=       5*2.5000E+03
GAMC1=     5*1.2000E+00
CC2=       5*2.5000E+03
GAMC2=     5*1.2000E+00
$END
$FDORC
NZON=          5
FTER=    20*1.0000E+00
$END
$MIX
 EM(1)= 9.003E-01,  1.000E+00
$END
$DEBUGC
DEBUG=   F
$END
$HIFIC
SHORT=   F
POC=       2.0000E-01,  2.0000E-01
$END
$DIST3DC
SHORT=   F
POC=       2.0000E-01,  2.0000E-01
PAMP=      2.0000E-01
MC=           11
LC=            8
MB=           11
LB=            8
IDMAX=        10
$END
$CRPC
NDPC=         16
NDTFQ=        16
NDTLF=      1000
NPRINT=       50
NSUMS=      3500
PAMPC=     2.0000E-01
NRAD=          3
NCIRC=         5
$END
$LEINJC
IDOMEM=        2
PAMPCH=    2.0000E-01
NTINJ=        16
USGF=      2.0000E-02
OGF=       2.0000E-02
DSGF=      2.0000E-02
FCDO=      1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XCDO=      1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
$END
$COMBUSTC
FALVM=     1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XALVM=     1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
FALTM=     1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XALTM=     1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
FRMM=      1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
```

```
XRMM=      1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
EMMULT=    1.0000E+00,  1.0000E+00
COMBXB=    5.0000E-01
AOMULT=    1.0000E+00
CCMULT=    1.0000E+00
ENMULT=    1.0000E+00
TAUMULT=   1.0000E+00
$END
$FDORCC
SHORT=   F
EPSIL=     2.0000E+01
ERROR=     1.0000E-01
LTS=            5
MTS=            5
NTS=           10
ITMAX=        100
RELX=      6.5000E-01
NEET=           3
NXFST=          3
NYFST=          3
NAFST=          3
MORE=    F
$END

   END OF INPUT ECHO
```

STABILITY MODEL INPUTS

RUN DESCRIPTOR

ROCCID POINT DESIGN TEST CASE 1
LOX/RP-1 LIKE DOUBLET PAIR WITH FIXED PC
APPROXIMATES -0100 SUBSCALE DOUBLET

SELECTED MODELS

BURNING MODEL=N-TAU   INJECTION MODEL=INJ   CHAMBER MODEL=HIFI

AXISYMETRIC=T   DEBUG OUTPUT=F

CHAMBER GEOMETRY AND OPERATING CONDITIONS

CHAMBER RADIUS, FT= 0.2795
CYLINDRICAL SECTION, FT= 0.9648
NOZZLE ENTRANCE RADIUS OF CURVATURE, FT= 0.1110

THROAT RADIUS, FT= 0.1852
CONVERGENCE HALF-ANGLE, DEG=30.0000
THROAT ENTRANCE RADIUS OF CURVATURE, FT= 0.1110

CHAMBER PRESSURE, PSIA=2141.10   MIXTURE RATIO= 2.8800
SOUND SPEED, FT/SEC=4065.80   GAMMA=1.1462

N-TAU BURNING MODEL INPUTS

PRESSURE INTERACTION INDEX, EN= 0.8679   SENSITIVE TIMELAG, TAU, SEC= 1.411E-04   SENSITIVE CIRCUIT=FUEL

LUMPED INJECTION MODEL INPUTS

PC, PSIA=2141.10

	% TOTAL FLOW	RESISTANCE	INERTANCE (SEC)	CAPACITANCE (SEC)	TIMELAG (SEC)
FUEL:	100.000	4.755E-01	3.888E-05	7.891E-04	5.014E-04
	0.000	4.755E-01	0.000E+00	7.891E-04	0.000E+00
	0.000	4.755E-01	0.000E+00	7.891E-04	0.000E+00
	0.000	4.755E-01	0.000E+00	7.891E-04	0.000E+00
OX:	100.000	4.755E-01	7.303E-05	5.916E-04	9.324E-04
	0.000	4.755E-01	0.000E+00	5.916E-04	0.000E+00
	0.000	4.755E-01	0.000E+00	5.916E-04	0.000E+00
	0.000	4.755E-01	0.000E+00	5.916E-04	0.000E+00

PC, PSIA=1551.40

% TOTAL FLOW	RESISTANCE	INERTANCE	CAPACITANCE	TIMELAG

			(SEC)	(SEC)	(SEC)
FUEL:	100.000	3.454E-01	3.893E-05	6.179E-04	6.820E-04
	0.000	3.454E-01	0.000E+00	6.179E-04	0.000E+00
	0.000	3.454E-01	0.000E+00	6.179E-04	0.000E+00
	0.000	3.454E-01	0.000E+00	6.179E-04	0.000E+00
OX:	100.000	3.454E-01	7.312E-05	6.175E-04	1.244E-03
	0.000	3.454E-01	0.000E+00	6.175E-04	0.000E+00
	0.000	3.454E-01	0.000E+00	6.175E-04	0.000E+00
	0.000	3.454E-01	0.000E+00	6.175E-04	0.000E+00

PC, PSIA= 767.34

	% TOTAL FLOW	RESISTANCE	INERTANCE (SEC)	CAPACITANCE (SEC)	TIMELAG (SEC)
FUEL:	100.000	1.721E-01	3.906E-05	6.605E-04	1.337E-03
	0.000	1.721E-01	0.000E+00	6.605E-04	0.000E+00
	0.000	1.721E-01	0.000E+00	6.605E-04	0.000E+00
	0.000	1.721E-01	0.000E+00	6.605E-04	0.000E+00
OX:	100.000	1.720E-01	7.338E-05	6.561E-04	2.340E-03
	0.000	1.720E-01	0.000E+00	6.561E-04	0.000E+00
	0.000	1.720E-01	0.000E+00	6.561E-04	0.000E+00
	0.000	1.720E-01	0.000E+00	6.561E-04	0.000E+00

HIFI CHAMBER MODEL INPUTS

COMBUSTION PLANE, FT= 2.612E-01   SHORT NOZZLE ASSUMED=F

ACOUSTIC CAVITY INPUTS

CAVITY TYPE=NONE
CAVITY TYPE 1:   NUMBER OF CAVITIES= 0   NUMBER OF PROPERTY SECTIONS= 1
CAVITY TYPE 2:   NUMBER OF CAVITIES= 0   NUMBER OF PROPERTY SECTIONS= 1
PARTITION THICKNESS, FT= 0.0000

PC (PSIA)	MAX. AMPLITUDE	FREQUENCY (HZ)	PHASE MARGIN (DEG)
2.141E+03	3.729E-01	5.058E+02	180.00
2.091E+03	3.835E-01	4.992E+02	180.00
2.041E+03	3.909E-01	4.935E+02	180.00
1.991E+03	3.981E-01	4.878E+02	180.00
1.941E+03	4.053E-01	4.819E+02	180.00
1.891E+03	4.122E-01	4.760E+02	180.00
1.841E+03	4.189E-01	4.700E+02	180.00
1.791E+03	4.253E-01	4.638E+02	180.00
1.741E+03	4.313E-01	4.575E+02	180.00
1.691E+03	4.370E-01	4.511E+02	180.00
1.641E+03	4.421E-01	4.445E+02	180.00
1.591E+03	4.468E-01	4.377E+02	180.00
1.541E+03	4.508E-01	4.307E+02	180.00
1.491E+03	4.541E-01	4.236E+02	180.00
1.441E+03	4.566E-01	4.162E+02	180.00
1.391E+03	4.584E-01	4.085E+02	180.00
1.341E+03	4.592E-01	4.006E+02	180.00
1.291E+03	4.590E-01	3.925E+02	180.00
1.241E+03	4.577E-01	3.840E+02	180.00
1.191E+03	4.553E-01	3.751E+02	180.00
1.141E+03	4.519E-01	3.659E+02	180.00
1.091E+03	4.472E-01	3.564E+02	180.00
1.041E+03	4.413E-01	3.464E+02	180.00
9.911E+02	4.349E-01	3.360E+02	180.00
9.411E+02	4.520E-01	6.727E+02	180.00
8.911E+02	4.877E-01	6.504E+02	180.00
8.411E+02	5.173E-01	6.275E+02	180.00
7.911E+02	5.377E-01	6.037E+02	180.00
7.411E+02	5.467E-01	5.786E+02	180.00
6.911E+02	5.434E-01	5.521E+02	180.00
6.411E+02	7.171E-01	8.109E+02	-119.37
5.911E+02	9.370E-01	7.654E+02	-19.25
5.411E+02	1.179E+00	7.210E+02	51.08
5.578E+02	1.098E+00	7.357E+02	28.36
5.744E+02	1.017E+00	7.505E+02	5.04
5.800E+02	9.901E-01	7.555E+02	-2.92

MARGINAL CHUG POINT FOUND:
PC= 579.99 PSIA FREQUENCY= 755.47 HZ

CHUG STABILITY ITERATION SUMMARY

THE CURRENT CONFIGURATION IS CHUG STABLE

DESIRED MARGINAL PC = 800.00 PSIA
CURRENT MARGINAL PC = 579.99 PSIA
CURRENT CHUG MARGIN = 220.01 PSI
CHUG FREQUENCY = 755.47 HZ

HIGH FREQUENCY COMBUSTION STABILITY CALCULATIONS

ROCCID
ROCket Combustor Interactive Design Methodology
Version 23-FEB-91

DIRECT INPUT ECHO FROM SUBROUTINE SINPUT

```
ROCCID POINT DESIGN TEST CASE 1
LOX/RP-1 LIKE DOUBLET PAIR WITH FIXED PC
APPROXIMATES -0100 SUBSCALE DOUBLET
 $MODELS
 MCHAM=        1
 MBURN=        2
 MINJ=         1
 $END
 $OPCOND
 PISPA=    8.9600E+01,  1.0940E+02,  1.3940E+02,  1.5880E+02,  1.7780E+02,
           2.0970E+02,  2.3550E+02,  2.5470E+02,  2.6700E+02,  2.7040E+02,
           2.7180E+02,  2.7190E+02,  2.7130E+02,  2.6980E+02,  2.6820E+02,
           2.6660E+02,  2.6500E+02,  2.6210E+02,  2.5920E+02,  2.5630E+02,
           2.5080E+02,  2.3840E+02,  2.2750E+02,  2.1100E+02,  2.0140E+02,
           1.5560E+02,  1.0970E+02,  8.0000E+01,
 PCSA=     1.7760E+03,  2.4660E+03,  3.4870E+03,  4.0740E+03,  4.5800E+03,
           5.0700E+03,  5.4540E+03,  5.7340E+03,  5.9060E+03,  5.9610E+03,
           5.9690E+03,  5.9540E+03,  5.9340E+03,  5.9090E+03,  5.8820E+03,
           5.8550E+03,  5.8260E+03,  5.7590E+03,  5.7000E+03,  5.6430E+03,
           5.5320E+03,  5.2750E+03,  5.0470E+03,  4.6760E+03,  4.4200E+03,
           3.4570E+03,  2.4940E+03,  1.4650E+03,
 FUEL=    'RP-1      '
 OX=      'LOX       '
 PC=       2.1411E+03
 XMR=      2.6600E+00
 FTMAN=    7.1000E+01
 XTMAN=   -2.7900E+02
 EMMAN=    1.0000E+00
 NPERFP=      28
 PMRA=     1.0000E-01,  3.0000E-01,  6.0000E-01,  8.0000E-01,  1.0000E+00,
           1.2500E+00,  1.5000E+00,  1.7500E+00,  2.0000E+00,  2.2000E+00,
           2.4000E+00,  2.5000E+00,  2.6000E+00,  2.7000E+00,  2.8000E+00,
           2.9000E+00,  3.0000E+00,  3.2000E+00,  3.4000E+00,  3.6000E+00,
           4.0000E+00,  5.0000E+00,  6.0000E+00,  8.0000E+00,  1.0000E+01,
           1.5000E+01,  2.0000E+01,  5.0000E+01,
 $END
 $GEOM
 RCHAMB=   2.7949E-01
 RTHRT=    1.8523E-01
 RNE=      1.1100E-01
 RTE=      1.1100E-01
 ALPHA=    3.0000E+01
 CHAMBL=   1.1875E+00
 XC=       9.6477E-01
 $END
 $CORE
 TYPE=    'LOL'
 NEL=         69
 FDJ=      6.6345E-02
 FCD=      9.1000E-01
 FIH=      1.1491E-01
 FIA=      3.0000E+01
```

```
FCANT=     1.6000E+01
FFACET=    2.8726E-01
XDJ=       1.0172E-01
XCD=       9.4000E-01
XIH=       1.7619E-01
XIA=       3.0000E+01
XCANT=     1.6000E+01
XFACET=    4.4047E-01
EMUNI=     6.5000E-01
$END
$BAFFLE
$END
$BARRIER
$END
$FFC
$END
$BURN
GAMMA=     1.1462E+00
AO=        4.0658E+03
GMW=       2.3216E+01
GPR=       5.9752E-01
GK=        5.4180E-05
GMU=       6.6324E-05
RML=       7.6242E+01
VJL=       3.0746E+02
TJL=       5.3100E+02
RHOL=      4.9895E+01
CPL=       4.7321E-01
PCRITL=    3.1500E+02
TCRITL=    1.2180E+03
TBOILL=    8.8200E+02
XMWL=      1.7200E+02
HVAPL=     1.2500E+02
EN=        8.6793E-01
TAUBEN=    1.4114E-04
ISEN=          1
$END
$INJ
FMAND=     6.7076E+00
XMAND=     6.7076E+00
FMANL=     3.3538E+00
XMANL=     3.3538E+00
PCA=       2.1411E+03,  1.5514E+03,  7.6734E+02
FRA=       4.7547E-01,  3.4543E-01,  1.7206E-01
FCAPA=     7.8914E-04,  8.1791E-04,  8.8053E-04
NFE=           4
FTLA=      5.0142E-04,  8.8196E-04,  1.3371E-03,
FINA=      3.8876E-05,  3.8928E-05,  3.9064E-05,
FFA=       1.0000E+00,  1.0000E+00,  1.0000E+00,
NXE=           4
XRA=       4.7547E-01,  3.4543E-01,  1.7206E-01
XCAPA=     5.9163E-04,  6.1747E-04,  6.5615E-04
XTLA=      9.3236E-04,  1.2439E-03,  2.3399E-03,
XINA=      7.3028E-05,  7.3126E-05,  7.3382E-05,
XFA=       1.0000E+00,  1.0000E+00,  1.0000E+00,
XUOR=      4.7880E-02,  7.3412E-02,
AUOR=      3.4570E-03,  8.1269E-03,
RUOR=      3.3172E-02,  5.0861E-02,
XOR=       4.7880E-02,  7.3412E-02,
AOR=       3.4570E-03,  8.1269E-03,
ROR=       3.3172E-02,  5.0861E-02,
XDOR=      9.5761E-02,  1.4682E-01,
ADOR=      3.4570E-03,  8.1269E-03,
RDOR=      3.3172E-02,  5.0861E-02,
```

```
WDOT=      4.6218E+01,  1.3311E+02,  3.3533E+01,  9.6576E+01,  1.6644E+01,
           4.7935E+01
$END
$CHAMBER
XB=        2.6125E-01
ZS=        1.1875E-01
ZE=        4.9875E-01
MUB=           3
T=         3.3000E-02
CC1=       5*2.5000E+03
GAMC1=     5*1.2000E+00
CC2=       5*2.5000E+03
GAMC2=     5*1.2000E+00
$END
$FDORC
NZON=          5
FTER=      20*1.0000E+00
$END
$MIX
 EM(1)= 9.003E-01,  1.000E+00
$END
$DEBUGC
DEBUG=     F
$END
$HIFIC
SHORT=     F
POC=       2.0000E-01,  2.0000E-01
$END
$DIST3DC
SHORT=     F
POC=       2.0000E-01,  2.0000E-01
PAMP=      2.0000E-01
MC=           11
LC=            6
MB=           11
LB=            6
IDMAX=        10
$END
$CRPC
NDPC=         16
NDTFQ=        16
NDTLF=      1000
NPRINT=       50
NSUMS=      3500
PAMPC=     2.0000E-01
NRAD=          3
NCIRC=         5
$END
$LEINJC
IDOMEM=        2
PAMPCH=    2.0000E-01
NTINJ=        18
USGF=      2.0000E-02
OGF=       2.0000E-02
DSGF=      2.0000E-02
FCDO=      1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XCDO=      1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
$END
$COMBUSTC
FALVM=     1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XALVM=     1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
FALTM=     1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XALTM=     1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
FRMM=      1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
```

```
XRMM=     1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
EMMULT=   1.0000E+00,  1.0000E+00
COMBXB=   5.0000E-01
AOMULT=   1.0000E+00
CCMULT=   1.0000E+00
ENMULT=   1.0000E+00
TAUMULT=  1.0000E+00
$END
$FDORCC
SHORT=   F
EPSIL=    2.0000E+01
ERROR=    1.0000E-01
LTS=            5
MTS=            5
NTS=           10
ITMAX=        100
RELX=     6.5000E-01
NEET=           3
NXFST=          3
NYFST=          3
NAFST=          3
MORE=    F
$END

   END OF INPUT ECHO
```

STABILITY MODEL INPUTS

RUN DESCRIPTOR

ROCCID POINT DESIGN TEST CASE 1
LOX/RP-1 LIKE DOUBLET PAIR WITH FIXED PC
APPROXIMATES -0100 SUBSCALE DOUBLET

SELECTED MODELS

BURNING MODEL=N-TAU   INJECTION MODEL=INJ   CHAMBER MODEL=HIFI

AXISYMETRIC=T   DEBUG OUTPUT=F

CHAMBER GEOMETRY AND OPERATING CONDITIONS

CHAMBER RADIUS, FT= 0.2795   THROAT RADIUS, FT= 0.1852
CYLINDRICAL SECTION, FT= 0.9848   CONVERGENCE HALF-ANGLE, DEG=30.0000
NOZZLE ENTRANCE RADIUS OF CURVATURE, FT= 0.1110   THROAT ENTRANCE RADIUS OF CURVATURE, FT= 0.1110

CHAMBER PRESSURE, PSIA=2141.10   MIXTURE RATIO= 2.8800
SOUND SPEED, FT/SEC=4065.60   GAMMA=1.1462

N-TAU BURNING MODEL INPUTS

PRESSURE INTERACTION INDEX, EN= 0.8679   SENSITIVE TIMELAG, TAU, SEC= 1.411E-04   SENSITIVE CIRCUIT=FUEL

LUMPED INJECTION MODEL INPUTS

PC, PSIA=2141.10

	% TOTAL FLOW	RESISTANCE	INERTANCE (SEC)	CAPACITANCE (SEC)	TIMELAG (SEC)
FUEL:	100.000	4.755E-01	3.888E-05	7.891E-04	5.014E-04
	0.000	4.755E-01	0.000E+00	7.891E-04	0.000E+00
	0.000	4.755E-01	0.000E+00	7.891E-04	0.000E+00
	0.000	4.755E-01	0.000E+00	7.891E-04	0.000E+00
OX:	100.000	4.755E-01	7.303E-05	5.916E-04	9.324E-04
	0.000	4.755E-01	0.000E+00	5.916E-04	0.000E+00
	0.000	4.755E-01	0.000E+00	5.916E-04	0.000E+00
	0.000	4.755E-01	0.000E+00	5.916E-04	0.000E+00

PC, PSIA=1551.40

% TOTAL FLOW	RESISTANCE	INERTANCE	CAPACITANCE	TIMELAG

			(SEC)	(SEC)	(SEC)
FUEL:	100.000	3.454E-01	3.893E-05	6.179E-04	6.820E-04
	0.000	3.454E-01	0.000E+00	6.179E-04	0.000E+00
	0.000	3.454E-01	0.000E+00	6.179E-04	0.000E+00
	0.000	3.454E-01	0.000E+00	6.179E-04	0.000E+00
OX:	100.000	3.454E-01	7.312E-05	6.175E-04	1.244E-03
	0.000	3.454E-01	0.000E+00	6.175E-04	0.000E+00
	0.000	3.454E-01	0.000E+00	6.175E-04	0.000E+00
	0.000	3.454E-01	0.000E+00	6.175E-04	0.000E+00

PC, PSIA= 767.34

	% TOTAL FLOW	RESISTANCE	INERTANCE (SEC)	CAPACITANCE (SEC)	TIMELAG (SEC)
FUEL:	100.000	1.721E-01	3.906E-05	8.606E-04	1.337E-03
	0.000	1.721E-01	0.000E+00	8.606E-04	0.000E+00
	0.000	1.721E-01	0.000E+00	8.606E-04	0.000E+00
	0.000	1.721E-01	0.000E+00	8.606E-04	0.000E+00
OX:	100.000	1.720E-01	7.336E-05	6.561E-04	2.340E-03
	0.000	1.720E-01	0.000E+00	6.561E-04	0.000E+00
	0.000	1.720E-01	0.000E+00	6.561E-04	0.000E+00
	0.000	1.720E-01	0.000E+00	6.561E-04	0.000E+00

HIFI CHAMBER MODEL INPUTS

COMBUSTION PLANE, FT= 2.612E-01   SHORT NOZZLE ASSUMED=F

ACOUSTIC CAVITY INPUTS

CAVITY TYPE=NONE
CAVITY TYPE 1:   NUMBER OF CAVITIES= 0   NUMBER OF PROPERTY SECTIONS= 1
CAVITY TYPE 2:   NUMBER OF CAVITIES= 0   NUMBER OF PROPERTY SECTIONS= 1
PARTITION THICKNESS, FT= 0.0000

HIGH FREQUENCY INSTABILITY IS BURNING-COUPLED

TANGENTIAL MODE	RADIAL MODE	FREQUENCY (HZ)	GAIN
1	0	4195.57	1.0233

```
                    HIGH FREQUENCY COMBUSTION STABILITY CALCULATIONS

                                        ROCCID
                      ROCket Combustor Interactive Design Methodology
                                  Version 23-FEB-91



   DIRECT INPUT ECHO FROM SUBROUTINE SINPUT

ROCCID POINT DESIGN TEST CASE 1
LOX/RP-1 LIKE DOUBLET PAIR WITH FIXED PC
APPROXIMATES .0100 SUBSCALE DOUBLET
 $MODELS
 MCHAM=        1
 MBURN=        2
 MINJ=         1
 $END
 $OPCOND
 PISPA=    8.9800E+01,  1.0940E+02,  1.3940E+02,  1.5880E+02,  1.7780E+02,
           2.0970E+02,  2.3550E+02,  2.5470E+02,  2.6700E+02,  2.7040E+02,
           2.7180E+02,  2.7190E+02,  2.7130E+02,  2.6980E+02,  2.6820E+02,
           2.6660E+02,  2.6500E+02,  2.6210E+02,  2.5920E+02,  2.5630E+02,
           2.5080E+02,  2.3840E+02,  2.2760E+02,  2.1100E+02,  2.0140E+02,
           1.5560E+02,  1.0970E+02,  8.0000E+01,
 PCSA=     1.7760E+03,  2.4660E+03,  3.4870E+03,  4.0740E+03,  4.6000E+03,
           5.0700E+03,  5.4540E+03,  5.7340E+03,  5.9080E+03,  5.9610E+03,
           5.9690E+03,  5.9540E+03,  5.9340E+03,  5.9090E+03,  5.8820E+03,
           5.8550E+03,  5.8260E+03,  5.7590E+03,  5.7000E+03,  5.6430E+03,
           5.5320E+03,  5.2750E+03,  5.0470E+03,  4.6760E+03,  4.4200E+03,
           3.4570E+03,  2.4940E+03,  1.4650E+03,
 FUEL=   'RP-1     '
 OX=     'LOX      '
 PC=       2.1411E+03
 XMR=      2.6800E+00
 FTMAN=    7.1000E+01
 XTMAN=   -2.7900E+02
 EMMAN=    1.0000E+00
 NPERFP=       28
 PMRA=     1.0000E-01,  3.0000E-01,  6.0000E-01,  8.0000E-01,  1.0000E+00,
           1.2500E+00,  1.5000E+00,  1.7500E+00,  2.0000E+00,  2.2000E+00,
           2.4000E+00,  2.5000E+00,  2.6000E+00,  2.7000E+00,  2.8000E+00,
           2.9000E+00,  3.0000E+00,  3.2000E+00,  3.4000E+00,  3.6000E+00,
           4.0000E+00,  5.0000E+00,  6.0000E+00,  8.0000E+00,  1.0000E+01,
           1.5000E+01,  2.0000E+01,  5.0000E+01,
 $END
 $GEOM
 RCHAMB=   2.7949E-01
 RTHRT=    1.6523E-01
 RNE=      1.1100E-01
 RTE=      1.1100E-01
 ALPHA=    3.0000E+01
 CHAMBL=   1.1875E+00
 XC=       9.6477E-01
 $END
 $CORE
 TYPE=   'LOL'
 NEL=          69
 FDJ=      6.6345E-02
 FCD=      9.1000E-01
 FIH=      1.1491E-01
 FIA=      3.0000E+01
```

```
FCANT=     1.6000E+01
FFACET=    2.6728E-01
XDJ=       1.0172E-01
XCD=       9.4000E-01
XIH=       1.7619E-01
XIA=       3.0000E+01
XCANT=     1.6000E+01
XFACET=    4.4047E-01
EMUNI=     6.5000E-01
$END
$BAFFLE
$END
$BARRIER
$END
$FFC
$END
$BURN
GAMMA=     1.1462E+00
AO=        4.0658E+03
GMW=       2.3218E+01
GPR=       5.9752E-01
GK=        5.4180E-05
GMU=       6.6324E-05
RML=       7.6242E+01
VJL=       3.0746E+02
TJL=       5.3100E+02
RHOL=      4.9695E+01
CPL=       4.7321E-01
PCRITL=    3.1500E+02
TCRITL=    1.2160E+03
TBOILL=    8.8200E+02
XMWL=      1.7200E+02
HVAPL=     1.2500E+02
EN=        6.6793E-01
TAUSEN=    1.4114E-04
ISEN=          1
$END
$INJ
FMAND=     6.7076E+00
XMAND=     6.7076E+00
FMANL=     3.3538E+00
XMANL=     3.3538E+00
PCA=       2.1411E+03,  1.5614E+03,  7.6734E+02
FRA=       4.7547E-01,  3.4543E-01,  1.7206E-01
FCAPA=     7.6914E-04,  8.1791E-04,  8.6053E-04
NFE=           4
FTLA=      5.0142E-04,  6.8196E-04,  1.3371E-03,
FINA=      3.8876E-05,  3.8928E-05,  3.9064E-05,
FFA=       1.0000E+00,  1.0000E+00,  1.0000E+00,
NXE=           4
XRA=       4.7547E-01,  3.4543E-01,  1.7206E-01
XCAPA=     5.9163E-04,  6.1747E-04,  6.6016E-04
XTLA=      9.3236E-04,  1.2439E-03,  2.3309E-03,
XINA=      7.3028E-05,  7.3125E-05,  7.3382E-05,
XFA=       1.0000E+00,  1.0000E+00,  1.0000E+00,
XUOR=      4.7660E-02,  7.3412E-02,
AUOR=      3.4570E-03,  8.1269E-03,
RUOR=      3.3172E-02,  5.0861E-02,
XOR=       4.7660E-02,  7.3412E-02,
AOR=       3.4570E-03,  8.1269E-03,
ROR=       3.3172E-02,  5.0861E-02,
XDOR=      9.5761E-02,  1.4682E-01,
ADOR=      3.4570E-03,  8.1269E-03,
RDOR=      3.3172E-02,  5.0861E-02,
```

```
 WDOT=      4.6218E+01,  1.3311E+02,  3.3533E+01,  9.6576E+01,  1.8644E+01,
            4.7936E+01
 $END
 $CHAMBER
 NCAV=           1,
 XB=        2.6125E-01
 ZS=        1.1875E-01
 ZE=        4.9875E-01
 MUB=            3
 T=         3.3000E-02
 WC=        2.0961E-02,
 AC=        3.6809E-02,
 ARATIO=    1.0000E+00,
 IDCAV=          1,
 DC1=       1.4000E-01,
 CC1=       5*2.5000E+03
 GAMC1=     5*1.2000E+00
 CC2=       5*2.5000E+03
 GAMC2=     5*1.2000E+00
 ICAV=           1
 $END
 $FDORC
 NZON=           5
 FTER=      20*1.0000E+00
 NCAV1=          1
 ICTYP1=         4,
 ZE1=       2.0961E-02,
 AE1=       3.6000E+02,
 APL1=      1.4000E-01,
 WC1=       1.9186E-01,
 ZLOW1=    -1.2315E-02,
 ZUP1=      2.0417E-01,
 $END
 $MIX
  EM(1)= 9.009E-01,  1.000E+00
 $END
 $DEBUGC
 DEBUG=    F
 $END
 $HIFIC
 SHORT=    F
 POC=       2.0000E-01,  2.0000E-01
 $END
 $DIST3DC
 SHORT=    F
 POC=       2.0000E-01,  2.0000E-01
 PAMP=      2.0000E-01
 MC=            11
 LC=             8
 MB=            11
 LB=             8
 IDMAX=         10
 $END
 $CRPC
 NDPC=          16
 NDTFQ=         16
 NDTLF=       1000
 NPRINT=        50
 NSUMS=       3500
 PAMPC=     2.0000E-01
 NRAD=           3
 NCIRC=          5
 $END
 $LEINJC
```

```
IDOMEM=         2
PAMPCH=    2.0000E-01
NTINJ=         16
USGF=      2.0000E-02
OGF=       2.0000E-02
DSGF=      2.0000E-02
FCDO=      1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XCDO=      1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
$END
$COMBUSTC
FALVM=     1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XALVM=     1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
FALTM=     1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XALTM=     1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
FRMM=      1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XRMM=      1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
EMMULT=    1.0000E+00,  1.0000E+00
COMBXB=    6.0000E-01
AOMULT=    1.0000E+00
CCMULT=    1.0000E+00
ENMULT=    1.0000E+00
TAUMULT=   1.0000E+00
$END
$FDORCC
SHORT=    F
EPSIL=     2.0000E+01
ERROR=     1.0000E-01
LTS=            6
MTS=            5
NTS=           10
ITMAX=        100
RELX=      6.5000E-01
NEET=           3
NXFST=          3
NYFST=          3
NAFST=          3
MORE=     F
$END

   END OF INPUT ECHO
```

STABILITY MODEL INPUTS

RUN DESCRIPTOR

ROCCID POINT DESIGN TEST CASE 1
LOX/RP-1 LIKE DOUBLET PAIR WITH FIXED PC
APPROXIMATES -0100 SUBSCALE DOUBLET

SELECTED MODELS

BURNING MODEL=N-TAU   INJECTION MODEL=INJ   CHAMBER MODEL=HIFI

AXISYMETRIC=T   DEBUG OUTPUT=F

CHAMBER GEOMETRY AND OPERATING CONDITIONS

CHAMBER RADIUS, FT= 0.2795
CYLINDRICAL SECTION, FT= 0.8648
NOZZLE ENTRANCE RADIUS OF CURVATURE, FT= 0.1110

THROAT RADIUS, FT= 0.1652
CONVERGENCE HALF-ANGLE, DEG=30.0000
THROAT ENTRANCE RADIUS OF CURVATURE, FT= 0.1110

CHAMBER PRESSURE, PSIA=2141.10   MIXTURE RATIO= 2.8800
SOUND SPEED, FT/SEC=4065.80   GAMMA=1.1462

N-TAU BURNING MODEL INPUTS

PRESSURE INTERACTION INDEX, EN= 0.8879   SENSITIVE TIMELAG, TAU, SEC= 1.411E-04   SENSITIVE CIRCUIT=FUEL

LUMPED INJECTION MODEL INPUTS

PC, PSIA=2141.10

	% TOTAL FLOW	RESISTANCE	INERTANCE (SEC)	CAPACITANCE (SEC)	TIMELAG (SEC)
FUEL:	100.000	4.758E-01	9.888E-05	7.891E-04	5.014E-04
	0.000	4.758E-01	0.000E+00	7.891E-04	0.000E+00
	0.000	4.758E-01	0.000E+00	7.891E-04	0.000E+00
	0.000	4.758E-01	0.000E+00	7.891E-04	0.000E+00
OX:	100.000	4.758E-01	7.303E-05	5.916E-04	9.324E-04
	0.000	4.758E-01	0.000E+00	5.916E-04	0.000E+00
	0.000	4.758E-01	0.000E+00	5.916E-04	0.000E+00
	0.000	4.758E-01	0.000E+00	5.916E-04	0.000E+00

PC, PSIA=1551.40

% TOTAL FLOW	RESISTANCE	INERTANCE	CAPACITANCE	TIMELAG

			(SEC)	(SEC)	(SEC)
FUEL:	100.000	3.454E-01	3.898E-05	6.179E-04	6.820E-04
	0.000	3.454E-01	0.000E+00	6.179E-04	0.000E+00
	0.000	3.454E-01	0.000E+00	6.179E-04	0.000E+00
	0.000	3.454E-01	0.000E+00	6.179E-04	0.000E+00
OX:	100.000	3.454E-01	7.312E-05	6.175E-04	1.244E-03
	0.000	3.454E-01	0.000E+00	6.175E-04	0.000E+00
	0.000	3.454E-01	0.000E+00	6.175E-04	0.000E+00
	0.000	3.454E-01	0.000E+00	6.175E-04	0.000E+00

PC, PSIA= 787.34

	% TOTAL FLOW	RESISTANCE	INERTANCE (SEC)	CAPACITANCE (SEC)	TIMELAG (SEC)
FUEL:	100.000	1.721E-01	3.906E-05	8.605E-04	1.337E-03
	0.000	1.721E-01	0.000E+00	8.605E-04	0.000E+00
	0.000	1.721E-01	0.000E+00	8.605E-04	0.000E+00
	0.000	1.721E-01	0.000E+00	8.605E-04	0.000E+00
OX:	100.000	1.720E-01	7.338E-05	6.561E-04	2.340E-03
	0.000	1.720E-01	0.000E+00	6.561E-04	0.000E+00
	0.000	1.720E-01	0.000E+00	6.561E-04	0.000E+00
	0.000	1.720E-01	0.000E+00	6.561E-04	0.000E+00

HIFI CHAMBER MODEL INPUTS

COMBUSTION PLANE, FT= 2.612E-01   SHORT NOZZLE ASSUMED=F

ACOUSTIC CAVITY INPUTS

CAVITY TYPE=1/4 WAVE
CAVITY TYPE 1:   NUMBER OF CAVITIES= 1   NUMBER OF PROPERTY SECTIONS= 1
CAVITY TYPE 2:   NUMBER OF CAVITIES= 0   NUMBER OF PROPERTY SECTIONS= 1
PARTITION THICKNESS, FT= 0.0000

	TOTAL DEPTH, FT	WIDTH, FT	AREA, SQ.FT	P'/PC	INLET TYPE
TYPE 1:	0.14000	0.02096	3.661E-02	0.200	0
TYPE 2:	0.00000	0.00000	0.000E+00	0.200	0

CAVITY TYPE ORIENTATION= 1

CAVITY GAS PROPERTIES

	SECT	LENGTH	VSONIC	GAMMA
TYPE 1:	1	0.1400	2500.00	1.2000

NO HIGH FREQUENCY INSTABILITY MODES OBSERVED

TANGENTIAL MODE	RADIAL MODE	GAIN MAGNITUDE	FREQUENCY (HZ)	|YB|/|YJ|
0	0	0.4905	1551.69	1.03
1	0	0.7915	4733.72	2.75

HIGH FREQUENCY COMBUSTION STABILITY CALCULATIONS

ROCCID
ROCket Combustor Interactive Design Methodology
Version 23-FEB-91

DIRECT INPUT ECHO FROM SUBROUTINE SINPUT

```
ROCCID POINT DESIGN TEST CASE 1
LOX/RP-1 LIKE DOUBLET PAIR WITH FIXED PC
APPROXIMATES -0100 SUBSCALE DOUBLET
 $MODELS
 MCHAM=          1
 MBURN=          2
 MINJ=           1
 $END
 $OPCOND
 PISPA=     8.9600E+01,  1.0940E+02,  1.3940E+02,  1.5880E+02,  1.7780E+02,
            2.0970E+02,  2.3550E+02,  2.5470E+02,  2.6700E+02,  2.7040E+02,
            2.7180E+02,  2.7190E+02,  2.7130E+02,  2.6980E+02,  2.6820E+02,
            2.6660E+02,  2.6500E+02,  2.6210E+02,  2.5920E+02,  2.5630E+02,
            2.5080E+02,  2.3840E+02,  2.2760E+02,  2.1100E+02,  2.0140E+02,
            1.5560E+02,  1.0970E+02,  6.0000E+01,
 PCSA=      1.7760E+03,  2.4560E+03,  3.4870E+03,  4.0740E+03,  4.5600E+03,
            5.0700E+03,  5.4540E+03,  5.7340E+03,  5.9080E+03,  5.9610E+03,
            5.9690E+03,  5.9540E+03,  5.9340E+03,  5.9090E+03,  5.8820E+03,
            5.8550E+03,  5.8260E+03,  5.7590E+03,  5.7000E+03,  5.6430E+03,
            5.5320E+03,  5 2750E+03,  5.0470E+03,  4.6760E+03,  4.4200E+03,
            3.4570E+03,  2.4940E+03,  1.4650E+03,
 FUEL=    'RP-1      '
 OX=      'LOX       '
 PC=        2.1411E+03
 XMR=       2.6800E+00
 FTMAN=     7.1000E+01
 XTMAN=    -2.7900E+02
 EMMAN=     1.0000E+00
 NPERFP=       28
 PMRA=      1.0000E-01,  3.0000E-01,  6.0000E-01,  8.0000E-01,  1.0000E+00,
            1.2500E+00,  1.5000E+00,  1.7500E+00,  2.0000E+00,  2.2000E+00,
            2.4000E+00,  2.5000E+00,  2.6000E+00,  2.7000E+00,  2.8000E+00,
            2.9000E+00,  3.0000E+00,  3.2000E+00,  3.4000E+00,  3.6000E+00,
            4.0000E+00,  5.0000E+00,  6.0000E+00,  8.0000E+00,  1.0000E+01,
            1.5000E+01,  2.0000E+01,  5.0000E+01,
 $END
 $GEOM
 RCHAMB=    2.7949E-01
 RTHRT=     1.6529E-01
 RNE=       1.1100E-01
 RTE=       1.1100E-01
 ALPHA=     3.0000E+01
 CHAMBL=    1.1875E+00
 XC=        9.6477E-01
 $END
 $CORE
 TYPE=    'LOL'
 NEL=          69
 FDJ=       6.6345E-02
 FCD=       9.1000E-01
 FIH=       1.1491E-01
 FIA=       3.0000E+01
```

```
FCANT=     1.6000E+01
FFACET=    2.8728E-01
XDJ=       1.0172E-01
XCD=       9.4000E-01
XIH=       1.7619E-01
XIA=       3.0000E+01
XCANT=     1.6000E+01
XFACET=    4.4047E-01
EMUNI=     6.5000E-01
$END
$BAFFLE
$END
$BARRIER
$END
$FFC
$END
$BURN
GAMMA=     1.1462E+00
AO=        4.0658E+03
GMW=       2.3218E+01
GPR=       5.9752E-01
GK=        5.4180E-05
GMU=       6.6324E-05
RML=       7.6242E+01
VJL=       3.0746E+02
TJL=       5.3100E+02
RHOL=      4.9895E+01
CPL=       4.7321E-01
PCRITL=    3.1500E+02
TCRITL=    1.2160E+03
TBOILL=    8.6200E+02
XMWL=      1.7200E+02
HVAPL=     1.2500E+02
EN=        8.6793E-01
TAUSEN=    1.4114E-04
ISEN=          1
$END
$INJ
FMAND=     6.7076E+00
XMAND=     6.7076E+00
FMANL=     3.3538E+00
XMANL=     3.3538E+00
PCA=       2.1411E+03,  1.6614E+03,  7.6734E+02
FRA=       4.7547E-01,  3.4543E-01,  1.7206E-01
FCAPA=     7.8914E-04,  8.1791E-04,  8.6053E-04
NFE=           4
FTLA=      5.0142E-04,  6.8196E-04,  1.3371E-03,
FINA=      3.8876E-05,  3.8928E-05,  3.9064E-05,
FFA=       1.0000E+00,  1.0000E+00,  1.0000E+00,
NXE=           4
XRA=       4.7547E-01,  3.4543E-01,  1.7206E-01
XCAPA=     5.9163E-04,  6.1747E-04,  6.5615E-04
XTLA=      9.3236E-04,  1.2439E-03,  2.3399E-03,
XINA=      7.3028E-05,  7.3125E-05,  7.3382E-05,
XFA=       1.0000E+00,  1.0000E+00,  1.0000E+00,
XUOR=      4.7880E-02,  7.3412E-02,
AUOR=      3.4570E-03,  8.1269E-03,
RUOR=      3.3172E-02,  5.0861E-02,
XOR=       4.7880E-02,  7.3412E-02,
AOR=       3.4570E-03,  8.1269E-03,
ROR=       3.3172E-02,  5.0861E-02,
XDOR=      9.5761E-02,  1.4682E-01,
ADOR=      3.4570E-03,  8.1269E-03,
RDOR=      3.3172E-02,  5.0861E-02,
```

```
WDOT=     4.6216E+01,  1.3311E+02,  3.3533E+01,  9.6576E+01,  1.6644E+01,
          4.7935E+01
 $END
 $CHAMBER
 NCAV=          1,
 XB=      2.6125E-01
 ZS=      1.1875E-01
 ZE=      4.9875E-01
 MUB=           3
 T=       3.3000E-02
 WC=      2.0961E-02,
 AC=      3.6809E-02,
 ARATIO=  1.0000E+00,
  IDCAV=        1,
 DC1=     1.4000E-01,
 CC1=     5*2.5000E+03
 GAMC1=   5*1.2000E+00
 CC2=     5*2.5000E+03
 GAMC2=   5*1.2000E+00
  ICAV=         1
 $END
 $FDORC
 NZON=          5
 FTER=  20*1.0000E+00
 NCAV1=         1
  ICTYP1=       4,
 ZE1=     2.0961E-02,
 AE1=     3.6000E+02,
 APL1=    1.4000E-01,
 WC1=     1.9186E-01,
 ZLOW1=  -1.2315E-02,
 ZUP1=    2.0417E-01,
 $END
 $MIX
  EM(1)= 9.003E-01,  1.000E+00
 $END
 $DEBUGC
 DEBUG=   F
 $END
 $HIFIC
 SHORT=   F
 POC=     2.0000E-01,  2.0000E-01
 $END
 $DISTSDC
 SHORT=   F
 POC=     2.0000E-01,  2.0000E-01
 PAMP=    2.0000E-01
 MC=          11
 LC=           8
 MB=          11
 LB=           6
 IDMAX=       10
 $END
 $CRPC
 NDPC=        16
 NDTFQ=       16
 NDTLF=     1000
 NPRINT=      50
 NSUMS=     3500
 PAMPC=   2.0000E-01
 NRAD=         3
 NCIRC=        5
 $END
 $LEINJC
```

```
IDOMEM=        2
PAMPCH=   2.0000E-01
NTINJ=        18
USGF=     2.0000E-02
OGF=      2.0000E-02
DSGF=     2.0000E-02
FCDO=     1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XCDO=     1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
$END
$COMBUSTC
FALVM=    1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XALVM=    1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
FALTM=    1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XALTM=    1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
FRMM=     1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XRMM=     1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
EMMULT=   1.0000E+00,  1.0000E+00
COMBXB=   5.0000E-01
ACMULT=   1.0000E+00
CCMULT=   1.0000E+00
ENMULT=   1.0000E+00
TAUMULT=  1.0000E+00
$END
$FDORCC
SHORT=   F
EPSIL=    2.0000E+01
ERROR=    1.0000E-01
LTS=           5
MTS=           5
NTS=          10
ITMAX=       100
RELX=     6.5000E-01
NEET=          3
NXFST=         3
NYFST=         3
NAFST=         3
MORE=    F
$END

   END OF INPUT ECHO
```

STABILITY MODEL INPUTS

RUN DESCRIPTOR

ROCCID POINT DESIGN TEST CASE 1
LOX/RP-1 LIKE DOUBLET PAIR WITH FIXED PC
APPROXIMATES -0100 SUBSCALE DOUBLET

SELECTED MODELS

BURNING MODEL=N-TAU   INJECTION MODEL=INJ   CHAMBER MODEL=HIFI

AXISYMETRIC=T   DEBUG OUTPUT=F

CHAMBER GEOMETRY AND OPERATING CONDITIONS

CHAMBER RADIUS, FT= 0.2795   THROAT RADIUS, FT= 0.1852
CYLINDRICAL SECTION, FT= 0.9648   CONVERGENCE HALF ANGLE, DEG=30.0000
NOZZLE ENTRANCE RADIUS OF CURVATURE, FT= 0.1110   THROAT ENTRANCE RADIUS OF CURVATURE, FT= 0.1110

CHAMBER PRESSURE, PSIA=2141.10   MIXTURE RATIO= 2.8800
SOUND SPEED, FT/SEC=4085.80   GAMMA=1.1462

N-TAU BURNING MODEL INPUTS

PRESSURE INTERACTION INDEX, EN= 0.8679   SENSITIVE TIMELAG, TAU, SEC= 1.411E-04   SENSITIVE CIRCUIT=FUEL

LUMPED INJECTION MODEL INPUTS

PC, PSIA=2141.10

	% TOTAL FLOW	RESISTANCE	INERTANCE (SEC)	CAPACITANCE (SEC)	TIMELAG (SEC)
FUEL:	100.000	4.755E-01	3.888E-05	7.891E-04	5.014E-04
	0.000	4.755E-01	0.000E+00	7.891E-04	0.000E+00
	0.000	4.755E-01	0.000E+00	7.891E-04	0.000E+00
	0.000	4.755E-01	0.000E+00	7.891E-04	0.000E+00
OX:	100.000	4.755E-01	7.303E-05	5.916E-04	9.324E-04
	0.000	4.755E-01	0.000E+00	5.916E-04	0.000E+00
	0.000	4.755E-01	0.000E+00	5.916E-04	0.000E+00
	0.000	4.755E-01	0.000E+00	5.916E-04	0.000E+00

PC, PSIA=1551.40

% TOTAL FLOW	RESISTANCE	INERTANCE	CAPACITANCE	TIMELAG

			(SEC)	(SEC)	(SEC)
FUEL:	100.000	3.454E-01	3.893E-05	8.179E-04	6.620E-04
	0.000	3.454E-01	0.000E+00	8.179E-04	0.000E+00
	0.000	3.454E-01	0.000E+00	8.179E-04	0.000E+00
	0.000	3.454E-01	0.000E+00	8.179E-04	0.000E+00
OX:	100.000	3.454E-01	7.312E-05	6.175E-04	1.244E-03
	0.000	3.454E-01	0.000E+00	6.175E-04	0.000E+00
	0.000	3.454E-01	0.000E+00	6.175E-04	0.000E+00
	0.000	3.454E-01	0.000E+00	6.175E-04	0.000E+00

PC, PSIA= 767.34

	% TOTAL FLOW	RESISTANCE	INERTANCE (SEC)	CAPACITANCE (SEC)	TIMELAG (SEC)
FUEL:	100.000	1.721E-01	3.906E-05	8.606E-04	1.337E-03
	0.000	1.721E-01	0.000E+00	8.605E-04	0.000E+00
	0.000	1.721E-01	0.000E+00	8.605E-04	0.000E+00
	0.000	1.721E-01	0.000E+00	8.605E-04	0.000E+00
OX:	100.000	1.720E-01	7.338E-05	6.561E-04	2.340E-03
	0.000	1.720E-01	0.000E+00	6.561E-04	0.000E+00
	0.000	1.720E-01	0.000E+00	6.561E-04	0.000E+00
	0.000	1.720E-01	0.000E+00	6.561E-04	0.000E+00

HIFI CHAMBER MODEL INPUTS

COMBUSTION PLANE, FT= 2.612E-01 SHORT NOZZLE ASSUMED=F

ACOUSTIC CAVITY INPUTS

CAVITY TYPE=1/4 WAVE
CAVITY TYPE 1: NUMBER OF CAVITIES= 1 NUMBER OF PROPERTY SECTIONS= 1
CAVITY TYPE 2: NUMBER OF CAVITIES= 0 NUMBER OF PROPERTY SECTIONS= 1
PARTITION THICKNESS, FT= 0.0000

	TOTAL DEPTH, FT	WIDTH, FT	AREA, SQ.FT	P'/PC	INLET TYPE
TYPE 1:	0.14000	0.02086	3.881E-02	0.200	0
TYPE 2:	0.00000	1.00000	0.000E+00	0.200	0

CAVITY TYPE ORIENTATION= 1

CAVITY GAS PROPERTIES

	SECT	LENGTH	VSONIC	GAMMA
TYPE 1:	1	0.1400	2500.00	1.2000

BEGIN CALCULATIONS FOR 0 TANGENTIAL + 0 RADIAL MODE

AL (1/SEC)	MAX. AMPLITUDE	FREQUENCY (HZ)	|Yb|/|Y||	PHASE MARGIN (DEG)
0.000E+00	4.905E-01	1.552E+03	1.029E+00	180.00
-1.000E+02	5.466E-01	1.553E+03	1.029E+00	180.00
-2.000E+02	6.177E-01	1.555E+03	1.029E+00	180.00
-3.000E+02	7.096E-01	1.556E+03	1.029E+00	180.00
-4.000E+02	8.316E-01	1.557E+03	1.029E+00	-32.00
-5.000E+02	9.966E-01	1.559E+03	1.029E+00	-0.52

BEGIN CALCULATIONS FOR 1 TANGENTIAL + 0 RADIAL MODE

AL (1/SEC)	MAX. AMPLITUDE	FREQUENCY (HZ)	|Yb|/|Y||	PHASE MARGIN (DEG)
0.000E+00	7.915E-01	4.734E+03	2.745E+00	180.00
-1.000E+02	8.238E-01	4.740E+03	2.745E+00	180.00
-2.000E+02	8.601E-01	4.745E+03	2.745E+00	180.00
-3.000E+02	9.010E-01	4.751E+03	2.745E+00	180.00
-4.000E+02	9.471E-01	4.758E+03	2.745E+00	9.85
-5.000E+02	9.991E-01	4.764E+03	2.826E+00	0.14

HIGH FREQUENCY STABILITY RESULTS

TANGENTIAL MODE	RADIAL MODE	GROWTH COEF. (1/S)	FREQUENCY (HZ)	|YB|/|YJ|
0	0	-500.0	1559.01	1.03
1	0	-500.0	4763.92	2.83

```
DIRECT INPUT ECHO FROM SUBROUTINE PINPUT

                         ROCCID
        ROCket Combustor Interactive Design Methodology
                   Version 23-FEB-91

ROCCID POINT DESIGN TEST CASE 1
LOX/RP-1 LIKE DOUBLET PAIR WITH FIXED PC
APPROXIMATES -0100 SUBSCALE DOUBLET
 $MODELS
 MCHAM=          1
 MBURN=          2
 MINJ=           1
 $END
 $OPCOND
 PISPA=     8.9600E+01,  1.0940E+02,  1.3940E+02,  1.5880E+02,  1.7780E+02,
            2.0970E+02,  2.3550E+02,  2.5470E+02,  2.6700E+02,  2.7040E+02,
            2.7180E+02,  2.7190E+02,  2.7130E+02,  2.6980E+02,  2.6820E+02,
            2.6660E+02,  2.6500E+02,  2.6210E+02,  2.5920E+02,  2.5630E+02,
            2.5080E+02,  2.3840E+02,  2.2750E+02,  2.1100E+02,  2.0140E+02,
            1.5560E+02,  1.0970E+02,  8.0000E+01,
 PCSA=      1.7760E+03,  2.4560E+03,  3.4870E+03,  4.0740E+03,  4.5800E+03,
            5.0700E+03,  5.4540E+03,  5.7340E+03,  5.9060E+03,  5.9610E+03,
            5.9690E+03,  5.9540E+03,  5.9340E+03,  5.9090E+03,  5.8820E+03,
            5.8550E+03,  5.8260E+03,  5.7590E+03,  5.7000E+03,  5.6430E+03,
            5.5320E+03,  5.2750E+03,  5.0470E+03,  4.6760E+03,  4.4200E+03,
            3.4570E+03,  2.4940E+03,  1.4650E+03,
 FUEL=    'RP-1      '
 OX=      'LOX       '
 PC=        2.1411E+03
 XMR=       2.8600E+00
 FTMAN=     7.1000E+01
 XTMAN=    -2.7900E+02
 EMMAN=     1.0000E+00
 NPERFP=        28
 PMRA=      1.0000E-01,  3.0000E-01,  6.0000E-01,  8.0000E-01,  1.0000E+00,
            1.2500E+00,  1.5000E+00,  1.7500E+00,  2.0000E+00,  2.2000E+00,
            2.4000E+00,  2.5000E+00,  2.6000E+00,  2.7000E+00,  2.8000E+00,
            2.9000E+00,  3.0000E+00,  3.2000E+00,  3.4000E+00,  3.6000E+00,
            4.0000E+00,  5.0000E+00,  6.0000E+00,  8.0000E+00,  1.0000E+01,
            1.5000E+01,  2.0000E+01,  5.0000E+01,
 $END
 $GEOM
 RCHAMB=    2.7949E-01
 RTHRT=     1.8523E-01
 RNE=       1.1100E-01
 RTE=       1.1100E-01
 ALPHA=     3.0000E+01
 CHAMBL=    1.1875E+00
 XC=        9.6477E-01
 $END
 $CORE
 TYPE=    'LOL'
 NEL=           69
 FDJ=       6.6345E-02
 FCD=       9.1000E-01
 FIH=       1.1491E-01
 FIA=       3.0000E+01
 FCANT=     1.6000E+01
 FFACET=    2.8728E-01
 XDJ=       1.0172E-01
 XCD=       9.4000E-01
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```
XIH=      1.7619E-01
XIA=      3.0000E+01
XCANT=    1.6000E+01
XFACET=   4.4047E-01
EMUNI=    6.5000E-01
$END
$BAFFLE
$END
$BARRIER
$END
$FFC
$END
$BURN
GAMMA=    1.1462E+00
AO=       4.0658E+03
GMW=      2.3218E+01
GPR=      5.9752E-01
GK=       5.4160E-05
GMU=      6.6324E-05
RML=      7.6242E+01
VJL=      3.0746E+02
TJL=      5.3100E+02
RHOL=     4.9695E+01
CPL=      4.7321E-01
PCRITL=   3.1500E+02
TCRITL=   1.2160E+03
TBOILL=   6.6200E+02
XMWL=     1.7200E+02
HVAPL=    1.2500E+02
EN=       6.6793E-01
TAUSEN=   1.4114E-04
ISEN=          1
$END
$INJ
FMAND=    6.7076E+00
XMAND=    6.7076E+00
FMANL=    3.3538E+00
XMANL=    3.3538E+00
PCA=      2.1411E+03,  1.5514E+03,  7.6734E+02
FRA=      4.7547E-01,  3.4543E-01,  1.7206E-01
FCAPA=    7.6914E-04,  6.1791E-04,  6.6053E-04
NFE=           4
FTLA=     5.0142E-04,  6.6196E-04,  1.3371E-03,
FINA=     3.6876E-05,  3.6928E-05,  3.9064E-05,
FFA=      1.0000E+00,  1.0000E+00,  1.0000E+00,
NXE=           4
XRA=      4.7547E-01,  3.4543E-01,  1.7205E-01
XCAPA=    5.9163E-04,  6.1747E-04,  6.5615E-04
XTLA=     9.3236E-04,  1.2439E-03,  2.3399E-03,
XINA=     7.3026E-05,  7.3125E-05,  7.3382E-05,
XFA=      1.0000E+00,  1.0000E+00,  1.0000E+00,
XUOR=     4.7660E-02,  7.3412E-02,
AUOR=     3.4570E-03,  6.1269E-03,
RUOR=     3.3172E-02,  5.0661E-02,
XOR=      4.7660E-02,  7.3412E-02,
AOR=      3.4570E-03,  6.1269E-03,
ROR=      3.3172E-02,  5.0661E-02,
XDOR=     9.5761E-02,  1.4662E-01,
ADOR=     3.4570E-03,  6.1269E-03,
RDOR=     3.3172E-02,  5.0661E-02,
WDOT=     4.6216E+01,  1.3311E+02,  3.3533E+01,  9.6576E+01,  1.6644E+01,
          4.7935E+01
$END
$CHAMBER
```

```
 NCAV=          1,
 XB=        2.6125E-01
 ZS=        1.1875E-01
 ZE=        4.9875E-01
 MUB=           3
 T=         3.3000E-02
 WC=        2.0961E-02,
 AC=        3.6609E-02,
 ARATIO=    1.0000E+00,
 IDCAV=         1,
 DC1=       1.4000E-01,
 CC1=       5*2.5000E+03
 GAMC1=     5*1.2000E+00
 CC2=       5*2.5000E+03
 GAMC2=     5*1.2000E+00
 ICAV=          1
 $END
 $FDORC
 NZON=          5
 FTER=    20*1.0000E+00
 NCAV1=         1
 ICTYP1=        4,
 ZE1=       2.0961E-02,
 AE1=       3.6000E+02,
 APL1=      1.4000E-01,
 WC1=       1.9166E-01,
 ZLOW1=    -1.2315E-02,
 ZUP1=      2.0417E-01,
 $END
 $MIX
  EM(1)= 9.003E-01,  1.000E+00
 $END
 $DEBUGC
 DEBUG=    F
 $END
 $HIFIC
 SHORT=    F
 POC=       2.0000E-01,  2.0000E-01
 $END
 $DIST3DC
 SHORT=    F
 POC=       2.0000E-01,  2.0000E-01
 PAMP=      2.0000E-01
 MC=           11
 LC=            8
 MB=           11
 LB=            9
 IDMAX=        10
 $END
 $CRPC
 NDPC=         16
 NDTFQ=        16
 NDTLF=      1000
 NPRINT=       50
 NSUMS=      3500
 PAMPC=     2.0000E-01
 NRAD=          3
 NCIRC=         5
 $END
 $LEINJC
 IDOMEM=        2
 PAMPCH=    2.0000E-01
 NTINJ=        18
 USGF=      2.0000E-02
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OGF=      2.0000E-02
DSGF=     2.0000E-02
FCDO=     1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XCDO=     1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
$END
$COMBUSTC
FALVM=    1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XALVM=    1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
FALTM=    1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XALTM=    1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
FRMM=     1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XRMM=     1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
EMMULT=   1.0000E+00,  1.0000E+00
COMBXB=   5.0000E-01
AOMULT=   1.0000E+00
CCMULT=   1.0000E+00
ENMULT=   1.0000E+00
TAUMULT=  1.0000E+00
$END
$FDORCC
SHORT=    F
EPSIL=    2.0000E+01
ERROR=    1.0000E-01
LTS=             5
MTS=             5
NTS=            10
ITMAX=         100
RELX=     6.5000E-01
NEET=            3
NXFST=           3
NYFST=           3
NAFST=           3
MORE=     F
$END

    END OF INPUT ECHO
```

STEADY STATE COMBUSTION ANALYSIS PROGRAM

RUN DESCRIPTORS

ROCCID POINT DESIGN TEST CASE 1
LOX/RP-1 LIKE DOUBLET PAIR WITH FIXED PC
APPROXIMATES -0100 SUBSCALE DOUBLET

PROPELLENT DESCRIPTION

FUEL=RP-1	Tman., F= 71.00
OX=LOX	Tman., F=-279.00

CHAMBER GEOMETRY

CHAMBER RADIUS = 3.3539 IN.	THROAT RADIUS = 2.2228 IN.
CYLINDRICAL SECTION =11.5770 IN.	CONVERGENT SECTION LENGTH = 2.6730 IN.
NOZZLE ENTRANCE RADIUS OF CURVATURE = 1.3320 IN.	THROAT ENTRANCE RADIUS OF CURVATURE = 1.3320 IN.
CONVERGENCE HALF-ANGLE =30.0000 DEG.	CONTRACTION RATIO = 2.28

INJECTOR DATA

INJECTOR CORE CONTAINS 89 LOL ELEMENTS

FUEL SIDE:	Orifice Diam. =6.634E-02 In.	Cd =0.9100	Impingement Height =0.115 In.
	Impingement Half-angle =30.00 Deg.	Unlike Cant Angle =16.00 Deg.	Faceplate Thickness = 0.2873 In.
OX SIDE:	Orifice Diam. =1.017E-01 In.	Cd =0.9400	Impingement Height =0.176 In.
	Impingement Half-angle =30.00 Deg.	Unlike Cant Angle =16.00 Deg.	Faceplate Thickness = 0.4405 In.

MIXING EFFICIENCIES

CORE MIXING EFFICIENCY=0.9003 BARRIER MIXING EFFICIENCY=1.0000

COMBUST CONTROL PARAMETERS

MULTIPLIERS:	CORE	BAFFLE	BARRIER	FFC
FUEL ATOMIZATION LENGTH FOR VAPORIZATION:	1.000	1.000	1.000	1.000
OX ATOMIZATION LENGTH FOR VAPORIZATION:	1.000	1.000	1.000	1.000
FUEL ATOMIZATION LENGTH FOR TIMELAGS:	1.000	1.000	1.000	1.000
OX ATOMIZATION LENGTH FOR TIMELAGS:	1.000	1.000	1.000	1.000
FUEL DROPSIZE:	1.000	1.000	1.000	1.000
OX DROPSIZE:	1.000	1.000	1.000	1.000
MIXING (Em):	1.000		1.000	

AO-Multiplier=1.000 CC-Multiplier=1.000 N-Multiplier=1.000 Tau-Multiplier=1.000
Eta-C* for XB=0.500

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                    BEGIN STEADY STATE COMBUSTION ANALYSIS
                         PC=2141.10 PSIA


                              PROPELLANT PROPERTIES

FUEL=RP-1     Phase=Liquid                          Tman., F=  71.00
              Injected Density= 49.89 Lbm/Cu. Ft    Viscosity=1.380E-03 Lbm/Ft-S    Surface Tension=1.857E-03 Lbf/Ft

  OX=LOX      Phase=Liquid                          Tman., F=-279.00
              Injected Density= 70.20 Lbm/Cu. Ft    Viscosity=1.187E-04 Lbm/Ft-S    Surface Tension=7.326E-04 Lbf/Ft

                              OPERATING CONDITIONS

PC FACE=2141.10 PSIA     PC THROAT=2054.41     MIXTURE RATIO= 2.880
FUEL INJECTION PRESSURE DROP= 502.74 Psia      FUEL INJECTION VELOCITY= 306.56 Ft/S
  OX INJECTION PRESSURE DROP= 501.82 Psia        OX INJECTION VELOCITY= 257.36 Ft/S

    FUEL FLOWRATE=  45.953     OX FLOWRATE= 132.345

                              ATOMIZATION OUTPUT


         DROPSIZE MODEL=AEROJET

ELEMENT TYPE 1 IS LOL
FUEL:     ATOMIZATION LENGTH, In.=1.06090    ATOMIZATION LENGTH FOR VAPORIZATION, In.=1.06090    DROPLET RADIUS, Microns=  76.29
  OX:     ATOMIZATION LENGTH, In.=2.32433    ATOMIZATION LENGTH FOR VAPORIZATION, In.=2.32433    DROPLET RADIUS, Microns=  84.56
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VAPORIZATION CALCULATIONS

X (In.)	CORE=LOL %FUEL VAP	CORE=LOL %OX VAP	BAFFLE= %FUEL VAP	BAFFLE= %OX VAP	BARRIER= %FUEL VAP	BARRIER= %OX VAP	FFC= %FUEL VAP	FFC= %OX VAP
0.0000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.2850	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.5700	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.8550	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.1400	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.4250	10.524	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.7100	20.465	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.9950	28.379	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2.2800	34.916	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2.5650	40.882	7.091	0.000	0.000	0.000	0.000	0.000	0.000
2.8500	45.300	31.605	0.000	0.000	0.000	0.000	0.000	0.000
3.1350	49.437	46.257	0.000	0.000	0.000	0.000	0.000	0.000
3.4200	53.230	56.252	0.000	0.000	0.000	0.000	0.000	0.000
3.7050	56.333	63.662	0.000	0.000	0.000	0.000	0.000	0.000
3.9900	59.435	69.225	0.000	0.000	0.000	0.000	0.000	0.000
4.2750	61.952	73.768	0.000	0.000	0.000	0.000	0.000	0.000
4.5600	64.339	77.514	0.000	0.000	0.000	0.000	0.000	0.000
4.8450	66.556	80.335	0.000	0.000	0.000	0.000	0.000	0.000
5.1300	68.386	82.910	0.000	0.000	0.000	0.000	0.000	0.000
5.4150	70.215	84.764	0.000	0.000	0.000	0.000	0.000	0.000
5.7000	71.856	86.619	0.000	0.000	0.000	0.000	0.000	0.000
5.9850	73.446	88.268	0.000	0.000	0.000	0.000	0.000	0.000
6.2700	74.962	89.542	0.000	0.000	0.000	0.000	0.000	0.000
6.5550	76.274	90.867	0.000	0.000	0.000	0.000	0.000	0.000
6.8400	77.587	91.849	0.000	0.000	0.000	0.000	0.000	0.000
7.1250	78.857	92.467	0.000	0.000	0.000	0.000	0.000	0.000
7.4100	79.852	93.194	0.000	0.000	0.000	0.000	0.000	0.000
7.6950	80.836	93.922	0.000	0.000	0.000	0.000	0.000	0.000
7.9800	81.591	94.487	0.000	0.000	0.000	0.000	0.000	0.000
8.2650	82.545	95.032	0.000	0.000	0.000	0.000	0.000	0.000
8.5500	83.296	95.562	0.000	0.000	0.000	0.000	0.000	0.000
8.8350	83.972	95.998	0.000	0.000	0.000	0.000	0.000	0.000
9.1200	84.648	96.401	0.000	0.000	0.000	0.000	0.000	0.000
9.4050	85.324	96.728	0.000	0.000	0.000	0.000	0.000	0.000
9.6900	86.001	97.056	0.000	0.000	0.000	0.000	0.000	0.000
9.9750	86.677	97.322	0.000	0.000	0.000	0.000	0.000	0.000
10.2600	87.353	97.540	0.000	0.000	0.000	0.000	0.000	0.000
10.5450	87.987	97.758	0.000	0.000	0.000	0.000	0.000	0.000
10.8300	88.445	97.976	0.000	0.000	0.000	0.000	0.000	0.000
11.1150	88.902	98.195	0.000	0.000	0.000	0.000	0.000	0.000
11.4000	89.360	98.380	0.000	0.000	0.000	0.000	0.000	0.000
11.6850	89.838	98.524	0.000	0.000	0.000	0.000	0.000	0.000
11.9700	90.317	98.668	0.000	0.000	0.000	0.000	0.000	0.000
12.2550	90.717	98.809	0.000	0.000	0.000	0.000	0.000	0.000
12.5400	91.118	98.938	0.000	0.000	0.000	0.000	0.000	0.000
12.8250	91.518	99.058	0.000	0.000	0.000	0.000	0.000	0.000
13.1100	91.919	99.141	0.000	0.000	0.000	0.000	0.000	0.000
13.3950	92.236	99.227	0.000	0.000	0.000	0.000	0.000	0.000
13.6800	92.533	99.312	0.000	0.000	0.000	0.000	0.000	0.000
13.9650	92.830	99.388	0.000	0.000	0.000	0.000	0.000	0.000
14.2500	93.126	99.447	0.000	0.000	0.000	0.000	0.000	0.000

OVERALL VAPORIZATION EFFICIENCIES
FUEL= 93.13%   OX= 99.45%

MASS DISTRIBUTION PROFILE

X (IN)	CORE (lbm/s) FUEL	CORE (lbm/s) OX	BARRIER (lbm/s) FUEL	BARRIER (lbm/s) OX	LOCAL VAPOR MIXTURE RATIO	ETA-C*
0.0000	0.000	0.000	0.000	0.000	0.00	0.0000
0.2850	0.000	0.000	0.000	0.000	0.00	0.0000
0.5700	0.000	0.000	0.000	0.000	0.00	0.0000
0.8550	0.000	0.000	0.000	0.000	0.00	0.0000
1.1400	0.000	0.000	0.000	0.000	0.00	0.0000
1.4250	4.636	0.000	0.000	0.000	0.00	0.0066
1.7100	9.404	0.000	0.000	0.000	0.00	0.0129
1.9950	13.041	0.000	0.000	0.000	0.00	0.0179
2.2800	16.045	0.000	0.000	0.000	0.00	0.0221
2.5650	18.787	9.385	0.000	0.000	0.50	0.0858
2.8500	20.817	41.828	0.000	0.000	2.01	0.3499
3.1350	22.718	61.219	0.000	0.000	2.69	0.4712
3.4200	24.461	74.446	0.000	0.000	3.04	0.5479
3.7050	25.887	84.253	0.000	0.000	3.25	0.6040
3.9900	27.312	91.617	0.000	0.000	3.35	0.6490
4.2750	28.469	97.829	0.000	0.000	3.43	0.6856
4.5600	29.566	102.586	0.000	0.000	3.47	0.7171
4.8450	30.585	106.319	0.000	0.000	3.48	0.7427
5.1300	31.425	109.727	0.000	0.000	3.49	0.7652
5.4150	32.266	112.182	0.000	0.000	3.48	0.7836
5.7000	33.020	114.636	0.000	0.000	3.47	0.8012
5.9850	33.751	116.645	0.000	0.000	3.46	0.8175
6.2700	34.447	118.505	0.000	0.000	3.44	0.8312
6.5550	35.061	119.984	0.000	0.000	3.42	0.8432
6.8400	35.654	121.293	0.000	0.000	3.40	0.8545
7.1250	36.146	122.376	0.000	0.000	3.39	0.8638
7.4100	36.602	123.338	0.000	0.000	3.37	0.8722
7.6950	37.055	124.301	0.000	0.000	3.35	0.8806
7.9800	37.494	125.049	0.000	0.000	3.34	0.8879
8.2650	37.932	125.770	0.000	0.000	3.32	0.8951
8.5500	38.277	126.472	0.000	0.000	3.30	0.9013
8.8350	38.588	127.049	0.000	0.000	3.29	0.9067
9.1200	38.899	127.582	0.000	0.000	3.28	0.9119
9.4050	39.209	128.015	0.000	0.000	3.26	0.9166
9.6900	39.520	128.448	0.000	0.000	3.25	0.9213
9.9750	39.831	128.801	0.000	0.000	3.23	0.9257
10.2600	40.141	129.090	0.000	0.000	3.22	0.9298
10.5450	40.433	129.378	0.000	0.000	3.20	0.9337
10.8300	40.643	129.667	0.000	0.000	3.19	0.9369
11.1150	40.853	129.956	0.000	0.000	3.18	0.9401
11.4000	41.064	130.174	0.000	0.000	3.17	0.9429
11.6850	41.283	130.391	0.000	0.000	3.16	0.9459
11.9700	41.503	130.580	0.000	0.000	3.15	0.9487
12.2550	41.687	130.768	0.000	0.000	3.14	0.9512
12.5400	41.871	130.938	0.000	0.000	3.13	0.9535
12.8250	42.066	131.096	0.000	0.000	3.12	0.9559
13.1100	42.239	131.209	0.000	0.000	3.11	0.9580
13.3950	42.386	131.322	0.000	0.000	3.10	0.9598
13.6800	42.522	131.435	0.000	0.000	3.09	0.9615
13.9650	42.658	131.548	0.000	0.000	3.08	0.9632
14.2500	42.794	131.614	0.000	0.000	3.08	0.9647

AXIAL PRESSURE PROFILE

X (in)	MACH #	Ptotal (psia)	Pstatic (psia)	Ttotal (R)	Tstatic (R)	Wdot (Lbm/s)	Local Radius (in)
1.20	0.001	2141.80	2142.76	1692.26	1686.27	0.74	3.354
1.30	0.002	2141.80	2142.75	1692.26	1686.27	2.46	3.354
1.61	0.006	2141.76	2142.69	1694.00	1688.01	7.88	3.354
1.91	0.008	2141.71	2142.59	1692.26	1686.27	12.04	3.354
2.21	0.011	2141.66	2142.49	1714.30	1708.23	15.13	3.354
2.51	0.018	2141.40	2141.97	1987.50	1980.45	23.75	3.354
2.81	0.076	2134.79	2128.73	5659.05	5637.47	57.98	3.354
3.11	0.120	2124.47	2107.97	6839.73	6811.23	82.57	3.354
3.41	0.145	2116.91	2092.70	6861.86	6831.71	98.53	3.354
3.71	0.163	2110.42	2079.57	6856.87	6825.41	110.41	3.354
4.01	0.178	2104.90	2068.35	6847.00	6814.45	119.59	3.354
4.32	0.190	2100.09	2058.55	6837.35	6803.85	127.02	3.354
4.62	0.199	2095.85	2049.90	6832.15	6797.78	133.17	3.354
4.92	0.207	2092.31	2042.67	6830.93	6795.81	138.04	3.354
5.22	0.214	2089.14	2036.16	6829.57	6793.77	142.25	3.354
5.52	0.220	2086.49	2030.73	6831.98	6795.58	145.62	3.354
5.82	0.226	2083.81	2025.22	6832.58	6795.58	148.96	3.354
6.12	0.231	2081.48	2020.40	6835.22	6797.69	151.78	3.354
6.42	0.235	2079.50	2016.35	6838.29	6800.30	154.09	3.354
6.72	0.238	2077.66	2012.57	6841.42	6803.00	156.20	3.354
7.02	0.242	2076.08	2009.31	6843.92	6805.12	158.00	3.354
7.33	0.244	2074.73	2006.52	6845.54	6806.42	159.52	3.354
7.63	0.247	2073.37	2003.70	6847.15	6807.71	161.03	3.354
7.93	0.249	2072.18	2001.25	6849.08	6809.35	162.33	3.354
8.23	0.251	2071.04	1998.90	6851.21	6811.21	163.56	3.354
8.53	0.253	2070.00	1996.74	6852.50	6812.25	164.66	3.354
8.83	0.255	2069.12	1994.90	6853.72	6813.25	165.62	3.354
9.13	0.257	2068.27	1993.16	6855.05	6814.36	166.51	3.354
9.43	0.258	2067.52	1991.60	6856.64	6815.76	167.30	3.354
9.73	0.260	2066.77	1990.04	6858.20	6817.16	168.08	3.354
10.04	0.261	2066.10	1988.66	6859.97	6818.76	168.76	3.354
10.34	0.262	2065.48	1987.37	6861.91	6820.53	169.39	3.354
10.64	0.263	2064.90	1986.17	6863.12	6821.60	169.96	3.354
10.94	0.264	2064.40	1985.13	6862.98	6821.35	170.50	3.354
11.24	0.265	2063.92	1984.09	6863.06	6821.30	171.00	3.354
11.54	0.266	2063.48	1983.22	6863.08	6821.23	171.45	3.354
11.84	0.271	2063.04	1979.58	6863.12	6820.03	171.90	3.328
12.14	0.291	2062.60	1966.57	6863.15	6814.89	172.31	3.226
12.44	0.326	2062.11	1940.85	6863.18	6804.36	172.69	3.061
12.74	0.377	2061.49	1902.92	6863.21	6788.55	173.06	2.886
13.05	0.439	2060.76	1846.36	6863.24	6765.20	173.39	2.712
13.35	0.525	2059.89	1764.18	6863.26	6727.74	173.67	2.539
13.65	0.657	2058.66	1617.13	6863.29	6658.19	173.93	2.387
13.95	0.820	2056.71	1415.52	6863.31	6553.61	174.19	2.257
14.25	0.999	2054.41	1186.32	6863.33	6421.46	174.41	2.223

PERFORMANCE SUMMARY

C* EFFICIENCY CALCULATIONS (ODK)

```
INJECTED MR= 2.8800      CSTAR=5860.40      CORE Em=0.9003      BARRIER Em=1.0000
CORE:          OVERALL MR= 2.8800      VAPOR MR= 3.0755      CSTAR-MIX=5779.65      MASS FRACTION= 1.0000
BARRIER:       OVERALL MR= 0.0000      VAPOR MR=99.9000      CSTAR-MIX=    0.00     MASS FRACTION= 0.0000
ENGINE:        OVERALL MR= 2.8800      VAPOR MR= 3.0755      CSTAR-DEL=5653.55
C* EFFICIENCY = 9.647E-01
```

ISP EFFICIENCY CALCULATIONS

```
ISP-ODK, INJ = 2.689E+02 SEC.
ISP-ODK, M.Z. INJ = 2.655E+02 SEC.          ISP-ODK, M.Z. VAPOR = 2.633E+02 SEC.
VAPORIZATION EFFICIENCY = 9.701E-01         MIXING EFFICIENCY = 9.947E-01
ENERGY RELEASE EFFICIENCY = 9.650E-01

NOTE: ISP-DEL = ISP-ODK, INJ. * ERE * ETADIV - DELISP-BL
```

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                    TIME-LAG CALCULATIONS, Milliseconds

Coham, In.=9.099E-03     FUEL Cohem, In.=2.293E+02     OX Cohem, In.=8.194E+01


ELEMENT 1 IS TYPE=LOL
FUEL:     Cinj, In.=1.444E-02     Lvap, In.= 0.519     ATOMIZATION LENGTH USED, In.= 1.061E+00
          Timp=3.619E-02     Tatom=2.893E-01     Tvap=1.415E-01     Total=4.670E-01

  OX:     Cinj, In.=1.474E-02     Lvap, In.= 0.189     ATOMIZATION LENGTH USED, In.= 2.324E+00
          Timp=6.588E-02     Tatom=7.526E-01     Tvap=6.126E-02     Total=8.798E-01


                    EFFECTIVE TIMELAGS, Milliseconds

FUEL:     Cinj, In.=1.444E-02     Lvap, In.= 0.519
          Timp=3.619E-02     Tatom=2.893E-01     Tvap=1.415E-01     Total=4.670E-01

  OX:     Cinj, In.=1.474E-02     Lvap, In.= 0.189
          Timp=6.588E-02     Tatom=7.526E-01     Tvap=6.126E-02     Total=8.798E-01
```

CHAMBER-NOZZLE OPTIMIZATION RESULTS

CHAMBER LENGTH (FEET)	ETA-C*	ETA-NOZ	OVERALL EFFICIENCY
0.0000	0.0000	0.8807	0.0000
0.1667	0.0180	0.8726	0.0157
0.3333	0.6503	0.8646	0.5623
0.5000	0.8182	0.8537	0.6985
0.6667	0.8884	0.8419	0.7480
0.8333	0.9261	0.8302	0.7689
1.0000	0.9489	0.8185	0.7767
1.1667	0.9634	0.8057	0.7762
1.3333	0.9739	0.7915	0.7708
1.5000	0.9844	0.7773	0.7651
1.6667	0.9946	0.7631	0.7591
1.8333	1.0000	0.7485	0.7485
2.0000	1.0000	0.7299	0.7299
2.1667	1.0000	0.7114	0.7114
2.3333	1.0000	0.6928	0.6928
2.5000	1.0000	0.6742	0.6742
2.6667	1.0000	0.6461	0.6461
2.8333	1.0000	0.6142	0.6142
3.0000	1.0000	0.5823	0.5823
3.1667	1.0000	0.5504	0.5504
3.3333	1.0000	0.5071	0.5071
3.5000	1.0000	0.4439	0.4439
3.6667	1.0000	0.3808	0.3808
3.8333	1.0000	0.3176	0.3176
4.0000	1.0000	0.2544	0.2544

OPTIMUM CHAMBER LENGTH= 1.0000 FT
MAXIMUM OVERALL EFFICIENCY= 0.7767

REDESIGNED CHAMBER RESULTS

NOMINAL CHAMBER PRESSURE	=	2.141E+03 PSIA
THROTTLED CHAMBER PRESSURE	=	1.535E+03 PSIA
FUEL INJECTION PRESSURE DROP	=	5.027E+02 PSI
OX INJECTION PRESSURE DROP	=	5.018E+02 PSI
CHAMBER RADIUS	=	2.795E-01 FT
THROAT RADIUS	=	1.552E-01 FT
NOZZLE ENTRANCE RADIUS OF CURVATURE	=	1.110E-01 FT
THROAT ENTRANCE RADIUS OF CURVATURE	=	1.110E-01 FT
NOZZLE CONVERGENCE HALF-ANGLE	=	3.000E+01 DEG
INJECTOR-TO-THROAT CHAMBER LENGTH	=	1.186E+00 FT
BARREL SECTION LENGTH	=	9.648E-01 FT

IMPINGING ELEMENT SIZING RESULTS

ELEMENT TYPE	=	LOL
NO. OF ELEMENTS	=	60
FUEL ORIFICE DIAMETER	=	7.115E-02 IN
OX ORIFICE DIAMETER	=	1.091E-01 IN

CORE ELEMENT SPACING RESULTS

ELEMENT TYPE	=	LOL
NUMBER OF ELEMENTS	=	60
FUEL ORIFICE/ANNULUS DIAMETER	=	7.115E-02 IN
OXIDIZER ORIFICE DIAMETER	=	1.091E-01 IN
FUEL INJECTION VELOCITY	=	3.056E+02 FT/S
OXIDIZER INJECTION VELOCITY	=	2.574E+02 FT/S

ROW	# ELEMENTS	MID-ROW RADIUS (IN)
1	6	7.347E-01
2	12	1.483E+00
3	18	2.231E+00
4	24	2.980E+00

DIRECT INPUT ECHO FROM SUBROUTINE PINPUT

ROCCID
ROCket Combustor Interactive Design Methodology
Version 23-FEB-91

```
ROCCID POINT DESIGN TEST CASE 1
LOX/RP-1 LIKE DOUBLET PAIR WITH FIXED PC
APPROXIMATES -0100 SUBSCALE DOUBLET
 $MODELS
 MCHAM=        1
 MBURN=        2
 MINJ=         1
 $END
 $OPCOND
 PISPA=     8.9600E+01,  1.0940E+02,  1.3940E+02,  1.5880E+02,  1.7780E+02,
            2.0970E+02,  2.3650E+02,  2.5470E+02,  2.6700E+02,  2.7040E+02,
            2.7180E+02,  2.7190E+02,  2.7130E+02,  2.6980E+02,  2.6820E+02,
            2.6660E+02,  2.6500E+02,  2.6210E+02,  2.5920E+02,  2.5630E+02,
            2.5080E+02,  2.3840E+02,  2.2750E+02,  2.1100E+02,  2.0140E+02,
            1.5560E+02,  1.0970E+02,  8.0000E+01,
 PCSA=      1.7760E+03,  2.4560E+03,  3.4870E+03,  4.0740E+03,  4.5800E+03,
            5.0700E+03,  5.4540E+03,  5.7340E+03,  5.9080E+03,  5.9810E+03,
            5.9690E+03,  5.9540E+03,  5.9340E+03,  5.9090E+03,  5.8820E+03,
            5.8550E+03,  5.8260E+03,  5.7590E+03,  5.7000E+03,  5.6430E+03,
            5.5320E+03,  5.2750E+03,  5.0470E+03,  4.6760E+03,  4.4200E+03,
            3.4570E+03,  2.4940E+03,  1.4650E+03,
 FUEL=     'RP-1     '
 OX=       'LOX      '
 PC=        2.1411E+03
 XMR=       2.6800E+00
 FTMAN=     7.1000E+01
 XTMAN=    -2.7900E+02
 EMMAN=     1.0000E+00
 NPERFP=        28
 PMRA=      1.0000E-01,  3.0000E-01,  6.0000E-01,  8.0000E-01,  1.0000E+00,
            1.2500E+00,  1.5000E+00,  1.7500E+00,  2.0000E+00,  2.2000E+00,
            2.4000E+00,  2.5000E+00,  2.6000E+00,  2.7000E+00,  2.8000E+00,
            2.9000E+00,  3.0000E+00,  3.2000E+00,  3.4000E+00,  3.6000E+00,
            4.0000E+00,  5.0000E+00,  6.0000E+00,  8.0000E+00,  1.0000E+01,
            1.5000E+01,  2.0000E+01,  5.0000E+01,
 $END
 $GEOM
 RCHAMB=    2.7949E-01
 RTHRT=     1.8523E-01
 RNE=       1.1100E-01
 RTE=       1.1100E-01
 ALPHA=     3.0000E+01
 CHAMBL=    1.1876E+00
 XC=        9.6477E-01
 $END
 $CORE
 TYPE=     'LOL'
 NEL=           60
 FDJ=       7.1147E-02
 FCD=       9.1000E-01
 FIH=       1.2323E-01
 FIA=       3.0000E+01
 FCANT=     1.6000E+01
 FFACET=    3.0808E-01
 XDJ=       1.0909E-01
 XCD=       9.4000E-01
```

```
XIH=      1.8894E-01
XIA=      3.0000E+01
XCANT=    1.6000E+01
XFACET=   4.7236E-01
EMUNI=    6.5000E-01
$END
$BAFFLE
$END
$BARRIER
$END
$FFC
$END
$BURN
GAMMA=    1.1462E+00
AO=       4.0658E+03
GMW=      2.3218E+01
GPR=      5.9752E-01
GK=       5.4180E-05
GMU=      6.6324E-05
RML=      7.6242E+01
VJL=      3.0746E+02
TJL=      5.3100E+02
RHOL=     4.9896E+01
CPL=      4.7321E-01
PCRITL=   3.1500E+02
TCRITL=   1.2180E+03
TBOILL=   8.6200E+02
XMWL=     1.7200E+02
HVAPL=    1.2500E+02
EN=       8.6793E-01
TAUSEN=   1.4114E-04
ISEN=          1
$END
$INJ
FMAND=    6.7076E+00
XMAND=    6.7076E+00
FMANL=    3.3538E+00
XMANL=    3.3538E+00
PCA=      2.1411E+03,  1.6514E+03,  7.6734E+02
FRA=      4.7547E-01,  3.4643E-01,  1.7206E-01
FCAPA=    7.8914E-04,  8.1791E-04,  8.6053E-04
NFE=           4
FTLA=     5.0142E-04,  6.8196E-04,  1.3371E-03,
FINA=     3.8676E-05,  3.8926E-05,  3.9064E-05,
FFA=      1.0000E+00,  1.0000E+00,  1.0000E+00,
NXE=           4
XRA=      4.7547E-01,  3.4643E-01,  1.7206E-01
XCAPA=    5.9163E-04,  6.1747E-04,  6.5615E-04
XTLA=     9.3236E-04,  1.2439E-03,  2.3399E-03,
XINA=     7.3026E-05,  7.3126E-05,  7.3382E-05,
XFA=      1.0000E+00,  1.0000E+00,  1.0000E+00,
XUOR=     4.7880E-02,  7.3412E-02,
AUOR=     3.4570E-03,  8.1269E-03,
RUOR=     3.3172E-02,  5.0881E-02,
XOR=      4.7880E-02,  7.3412E-02,
AOR=      3.4570E-03,  8.1269E-03,
ROR=      3.3172E-02,  5.0861E-02,
XDOR=     9.5761E-02,  1.4682E-01,
ADOR=     3.4570E-03,  8.1269E-03,
RDOR=     3.3172E-02,  5.0881E-02,
WDOT=     4.6218E+01,  1.3811E+02,  3.3533E+01,  9.6576E+01,  1.6844E+01,
          4.7935E+01
$END
$CHAMBER
```

```
NCAV=          1,
XB=        2.6125E-01
ZS=        1.1875E-01
ZE=        4.9875E-01
MUB=           3
T=         3.3000E-02
WC=        2.0961E-02,
AC=        3.6809E-02,
ARATIO=    1.0000E+00,
 IDCAV=        1,
DC1=       1.4000E-01,
CC1=       5*2.5000E+03
GAMC1=     5*1.2000E+00
CC2=       5*2.5000E+03
GAMC2=     5*1.2000E+00
 ICAV=         1
$END
$FDORC
NZON=          5
FTER=    20*1.0000E+00
NCAV1=         1
 ICTYP1=       4,
ZE1=       2.0961E-02,
AE1=       3.6000E+02,
APL1=      1.4000E-01,
WC1=       1.9166E-01,
ZLOW1=    -1.2315E-02,
ZUP1=      2.0417E-01,
$END
$MIX
 EM(1)= 8.930E-01,  1.000E+00
$END
$DEBUGC
DEBUG=   F
$END
$HIFIC
SHORT=   F
POC=       2.0000E-01,  2.0000E-01
$END
$DIST3DC
SHORT=   F
POC=       2.0000E-01,  2.0000E-01
PAMP=      2.0000E-01
MC=           11
LC=            8
MB=           11
LB=            8
 IDMAX=       10
$END
$CRPC
NDPC=         16
NDTFQ=        16
NDTLF=      1000
NPRINT=       50
NSUMS=      3500
PAMPC=     2.0000E-01
NRAD=          3
NCIRC=         5
$END
$LEINJC
 IDOMEM=       2
PAMPCH=    2.0000E-01
NTINJ=        16
USGF=      2.0000E-02
```

```
OGF=      2.0000E-02
DSGF=     2.0000E-02
FCDO=     1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XCDO=     1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
$END
$COMBUSTC
FALVM=    1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XALVM=    1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
FALTM=    1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XALTM=    1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
FRMM=     1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XRMM=     1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
EMMULT=   1.0000E+00,  1.0000E+00
COMBXB=   5.0000E-01
AOMULT=   1.0000E+00
CCMULT=   1.0000E+00
ENMULT=   1.0000E+00
TAUMULT=  1.0000E+00
$END
$FDORCC
SHORT=   F
EPSIL=    2.0000E+01
ERROR=    1.0000E-01
LTS=           5
MTS=           5
NTS=          10
ITMAX=       100
RELX=     6.5000E-01
NEET=          3
NXFST=         3
NYFST=         3
NAFST=         3
MORE=    F
$END

   END OF INPUT ECHO
```

STEADY STATE COMBUSTION ANALYSIS PROGRAM

RUN DESCRIPTORS

ROCCID POINT DESIGN TEST CASE 1
LOX/RP-1 LIKE DOUBLET PAIR WITH FIXED PC
APPROXIMATES -0100 SUBSCALE DOUBLET

PROPELLENT DESCRIPTION

FUEL=RP-1	Tman., F= 71.00
OX=LOX	Tman., F=-279.00

CHAMBER GEOMETRY

CHAMBER RADIUS = 3.3539 IN.
CYLINDRICAL SECTION =11.5770 IN.
NOZZLE ENTRANCE RADIUS OF CURVATURE = 1.3320 IN.
CONVERGENCE HALF-ANGLE =30.0000 DEG.

THROAT RADIUS = 2.2228 IN.
CONVERGENT SECTION LENGTH = 2.6730 IN.
THROAT ENTRANCE RADIUS OF CURVATURE = 1.3320 IN.
CONTRACTION RATIO = 2.28

INJECTOR DATA

INJECTOR CORE CONTAINS 60 LOL ELEMENTS

FUEL SIDE:	Orifice Diam. =7.115E-02 In.	Cd =0.9100	Impingement Height =0.123 In.
	Impingement Half-angle =30.00 Deg.	Unlike Cant Angle =16.00 Deg.	Faceplate Thickness = 0.3081 In.
OX SIDE:	Orifice Diam. =1.091E-01 In.	Cd =0.9400	Impingement Height =0.169 In.
	Impingement Half-angle =30.00 Deg.	Unlike Cant Angle =16.00 Deg.	Faceplate Thickness = 0.4724 In.

MIXING EFFICIENCIES

CORE MIXING EFFICIENCY=0.8930 BARRIER MIXING EFFICIENCY=1.0000

COMBUST CONTROL PARAMETERS

MULTIPLIERS:	CORE	BAFFLE	BARRIER	FFC
FUEL ATOMIZATION LENGTH FOR VAPORIZATION:	1.000	1.000	1.000	1.000
OX ATOMIZATION LENGTH FOR VAPORIZATION:	1.000	1.000	1.000	1.000
FUEL ATOMIZATION LENGTH FOR TIMELAGS:	1.000	1.000	1.000	1.000
OX ATOMIZATION LENGTH FOR TIMELAGS:	1.000	1.000	1.000	1.000
FUEL DROPSIZE:	1.000	1.000	1.000	1.000
OX DROPSIZE:	1.000	1.000	1.000	1.000
MIXING (Em):	1.000		1.000	

AO-Multiplier=1.000 CC-Multiplier=1.000 N-Multiplier=1.000 Tau-Multiplier=1.000
Eta-C* for XB=0.500

```
BEGIN STEADY STATE COMBUSTION ANALYSIS
     PC=2141.10 PSIA


                PROPELLANT PROPERTIES

FUEL=RP-1    Phase=Liquid                          Tman., F=  71.00
             Injected Density= 49.69 Lbm/Cu. Ft    Viscosity=1.360E-03 Lbm/Ft-S    Surface Tension=1.657E-03 Lbf/Ft

  OX=LOX     Phase=Liquid                          Tman., F=-279.00
             Injected Density= 70.20 Lbm/Cu. Ft    Viscosity=1.187E-04 Lbm/Ft-S    Surface Tension=7.326E-04 Lbf/Ft

                OPERATING CONDITIONS

PC FACE=2141.10 PSIA     PC THROAT=2052.79      MIXTURE RATIO= 2.880
FUEL INJECTION PRESSURE DROP= 510.07 Psia       FUEL INJECTION VELOCITY= 307.78 Ft/S
  OX INJECTION PRESSURE DROP= 509.14 Psia         OX INJECTION VELOCITY= 259.23 Ft/S

    FUEL FLOWRATE=  46.277     OX FLOWRATE= 133.277

                ATOMIZATION OUTPUT


       DROPSIZE MODEL=AEROJET

ELEMENT TYPE 1 IS LOL
FUEL:    ATOMIZATION LENGTH, In.=1.14748    ATOMIZATION LENGTH FOR VAPORIZATION, In.=1.14748    DROPLET RADIUS, Microns=  61.12
  OX:    ATOMIZATION LENGTH, In.=2.51421    ATOMIZATION LENGTH FOR VAPORIZATION, In.=2.51421    DROPLET RADIUS, Microns=  69.91
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VAPORIZATION CALCULATIONS

X (In.)	CORE=LOL %FUEL VAP	CORE=LOL %OX VAP	BAFFLE= %FUEL VAP	BAFFLE= %OX VAP	BARRIER= %FUEL VAP	BARRIER= %OX VAP	FFC= %FUEL VAP	FFC= %OX VAP
0.0000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.2850	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.5700	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.8550	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.1400	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.4250	5.403	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.7100	16.248	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.9950	24.257	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2.2800	30.678	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2.5650	36.456	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2.8500	41.859	15.086	0.000	0.000	0.000	0.000	0.000	0.000
3.1350	45.624	34.360	0.000	0.000	0.000	0.000	0.000	0.000
3.4200	49.368	46.965	0.000	0.000	0.000	0.000	0.000	0.000
3.7050	52.914	56.016	0.000	0.000	0.000	0.000	0.000	0.000
3.9900	55.737	62.691	0.000	0.000	0.000	0.000	0.000	0.000
4.2750	58.561	68.182	0.000	0.000	0.000	0.000	0.000	0.000
4.5600	61.064	72.468	0.000	0.000	0.000	0.000	0.000	0.000
4.8450	63.236	76.117	0.000	0.000	0.000	0.000	0.000	0.000
5.1300	65.408	79.030	0.000	0.000	0.000	0.000	0.000	0.000
5.4150	67.211	81.467	0.000	0.000	0.000	0.000	0.000	0.000
5.7000	68.876	83.543	0.000	0.000	0.000	0.000	0.000	0.000
5.9850	70.641	85.231	0.000	0.000	0.000	0.000	0.000	0.000
6.2700	71.996	86.916	0.000	0.000	0.000	0.000	0.000	0.000
6.5550	73.444	88.377	0.000	0.000	0.000	0.000	0.000	0.000
6.8400	74.841	89.519	0.000	0.000	0.000	0.000	0.000	0.000
7.1250	76.035	90.560	0.000	0.000	0.000	0.000	0.000	0.000
7.4100	77.230	91.454	0.000	0.000	0.000	0.000	0.000	0.000
7.6950	78.297	92.257	0.000	0.000	0.000	0.000	0.000	0.000
7.9800	79.202	92.919	0.000	0.000	0.000	0.000	0.000	0.000
8.2650	80.107	93.580	0.000	0.000	0.000	0.000	0.000	0.000
8.5500	80.987	94.182	0.000	0.000	0.000	0.000	0.000	0.000
8.8350	81.856	94.678	0.000	0.000	0.000	0.000	0.000	0.000
9.1200	82.725	95.174	0.000	0.000	0.000	0.000	0.000	0.000
9.4050	83.382	95.636	0.000	0.000	0.000	0.000	0.000	0.000
9.6900	83.977	96.033	0.000	0.000	0.000	0.000	0.000	0.000
9.9750	84.593	96.368	0.000	0.000	0.000	0.000	0.000	0.000
10.2600	85.208	96.696	0.000	0.000	0.000	0.000	0.000	0.000
10.5450	85.823	96.998	0.000	0.000	0.000	0.000	0.000	0.000
10.8300	86.439	97.261	0.000	0.000	0.000	0.000	0.000	0.000
11.1150	87.054	97.459	0.000	0.000	0.000	0.000	0.000	0.000
11.4000	87.669	97.658	0.000	0.000	0.000	0.000	0.000	0.000
11.6850	88.179	97.865	0.000	0.000	0.000	0.000	0.000	0.000
11.9700	88.644	98.087	0.000	0.000	0.000	0.000	0.000	0.000
12.2550	89.110	98.282	0.000	0.000	0.000	0.000	0.000	0.000
12.5400	89.576	98.449	0.000	0.000	0.000	0.000	0.000	0.000
12.8250	90.041	98.590	0.000	0.000	0.000	0.000	0.000	0.000
13.1100	90.440	98.719	0.000	0.000	0.000	0.000	0.000	0.000
13.3950	90.804	98.849	0.000	0.000	0.000	0.000	0.000	0.000
13.6800	91.169	98.960	0.000	0.000	0.000	0.000	0.000	0.000
13.9650	91.533	99.065	0.000	0.000	0.000	0.000	0.000	0.000
14.2500	91.898	99.142	0.000	0.000	0.000	0.000	0.000	0.000

OVERALL VAPORIZATION EFFICIENCIES
FUEL= 91.90% OX= 99.14%

MASS DISTRIBUTION PROFILE

X (IN)	CORE (lbm/s) FUEL	CORE (lbm/s) OX	BARRIER (lbm/s) FUEL	BARRIER (lbm/s) OX	LOCAL VAPOR MIXTURE RATIO	ETA-C*
0.0000	0.000	0.000	0.000	0.000	0.00	0.0000
0.2850	0.000	0.000	0.000	0.000	0.00	0.0000
0.5700	0.000	0.000	0.000	0.000	0.00	0.0000
0.8550	0.000	0.000	0.000	0.000	0.00	0.0000
1.1400	0.000	0.000	0.000	0.000	0.00	0.0000
1.4250	2.500	0.000	0.000	0.000	0.00	0.0034
1.7100	7.519	0.000	0.000	0.000	0.00	0.0103
1.9950	11.225	0.000	0.000	0.000	0.00	0.0153
2.2800	14.197	0.000	0.000	0.000	0.00	0.0194
2.5650	16.871	0.000	0.000	0.000	0.00	0.0230
2.8500	19.371	20.108	0.000	0.000	1.04	0.1750
3.1350	21.113	45.794	0.000	0.000	2.17	0.3732
3.4200	22.865	62.593	0.000	0.000	2.74	0.4762
3.7050	24.487	74.656	0.000	0.000	3.06	0.5449
3.9900	25.793	83.819	0.000	0.000	3.25	0.5968
4.2750	27.100	90.671	0.000	0.000	3.35	0.6390
4.5600	28.259	96.583	0.000	0.000	3.42	0.6742
4.8450	29.264	101.446	0.000	0.000	3.47	0.7042
5.1300	30.269	105.329	0.000	0.000	3.48	0.7301
5.4150	31.103	108.577	0.000	0.000	3.49	0.7516
5.7000	31.674	111.344	0.000	0.000	3.49	0.7706
5.9850	32.644	113.593	0.000	0.000	3.48	0.7874
6.2700	33.318	115.642	0.000	0.000	3.48	0.8032
6.5550	33.988	117.787	0.000	0.000	3.47	0.8177
6.8400	34.634	119.308	0.000	0.000	3.44	0.8303
7.1250	35.187	120.698	0.000	0.000	3.43	0.8413
7.4100	35.739	121.886	0.000	0.000	3.41	0.8515
7.6950	36.233	122.957	0.000	0.000	3.39	0.8607
7.9800	36.652	123.839	0.000	0.000	3.38	0.8683
8.2650	37.071	124.721	0.000	0.000	3.36	0.8759
8.5500	37.478	125.522	0.000	0.000	3.35	0.8831
8.8350	37.880	126.184	0.000	0.000	3.33	0.8897
9.1200	38.282	126.845	0.000	0.000	3.31	0.8962
9.4050	38.577	127.461	0.000	0.000	3.30	0.9016
9.6900	38.862	127.990	0.000	0.000	3.29	0.9065
9.9750	39.147	128.478	0.000	0.000	3.28	0.9112
10.2600	39.431	128.878	0.000	0.000	3.27	0.9155
10.5450	39.716	129.270	0.000	0.000	3.26	0.9198
10.8300	40.001	129.626	0.000	0.000	3.24	0.9240
11.1150	40.286	129.891	0.000	0.000	3.22	0.9277
11.4000	40.570	130.155	0.000	0.000	3.21	0.9314
11.6850	40.806	130.432	0.000	0.000	3.20	0.9348
11.9700	41.022	130.728	0.000	0.000	3.19	0.9380
12.2550	41.237	130.987	0.000	0.000	3.18	0.9410
12.5400	41.453	131.209	0.000	0.000	3.17	0.9439
12.8250	41.668	131.397	0.000	0.000	3.16	0.9466
13.1100	41.853	131.570	0.000	0.000	3.14	0.9490
13.3950	42.021	131.742	0.000	0.000	3.14	0.9513
13.6800	42.190	131.881	0.000	0.000	3.13	0.9534
13.9650	42.359	132.030	0.000	0.000	3.12	0.9555
14.2500	42.527	132.134	0.000	0.000	3.11	0.9575

AXIAL PRESSURE PROFILE

X (in)	MACH #	Ptotal (psia)	Pstatic (psia)	Ttotal (R)	Tstatic (R)	Wdot (Lbm/s)	Local Radius (in)
1.20	0.000	2141.73	2142.70	1692.26	1685.71	0.27	3.354
1.30	0.001	2141.73	2142.70	1692.26	1685.71	1.02	3.354
1.61	0.004	2141.71	2142.66	1693.07	1686.51	5.69	3.354
1.91	0.007	2141.66	2142.58	1692.26	1685.70	10.12	3.354
2.21	0.010	2141.61	2142.47	1702.52	1696.92	13.65	3.354
2.51	0.011	2141.59	2142.43	1692.26	1685.70	16.13	3.354
2.81	0.031	2140.65	2140.34	2602.19	2592.00	35.47	3.354
3.11	0.089	2132.16	2128.53	6180.49	6154.17	64.86	3.354
3.41	0.124	2123.41	2106.91	6846.39	6815.26	86.01	3.354
3.71	0.146	2116.46	2091.87	6863.41	6830.77	99.48	3.354
4.01	0.163	2110.52	2079.84	6855.70	6821.89	110.39	3.354
4.32	0.176	2105.36	2069.36	6847.06	6812.22	119.02	3.354
4.62	0.188	2100.84	2060.16	6839.56	6802.82	126.07	3.354
4.92	0.197	2096.79	2051.91	6832.11	6795.55	132.04	3.354
5.22	0.205	2093.29	2044.74	6830.66	6793.25	136.93	3.354
5.52	0.212	2090.24	2038.50	6828.90	6790.96	141.04	3.354
5.82	0.218	2087.55	2032.99	6829.61	6791.27	144.53	3.354
6.12	0.223	2085.07	2027.90	6831.33	6792.25	147.65	3.354
6.42	0.228	2082.66	2022.96	6832.07	6792.45	150.62	3.354
6.72	0.232	2080.56	2018.68	6836.02	6794.92	153.10	3.354
7.02	0.236	2078.77	2014.94	6837.66	6797.16	155.22	3.354
7.33	0.239	2077.11	2011.51	6840.59	6799.61	157.13	3.354
7.63	0.242	2075.59	2008.39	6843.20	6801.91	158.84	3.354
7.93	0.245	2074.33	2005.78	6844.86	6803.27	160.26	3.354
8.23	0.247	2073.10	2003.23	6846.36	6804.48	161.63	3.354
8.53	0.250	2071.92	2000.79	6847.95	6805.79	162.92	3.354
8.83	0.252	2070.87	1998.63	6849.84	6807.43	164.05	3.354
9.13	0.254	2069.83	1996.47	6851.69	6809.03	165.17	3.354
9.43	0.255	2068.94	1994.63	6852.67	6809.79	166.12	3.354
9.73	0.257	2068.14	1992.96	6853.81	6810.73	166.98	3.354
10.04	0.258	2067.38	1991.36	6855.06	6811.80	167.77	3.354
10.34	0.260	2066.69	1989.96	6856.52	6813.09	168.49	3.354
10.64	0.261	2066.00	1988.52	6857.94	6814.34	169.20	3.354
10.94	0.262	2065.37	1987.22	6859.52	6815.76	169.84	3.354
11.24	0.263	2064.80	1986.00	6861.31	6817.38	170.42	3.354
11.54	0.264	2064.24	1984.86	6862.70	6818.64	170.98	3.354
11.84	0.270	2063.71	1981.09	6863.05	6817.75	171.52	3.328
12.14	0.290	2063.16	1967.96	6863.09	6812.58	172.04	3.225
12.44	0.327	2062.55	1942.19	6863.07	6802.15	172.52	3.061
12.74	0.376	2061.81	1904.29	6863.10	6786.44	172.96	2.886
13.05	0.438	2060.95	1849.83	6863.13	6763.24	173.34	2.712
13.35	0.523	2059.82	1765.63	6863.16	6726.00	173.71	2.539
13.65	0.655	2058.26	1616.74	6863.19	6656.88	174.05	2.387
13.95	0.816	2055.86	1417.59	6863.21	6559.38	174.37	2.257
14.25	0.999	2052.79	1185.39	6863.24	6421.38	174.66	2.223

PERFORMANCE SUMMARY

C* EFFICIENCY CALCULATIONS (ODK)

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INJECTED MR= 2.8800      CSTAR=5660.40      CORE Em=0.8930      BARRIER Em=1.0000
CORE:          OVERALL MR= 2.8800      VAPOR MR= 3.1070      CSTAR-MIX=5768.35      MASS FRACTION= 1.0000
BARRIER:       OVERALL MR= 0.0000      VAPOR MR=99.9000      CSTAR-MIX=    0.00      MASS FRACTION= 0.0000
ENGINE:        OVERALL MR= 2.8800      VAPOR MR= 3.1070      CSTAR-DEL=5611.17
C* EFFICIENCY = 9.575E-01
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ISP EFFICIENCY CALCULATIONS

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ISP-ODK, INJ = 2.669E+02 SEC.
ISP-ODK, M.Z. INJ = 2.652E+02 SEC.          ISP-ODK, M.Z. VAPOR = 2.628E+02 SEC.
VAPORIZATION EFFICIENCY = 9.638E-01         MIXING EFFICIENCY = 9.935E-01
ENERGY RELEASE EFFICIENCY = 9.576E-01

NOTE: ISP-DEL = ISP-ODK, INJ. * ERE * ETADIV - DELISP-BL
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                    TIME-LAG CALCULATIONS, Milliseconds

Coham, In.=9.099E-03     FUEL Cohem, In.=2.293E+02     OX Cohem, In.=8.194E+01

ELEMENT 1 IS TYPE=LOL
FUEL:     Cinj, In.=1.587E-02     Lvap, In.= 0.570     ATOMIZATION LENGTH USED, In.= 1.147E+00
          Timp=3.853E-02     Tatom=3.107E-01     Tvap=1.544E-01     Total=5.036E-01

  OX:     Cinj, In.=1.620E-02     Lvap, In.= 0.208     ATOMIZATION LENGTH USED, In.= 2.514E+00
          Timp=7.013E-02     Tatom=8.082E-01     Tvap=6.684E-02     Total=9.452E-01

                    EFFECTIVE TIMELAGS, Milliseconds

FUEL:     Cinj, In.=1.587E-02     Lvap, In.= 0.570
          Timp=3.853E-02     Tatom=3.107E-01     Tvap=1.544E-01     Total=5.036E-01

  OX:     Cinj, In.=1.620E-02     Lvap, In.= 0.208
          Timp=7.013E-02     Tatom=8.082E-01     Tvap=6.684E-02     Total=9.452E-01
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CHAMBER-NOZZLE OPTIMIZATION RESULTS

CHAMBER LENGTH (FEET)	ETA-C*	ETA-NOZ	OVERALL EFFICIENCY
0.0000	0.0000	0.8807	0.0000
0.1667	0.0154	0.8726	0.0134
0.3333	0.5983	0.8646	0.5173
0.5000	0.7882	0.8537	0.6728
0.6667	0.8688	0.8419	0.7315
0.8333	0.9116	0.8302	0.7568
1.0000	0.9383	0.8185	0.7680
1.1667	0.9558	0.8057	0.7701
1.3333	0.9694	0.7915	0.7673
1.5000	0.9830	0.7773	0.7641
1.6667	0.9966	0.7631	0.7605
1.8333	1.0000	0.7465	0.7465
2.0000	1.0000	0.7299	0.7299
2.1667	1.0000	0.7114	0.7114
2.3333	1.0000	0.6928	0.6928
2.5000	1.0000	0.6742	0.6742
2.6667	1.0000	0.6461	0.6461
2.8333	1.0000	0.6142	0.6142
3.0000	1.0000	0.5823	0.5823
3.1667	1.0000	0.5504	0.5504
3.3333	1.0000	0.5071	0.5071
3.5000	1.0000	0.4439	0.4439
3.6667	1.0000	0.3808	0.3808
3.8333	1.0000	0.3176	0.3176
4.0000	1.0000	0.2544	0.2544

OPTIMUM CHAMBER LENGTH= 1.1667 FT
MAXIMUM OVERALL EFFICIENCY= 0.7701

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REDESIGNED CHAMBER RESULTS

NOMINAL CHAMBER PRESSURE                 =  2.141E+03 PSIA
THROTTLED CHAMBER PRESSURE               =  1.535E+03 PSIA
FUEL INJECTION PRESSURE DROP             =  5.101E+02 PSI
OX INJECTION PRESSURE DROP               =  5.091E+02 PSI
CHAMBER RADIUS                           =  2.795E-01 FT
THROAT RADIUS                            =  1.852E-01 FT
NOZZLE ENTRANCE RADIUS OF CURVATURE      =  1.110E-01 FT
THROAT ENTRANCE RADIUS OF CURVATURE      =  1.110E-01 FT
NOZZLE CONVERGENCE HALF-ANGLE            =  3.000E+01 DEG
INJECTOR-TO-THROAT CHAMBER LENGTH        =  1.190E+00 FT
BARREL SECTION LENGTH                    =  9.673E-01 FT


IMPINGING ELEMENT SIZING RESULTS

ELEMENT TYPE                 =LOL
NO. OF ELEMENTS              =     60
FUEL ORIFICE DIAMETER        =  7.115E-02 IN
OX ORIFICE DIAMETER          =  1.091E-01 IN
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DIRECT INPUT ECHO FROM SUBROUTINE PINPUT

                                  ROCCID
                 ROCket Combustor Interactive Design Methodology
                             Version 23-FEB-91

ROCCID POINT DESIGN TEST CASE 1
LOX/RP-1 LIKE DOUBLET PAIR WITH FIXED PC
APPROXIMATES -0100 SUBSCALE DOUBLET
 $MODELS
 MCHAM=         1
 MBURN=         2
 MINJ=          1
 $END
 $OPCOND
 PISPA=     8.9600E+01,  1.0940E+02,  1.3940E+02,  1.5860E+02,  1.7780E+02,
            2.0970E+02,  2.3550E+02,  2.5470E+02,  2.6700E+02,  2.7040E+02,
            2.7180E+02,  2.7190E+02,  2.7130E+02,  2.6960E+02,  2.6820E+02,
            2.6660E+02,  2.6500E+02,  2.6210E+02,  2.5920E+02,  2.5630E+02,
            2.5080E+02,  2.3840E+02,  2.2750E+02,  2.1100E+02,  2.0140E+02,
            1.5560E+02,  1.0970E+02,  8.0000E+01,
 PCSA=      1.7760E+03,  2.4560E+03,  3.4870E+03,  4.0740E+03,  4.5800E+03,
            5.0700E+03,  5.4540E+03,  5.7340E+03,  5.9080E+03,  5.9610E+03,
            5.9690E+03,  5.9540E+03,  5.9340E+03,  5.9090E+03,  5.8820E+03,
            5.8550E+03,  5.8260E+03,  5.7590E+03,  5.7000E+03,  5.6430E+03,
            5.5320E+03,  5.2750E+03,  5.0470E+03,  4.6760E+03,  4.4200E+03,
            3.4570E+03,  2.4940E+03,  1.4650E+03,
 FUEL=     'RP-1      '
 OX=       'LOX       '
 PC=        2.1411E+03
 XMR=       2.8800E+00
 FTMAN=     7.1000E+01
 XTMAN=    -2.7900E+02
 EMMAN=     1.0000E+00
 NPERFP=        28
 PMRA=      1.0000E-01,  3.0000E-01,  5.0000E-01,  8.0000E-01,  1.0000E+00,
            1.2500E+00,  1.5000E+00,  1.7500E+00,  2.0000E+00,  2.2000E+00,
            2.4000E+00,  2.5000E+00,  2.6000E+00,  2.7000E+00,  2.8000E+00,
            2.9000E+00,  3.0000E+00,  3.2000E+00,  3.4000E+00,  3.6000E+00,
            4.0000E+00,  5.0000E+00,  6.0000E+00,  8.0000E+00,  1.0000E+01,
            1.5000E+01,  2.0000E+01,  5.0000E+01,
 $END
 $GEOM
 RCHAMB=    2.7949E-01
 RTHRT=     1.8523E-01
 RNE=       1.1100E-01
 RTE=       1.1100E-01
 ALPHA=     3.0000E+01
 CHAMBL=    1.1900E+00
 XC=        9.6727E-01
 $END
 $CORE
 TYPE=     'LOL'
 NEL=           60
 FDJ=       7.1147E-02
 FOD=       9.1000E-01
 FIH=       1.2323E-01
 FIA=       3.0000E+01
 FCANT=     1.6000E+01
 FFACET=    3.0808E-01
 XDJ=       1.0909E-01
 XOD=       9.4000E-01
```

```
XIH=      1.8894E-01
XIA=      3.0000E+01
XCANT=    1.6000E+01
XFACET=   4.7235E-01
EMUNI=    6.5000E-01
$END
$BAFFLE
$END
$BARRIER
$END
$FFC
$END
$BURN
GAMMA=    1.1462E+00
AO=       4.0658E+03
GMW=      2.3218E+01
GPR=      5.9752E-01
GK=       5.4180E-05
GMU=      6.6324E-05
RML=      7.6242E+01
VJL=      3.0746E+02
TJL=      5.3100E+02
RHOL=     4.9895E+01
CPL=      4.7321E-01
PCRITL=   3.1500E+02
TCRITL=   1.2180E+03
TBOILL=   8.6200E+02
XMWL=     1.7200E+02
HVAPL=    1.2500E+02
EN=       6.6793E-01
TAUSEN=   1.4114E-04
ISEN=          1
$END
$INJ
FMAND=    6.7076E+00
XMAND=    6.7076E+00
FMANL=    3.3538E+00
XMANL=    3.3538E+00
PCA=      2.1411E+03,  1.5514E+03,  7.6734E+02
FRA=      4.7547E-01,  3.4543E-01,  1.7206E-01
FCAPA=    7.8914E-04,  8.1791E-04,  8.6053E-04
NFE=           4
FTLA=     5.0142E-04,  6.8196E-04,  1.3371E-03,
FINA=     3.8876E-05,  3.8926E-05,  3.9064E-05,
FFA=      1.0000E+00,  1.0000E+00,  1.0000E+00,
NXE=           4
XRA=      4.7547E-01,  3.4543E-01,  1.7206E-01
XCAPA=    5.9163E-04,  6.1747E-04,  6.5615E-04
XTLA=     9.3236E-04,  1.2439E-03,  2.3399E-03,
XINA=     7.3026E-05,  7.3126E-05,  7.3382E-05,
XFA=      1.0000E+00,  1.0000E+00,  1.0000E+00,
XUOR=     4.7880E-02,  7.3412E-02,
AUOR=     3.4570E-03,  8.1269E-03,
RUOR=     3.3172E-02,  5.0861E-02,
XOR=      4.7880E-02,  7.3412E-02,
AOR=      3.4570E-03,  8.1269E-03,
ROR=      3.3172E-02,  5.0861E-02,
XDOR=     9.5761E-02,  1.4682E-01,
ADOR=     3.4570E-03,  8.1269E-03,
RDOR=     3.3172E-02,  5.0861E-02,
WDOT=     4.6216E+01,  1.3311E+02,  3.3533E+01,  9.6576E+01,  1.6644E+01,
          4.7935E+01
$END
$CHAMBER
```

```
NCAV=        1,
XB=       2.6125E-01
ZS=       1.1675E-01
ZE=       4.9875E-01
MUB=         3
T=        3.3000E-02
WC=       2.0961E-02,
AC=       3.6609E-02,
ARATIO=   1.0000E+00,
IDCAV=       1,
DC1=      1.4000E-01,
CC1=      5*2.5000E+03
GAMC1=    5*1.2000E+00
CC2=      5*2.5000E+03
GAMC2=    5*1.2000E+00
ICAV=        1
$END
$FDORC
NZON=        5
FTER=    20*1.0000E+00
NCAV1=       1
ICTYP1=      4,
ZE1=      2.0961E-02,
AE1=      3.6000E+02,
APL1=     1.4000E-01,
WC1=      1.9166E-01,
ZLOW1=   -1.2315E-02,
ZUP1=     2.0417E-01,
$END
$MIX
 EM(1)= 6.930E-01,  1.000E+00
$END
$DEBUGC
DEBUG=   F
$END
$HIFIC
SHORT=   F
POC=      2.0000E-01,  2.0000E-01
$END
$DISTSDC
SHORT=   F
POC=      2.0000E-01,  2.0000E-01
PAMP=     2.0000E-01
MC=         11
LC=          8
MB=         11
LB=          8
IDMAX=      10
$END
$CRPC
NDPC=       16
NDTFQ=      16
NDTLF=    1000
NPRINT=     50
NSUMS=    3500
PAMPC=    2.0000E-01
NRAD=        3
NCIRC=       5
$END
$LEINJC
IDOMEM=      2
PAMPCH=   2.0000E-01
NTINJ=      18
USGF=     2.0000E-02
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OGF=       2.0000E-02
DSGF=      2.0000E-02
FCDO=      1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XCDO=      1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
$END
$COMBUSTC
FALVM=     1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XALVM=     1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
FALTM=     1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XALTM=     1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
FRMM=      1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
XRMM=      1.0000E+00,  1.0000E+00,  1.0000E+00,  1.0000E+00
EMMULT=    1.0000E+00,  1.0000E+00
COMBXB=    5.0000E-01
ACMULT=    1.0000E+00
CCMULT=    1.0000E+00
ENMULT=    1.0000E+00
TAUMULT=   1.0000E+00
$END
$FDORCC
SHORT=   F
EPSIL=     2.0000E+01
ERROR=     1.0000E-01
LTS=            5
MTS=            5
NTS=           10
ITMAX=        100
RELX=      6.5000E-01
NEET=           3
NXFST=          3
NYFST=          3
NAFST=          3
MORE=    F
$END

    END OF INPUT ECHO
```

STEADY STATE COMBUSTION ANALYSIS PROGRAM

RUN DESCRIPTORS

ROCCID POINT DESIGN TEST CASE 1
LOX/RP-1 LIKE DOUBLET PAIR WITH FIXED PC
APPROXIMATES -0100 SUBSCALE DOUBLET

PROPELLENT DESCRIPTION

FUEL=RP-1	Tman., F= 71.00
OX=LOX	Tman., F=-279.00

CHAMBER GEOMETRY

CHAMBER RADIUS = 3.3539 IN.	THROAT RADIUS = 2.2228 IN.
CYLINDRICAL SECTION =11.6070 IN.	CONVERGENT SECTION LENGTH = 2.6730 IN.
NOZZLE ENTRANCE RADIUS OF CURVATURE = 1.3320 IN.	THROAT ENTRANCE RADIUS OF CURVATURE = 1.3320 IN.
CONVERGENCE HALF-ANGLE =30.0000 DEG.	CONTRACTION RATIO = 2.28

INJECTOR DATA

INJECTOR CORE CONTAINS 60 LOL ELEMENTS

FUEL SIDE:	Orifice Diam. =7.115E-02 In.	Cd =0.9100	Impingement Height =0.123 In.
	Impingement Half-angle =30.00 Deg.	Unlike Cant Angle =16.00 Deg.	Faceplate Thickness = 0.3081 In.
OX SIDE:	Orifice Diam. =1.091E-01 In.	Cd =0.9400	Impingement Height =0.189 In.
	Impingement Half-angle =30.00 Deg.	Unlike Cant Angle =16.00 Deg.	Faceplate Thickness = 0.4724 In.

MIXING EFFICIENCIES

CORE MIXING EFFICIENCY=0.8930   BARRIER MIXING EFFICIENCY=1.0000

COMBUST CONTROL PARAMETERS

MULTIPLIERS:	CORE	BAFFLE	BARRIER	FFC
FUEL ATOMIZATION LENGTH FOR VAPORIZATION:	1.000	1.000	1.000	1.000
OX ATOMIZATION LENGTH FOR VAPORIZATION:	1.000	1.000	1.000	1.000
FUEL ATOMIZATION LENGTH FOR TIMELAGS:	1.000	1.000	1.000	1.000
OX ATOMIZATION LENGTH FOR TIMELAGS:	1.000	1.000	1.000	1.000
FUEL DROPSIZE:	1.000	1.000	1.000	1.000
OX DROPSIZE:	1.000	1.000	1.000	1.000
MIXING (Em):	1.000		1.000	

AO-Multiplier=1.000   CC-Multiplier=1.000   N-Multiplier=1.000   Tau-Multiplier=1.000
Eta-C* for XB=0.500

```
BEGIN STEADY STATE COMBUSTION ANALYSIS
     PC=2141.10 PSIA


                PROPELLANT PROPERTIES

FUEL=RP-1     Phase=Liquid                              Tman., F=  71.00
              Injected Density= 49.89 Lbm/Cu. Ft        Viscosity=1.380E-03 Lbm/Ft-S      Surface Tension=1.857E-03 Lbf/Ft

  OX=LOX      Phase=Liquid                              Tman., F=-279.00
              Injected Density= 70.20 Lbm/Cu. Ft        Viscosity=1.187E-04 Lbm/Ft-S      Surface Tension=7.326E-04 Lbf/Ft

                OPERATING CONDITIONS

PC FACE=2141.10 PSIA     PC THROAT=2052.82       MIXTURE RATIO= 2.880
FUEL INJECTION PRESSURE DROP= 509.96 Psia        FUEL INJECTION VELOCITY= 307.74 Ft/S
  OX INJECTION PRESSURE DROP= 507.82 Psia          OX INJECTION VELOCITY= 258.90 Ft/S

    FUEL FLOWRATE=  46.252     OX FLOWRATE= 133.206

                ATOMIZATION OUTPUT


        DROPSIZE MODEL=AEROJET

ELEMENT TYPE 1 IS LOL
FUEL:     ATOMIZATION LENGTH, In.=1.14746     ATOMIZATION LENGTH FOR VAPORIZATION, In.=1.14746     DROPLET RADIUS, Microns=  61.12
  OX:     ATOMIZATION LENGTH, In.=2.51385     ATOMIZATION LENGTH FOR VAPORIZATION, In.=2.51385     DROPLET RADIUS, Microns=  59.92
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VAPORIZATION CALCULATIONS

	CORE=LOL		BAFFLE=		BARRIER=		FFC=	
X (In.)	%FUEL VAP	%OX VAP	%FUEL VAP	%OX VAP	%FUEL VAP	%OX VAP	%FUEL VAP	%OX VAP
0.0000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.2856	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.5712	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.8568	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.1424	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.4280	5.495	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.7136	16.363	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.9992	24.374	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2.2848	30.781	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2.5704	36.561	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2.8560	41.940	15.650	0.000	0.000	0.000	0.000	0.000	0.000
3.1416	45.713	34.742	0.000	0.000	0.000	0.000	0.000	0.000
3.4272	49.485	47.259	0.000	0.000	0.000	0.000	0.000	0.000
3.7128	52.993	56.256	0.000	0.000	0.000	0.000	0.000	0.000
3.9984	55.822	63.095	0.000	0.000	0.000	0.000	0.000	0.000
4.2840	58.652	68.351	0.000	0.000	0.000	0.000	0.000	0.000
4.5696	61.139	72.627	0.000	0.000	0.000	0.000	0.000	0.000
4.8552	63.316	76.257	0.000	0.000	0.000	0.000	0.000	0.000
5.1408	65.492	79.144	0.000	0.000	0.000	0.000	0.000	0.000
5.4264	67.279	81.583	0.000	0.000	0.000	0.000	0.000	0.000
5.7120	68.948	83.830	0.000	0.000	0.000	0.000	0.000	0.000
5.9976	70.614	85.322	0.000	0.000	0.000	0.000	0.000	0.000
6.2832	72.065	87.015	0.000	0.000	0.000	0.000	0.000	0.000
6.5688	73.516	88.446	0.000	0.000	0.000	0.000	0.000	0.000
6.8544	74.903	89.591	0.000	0.000	0.000	0.000	0.000	0.000
7.1400	76.100	90.619	0.000	0.000	0.000	0.000	0.000	0.000
7.4256	77.297	91.515	0.000	0.000	0.000	0.000	0.000	0.000
7.7112	78.350	92.304	0.000	0.000	0.000	0.000	0.000	0.000
7.9968	79.257	92.968	0.000	0.000	0.000	0.000	0.000	0.000
8.2824	80.164	93.632	0.000	0.000	0.000	0.000	0.000	0.000
8.5680	81.044	94.221	0.000	0.000	0.000	0.000	0.000	0.000
8.8536	81.914	94.719	0.000	0.000	0.000	0.000	0.000	0.000
9.1392	82.785	95.217	0.000	0.000	0.000	0.000	0.000	0.000
9.4248	83.406	95.672	0.000	0.000	0.000	0.000	0.000	0.000
9.7104	84.023	96.070	0.000	0.000	0.000	0.000	0.000	0.000
9.9960	84.639	96.426	0.000	0.000	0.000	0.000	0.000	0.000
10.2816	85.256	96.725	0.000	0.000	0.000	0.000	0.000	0.000
10.5672	85.872	97.023	0.000	0.000	0.000	0.000	0.000	0.000
10.8528	86.489	97.281	0.000	0.000	0.000	0.000	0.000	0.000
11.1384	87.106	97.480	0.000	0.000	0.000	0.000	0.000	0.000
11.4240	87.722	97.679	0.000	0.000	0.000	0.000	0.000	0.000
11.7096	88.215	97.887	0.000	0.000	0.000	0.000	0.000	0.000
11.9952	88.681	98.110	0.000	0.000	0.000	0.000	0.000	0.000
12.2808	89.148	98.299	0.000	0.000	0.000	0.000	0.000	0.000
12.5664	89.615	98.466	0.000	0.000	0.000	0.000	0.000	0.000
12.8520	90.081	98.604	0.000	0.000	0.000	0.000	0.000	0.000
13.1376	90.472	98.734	0.000	0.000	0.000	0.000	0.000	0.000
13.4232	90.837	98.862	0.000	0.000	0.000	0.000	0.000	0.000
13.7088	91.203	98.973	0.000	0.000	0.000	0.000	0.000	0.000
13.9944	91.568	99.074	0.000	0.000	0.000	0.000	0.000	0.000
14.2800	91.933	99.152	0.000	0.000	0.000	0.000	0.000	0.000

OVERALL VAPORIZATION EFFICIENCIES
FUEL= 91.93% OX= 99.15%

MASS DISTRIBUTION PROFILE

X (IN)	CORE (lbm/s) FUEL	CORE (lbm/s) OX	BARRIER (lbm/s) FUEL	BARRIER (lbm/s) OX	LOCAL VAPOR MIXTURE RATIO	ETA-C*
0.0000	0.000	0.000	0.000	0.000	0.00	0.0000
0.2856	0.000	0.000	0.000	0.000	0.00	0.0000
0.5712	0.000	0.000	0.000	0.000	0.00	0.0000
0.8568	0.000	0.000	0.000	0.000	0.00	0.0000
1.1424	0.000	0.000	0.000	0.000	0.00	0.0000
1.4280	2.542	0.000	0.000	0.000	0.00	0.0035
1.7136	7.568	0.000	0.000	0.000	0.00	0.0103
1.9992	11.274	0.000	0.000	0.000	0.00	0.0164
2.2848	14.237	0.000	0.000	0.000	0.00	0.0194
2.5704	16.910	0.000	0.000	0.000	0.00	0.0231
2.8560	19.398	20.847	0.000	0.000	1.07	0.1814
3.1416	21.143	46.278	0.000	0.000	2.19	0.3764
3.4272	22.888	62.952	0.000	0.000	2.76	0.4776
3.7128	24.510	74.940	0.000	0.000	3.06	0.5467
3.9984	25.819	84.046	0.000	0.000	3.26	0.5983
4.2840	27.128	91.048	0.000	0.000	3.36	0.6404
4.5696	28.278	96.743	0.000	0.000	3.42	0.6754
4.8552	29.265	101.579	0.000	0.000	3.47	0.7058
5.1408	30.292	105.424	0.000	0.000	3.48	0.7311
5.4264	31.118	108.674	0.000	0.000	3.49	0.7526
5.7120	31.890	111.401	0.000	0.000	3.49	0.7714
5.9976	32.661	113.655	0.000	0.000	3.48	0.7882
6.2832	33.332	115.909	0.000	0.000	3.48	0.8040
6.5688	34.003	117.815	0.000	0.000	3.46	0.8184
6.8544	34.644	119.340	0.000	0.000	3.44	0.8309
7.1400	35.198	120.710	0.000	0.000	3.43	0.8419
7.4256	35.751	121.904	0.000	0.000	3.41	0.8522
7.7112	36.239	122.955	0.000	0.000	3.39	0.8611
7.9968	36.656	123.839	0.000	0.000	3.38	0.8688
8.2824	37.077	124.728	0.000	0.000	3.36	0.8765
8.5680	37.484	125.509	0.000	0.000	3.35	0.8836
8.8536	37.887	126.172	0.000	0.000	3.33	0.8902
9.1392	38.290	126.835	0.000	0.000	3.31	0.8967
9.4248	38.577	127.441	0.000	0.000	3.30	0.9020
9.7104	38.862	127.971	0.000	0.000	3.29	0.9069
9.9960	39.147	128.445	0.000	0.000	3.28	0.9116
10.2816	39.433	128.843	0.000	0.000	3.27	0.9159
10.5672	39.716	129.241	0.000	0.000	3.25	0.9202
10.8528	40.003	129.585	0.000	0.000	3.24	0.9243
11.1384	40.288	129.850	0.000	0.000	3.22	0.9280
11.4240	40.574	130.115	0.000	0.000	3.21	0.9316
11.7096	40.801	130.392	0.000	0.000	3.20	0.9350
11.9952	41.017	130.688	0.000	0.000	3.19	0.9383
12.2808	41.233	130.941	0.000	0.000	3.18	0.9413
12.5664	41.449	131.163	0.000	0.000	3.16	0.9442
12.8520	41.665	131.346	0.000	0.000	3.15	0.9469
13.1376	41.845	131.519	0.000	0.000	3.14	0.9493
13.4232	42.014	131.690	0.000	0.000	3.13	0.9515
13.7088	42.183	131.838	0.000	0.000	3.13	0.9536
13.9944	42.352	131.973	0.000	0.000	3.12	0.9557
14.2800	42.521	132.077	0.000	0.000	3.11	0.9577

AXIAL PRESSURE PROFILE

X (in)	MACH #	Ptotal (psia)	Pstatic (psia)	Ttotal (R)	Tstatic (R)	Wdot (Lbm/s)	Local Radius (in)
1.21	0.000	2141.71	2142.69	1692.26	1685.71	0.28	3.354
1.31	0.001	2141.71	2142.69	1692.26	1685.71	1.05	3.354
1.61	0.004	2141.69	2142.65	1693.22	1686.68	5.74	3.354
1.91	0.007	2141.65	2142.56	1692.26	1685.71	10.16	3.354
2.21	0.010	2141.60	2142.45	1704.47	1697.87	13.91	3.354
2.51	0.011	2141.58	2142.42	1692.26	1685.71	15.10	3.354
2.82	0.032	2140.45	2140.17	2665.03	2654.61	36.18	3.354
3.12	0.090	2131.91	2123.04	6222.30	6195.78	65.43	3.354
3.42	0.125	2123.20	2105.51	6849.21	6818.06	85.41	3.354
3.72	0.147	2116.27	2091.50	6863.38	6830.74	99.78	3.354
4.02	0.163	2110.34	2079.49	6855.10	6821.29	110.64	3.354
4.32	0.177	2105.19	2069.04	6846.76	6811.93	119.22	3.354
4.63	0.188	2100.68	2059.85	6838.05	6802.32	126.25	3.354
4.93	0.197	2096.64	2051.61	6831.69	6795.35	132.18	3.354
5.23	0.205	2093.15	2044.48	6830.43	6793.15	137.05	3.354
5.53	0.212	2090.11	2038.26	6828.75	6790.82	141.14	3.354
5.83	0.218	2087.44	2032.77	6829.64	6791.32	144.60	3.354
6.13	0.223	2084.94	2027.66	6831.26	6792.18	147.74	3.354
6.44	0.228	2082.55	2022.74	6832.10	6792.49	150.66	3.354
6.74	0.232	2080.49	2018.49	6835.08	6794.99	153.14	3.354
7.04	0.236	2078.68	2014.76	6837.74	6797.22	155.25	3.354
7.34	0.239	2077.02	2011.34	6840.65	6799.74	157.16	3.354
7.64	0.242	2075.52	2008.25	6843.26	6801.99	158.85	3.354
7.94	0.245	2074.26	2005.54	6844.91	6803.34	160.26	3.354
8.25	0.247	2073.02	2003.08	6846.41	6804.55	161.64	3.354
8.55	0.250	2071.85	2000.67	6848.04	6805.90	162.91	3.354
8.85	0.252	2070.81	1998.51	6849.93	6807.54	164.04	3.354
9.15	0.254	2069.76	1996.34	6851.78	6809.14	165.17	3.354
9.45	0.255	2068.89	1994.53	6852.72	6809.86	166.10	3.354
9.75	0.257	2068.08	1992.86	6853.87	6810.81	166.96	3.354
10.06	0.258	2067.33	1991.30	6855.15	6811.92	167.74	3.354
10.36	0.260	2066.64	1989.87	6856.60	6813.19	168.46	3.354
10.66	0.261	2065.95	1988.44	6858.04	6814.46	169.17	3.354
10.96	0.262	2065.33	1987.16	6859.64	6815.91	169.80	3.354
11.26	0.263	2064.76	1985.93	6861.44	6817.54	170.38	3.354
11.56	0.264	2064.21	1984.82	6862.76	6818.74	170.94	3.354
11.87	0.270	2063.68	1981.14	6863.04	6817.81	171.48	3.329
12.17	0.289	2063.13	1968.18	6863.05	6812.73	171.99	3.228
12.47	0.326	2062.52	1942.54	6863.07	6802.34	172.47	3.069
12.77	0.375	2061.80	1904.69	6863.11	6786.66	172.90	2.887
13.07	0.437	2060.94	1860.34	6863.14	6763.50	173.29	2.713
13.37	0.523	2059.82	1766.26	6863.16	6728.32	173.66	2.540
13.68	0.654	2058.26	1619.42	6863.19	6657.24	173.99	2.367
13.98	0.817	2055.91	1418.06	6863.22	6553.62	174.31	2.257
14.28	0.999	2052.82	1185.41	6863.25	6421.38	174.60	2.228

PERFORMANCE SUMMARY

C* EFFICIENCY CALCULATIONS (ODK)

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INJECTED MR= 2.8800      CSTAR=5860.40      CORE Em=0.8930      BARRIER Em=1.0000
CORE:          OVERALL MR= 2.8800      VAPOR MR= 3.1062      CSTAR-MIX=5768.60      MASS FRACTION= 1.0000
BARRIER:       OVERALL MR= 0.0000      VAPOR MR=99.9000      CSTAR-MIX=    0.00     MASS FRACTION= 0.0000
ENGINE:        OVERALL MR= 2.8800      VAPOR MR= 3.1062      CSTAR-DEL=5612.35
C* EFFICIENCY = 9.577E-01
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ISP EFFICIENCY CALCULATIONS

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ISP-ODK, INJ = 2.669E+02 SEC.
ISP-ODK, M.Z. INJ = 2.652E+02 SEC.          ISP-ODK, M.Z. VAPOR = 2.628E+02 SEC.
VAPORIZATION EFFICIENCY = 9.640E-01         MIXING EFFICIENCY = 9.935E-01
ENERGY RELEASE EFFICIENCY = 9.578E-01

NOTE: ISP-DEL = ISP-ODK, INJ. * ERE * ETADIV - DELISP-BL
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                    TIME-LAG CALCULATIONS, Milliseconds

Coham, In.=9.099E-03    FUEL Cohem, In.=2.293E+02    OX Cohem, In.=8.194E+01


ELEMENT 1 IS TYPE=LOL
FUEL:    Cinj, In.=1.587E-02     Lvap, In.= 0.570     ATOMIZATION LENGTH USED, In.= 1.147E+00
         Timp=3.853E-02     Tatom=3.107E-01     Tvap=1.544E-01     Total=5.036E-01

  OX:    Cinj, In.=1.618E-02     Lvap, In.= 0.208     ATOMIZATION LENGTH USED, In.= 2.514E+00
         Timp=7.022E-02     Tatom=8.092E-01     Tvap=6.687E-02     Total=9.463E-01


                    EFFECTIVE TIMELAGS, Milliseconds

FUEL:    Cinj, In.=1.587E-02     Lvap, In.= 0.570
         Timp=3.853E-02     Tatom=3.107E-01     Tvap=1.544E-01     Total=5.036E-01

  OX:    Cinj, In.=1.618E-02     Lvap, In.= 0.208
         Timp=7.022E-02     Tatom=8.092E-01     Tvap=6.687E-02     Total=9.463E-01
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CHAMBER-NOZZLE OPTIMIZATION RESULTS

CHAMBER LENGTH (FEET)	ETA-C*	ETA-NOZ	OVERALL EFFICIENCY
0.0000	0.0000	0.8807	0.0000
0.1667	0.0154	0.8726	0.0134
0.3333	0.5986	0.8646	0.5175
0.5000	0.7883	0.8537	0.6730
0.6667	0.8689	0.8419	0.7316
0.8333	0.9116	0.8302	0.7569
1.0000	0.9383	0.8185	0.7680
1.1667	0.9558	0.8057	0.7701
1.3333	0.9694	0.7915	0.7673
1.5000	0.9830	0.7773	0.7641
1.6667	0.9966	0.7631	0.7605
1.8333	1.0000	0.7485	0.7485
2.0000	1.0000	0.7299	0.7299
2.1667	1.0000	0.7114	0.7114
2.3333	1.0000	0.6928	0.6928
2.5000	1.0000	0.6742	0.6742
2.6667	1.0000	0.6461	0.6461
2.8333	1.0000	0.6142	0.6142
3.0000	1.0000	0.5823	0.5823
3.1667	1.0000	0.5504	0.5504
3.3333	1.0000	0.5071	0.5071
3.5000	1.0000	0.4439	0.4439
3.6667	1.0000	0.3808	0.3808
3.8333	1.0000	0.3176	0.3176
4.0000	1.0000	0.2544	0.2544

OPTIMUM CHAMBER LENGTH= 1.1667 FT
MAXIMUM OVERALL EFFICIENCY= 0.7701

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BEGIN STEADY STATE COMBUSTION ANALYSIS
     PC=1551.40 PSIA


                     PROPELLANT PROPERTIES

FUEL=RP-1    Phase=Liquid                       Tman., F=  71.00
             Injected Density= 49.59 Lbm/Cu. Ft  Viscosity=1.380E-03 Lbm/Ft-S   Surface Tension=1.657E-03 Lbf/Ft

  OX=LOX     Phase=Liquid                       Tman., F=-279.00
             Injected Density= 69.62 Lbm/Cu. Ft  Viscosity=1.143E-04 Lbm/Ft-S   Surface Tension=7.326E-04 Lbf/Ft

                     OPERATING CONDITIONS

PC FACE=1551.40 PSIA    PC THROAT=1487.36    MIXTURE RATIO= 2.880
FUEL INJECTION PRESSURE DROP= 268.15 Psia    FUEL INJECTION VELOCITY= 223.16 Ft/S
  OX INJECTION PRESSURE DROP= 270.43 Psia      OX INJECTION VELOCITY= 189.72 Ft/S

    FUEL FLOWRATE=  33.566     OX FLOWRATE=  96.669

                     ATOMIZATION OUTPUT


         DROPSIZE MODEL=AEROJET

ELEMENT TYPE 1 IS LOL
FUEL:     ATOMIZATION LENGTH, In.=1.10721    ATOMIZATION LENGTH FOR VAPORIZATION, In.=1.10721    DROPLET RADIUS, Microns=  84.07
  OX:     ATOMIZATION LENGTH, In.=2.43655    ATOMIZATION LENGTH FOR VAPORIZATION, In.=2.43655    DROPLET RADIUS, Microns=  92.78
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VAPORIZATION CALCULATIONS

X (in.)	CORE=LOL %FUEL VAP	CORE=LOL %OX VAP	BAFFLE= %FUEL VAP	BAFFLE= %OX VAP	BARRIER= %FUEL VAP	BARRIER= %OX VAP	FFC= %FUEL VAP	FFC= %OX VAP
0.0000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.2856	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.5712	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.8568	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.1424	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.4280	7.034	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.7136	17.287	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.9992	24.996	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2.2848	31.116	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2.5704	36.738	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2.8560	41.976	21.297	0.000	0.000	0.000	0.000	0.000	0.000
3.1416	45.861	38.123	0.000	0.000	0.000	0.000	0.000	0.000
3.4272	49.347	49.350	0.000	0.000	0.000	0.000	0.000	0.000
3.7128	52.624	57.637	0.000	0.000	0.000	0.000	0.000	0.000
3.9984	55.566	64.009	0.000	0.000	0.000	0.000	0.000	0.000
4.2840	58.352	68.940	0.000	0.000	0.000	0.000	0.000	0.000
4.5696	60.858	73.041	0.000	0.000	0.000	0.000	0.000	0.000
4.8552	62.985	76.519	0.000	0.000	0.000	0.000	0.000	0.000
5.1408	65.111	79.281	0.000	0.000	0.000	0.000	0.000	0.000
5.4264	66.946	81.657	0.000	0.000	0.000	0.000	0.000	0.000
5.7120	68.578	83.641	0.000	0.000	0.000	0.000	0.000	0.000
5.9976	70.208	85.292	0.000	0.000	0.000	0.000	0.000	0.000
6.2832	71.677	86.943	0.000	0.000	0.000	0.000	0.000	0.000
6.5688	73.094	88.369	0.000	0.000	0.000	0.000	0.000	0.000
6.8544	74.512	89.466	0.000	0.000	0.000	0.000	0.000	0.000
7.1400	75.897	90.515	0.000	0.000	0.000	0.000	0.000	0.000
7.4256	76.866	91.369	0.000	0.000	0.000	0.000	0.000	0.000
7.7112	78.003	92.195	0.000	0.000	0.000	0.000	0.000	0.000
7.9968	78.888	92.842	0.000	0.000	0.000	0.000	0.000	0.000
8.2824	79.774	93.490	0.000	0.000	0.000	0.000	0.000	0.000
8.5680	80.650	94.103	0.000	0.000	0.000	0.000	0.000	0.000
8.8536	81.500	94.586	0.000	0.000	0.000	0.000	0.000	0.000
9.1392	82.351	95.074	0.000	0.000	0.000	0.000	0.000	0.000
9.4248	83.084	95.548	0.000	0.000	0.000	0.000	0.000	0.000
9.7104	83.687	95.936	0.000	0.000	0.000	0.000	0.000	0.000
9.9960	84.289	96.318	0.000	0.000	0.000	0.000	0.000	0.000
10.2816	84.891	96.610	0.000	0.000	0.000	0.000	0.000	0.000
10.5672	85.494	96.901	0.000	0.000	0.000	0.000	0.000	0.000
10.8528	86.096	97.192	0.000	0.000	0.000	0.000	0.000	0.000
11.1384	86.699	97.369	0.000	0.000	0.000	0.000	0.000	0.000
11.4240	87.301	97.583	0.000	0.000	0.000	0.000	0.000	0.000
11.7096	87.920	97.786	0.000	0.000	0.000	0.000	0.000	0.000
11.9952	88.376	98.003	0.000	0.000	0.000	0.000	0.000	0.000
12.2808	88.831	98.216	0.000	0.000	0.000	0.000	0.000	0.000
12.5664	89.287	98.378	0.000	0.000	0.000	0.000	0.000	0.000
12.8520	89.743	98.532	0.000	0.000	0.000	0.000	0.000	0.000
13.1376	90.199	98.659	0.000	0.000	0.000	0.000	0.000	0.000
13.4232	90.556	98.785	0.000	0.000	0.000	0.000	0.000	0.000
13.7088	90.913	98.903	0.000	0.000	0.000	0.000	0.000	0.000
13.9944	91.269	99.012	0.000	0.000	0.000	0.000	0.000	0.000
14.2800	91.626	99.099	0.000	0.000	0.000	0.000	0.000	0.000

OVERALL VAPORIZATION EFFICIENCIES
FUEL= 91.63%   OX= 99.10%

MASS DISTRIBUTION PROFILE

X (IN)	CORE (lbm/s) FUEL	CORE (lbm/s) OX	BARRIER (lbm/s) FUEL	BARRIER (lbm/s) OX	LOCAL VAPOR MIXTURE RATIO	ETA-C*
0.0000	0.000	0.000	0.000	0.000	0.00	0.0000
0.2856	0.000	0.000	0.000	0.000	0.00	0.0000
0.5712	0.000	0.000	0.000	0.000	0.00	0.0000
0.8568	0.000	0.000	0.000	0.000	0.00	0.0000
1.1424	0.000	0.000	0.000	0.000	0.00	0.0000
1.4280	2.361	0.000	0.000	0.000	0.00	0.0044
1.7136	5.803	0.000	0.000	0.000	0.00	0.0109
1.9992	8.390	0.000	0.000	0.000	0.00	0.0156
2.2848	10.444	0.000	0.000	0.000	0.00	0.0197
2.5704	12.331	0.000	0.000	0.000	0.00	0.0232
2.8560	14.090	20.587	0.000	0.000	1.46	0.2446
3.1416	15.327	36.853	0.000	0.000	2.40	0.4028
3.4272	16.564	47.706	0.000	0.000	2.88	0.4905
3.7128	17.731	55.717	0.000	0.000	3.14	0.5542
3.9984	18.658	61.877	0.000	0.000	3.32	0.6026
4.2840	19.566	66.644	0.000	0.000	3.40	0.6425
4.5696	20.428	70.608	0.000	0.000	3.46	0.6765
4.8552	21.141	73.970	0.000	0.000	3.50	0.7054
5.1408	21.855	76.641	0.000	0.000	3.51	0.7302
5.4264	22.472	78.937	0.000	0.000	3.51	0.7516
5.7120	23.019	80.855	0.000	0.000	3.51	0.7698
5.9976	23.566	82.451	0.000	0.000	3.50	0.7862
6.2832	24.059	84.047	0.000	0.000	3.49	0.8019
6.5688	24.535	85.426	0.000	0.000	3.48	0.8162
6.8544	25.010	86.505	0.000	0.000	3.46	0.8288
7.1400	25.408	87.500	0.000	0.000	3.44	0.8396
7.4256	25.801	88.345	0.000	0.000	3.42	0.8496
7.7112	26.182	89.124	0.000	0.000	3.40	0.8590
7.9968	26.479	89.750	0.000	0.000	3.39	0.8665
8.2824	26.777	90.376	0.000	0.000	3.38	0.8740
8.5680	27.071	90.968	0.000	0.000	3.36	0.8812
8.8536	27.358	91.438	0.000	0.000	3.34	0.8877
9.1392	27.642	91.907	0.000	0.000	3.32	0.8941
9.4248	27.888	92.365	0.000	0.000	3.31	0.8999
9.7104	28.090	92.741	0.000	0.000	3.30	0.9047
9.9960	28.292	93.110	0.000	0.000	3.29	0.9094
10.2816	28.494	93.392	0.000	0.000	3.28	0.9137
10.5672	28.697	93.673	0.000	0.000	3.26	0.9179
10.8528	28.899	93.955	0.000	0.000	3.25	0.9221
11.1384	29.101	94.145	0.000	0.000	3.24	0.9258
11.4240	29.303	94.333	0.000	0.000	3.22	0.9294
11.7096	29.511	94.529	0.000	0.000	3.20	0.9332
11.9952	29.684	94.739	0.000	0.000	3.19	0.9364
12.2808	29.817	94.944	0.000	0.000	3.18	0.9395
12.5664	29.970	95.101	0.000	0.000	3.17	0.9423
12.8520	30.123	95.250	0.000	0.000	3.16	0.9451
13.1376	30.276	95.373	0.000	0.000	3.15	0.9477
13.4232	30.396	95.495	0.000	0.000	3.14	0.9499
13.7088	30.515	95.609	0.000	0.000	3.13	0.9521
13.9944	30.635	95.714	0.000	0.000	3.12	0.9541
14.2800	30.755	95.799	0.000	0.000	3.11	0.9561

AXIAL PRESSURE PROFILE

X (in)	MACH #	Ptotal (psia)	Pstatic (psia)	Ttotal (R)	Tstatic (R)	Wdot (Lbm/s)	Local Radius (in)
1.21	0.000	1551.87	1552.58	1677.18	1670.71	0.31	3.354
1.31	0.001	1551.87	1552.58	1677.18	1670.71	1.08	3.354
1.61	0.004	1551.85	1552.54	1681.33	1674.84	4.61	3.354
1.91	0.007	1551.82	1552.48	1677.18	1670.70	7.55	3.354
2.21	0.010	1551.78	1552.40	1729.62	1722.93	10.39	3.354
2.51	0.010	1551.78	1552.40	1677.18	1670.70	10.51	3.354
2.82	0.047	1549.96	1546.75	3846.96	3831.73	31.26	3.354
3.12	0.100	1543.17	1535.14	6492.51	6464.48	51.01	3.354
3.42	0.129	1537.52	1523.75	6771.12	6740.25	63.97	3.354
3.72	0.149	1532.76	1514.12	6769.46	6737.30	73.67	3.354
4.02	0.165	1528.69	1505.88	6753.18	6719.97	81.06	3.354
4.32	0.178	1525.14	1498.66	6745.81	6711.66	86.95	3.354
4.63	0.189	1521.95	1492.17	6738.70	6703.70	91.90	3.354
4.93	0.198	1519.13	1486.42	6734.53	6698.75	96.03	3.354
5.23	0.206	1516.67	1481.40	6733.92	6697.43	99.44	3.354
5.53	0.212	1514.60	1476.95	6733.20	6696.10	102.36	3.354
5.83	0.218	1512.62	1473.10	6734.06	6696.40	104.80	3.354
6.13	0.223	1510.86	1469.48	6735.43	6697.24	107.03	3.354
6.44	0.228	1509.15	1465.96	6736.18	6697.48	109.14	3.354
6.74	0.232	1507.67	1462.92	6738.66	6699.50	110.91	3.354
7.04	0.236	1506.37	1460.24	6740.93	6701.37	112.44	3.354
7.34	0.239	1505.20	1457.83	6743.09	6703.15	113.79	3.354
7.64	0.242	1504.09	1455.54	6745.72	6705.43	115.05	3.354
7.94	0.245	1503.18	1453.66	6747.50	6706.92	116.07	3.354
8.25	0.247	1502.31	1451.87	6748.99	6708.14	117.03	3.354
8.55	0.249	1501.45	1450.09	6750.54	6709.41	117.98	3.354
8.85	0.251	1500.71	1448.56	6752.41	6711.04	118.76	3.354
9.15	0.253	1499.97	1447.02	6754.26	6712.64	119.56	3.354
9.45	0.255	1499.28	1445.60	6755.60	6713.76	120.31	3.354
9.75	0.257	1498.71	1444.42	6758.69	6714.86	120.92	3.354
10.06	0.258	1498.15	1443.26	6757.85	6715.65	121.51	3.354
10.36	0.259	1497.67	1442.28	6759.30	6716.93	122.01	3.354
10.66	0.261	1497.17	1441.22	6760.67	6718.13	122.53	3.354
10.96	0.262	1496.70	1440.25	6762.16	6719.47	123.01	3.354
11.26	0.263	1496.31	1439.40	6763.86	6721.01	123.41	3.354
11.56	0.264	1495.89	1438.55	6765.64	6722.66	123.84	3.354
11.87	0.268	1495.48	1435.85	6766.75	6722.60	124.24	3.329
12.17	0.289	1495.08	1426.46	6767.06	6717.98	124.62	3.228
12.47	0.326	1494.63	1407.92	6767.43	6708.23	124.97	3.069
12.77	0.375	1494.09	1380.54	6767.80	6693.34	125.29	2.887
13.07	0.437	1493.42	1341.12	6768.21	6671.23	125.59	2.713
13.37	0.523	1492.60	1280.31	6768.51	6635.41	125.85	2.540
13.68	0.654	1491.45	1174.09	6768.80	6568.61	126.10	2.387
13.98	0.817	1489.89	1028.38	6769.10	6468.28	126.34	2.257
14.28	0.999	1487.36	859.58	6769.42	6339.95	126.55	2.223

```
                PERFORMANCE SUMMARY

              C* EFFICIENCY CALCULATIONS (ODK)

INJECTED MR= 2.8800      CSTAR=5880.40      CORE Em=0.8930      BARRIER Em=1.0000
CORE:         OVERALL MR= 2.8800      VAPOR MR= 3.1149      CSTAR-MIX=5766.22      MASS FRACTION= 1.0000
BARRIER:      OVERALL MR= 0.0000      VAPOR MR=99.9000      CSTAR-MIX=    0.00      MASS FRACTION= 0.0000
ENGINE:       OVERALL MR= 2.8800      VAPOR MR= 3.1149      CSTAR-DEL=5603.22
C* EFFICIENCY = 9.561E-01

              ISP EFFICIENCY CALCULATIONS

ISP-ODK, INJ = 2.669E+02 SEC.
ISP-ODK, M.Z. INJ = 2.652E+02 SEC.          ISP-ODK, M.Z. VAPOR = 2.626E+02 SEC.
VAPORIZATION EFFICIENCY = 9.624E-01         MIXING EFFICIENCY = 9.935E-01
ENERGY RELEASE EFFICIENCY = 9.562E-01

NOTE: ISP-DEL = ISP-ODK, INJ. * ERE * ETADIV - DELISP-BL
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                     TIME-LAG CALCULATIONS, Milliseconds

Coham, In.=1.125E-02    FUEL Cohem, In.=2.293E+02    OX Cohem, In.=8.194E+01

ELEMENT 1 IS TYPE=LOL
FUEL:     CInj, In.=1.313E-02     Lvap, In.= 0.584     ATOMIZATION LENGTH USED, In.= 1.107E+00
          Timp=5.314E-02     Tatom=4.135E-01     Tvap=2.179E-01     Total=6.845E-01

  OX:     CInj, In.=1.341E-02     Lvap, In.= 0.213     ATOMIZATION LENGTH USED, In.= 2.437E+00
          Timp=9.583E-02     Tatom=1.070E+00     Tvap=9.354E-02     Total=1.260E+00

                     EFFECTIVE TIMELAGS, Milliseconds

FUEL:     CInj, In.=1.313E-02     Lvap, In.= 0.584
          Timp=5.314E-02     Tatom=4.135E-01     Tvap=2.179E-01     Total=6.845E-01

  OX:     CInj, In.=1.341E-02     Lvap, In.= 0.213
          Timp=9.583E-02     Tatom=1.070E+00     Tvap=9.354E-02     Total=1.260E+00
```

```
                BEGIN STEADY STATE COMBUSTION ANALYSIS
                     PC= 767.34 PSIA


                          PROPELLANT PROPERTIES

FUEL=RP-1      Phase=Liquid                          Tman., F=  71.00
               Injected Density= 49.89 Lbm/Cu. Ft    Viscosity=1.380E-03 Lbm/Ft-S    Surface Tension=1.857E-03 Lbf/Ft

  OX=LOX       Phase=Liquid                          Tman., F=-279.00
               Injected Density= 68.77 Lbm/Cu. Ft    Viscosity=1.082E-04 Lbm/Ft-S    Surface Tension=7.326E-04 Lbf/Ft

                          OPERATING CONDITIONS

PC FACE= 767.34 PSIA     PC THROAT= 735.59     MIXTURE RATIO= 2.880
FUEL INJECTION PRESSURE DROP=  66.11 Psia      FUEL INJECTION VELOCITY= 110.80 Ft/S
  OX INJECTION PRESSURE DROP=  67.34 Psia        OX INJECTION VELOCITY=  95.25 Ft/S

    FUEL FLOWRATE=  16.662     OX FLOWRATE=  47.986

                          ATOMIZATION OUTPUT


         DROPSIZE MODEL=AEROJET

ELEMENT TYPE 1 IS LOL
FUEL:     ATOMIZATION LENGTH, In.=1.02434    ATOMIZATION LENGTH FOR VAPORIZATION, In.=1.02434    DROPLET RADIUS, Microns=  90.87
  OX:     ATOMIZATION LENGTH, In.=2.26767    ATOMIZATION LENGTH FOR VAPORIZATION, In.=2.26767    DROPLET RADIUS, Microns=  99.68
```

VAPORIZATION CALCULATIONS

X (In.)	CORE=LOL %FUEL VAP	CORE=LOL %OX VAP	BAFFLE= %FUEL VAP	BAFFLE= %OX VAP	BARRIER= %FUEL VAP	BARRIER= %OX VAP	FFC= %FUEL VAP	FFC= %OX VAP
0.0000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.2856	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.5712	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.8568	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.1424	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.4280	9.927	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.7136	16.746	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.9992	26.046	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2.2848	31.629	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2.5704	36.931	11.186	0.000	0.000	0.000	0.000	0.000	0.000
2.8560	41.922	30.800	0.000	0.000	0.000	0.000	0.000	0.000
3.1416	45.419	43.995	0.000	0.000	0.000	0.000	0.000	0.000
3.4272	48.917	53.237	0.000	0.000	0.000	0.000	0.000	0.000
3.7128	52.361	60.329	0.000	0.000	0.000	0.000	0.000	0.000
3.9984	54.984	65.660	0.000	0.000	0.000	0.000	0.000	0.000
4.2840	57.607	70.133	0.000	0.000	0.000	0.000	0.000	0.000
4.5696	60.177	73.882	0.000	0.000	0.000	0.000	0.000	0.000
4.8552	62.195	77.050	0.000	0.000	0.000	0.000	0.000	0.000
5.1408	64.212	79.661	0.000	0.000	0.000	0.000	0.000	0.000
5.4264	66.176	81.807	0.000	0.000	0.000	0.000	0.000	0.000
5.7120	67.728	83.664	0.000	0.000	0.000	0.000	0.000	0.000
5.9976	69.270	85.231	0.000	0.000	0.000	0.000	0.000	0.000
6.2832	70.769	86.798	0.000	0.000	0.000	0.000	0.000	0.000
6.5688	72.134	88.215	0.000	0.000	0.000	0.000	0.000	0.000
6.8544	73.479	89.275	0.000	0.000	0.000	0.000	0.000	0.000
7.1400	74.785	90.306	0.000	0.000	0.000	0.000	0.000	0.000
7.4256	75.895	91.135	0.000	0.000	0.000	0.000	0.000	0.000
7.7112	77.006	91.965	0.000	0.000	0.000	0.000	0.000	0.000
7.9968	78.063	92.589	0.000	0.000	0.000	0.000	0.000	0.000
8.2824	78.903	93.203	0.000	0.000	0.000	0.000	0.000	0.000
8.5680	79.744	93.816	0.000	0.000	0.000	0.000	0.000	0.000
8.8536	80.577	94.324	0.000	0.000	0.000	0.000	0.000	0.000
9.1392	81.385	94.785	0.000	0.000	0.000	0.000	0.000	0.000
9.4248	82.192	95.246	0.000	0.000	0.000	0.000	0.000	0.000
9.7104	82.941	95.666	0.000	0.000	0.000	0.000	0.000	0.000
9.9960	83.512	96.034	0.000	0.000	0.000	0.000	0.000	0.000
10.2816	84.084	96.377	0.000	0.000	0.000	0.000	0.000	0.000
10.5672	84.656	96.654	0.000	0.000	0.000	0.000	0.000	0.000
10.8528	85.228	96.931	0.000	0.000	0.000	0.000	0.000	0.000
11.1384	85.799	97.205	0.000	0.000	0.000	0.000	0.000	0.000
11.4240	86.371	97.389	0.000	0.000	0.000	0.000	0.000	0.000
11.7096	86.967	97.581	0.000	0.000	0.000	0.000	0.000	0.000
11.9952	87.607	97.788	0.000	0.000	0.000	0.000	0.000	0.000
12.2808	88.134	97.994	0.000	0.000	0.000	0.000	0.000	0.000
12.5664	88.567	98.200	0.000	0.000	0.000	0.000	0.000	0.000
12.8520	88.999	98.366	0.000	0.000	0.000	0.000	0.000	0.000
13.1376	89.432	98.507	0.000	0.000	0.000	0.000	0.000	0.000
13.4232	89.865	98.628	0.000	0.000	0.000	0.000	0.000	0.000
13.7088	90.278	98.748	0.000	0.000	0.000	0.000	0.000	0.000
13.9944	90.615	98.866	0.000	0.000	0.000	0.000	0.000	0.000
14.2800	90.953	98.969	0.000	0.000	0.000	0.000	0.000	0.000

OVERALL VAPORIZATION EFFICIENCIES

FUEL= 90.95% OX= 98.97%

MASS DISTRIBUTION PROFILE

X (IN)	CORE (lbm/s) FUEL	CORE (lbm/s) OX	BARRIER (lbm/s) FUEL	BARRIER (lbm/s) OX	LOCAL VAPOR MIXTURE RATIO	ETA-C*
0.0000	0.000	0.000	0.000	0.000	0.00	0.0000
0.2856	0.000	0.000	0.000	0.000	0.00	0.0000
0.5712	0.000	0.000	0.000	0.000	0.00	0.0000
0.8568	0.000	0.000	0.000	0.000	0.00	0.0000
1.1424	0.000	0.000	0.000	0.000	0.00	0.0000
1.4280	1.654	0.000	0.000	0.000	0.00	0.0063
1.7136	3.124	0.000	0.000	0.000	0.00	0.0118
1.9992	4.340	0.000	0.000	0.000	0.00	0.0164
2.2848	5.270	0.000	0.000	0.000	0.00	0.0200
2.5704	6.153	5.369	0.000	0.000	0.87	0.1302
2.8560	6.985	14.780	0.000	0.000	2.12	0.3367
3.1416	7.568	21.112	0.000	0.000	2.79	0.4423
3.4272	8.150	25.548	0.000	0.000	3.13	0.5124
3.7128	8.724	28.950	0.000	0.000	3.32	0.5678
3.9984	9.161	31.604	0.000	0.000	3.45	0.6105
4.2840	9.598	33.654	0.000	0.000	3.51	0.6460
4.5696	10.027	35.453	0.000	0.000	3.54	0.6782
4.8552	10.363	36.973	0.000	0.000	3.57	0.7048
5.1408	10.699	38.178	0.000	0.000	3.57	0.7277
5.4264	11.028	39.258	0.000	0.000	3.56	0.7489
5.7120	11.284	40.147	0.000	0.000	3.56	0.7662
5.9976	11.542	40.899	0.000	0.000	3.54	0.7818
6.2832	11.796	41.651	0.000	0.000	3.53	0.7972
6.5688	12.019	42.331	0.000	0.000	3.52	0.8111
6.8544	12.243	42.840	0.000	0.000	3.50	0.8229
7.1400	12.461	43.334	0.000	0.000	3.48	0.8344
7.4256	12.646	43.732	0.000	0.000	3.46	0.8438
7.7112	12.830	44.131	0.000	0.000	3.44	0.8535
7.9968	13.007	44.430	0.000	0.000	3.42	0.8615
8.2824	13.147	44.725	0.000	0.000	3.40	0.8686
8.5680	13.287	45.020	0.000	0.000	3.39	0.8757
8.8536	13.426	45.263	0.000	0.000	3.37	0.8822
9.1392	13.560	45.484	0.000	0.000	3.35	0.8883
9.4248	13.695	45.705	0.000	0.000	3.34	0.8944
9.7104	13.820	45.906	0.000	0.000	3.32	0.9000
9.9960	13.915	46.083	0.000	0.000	3.31	0.9045
10.2816	14.010	46.248	0.000	0.000	3.30	0.9089
10.5672	14.105	46.381	0.000	0.000	3.29	0.9129
10.8528	14.201	46.513	0.000	0.000	3.28	0.9169
11.1384	14.296	46.645	0.000	0.000	3.26	0.9209
11.4240	14.391	46.733	0.000	0.000	3.25	0.9244
11.7096	14.490	46.826	0.000	0.000	3.23	0.9280
11.9952	14.597	46.925	0.000	0.000	3.21	0.9319
12.2808	14.685	47.024	0.000	0.000	3.20	0.9353
12.5664	14.757	47.123	0.000	0.000	3.19	0.9383
12.8520	14.829	47.197	0.000	0.000	3.18	0.9410
13.1376	14.901	47.270	0.000	0.000	3.17	0.9437
13.4232	14.973	47.328	0.000	0.000	3.16	0.9461
13.7088	15.042	47.385	0.000	0.000	3.15	0.9485
13.9944	15.098	47.442	0.000	0.000	3.14	0.9506
14.2800	15.155	47.491	0.000	0.000	3.13	0.9526

AXIAL PRESSURE PROFILE

X (in)	MACH #	Ptotal (psia)	Pstatic (psia)	Ttotal (R)	Tstatic (R)	Wdot (Lbm/s)	Local Radius (in)
1.21	0.001	767.56	767.90	1636.15	1629.90	0.26	3.354
1.31	0.002	767.55	767.90	1636.23	1629.98	0.86	3.354
1.61	0.005	767.54	767.88	1636.06	1629.83	2.61	3.354
1.91	0.008	767.53	767.85	1636.11	1631.65	4.06	3.354
2.21	0.009	767.52	767.83	1636.08	1629.83	4.73	3.354
2.51	0.022	767.34	767.46	2167.25	2156.93	9.79	3.354
2.82	0.077	765.01	762.81	5744.05	5720.55	20.42	3.354
3.12	0.114	761.96	756.67	6575.67	6546.99	26.21	3.354
3.42	0.137	759.59	751.90	6573.60	6543.70	33.57	3.354
3.72	0.155	757.46	747.58	6559.48	6528.53	37.77	3.354
4.02	0.169	755.64	743.90	6544.49	6512.67	40.99	3.354
4.32	0.180	754.07	740.70	6535.91	6503.30	43.58	3.354
4.63	0.190	752.60	737.86	6531.48	6498.09	45.88	3.354
4.93	0.199	751.30	735.05	6527.25	6493.19	47.75	3.354
5.23	0.206	750.10	732.72	6526.10	6493.42	49.33	3.354
5.53	0.212	749.12	730.59	6526.94	6493.67	50.73	3.354
5.83	0.218	748.26	728.61	6529.92	6494.16	51.86	3.354
6.13	0.223	747.41	727.09	6532.30	6496.06	52.93	3.354
6.44	0.228	746.60	725.38	6533.67	6498.95	53.95	3.354
6.74	0.232	745.88	723.95	6536.32	6499.19	54.79	3.354
7.04	0.235	745.23	722.61	6539.92	6502.39	55.55	3.354
7.34	0.238	744.67	721.44	6543.00	6505.12	56.21	3.354
7.64	0.242	744.13	720.33	6545.83	6507.62	56.83	3.354
7.94	0.244	743.66	719.35	6549.45	6510.94	57.36	3.354
8.25	0.246	743.24	718.49	6551.68	6513.11	57.82	3.354
8.55	0.249	742.82	717.63	6553.43	6514.40	58.26	3.354
8.85	0.251	742.45	716.86	6555.20	6515.95	58.68	3.354
9.15	0.253	742.10	716.14	6557.01	6517.54	59.06	3.354
9.45	0.255	741.75	715.42	6558.79	6519.09	59.43	3.354
9.75	0.256	741.44	714.76	6560.36	6520.47	59.77	3.354
10.06	0.258	741.17	714.21	6561.39	6521.32	60.05	3.354
10.36	0.259	740.92	713.66	6562.59	6522.37	60.32	3.354
10.66	0.260	740.69	713.21	6563.97	6523.60	60.56	3.354
10.96	0.262	740.45	712.72	6565.28	6524.76	60.80	3.354
11.26	0.263	740.24	712.26	6566.73	6526.06	61.02	3.354
11.56	0.264	740.05	711.88	6568.40	6527.61	61.22	3.354
11.87	0.269	739.83	710.52	6570.15	6528.24	61.43	3.329
12.17	0.289	739.61	705.85	6571.74	6525.19	61.64	3.228
12.47	0.326	739.37	696.67	6572.55	6516.47	61.82	3.063
12.77	0.375	739.10	683.18	6573.07	6502.66	61.99	2.887
13.07	0.437	738.75	663.75	6573.63	6482.04	62.14	2.713
13.37	0.523	738.31	633.71	6574.22	6448.64	62.28	2.540
13.68	0.654	737.68	581.21	6574.80	6386.03	62.41	2.367
13.98	0.817	736.80	509.34	6575.23	6291.75	62.53	2.257
14.28	0.999	735.59	425.74	6575.67	6170.86	62.65	2.223

PERFORMANCE SUMMARY

C* EFFICIENCY CALCULATIONS (ODK)

```
INJECTED MR= 2.8800     CSTAR=5860.40     CORE Em=0.8930     BARRIER Em=1.0000
CORE:          OVERALL MR= 2.8800     VAPOR MR= 3.1338     CSTAR-MIX=5761.07     MASS FRACTION= 1.0000
BARRIER:       OVERALL MR= 0.0000     VAPOR MR=99.0000     CSTAR-MIX=    0.00     MASS FRACTION= 0.0000
ENGINE:        OVERALL MR= 2.8800     VAPOR MR= 3.1338     CSTAR-DEL=5582.64
C* EFFICIENCY = 9.526E-01
```

ISP EFFICIENCY CALCULATIONS

```
ISP-ODK, INJ = 2.669E+02 SEC.
ISP-ODK, M.Z. INJ = 2.652E+02 SEC.        ISP-ODK, M.Z. VAPOR = 2.624E+02 SEC.
VAPORIZATION EFFICIENCY = 9.597E-01       MIXING EFFICIENCY = 9.935E-01
ENERGY RELEASE EFFICIENCY = 9.529E-01

NOTE: ISP-DEL = ISP-ODK, INJ. * ERE * ETADIV - DELISP-BL
```

TIME-LAG CALCULATIONS, Milliseconds

Coham, In.=1.791E-02   FUEL Cohem, In.=2.293E+02   OX Cohem, In.=6.194E+01

```
ELEMENT 1 IS TYPE=LOL
FUEL:    Cinj, In.=6.695E-03    Lvap, In.= 0.615    ATOMIZATION LENGTH USED, In.= 1.024E+00
         Timp=1.070E-01    Tatom=7.704E-01    Tvap=4.625E-01    Total=1.340E+00

  OX:    Cinj, In.=6.676E-03    Lvap, In.= 0.224    ATOMIZATION LENGTH USED, In.= 2.268E+00
         Timp=1.909E-01    Tatom=1.984E+00    Tvap=1.963E-01    Total=2.371E+00
```

EFFECTIVE TIMELAGS, Milliseconds

```
FUEL:    Cinj, In.=6.695E-03    Lvap, In.= 0.615
         Timp=1.070E-01    Tatom=7.704E-01    Tvap=4.625E-01    Total=1.340E+00

  OX:    Cinj, In.=6.676E-03    Lvap, In.= 0.224
         Timp=1.909E-01    Tatom=1.984E+00    Tvap=1.963E-01    Total=2.371E+00
```


C-4

APPENDIX J

COMPONENT MODEL DOCUMENTATION

PART A

HIGH FREQUECY ACOUSTIC CHAMBER RESPONSE MODEL (HIFI)

Aerojet TechSystems Company

ENGINEERING AND DEVELOPMENT

THERMODYNAMIC ANALYSIS REPORT

NUMBER: 9980:1807
DATE: 6 Feb.1987

SUBJECT:

COMPUTER CODE FOR USE IN HIGH FREQUENCY COMBUSTION STABILITY ANALYSES

PAGE 1 OF

NO. OF ENCLOSURES

NO. OF APPENDICES

ADDITIONAL INFORMATION AND WORK NOTES INCLUDED IN MICROFILM FILE CDN

PREPARED FOR: J. L. Pieper

A computer code, HIFI has been developed for use in high frequency combustion stability analyses of rectangular or cylindrical cross-sectional chambers.

The code is capable of calculating the burning admittance and the n-τ neutral stability curve. It is operational on the VAX computer system at ATC.

The attachment describes the theory, the computer code and the calculated results.

KEYWORDS: Misc (21), Chamber (52), Nozzle (53), Combustion Stability (105), LOX/HC (153), Model Development (209), Computer Program - New Develop. (210), 1986 (271), T. V. Nguyen (357)

DISTRIBUTION:

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S. Mercer, J. Muss, K. Niiya,
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W.O. NO: KAE626 J-3

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COMPUTER CODE FOR USE

IN

HIGH FREQUENCY COMBUSTION STABILITY ANALYSES

by

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Figure 4.15: Effects of acoustic cavities on burning admittance phase angle in a 1W mode.

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I. INTRODUCTION

Aerojet TechSystems Company is currently conducting a program (contract F04611-85-C-0100) to formulate a procedure (Ref. 1) which can accurately characterize injector designs for large thrust (0.5 to 2.0 million pounds) high pressure (500 to 3000 psia) LOX/hydrocarbon engines. In this procedure, rectangular cross-sectional (hereafter will be refered to simply as rectangular) combustion chambers are to be used to simulate the lower tranverse frequency modes of the large scale chamber. This requires the development of stability models for rectangular chambers.

As part of the development of models for use in combustion stability analyses of rectangular chambers, a computer code, HIgh Frequency Intrinsic Stability Analysis (HIFI) has been developed to calculate the burning admittances and the n-τ neutral stability curves. The code can be applied not only to rectangular chambers but also to cylindrical chambers.

1.1 High Frequency Intrinsic Combustion Stability

Combustion instability, characterized by organized pressure oscillations in rocket combustion chamber, can cause severe vibrations on various engine system components and payloads. In addition, combustion instabilities may cause excessive mechanical stresses and heat loads on the injector and combustion chamber walls.

Combustion instabilities have been generally classified according to their frequency range: low, intermediate and high frequency. Significant efforts have been devoted to the understanding of high frequency instability because it is the most common in new engine developments and is the most destructive. High frequency instability results from the coupling between the combustion process and the acoustic waves in the chamber.

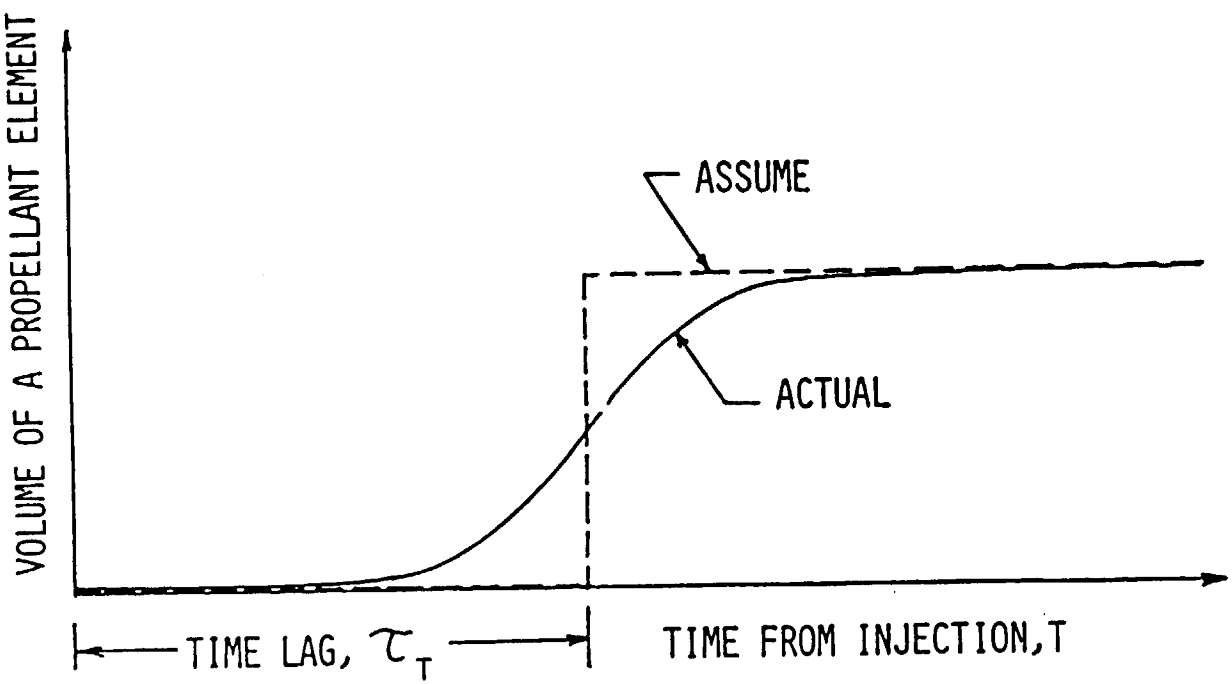
1.2 Concentrated Combustion and Sensitive Time-Lag Approach

Analytical models capable of characterizing combustion instability are obviously useful and valuable to engine designers during the development stage. Basic approaches in the modelling of high frequency combustion stability are described in reference 3. The concentrated combustion and sensitive time-lag approach developed by Crocco (Ref. 4) is dicussed here since it is adopted in the present study. In this approach, the burning of propellant elements is assumed to occur ~~s~~ instantaneously as shown in Figure 1.1. The time period between the instant of the injection and the burning of the propellant element is called the total time lag, τ_T. All physical factors, e.g. pressure, temperature, that affect the burning process are assumed to correlate with the value of the local pressure. Consequently, the effects of these physical factors can be implicitly taken into accounts by relating the burning rate, $\dot{m}_b$ to the instantaneous local pressure, p. The relation between $\dot{m}_b$ and p is in the form:

$$\dot{m}_b \sim p^n$$

where n is called the (pressure) interaction index. The value

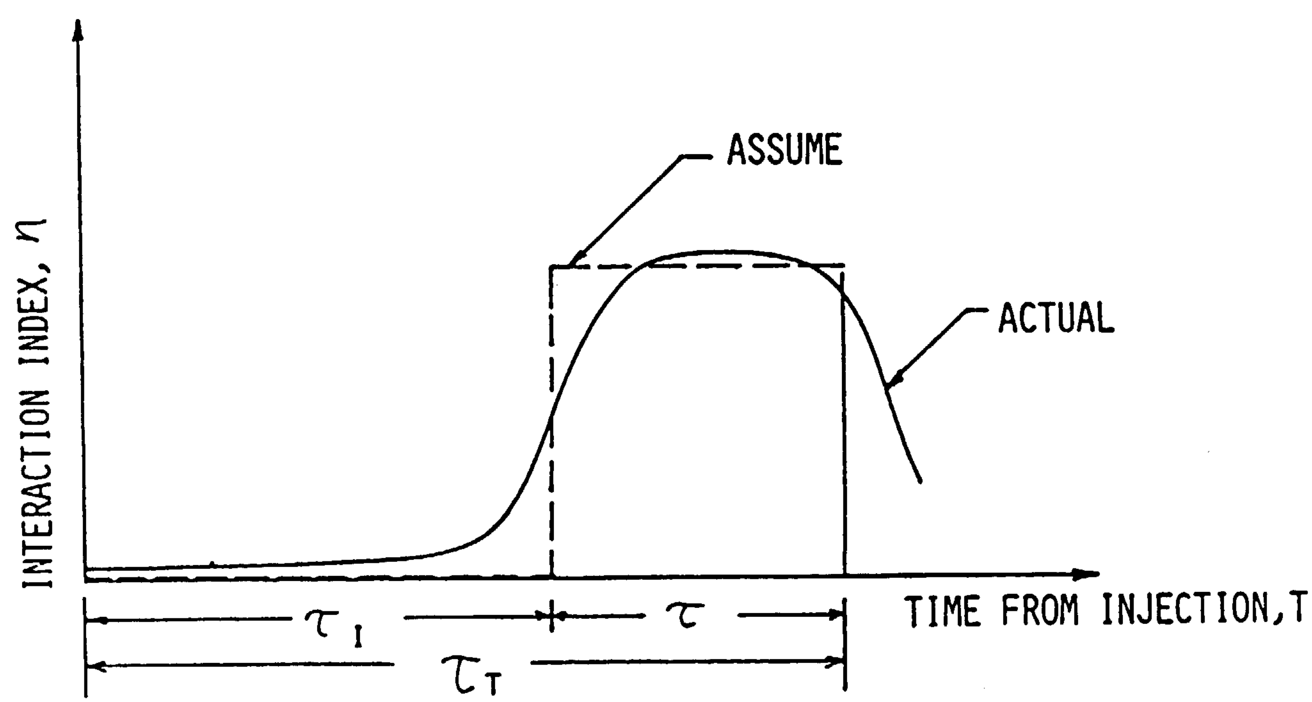
FIGURE 1.1 : DIAGRAM SHOWING COMBUSTION TIME LAG CONCEPT



of the interaction index is assumed to be zero during a time period called "insensitive" time lag, τ_I and discontinuously becomes n during a time period called "sensitive" time lag, τ. The sum of the insensitive time lag and the sensitive time lag equals to the total combustion time lag. Figure 1.2 is a schematic showing the relation between the interaction index, the insensitive time lag, the sensitive time lag and the total time lag. This sensitive time lag approach was first applied by Crocco (Ref. 4) in one-dimensional combustion stability analyses with both concentrated combustion and distributed combustion. As the names imply, the concentrated combustion approach assumes that the combustion concentrates in a plane at some distance from the injector face whereas in the distributed combustion approach the combustion distributes arbitrarily along the combustion chamber axis. In the concentrated-combustion approach, the combustion plane divides the chamber into two regions: the first region upstream of the combustion plane where the mean velocity is assumed to be zero and the second region downstream of the combustion plane where the velocity is non-zero and is assumed to be constant. This greatly simplifies the analysis since the equations which describe the flow dynamics in the two regions have no source terms. It is obvious that the concentrated combustion approach is not as realistic as the distributed combustion approach but it greatly simplifies the mathematical treatment of the analysis.

Crocco's original study was subsequently continued and

FIGURE 1.2 : SCHEMATIC SHOWING THE RELATION BETWEEN THE PRESSURE INTERACTION INDEX η, THE INSENSITIVE TIME LAG τ_I, THE SENSITIVE TIME LAG τ AND THE TOTAL TIME LAG τ_T



improved by several authors. Reference 3 describes subsequent studies following Crocco's original study. The reference also gives a brief history of the development of the sensitive time lag theory. The study of Crocco was first extended to tranverse modes by Scala (Ref. 5). Reardon then introduced the velocity interaction index to include the sensitivity of the burning rate to the tranverse components of the oscillating gas velocity (Ref. 6). This study also accounts for the effects of the non-uniform distribution of the propellant injection. The assumption of low Mach number in the chamber, which are used in all aforementioned models, was eliminated in the studies of longitudinal modes by Mitchell (Ref. 7) and by Harrje (Ref. 8.) and of tranverse modes by Smith (Ref. 2).

The concentrated-combustion and sensitive time-lag theory has been used extensively at Aerojet. Its evolution at Aerojet resulted into a computer code known as IFAR (Ref. 9). This computer code has been used in combustion stability analyses of virtually all liquid-propellant rocket engines developed in recent years at Aerojet. In general, the prediction capability of the code is satisfactory.

1.3 Objectives of the Present Study

The objective of the present work is to provide a computer code to predict the burning admittances and the n and τ neutral stability curves for rectangular chambers. Although the objective is to provide a computer code for use in combustion stability analyses of rectangular chambers, the code developed in the present study can also be used for cylindrical chambers. The code has many new features which are not available in IFAR. These features are:

* Values of nozzle admittances can be input in tabular forms as in IFAR or calculated internally by the program. If the nozzle admittances are calculated, the program will automatically generate~~s~~ a table that is ~~are~~ to be used for any subsequent runs in which the values of the nozzle admittances do not change. The nozzle admittance values are calculated at the frequencies at which the burning admittance, its corresponding n and τ are calculated, therefore no interpolation errors are introduced into the solutions.

* The user is not required to determine the Mach number apriori since it is calculated internally by the program given the specific heat ratio and the contraction ratio.

* Variables used in the theory and in the computer code are retained in the forms of complex variables. For users who wish to understand the theory or to make modifications to the code, this feature makes the theory described in the next section and the logic used in the code easy for them to follow.

* The code generates output files in the format which can be input to a computer graphic program, for example TELLEGRAF, to plot the calculated results.

* The Mach number in the chamber is no longer assumed to be small.

1.4 Approach

The present study follows the approach taken in the development of IFAR (Ref. 9). The difference between the present study and IFAR is in the calculation of chamber admittances. IFAR calculates the admittances by solving the pressure wave equation which has been derived on the assumption of low Mach number in the chamber. This assumption is also used to implement the boundary condition to the solutions of the equation and in the calculation of the burning admittance. The present study calculates chamber admittances by solving the wave equation for a velocity potential function (see Refs. 10 and 11). This has the advantage that the Mach number in the chamber is no longer assumed to be small, thus the code can be used for chambers having small contraction ratios.

II. THEORY

The theory in the present study follows closely reference 9 to calculate the cavity admittance, the burning admittance and the n-τ neutral stability curve. The nozzle-admittance model of reference 11 is extended to calculate the chamber admittances.

2.1 Theory Description

First, the continuity and momentum equations are written for an ideal gas. The thermodynamic variables, i.e. pressure density, etc., are decomposed into their mean and fluctuating components. These components are then normalized by the corresponding steady-state values. The mean components do not vary with time and are assumed to be uniform in the regions upstream and downstream of the combustion plane although they may be discontinuous at the combustion plane. The fluctuating components, however, vary in all directions and are functions of time. The velocity is also decomposed into a mean and a fluctuating component. The mean velocity is assumed to be only in the axial direction while the fluctuating component can vary in all directions. The fluctuating components of the velocity and the thermodynamic variables are assumed to be so small that the products of any two components can be neglected. As a result, equations for the fluctuating components are linear in time, thus their oscillations can be assumed to be sinusoidal. The flow is assumed to be irrotational and the fluctuating velocity components are defined to be the gradients of a velocity potential function. The continuity and momentum equations and an isentropic relation are combined to yield a governing equation for the velocity potential function. The resulting equation is then written in the cartesian coordinate system for rectangular chambers and in the cylindrical coordinate system for cylindrical chambers.

Using the separation of variables technique, the partial differential equation governing the evolution of the potential function is separated into three second-degree ordinary differential equations. Using boundary conditions at the chamber walls two of the equations in the tranverse and lateral directions are solved explicitly to give the eigenvalues that correspond to tranverse and lateral resonance modes for rectangular chambers. Similarly for cylindrical chambers, boundary conditions at the chamber wall and at the axis of symmetry are used to calculate the eigenvalues that correspond to radial resonance modes. The eigenvalues that correspond to tangential resonance modes in cylindrical chambers are determined by requiring the solutions to the differential equation being single value functions. A general solution is obtained by solving the differential equation in the axial direction. The boundary condition at the injector face is then applied to calculate the chamber admittance upstream of the combustion plane. Using the nozzle admittance as the boundary equation, the chamber admittance downstream of the combustion plane is calculated. the Continuity condition is then applied at the combustion plane to relate the burning admittance to the upstream and downstream chamber admittances. Finally, the pressure interaction index , n and the sensitive time lag, τ for neutral stability condition is calculated using the expression derived by Crocco in reference 3 which relates n and τ to the burning admittance.

2.2 Equation Derivations and Solutions

The continuity and momentum equations for an inviscid compressible gas are:

$$\frac{\partial \rho^*}{\partial t^*} + \nabla^*(\rho^* \vec{u}^*) = 0 \;, \tag{1}$$

and

$$\rho^*\left(\frac{\partial \vec{u}^*}{\partial t^*} + \vec{u}^* \nabla^* \vec{u}^*\right) + \nabla^* p^* = 0 \;, \tag{2}$$

where t is the time, ρ is the gas density, u is the gas velocity and p is the gas pressure, the notation $\rightarrow$ denotes vector quantities, and the supercript $*$ denotes demensional quantities. An Additional equation needed to close the above conservation equations is the following isentropic relation:

$$\frac{dp^*}{p^*} = \gamma \frac{d\rho^*}{\rho^*} \tag{3}$$

where γ is the gas specific heat ratio. Equations (1), (2) and (3) can be written in non-dimensional form as:

$$\frac{\partial \rho}{\partial t} + \nabla(\rho \vec{u}) = 0 \;, \tag{4}$$

$$\rho\left(\frac{\partial \vec{u}}{\partial t} + \vec{u}\nabla\vec{u}\right) + \frac{1}{\gamma}\nabla p = 0 \;, \tag{5}$$

and $$dp = \gamma \, d\rho \tag{6}$$

In equations (4), (5), and (6) the density and the pressure are non-dimensionalized by their corresponding mean values; the velocity by the sound speed; length scales by some characteristic length, e.g. chamber radius or chamber half-width; and time by the sound speed and the chracteristic length.

All non-dimensionalized dependent variables are then decomposed into the mean components which are time indepedent, and the perturbation components which are time depedent, i.e:

$$\vec{u} = \bar{\vec{u}} + \vec{u}', \qquad p = 1 + p', \qquad \rho = 1 + \rho', \tag{7}$$

where the bar and the superscript ' denote the mean and the perturbation components, respectively. It should be noted that the mean velocity $\bar{\vec{u}}$ shown in the above equation has been non-dimensionalized by the sound speed and thus it is the same as the Mach number.

Assume there exists a velocity potential function, ϕ, such that:

$$u' = \nabla \phi \tag{8}$$

and that the flow is irrotational, equations (4), (5) and (6) can be combined to yield the following relation:

$$\rho' = -\gamma\left(\frac{\partial\phi}{\partial t} + (\bar{\vec{u}}.\nabla)\phi\right), \tag{9}$$

and the following equation governing the evolution of the velocity potential function:

$$\frac{\partial^2\phi}{\partial t^2} - \nabla^2\phi + \bar{\vec{u}}\left[\nabla(\bar{\vec{u}}.\nabla\phi)\right] + 2\bar{\vec{u}}\,\frac{\partial\nabla\phi}{\partial t} = 0\ . \tag{10}$$

Assume that:

$$\phi = \phi e^{st} \tag{11}$$

where s is a complex quantity with its imaginary part representing the angular frequency of the oscillation and its real part representing the amplification coefficient of the oscillation. Equation (10) can then be written as:

$$s^2\phi_0 - \nabla^2\phi_0 + \bar{\vec{u}}\left[\nabla(\bar{\vec{u}}.\nabla\phi)\right] + 2\bar{\vec{u}}s\nabla\phi_0 = 0\ . \tag{12}$$

Assume the mean flow velocity exists only in the axial direction and its magnitude, $\bar{u}$ is constant. Equation (12) can be written in the cylindrical coordinate system for cylindrical chambers and in the cartesian coordinate system for rectangular chambers. In each case, the separation of variables technique is used to separate the equation into three ordinary differential equations, of which the equation in the axial direction has the following form:

$$(1-\bar{u}^2)\,\phi_x^{(\prime\prime)} - 2\bar{u}s\,\phi_x^{(\prime)} - (s^2 + s_{mn}^2)\,\phi_x = 0, \tag{13}$$

where the superscripts $(')$ and $('')$ denote the first derivative and the second derivative of ϕ_x with respect to x, the axial coordinate. ϕ_x is the component of ϕ that is depedent only on x. For rectangular chamber cases, the value of S_{mn} is:

$$S_{mn} = \frac{\pi}{2}\sqrt{m^2 + \frac{n^2}{b}} \tag{14}$$

where b is the ratio of the chamber thickness to the chamber width. The values of S_{mn} for cylindrical chamber cases are given in table 2.1 for selected values of m and n. The subscripts m and n correspond to the m^{th} tangential (tranverse or width) and the n^{th} radial (lateral or thickness) resonance modes. In rectangular chamber cases, the values of S_{mn} are determined by applying appropriate boundary conditions at the chamber walls to the solutions of the differential equations in the tranverse and the lateral directions. In cylindrical chamber cases, the values of S_{mn} are determined by requiring the solution to the differential equation in the circumferential direction being a single value function and by applying appropriate boundary conditions at the chamber wall and at the axis of symmetry to the solution of the differential equation in the radial direction.

The axial equation (Equation 12) is applicable to both regions upstream and downstream of the combustion plane in a cylindrical or a rectangular chamber. Applying the boundary condition at the injector face to the solution of the equation yields the following expression for the upstream chamber admittance:

m \ n	0	1	2	3	4
0	0.0000	3.8318	7.0155	10.1734	13.3238
1	1.8413	5.3313	8.5263	11.7059	14.8635
2	3.0543	6.7060	9.9695	13.1705	16.3476
3	4.2013	8.0151	11.3459	14.5858	17.7890
4	5.3175	9.2825	12.6820	15.9640	19.1961
5	6.4154	10.5199	13.9873	17.3127	20.5755
6	7.5012	11.7348	15.2681	18.6375	21.9318
7	8.5778	12.9324	16.5295	19.9419	23.2682
8	9.6475	14.1155	17.7739	21.2290	24.5874

Table 2.1: Selected values of S_{mn}.

$$Y_I = \frac{u_x'}{p'}\bigg|_I = \frac{\left(\frac{\alpha}{\gamma s}\right)\left(e^{\alpha x_p} - e^{-\alpha x_p}\right) - \Psi_p\left(\frac{\alpha}{\gamma s}\right)\left(e^{\alpha x_p} + e^{-\alpha x_p}\right)}{\Psi_p\left(e^{\alpha x_p} - e^{-\alpha x_p}\right) - \left(\frac{\alpha}{\gamma s}\right)\left(e^{\alpha x_p} + e^{-\alpha x_p}\right)}, \quad (15)$$

where the subscript I denotes the quantities evaluated at the location immediately upstream of the combustion plane, u_x' is the axial component of the local (non-dimensionalized) perturbation velocity, and x_p is the distance between the injector face and the combustion plane. Other quantities in the equation are defined as follows:

$$\alpha = \sqrt{s^2 + S_{mn}^2} \quad , \quad (16)$$

and Ψ_p is a quantity that is determined from the boundary conditions at the injector face. This quantity is described below.

For cylindrical chamber cases, suppose that the admittance, which is defined as the ratio of the local axial (non-dimensionalized) perturbation velocity to the local (non-dimensionalized) pressure perturbation, at the injector face can be expressed as:

$$Y\Big|_{x=0} = Y_r(r)\,Y_\theta(\theta) \quad , \quad (17)$$

where r and θ are the radial and tangential coordinates, respectively. Then for a spinning m^{th} tangential mode, the expression for Ψ_p can be written as:

$$\Psi_p = \frac{\left(\int_0^1 Y_r(r)\,J_m^2(s_{mn}r)\,r\,dr\right)\left(\int_0^{2\pi} Y_\theta(\theta)\,d\theta\right)}{2\pi\int_0^1 J_m^2(s_{mn}r)\,r\,dr} \quad (18)$$

and for a standing m^{th} tangential mode, it can be written as:

$$\Psi_p = \frac{\left(\int_0^1 Y_r(r) J_m^2(s_{mn} r)\, r\, dr\right)\left(\int_0^{2\pi} Y_\theta(\theta) \cos^2(m\theta)\, d\theta\right)}{\pi \int_0^1 J_m^2(s_{mn} r)\, r\, dr} . \tag{19}$$

In the above expressions for Ψ_p, J_m is the m^{th} order Bessel function of the first kind.

For rectangular chamber cases, the expression for Ψ_p is written as:

$$\Psi_p = \int_{-1}^{1} Y_y(y) \cos^2\left(\frac{m\pi}{2}[y+1]\right) dy \tag{20}$$

In equation (20), it has been assumed that the admittance at the injector face varies only in the y (width) direction and that oscillations in the z (thickness) direction do not exist. In the cases where oscillations in the z direction do exist, the value of Ψ_p will be different from that given by the above expression. In general cases, the difference and its effects on the overall solutions are believed to be small, thus the model is considered not to be limited to two-dimensional oscillations.

It should be noted that the admittances of acoustic cavities are included in $Y_r(r)$, $Y_\theta(\theta)$ and $Y_y(y)$ in equations (18), (19) and (20). In the present study, the width of the cavities is assumed to be small compared to the radius or the width of the chamber. Furthermore, the cavities are assumed to locate at the circumference of the injector of the cylindrical chamber or they are assumed to locate at the edge of the width of the rectangular chamber. These assumptions simplify the analysis since they allow the above expressions for ψ_p being approximated analytically.

Applying the boundary condition at the nozzle entrance (nozzle admittance) to the solution of equation (13) yields the following expression for the downstream chamber admittance:

$$Y_{II} = \left.\frac{u'_x}{p'}\right|_{II} = \frac{\alpha_1 e^{-\alpha_1 x_q} + \kappa_2 A e^{-\kappa_2 x_q}}{-\gamma\left(s e^{-\kappa_1 x_q} + sAe^{-\kappa_2 x_q} + \bar{u}\kappa_1 e^{-\kappa_1 x_q} + \bar{u}\kappa_2 A e^{-\kappa_2 x_q}\right)}, \quad (21)$$

where the subscript II denotes the quantities evaluated at the location immediately downstream of the combustion plane, and

$$\alpha_1 = \frac{1}{1-\bar{u}^2}\left(\bar{u}s - \sqrt{s^2 + s_{mn}^2(1-\bar{u}^2)}\right), \quad (22)$$

$$\alpha_2 = \frac{1}{1-\bar{u}^2}\left(\bar{u}s - \sqrt{s^2 + s_{mn}^2(1-\bar{u}^2)}\right), \quad (23)$$

$$A = -\frac{\gamma s \psi_q + \gamma \bar{u} \kappa_1 \psi_q + \alpha_1}{\gamma s \psi_q + \gamma \bar{u} \kappa_2 \psi_q + \alpha_2}, \quad (24)$$

ψ_q is the nozzle admittance and x_q is the distance from the combustion plane to the nozzle entrance.

Continuity is then applied at the combustion plane to give the following expression for the burning admittance:

$$y = \frac{m_b'}{p'} = \frac{1}{\bar{u}}\left(Y_{II} - \frac{\bar{\rho}_I a_I}{\bar{\rho}_{II} a_{II}} Y_I\right) + \frac{1}{\gamma}, \quad (25)$$

where m_b' is the burning rate perturbation normalized by its mean value. In this expression, the non-dimensionalized pressure perturbations upstream and downstream of the combustion plane are assumed to be equal.

The concentrated-combustion analyses tend to give results that indicate the combustion is less stable than the more realistic distributed-combustion approach (private communication with J. Fang). In an attempt to compensate for this problem, a constant 1.0 is added to the right-hand side of equation (25) in reference 9; predictions using this practice appear to correlate better with test data (private communication with J. Fang). For these reasons, the present study follows the practice.

Finally, n and τ can be related to the real part, $\mathcal{Y}_R$ and the imaginary part, $\mathcal{Y}_I$ of the burning admittance:

$$n = \frac{\mathcal{Y}_R^2 + \mathcal{Y}_I^2}{2\mathcal{Y}_R} \tag{26}$$

$$\tau = \frac{1}{\omega} \arctan\left(\frac{2\mathcal{Y}_I}{\mathcal{Y}_I^2/\mathcal{Y}_R - \mathcal{Y}_R}\right) \tag{27}$$

where ω is the imaginary part of s which is the angular frequency of the oscillation.

III. PROGRAM DESCRIPTION

The High Frequency Instability Analysis computer program HIFI consists of a main program and eight subroutines which are described in the next section. Program input and output are described in Sections 2 and 3. A listing of the computer code is provided in appendix A. Input and output for a sample case are provided in appendix B.

3.1 Program Description

All input to the code are made in the main program. The input include chamber and nozzle geometry, location of the combustion plane, chamber gas properties, cavity geometry, cavity gas properties, chamber acoustic resonance mode, and frequency range of interests. For each frequency in the specified range, the main program calculates chamber admittance upstream of the combustion plane after calling subroutines TED and CAP2 to calculate cavity admittances. Next, it calls subroutine NOZADM to calculate nozzle admittance or it obtains the nozzle admittance value from a table generated by a previous run. If the nozzle admittance is calculated, its value is written to a file NOADTA.DAT for future runs in which the nozzle geometry and resonance modes are the same as the run that generates the nozzle admittance file. After the nozzle admittance value is determined, the main program calculates chamber admittance downstream of the combustion plane. Finally, it calculates and output the burning admittance and the corresponding values of n and . In addition, it outputs the value of the chamber admittances upstream and downstream of the combustion plane.

- Subroutine CALADM: called by subroutine NOZADM to calculate nozzle admittance.

- Subroutine CAP2: calculates cavity admittances. This subroutine is taken from the computer code IFAR (Ref. 9).

- Subroutine INTGRT: called by subroutine NOZADM to perform numerical integration. See reference 11 for more description of this subroutine.

- Subroutine MACH: calculates Mach number as function of area ratio and specific heat ratio using sucessive iteration techniques.

- Subroutine NOZADM: "main" program of the computer code for calculating nozzle admittance. See reference 11 for more description of this subroutine.

- Subroutine NOZINI: calculates values of variables that are independent of the frequency and are frequently used by subroutine NOZADM. This reduces computer time by avoiding repititive calculations of these variables every time NOZADM is called.

- Subroutine NOZTAB: obtains the value of nozzle admittance from a previously generated table.

- Subroutine TED: calculates the effect of cavity distribution with respect to mode orientation. This subroutine is taken from the computer code IFAR (Ref. 9)

3.2 Input Description

Input to the computer code is divided into four groups: the first group is the problem description; the second group is the namelist CNTRL which specifies chamber type (rectangular or cylindrical) and file generation options; the third group is the namelist INPUT which specifies the chamber and nozzle geometry, the chamber gas properties, the chamber acoustic resonance mode and the frequency range of interests; and the fourth group is the data specifying cavity geometries and cavity gas properties. A sample input file is provided in Appendix B.1.

The problem description can be specified using any number of lines but at least one line must be used although it can be a blank line. Following the problem description is the namelist CNTRL and subsequently the namelist INPUT. Variables in the namelists CNTRL and INPUT are described in tables 3.1 and 3.2, respectively. The last group of input data pertaining to cavity geometries and cavity gas properties immediately follows the namelist INPUT. This last group of data is described line-by-line here:

CARD 1: Variables NCAV1, NCAV2, NSEC1, NSEC2, NTESTM
Format (5I10)

Variable name	Unit	Description
NCAV1	----	Number of group 1 cavities
NCAV2	----	Number of group 2 cavities

Name	Type	Unit	Description and Remarks
AXISYM	L		=TRUE for cylindrical chambers =FALSE for rectangular chambers
PLOT	L		=TRUE if plot files are to be generated =FALSE if plot files are NOT to be generated
TABLE	L		=TRUE if nozzle admittance is obtained from a file that has been generated by a previous run. =FALSE if nozzle admittance is to be calculated internally.

Table 3.1: Descriptions of namelist CNTRL variables

Name	Type	Unit	Description and Remarks (*)
GAMMA	R	None	Specific heat ratio
HST	R	ft	Throat radius (throat half-height)
RC	R	ft	Radius of curvature at the throat
XSSL	R	ft	Chamber straight-section length
XB	R	ft	Distance from injector face to combustion plane
RCHAMB	R	ft	Chamber radius (chamber half-height)
RWI	R	ft	Not used for axisymmetric case. (Chamber half-thickness)
RE	R	ft	Radius of curvature at nozzle entrance
ALPHA	R	deg.	Nozzle convergence half-angle
AO	R	ft/s	Speed of sound at stagnation condition
PCHAMB	R	psf	Chamber pressure
WS	R	Hertz	Initial frequency
DW	R	Hertz	Frequency increment
NW	I	None	Number of frequency values
M	I	None	Tangential (tranverse or width) mode number
N	I	None	Radial (lateral or thickness) mode number

Table 3.2: Description of namelist INPUT variables

(*) Descriptions enclosed in parenthese are for rectangular chamber cases.

NSEC1	----	Number of sections of group 1 cavities
NSEC2	----	Number of sections of group 2 cavities
NTESTM	----	Maximum number of iterations when calculating cavity admittance.

```
|-----------------------------------------------|
| *** The following input are not required *** |
|   *** if NCAV1=0 and NCAV2=0 in card 1 ***    |
|-----------------------------------------------|
```

CARD 2: Variables WD, AC, LC, LOGIC1, LOGIC2, LOGIC3, LOGIC4
Format (3E10.3, 4I10)

Variable name	Unit	Description
WD	ft.	Width of cavity section
AC	ft**2	Cross-sectional area of cavity section
LC	ft.	Length of cavity section
LOGIC1	----	Cavity inlet chracteristic =0, square edged inlet =1, rounded inlet =2, well-rounded inlet
LOGIC2	----	Switch to specify whether or not to consider sound absorption coefficient. =0, not considered =1, considered
LOGIC3	----	Switch to specify data to be used =0, use cavity inlet data =1, use data inside cavity
LOGIC4	----	Switch to specify cavity type =0, circular cross-sectional cavity =1, rectangular cross-sectional cavity

CARD 3: Variables RHOC, CC, GAMMAC, PO, PRTL, VIS
Format (6E10.3)

Variable name	Unit	Description
RHOC	lb/ft3	Cavity gas density

CC	ft/s	Sound speed in cavity
GAMMAC	----	Specific heat ratio of cavity gas
PO	----	Cavity inlet pressure amplitude normalized by mean chamber pressure
PRTL	----	Prandtl number of cavity gas
VIS	lbf-s/ft2	Viscosity of cavity gas

Cards 2 and 3 are repeated for NSEC1 sections of group 1 cavities, then they are repeated for NSEC2 sections of group 2 cavities. If NCAV1=0 in Card 1, then Cards 2 and 3 begin with the first section of group 2 cavities. Likewise, if NCAV2=0 Cards 2 and 3 end with last section of group 1 cavities.

For each group of cavity, the input for the sections must be in sequential order beginning with the section at the end of the cavity and ending with the section at the cavity entrance.

It should be noted here that for rectangular chamber cases, the cavities are assumed to be located at the edge of the chamber width. Although the effects of the cavities themselves are considered, the effects of the cavity distribution with respect to the lateral (thickness) modes are not considered. Minor modifications can be made to the code to account for the cavity distribution effects.

```
|-------------------------------------------|
| *** The following input are not required *** |
|     *** if AXISYM=F in namelist CNTRL ***    |
|-------------------------------------------|
```

CARD 4: Variables MO
Format (I10)

Variable name	Unit	Descriptions
MO	----	Mode orientation number =1, mode orientation in which group 2 cavities are more effective than they are in other mode orientations =2, mode orientation in which group 1 cavities are more effective than they are in other mode orientations

CARD 5: Variables (IDCAV(I),I=1,NCAV1+NCAV2)
Format (20I4)

Variable name	Unit	Descriptions
IDCAV	----	Cavity group number distribution. For example, there are 6 group-1 cavities and 3 group-2 cavities and the distribution such that there is one group-2 cavity followed by two group-1 cavities. Card 5 should be input as follow: 2 1 1 2 1 1 2 1 1

3.3 Ouput Description

Output from the code begin with the echo of input data which includes a problem description, variables in namelists CNTRL and INPUT, and cavity input data. Although the problem description can be input using any number of lines, only the first line is output. Following the echo of the input data is the chamber Mach number. The last section of the output is the calculated stability results which include the amplitude and phase of the burning admittance, n and τ, the real parts and the imaginary parts of the chamber admittances upstream and downstream of the combustion plane, the real part and the imaginary part of the burning admittance. These results are calculated and output for each frequency in the range specified in namelist INPUT. A sample output file is provided in Appendix B.2.

In addition to the output described above, a file NOADTA.DAT is also output by the code if the variable TABLE in the namelist CNTRL is equal to FALSE. This file contains a table of the calculated nozzle admittance vs. frequency. For future runs with the same nozzle geometry and resonance modes, the code obtaines the values of nozzle admittances from the table instead of re-calculating them. This option saves computer time and can be selected by setting the variable TABLE in the namelist CNTRL to TRUE.

If the variable PLOT in the namelist CNTRL is equal to TRUE, three additional files are generated by the code. These files can be input to any x-y plotting package, for example TELLEGRAF, to plot the calculated results. The first file, AMPLD.PLT contains the amplitude of the burning admittance vs. frequency. The second file, PHASE.PLT contains the phase angle of the burning admittance vs. frequency. The third file, NTAU.PLT contains the pressure interaction index, n vs. the sensitive time lag, τ.

IV. RESULTS AND DISCUSSION.

Calculations of the burning admittances and n-τ neutral stability curves for a cylindrical chamber and a rectangular chamber were made using the computer code HIFI. Input parameters for the two cases are shown in figures 4.1 and 4.2, respectively. Results are compared with the IFAR predictions.

A typical run for 100 frequency values, in which the nozzle admittance are calculated internally, requires approximately 40 CPU seconds on the micro-VAX at Aerojet TechSystems. A similar run, in which nozzle admittance is provided as a table, requires approximately 4 CPU seconds.

Figures 4.3 shows the n-τ neutral stability curves. Figures 4.4 and 4.5 show the burning-admittance amplitudes and the burning admittance phase angles versus frequency. Figure 4.6 is a replot of the burning admittance amplitude shown in Figure 4.4 but is shown on a larger scale to show the results near resonance frequencies. These results are calculated using the computer codes HIFI and IFAR for mixed 1T and longitudinal modes of a cylindrical chamber without acoustic cavities. The figures show that the differences between HIFI and IFAR predictions are small near resonance. The differences become larger at off-resonance frequencies but this is not important since we are more interested in the region near resonance.

Calculations are then made for the 1T mode of a cylindrical chamber with and without acoustic cavities using computer codes HIFI and IFAR . The calculations were made to

(a)

```
HIFI, AX, 1T
$CNTRL
 AXISYM=T, TABLE=F, PLOT= T,
$END
$INPUT
 RC=0.216, RE=0.216, ALPHA=45.0, HST=0.208, RCHAMB=0.623, RWI=0.2,
 GAMMA=1.14, AO=3850.0, WS=1600.0, DW=5.0, NW=100, M=1, N=0,
 XSSL=1.0, XB=0.21, PCHAMB=2.088E+05,
$END
        0          0          1          1        100
```

(b)

```
HIFI, AX, 1T
$CNTRL
 AXISYM=T, TABLE=T, PLOT= T,
$END
$INPUT
 RC=0.216, RE=0.216, ALPHA=45.0, HST=0.208, RCHAMB=0.623, RWI=0.2,
 GAMMA=1.14, AO=3850.0, WS=1600.0, DW=5.0, NW=100, M=1, N=0,
 XSSL=1.0, XB=0.21, PCHAMB=2.088E+05,
$END
       10          0          1          1        100
1.500E-01 0.750E-02 0.320E+00          2          1          0          1
0.514E-00 2.750E+03 1.250E+00 0.100E+00 0.472E+00 4.580E-05
        2
  1   1   1   1   1   1   1   1   1   1
```

Figure 4.1: Input data for a 1T mode in a cylindrical chamber.
(a) without cavities, (b) with cavities.

(a)

```
HIFI, 2D, 1W
$CNTRL
 AXISYM=F, TABLE=F, PLOT= T,
$END
$INPUT
 RC=0.216, RE=0.216, ALPHA=45.0, HST=0.208, RCHAMB=0.623, RWI=0.2,
 GAMMA=1.14, AO=3850.0, WS=1300.0, DW=5.0, NW=100, M=1, N=0,
 XSSL=1.0, XB=0.21, PCHAMB=2.088E+05,
$END
         0          0          1          1         100
```

(b)

```
HIFI, 2D, 1W
$CNTRL
 AXISYM=F, TABLE=T, PLOT= T,
$END
$INPUT
 RC=0.216, RE=0.216, ALPHA=45.0, HST=0.208, RCHAMB=0.623, RWI=0.2,
 GAMMA=1.14, AO=3850.0, WS=1300.0, DW=5.0, NW=100, M=1, N=0,
 XSSL=1.0, XB=0.21, PCHAMB=2.088E+05,
$END
         2          0          1          1         100
1.500E-01 0.750E-02 0.420E+00          2          1          0          1
0.514E-00 2.750E+03 1.250E+00 0.100E+00 0.472E+00 4.580E-05
```

Figure 4.2: Input data for a 1W mode in a rectangular chamber.
(a) without cavities, (b) with cavities.

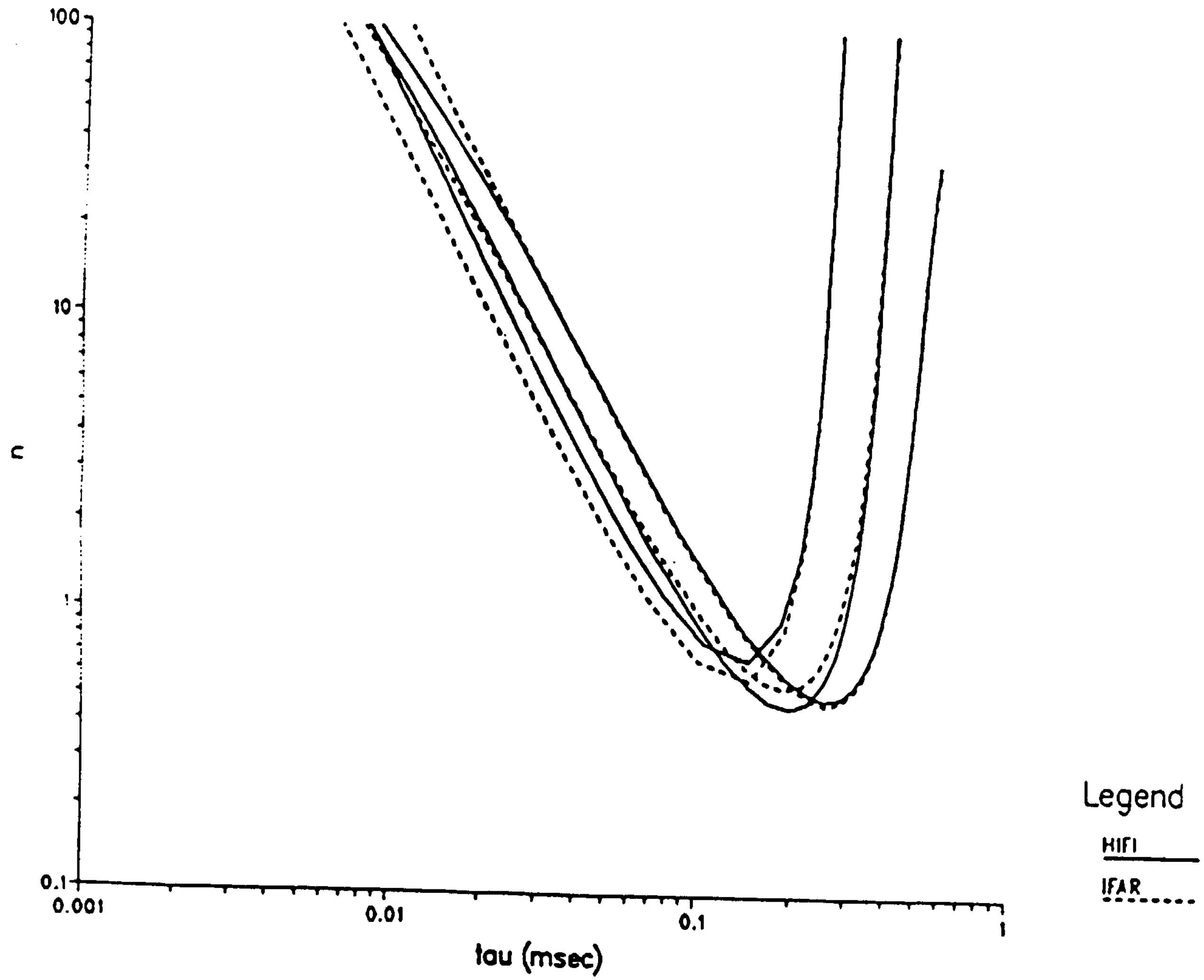


Figure 4.3 : Comparisons between HIFI and IFAR predictions of neutral stability curve in a 1T mode.

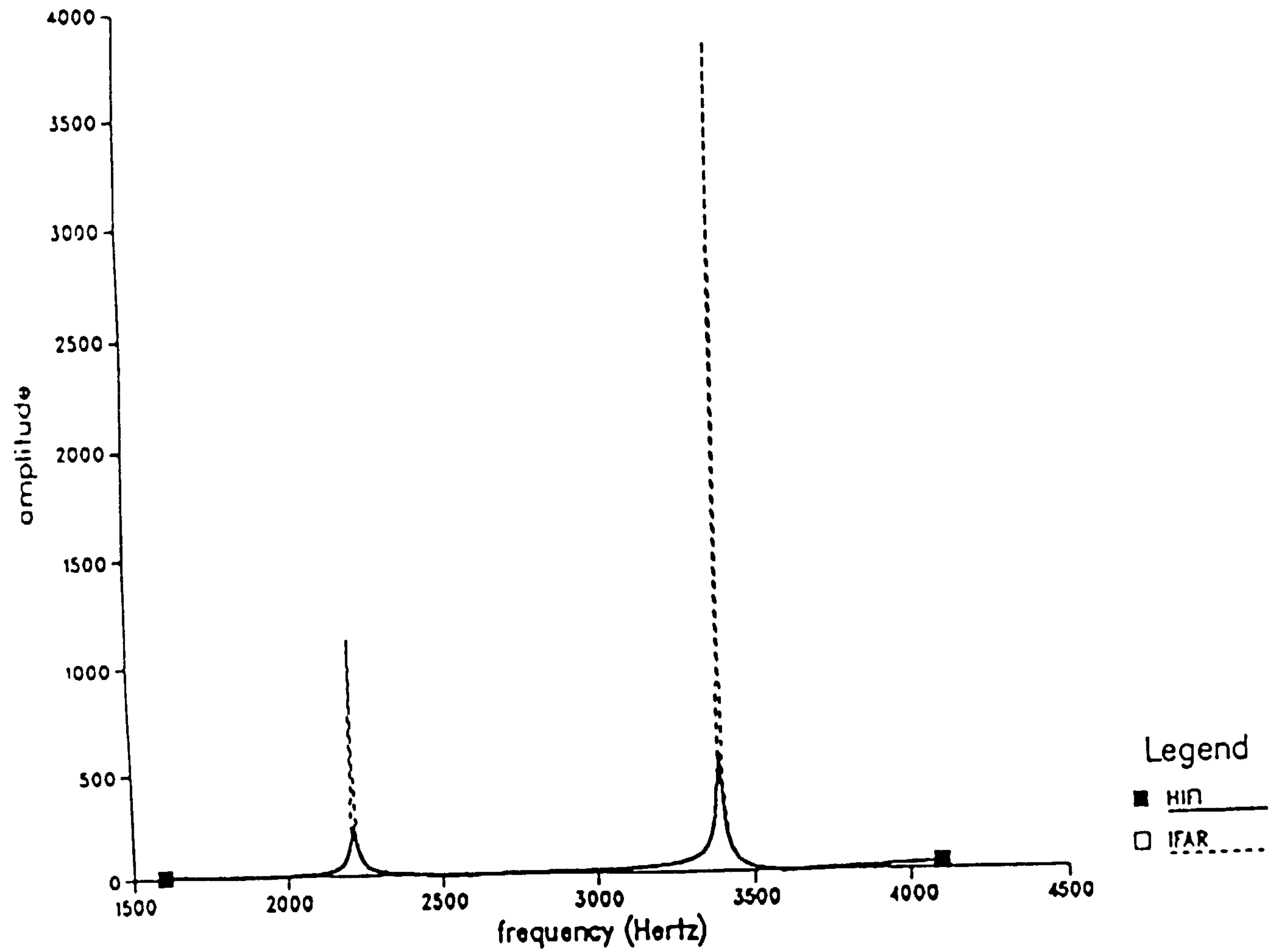


Figure 4.4 : Comparisons between HIFI and IFAR predictions of burning admittance amplitude in a 1T mode.

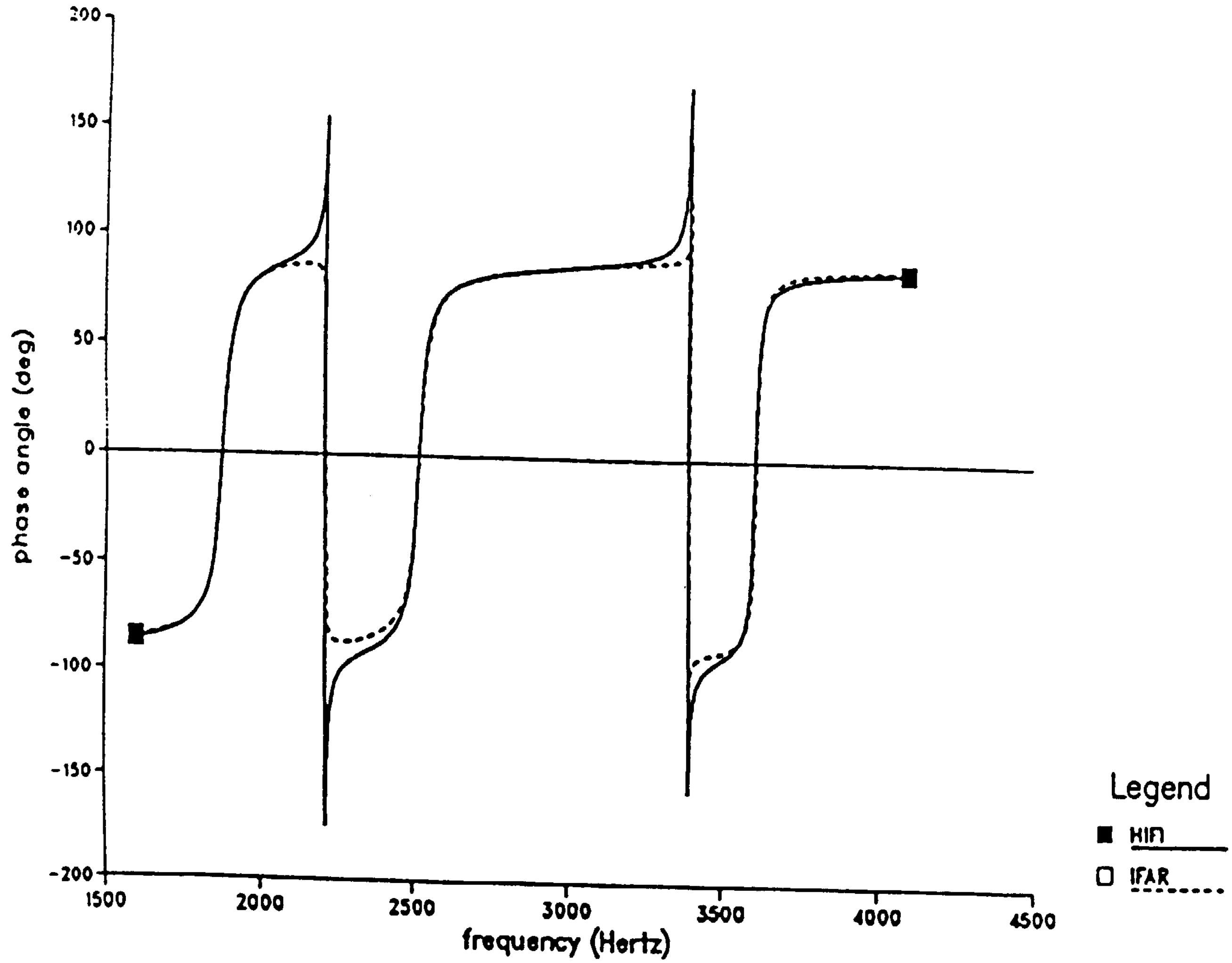


Figure 4.5 : Comparisons between HIFI and IFAR predictions of burning admittance phase angle in a 1T mode.

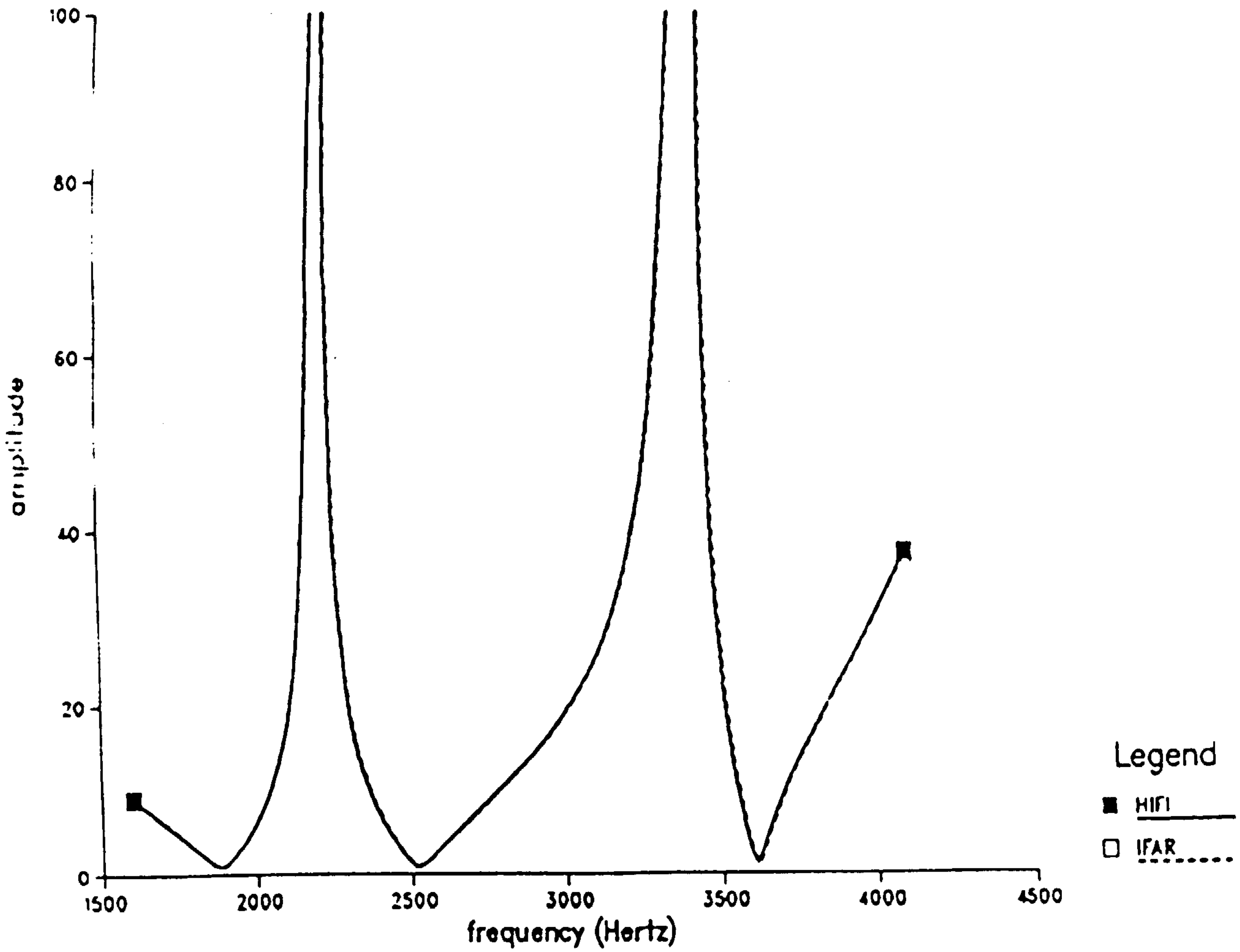


Figure 4.6 : Comparisons between HIFI and IFAR predictions of burning admittance amplitude in a 1T mode.

study the effects of acoustic cavities on combustion stability, and to provide further comparisons between HIFI and IFAR predictions. Figures 4.7, 4.8 and 4.9 show the calculated results. Again, the differences between HIFI and IFAR predictions are small. Both computer codes predict the stabilizing effects of the acoustic cavities as shown by the higher value of the n minimum, the minimum interaction index that can support linearly instability. Another effect of acoustic cavities predicted by the computer codes is to shift the value of τ where the n minimum occurs to a higher value (Fig. 4.7) and to shift the resonance frequency to a lower value (Fig. 4.8).

Figures 4.10, 4.11 and 4.12 show the comparisons between HIFI and IFAR calculated results for a 1W mode of a rectangular chamber. Similar to the cylindrical case, the differences between the predictions are small.

Figures 4.13, 4.14 and 4.15 show the effects of acoustic cavities on the stability results for the 1W mode of a rectangular chamber. The effects are similar to those discussed above for the 1T mode of the cylindrical chamber.

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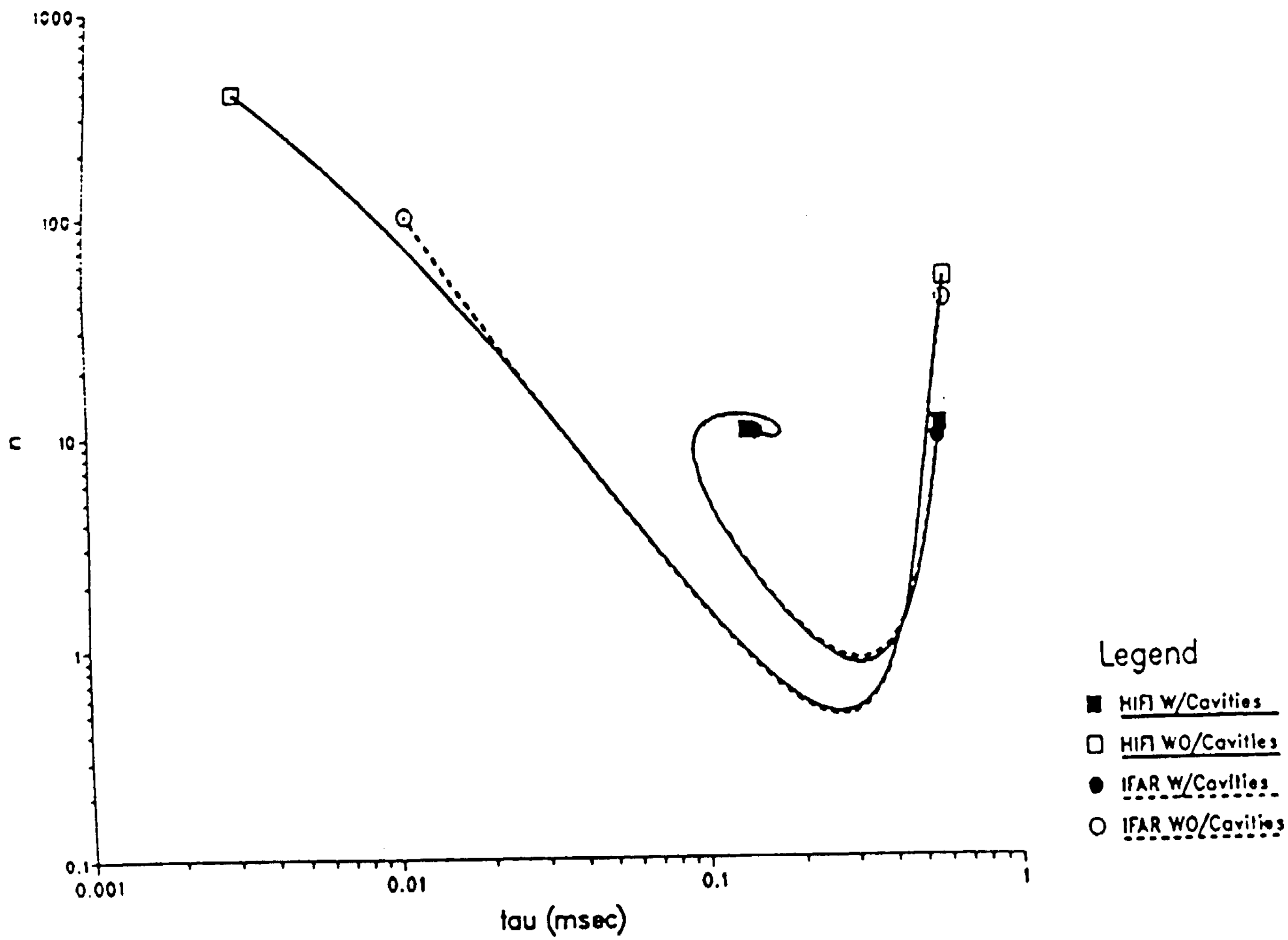

Figure 4.7 : Effects of acoustic cavities on neutral stability curve in a 1T mode. Comparisons between HIFI and IFAR predictions.

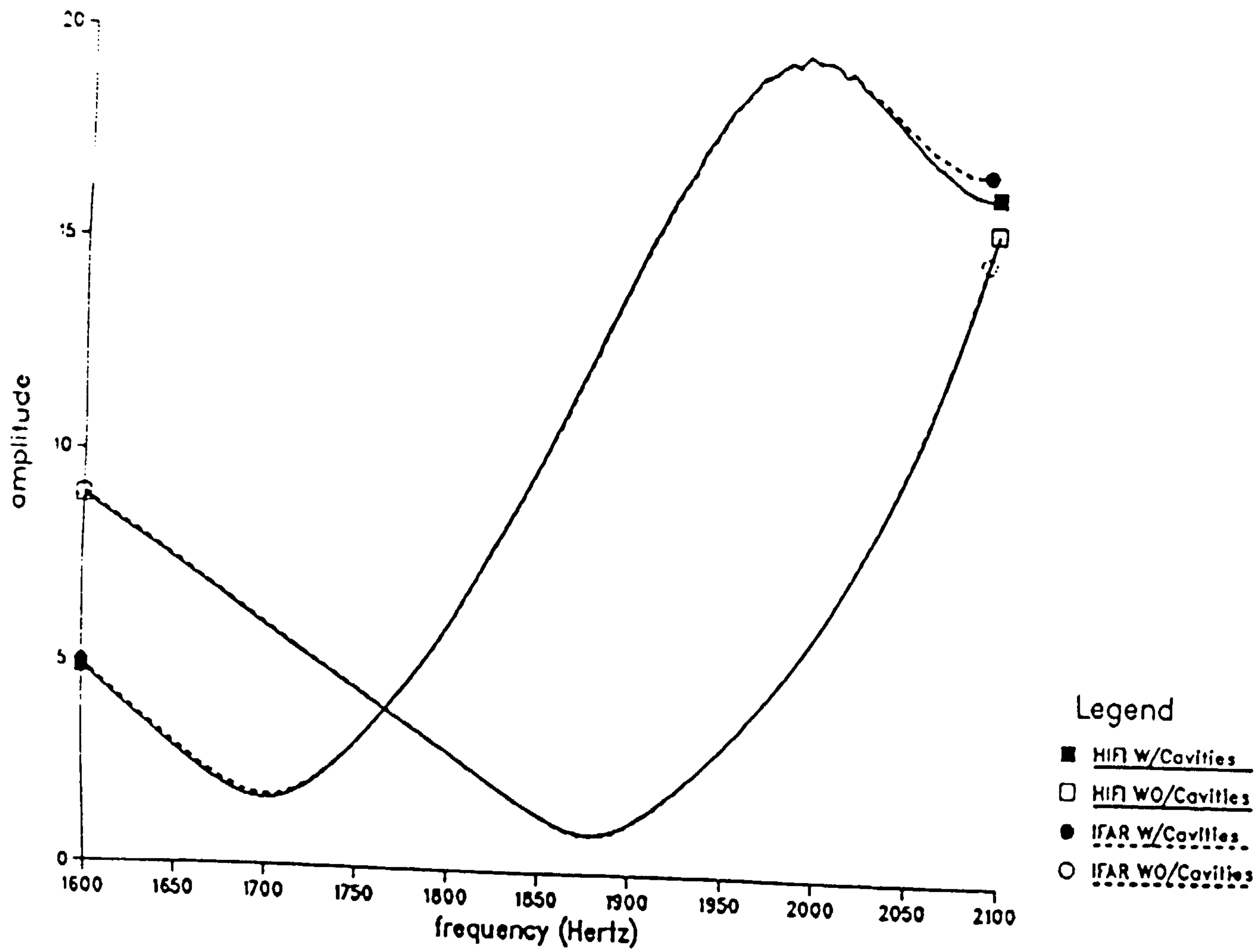

Figure 4.8 : Effects of acoustic cavities on burning admittance amplitude in a 1T mode. Comparisons between HIFI and IFAR predictions.

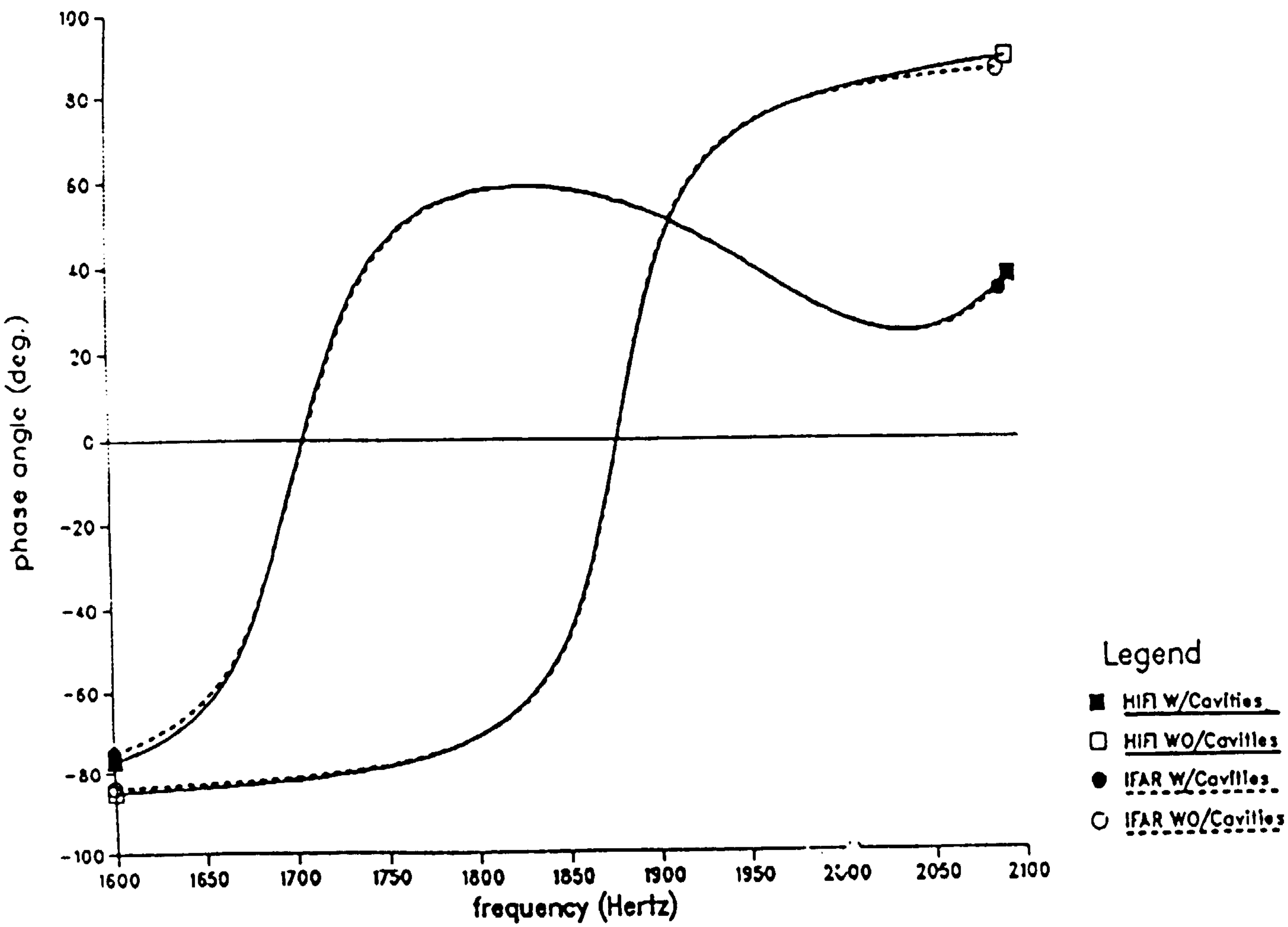

Figure 4.9 : **Effects of acoustic cavities on burning admittance phase angle in a 1T mode. Comparisons between HIFI and IFAR predictions.**

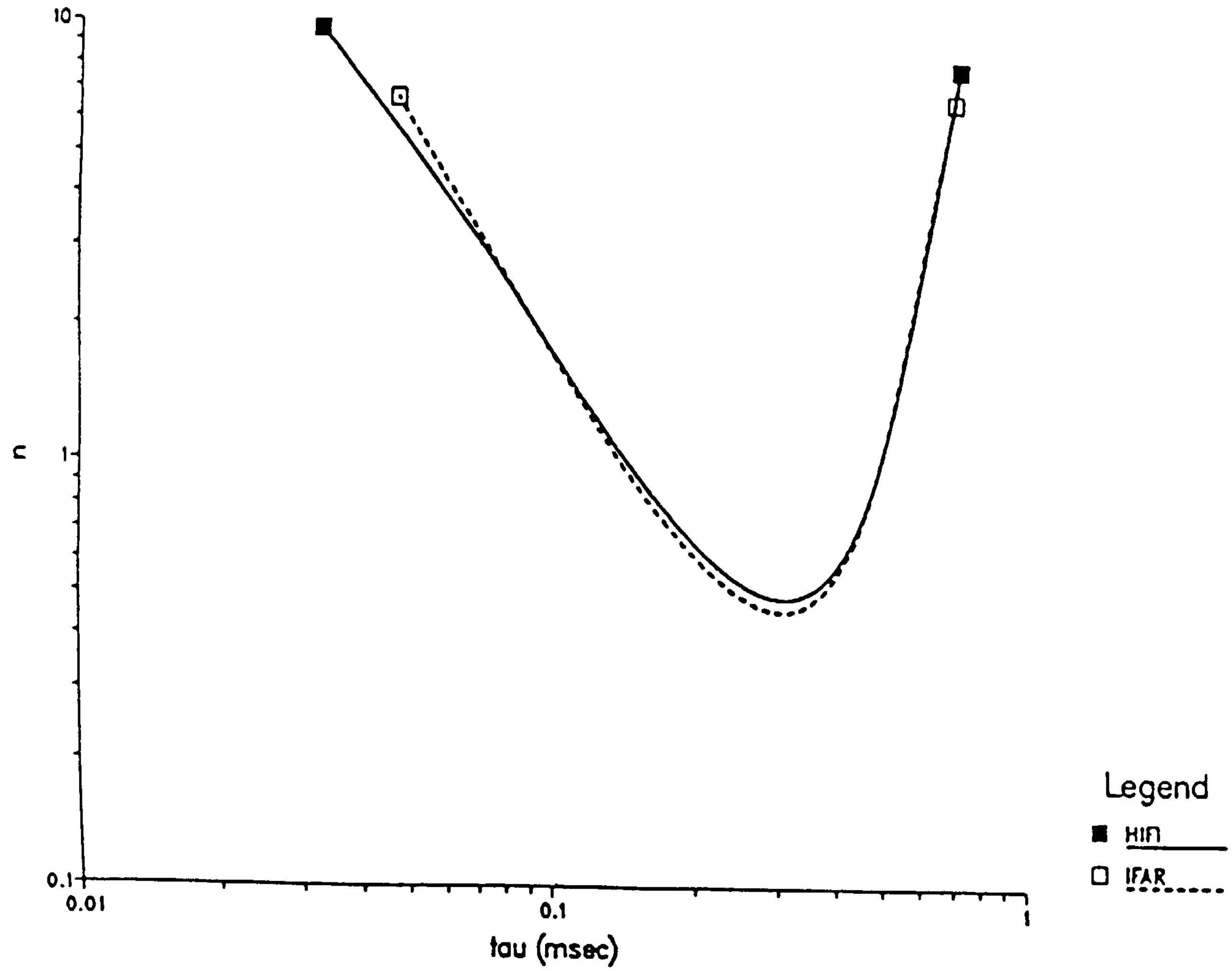

Figure 4.10: Comparisons between HIFI and IFAR predictions of neutral stability curve in a 1W mode.

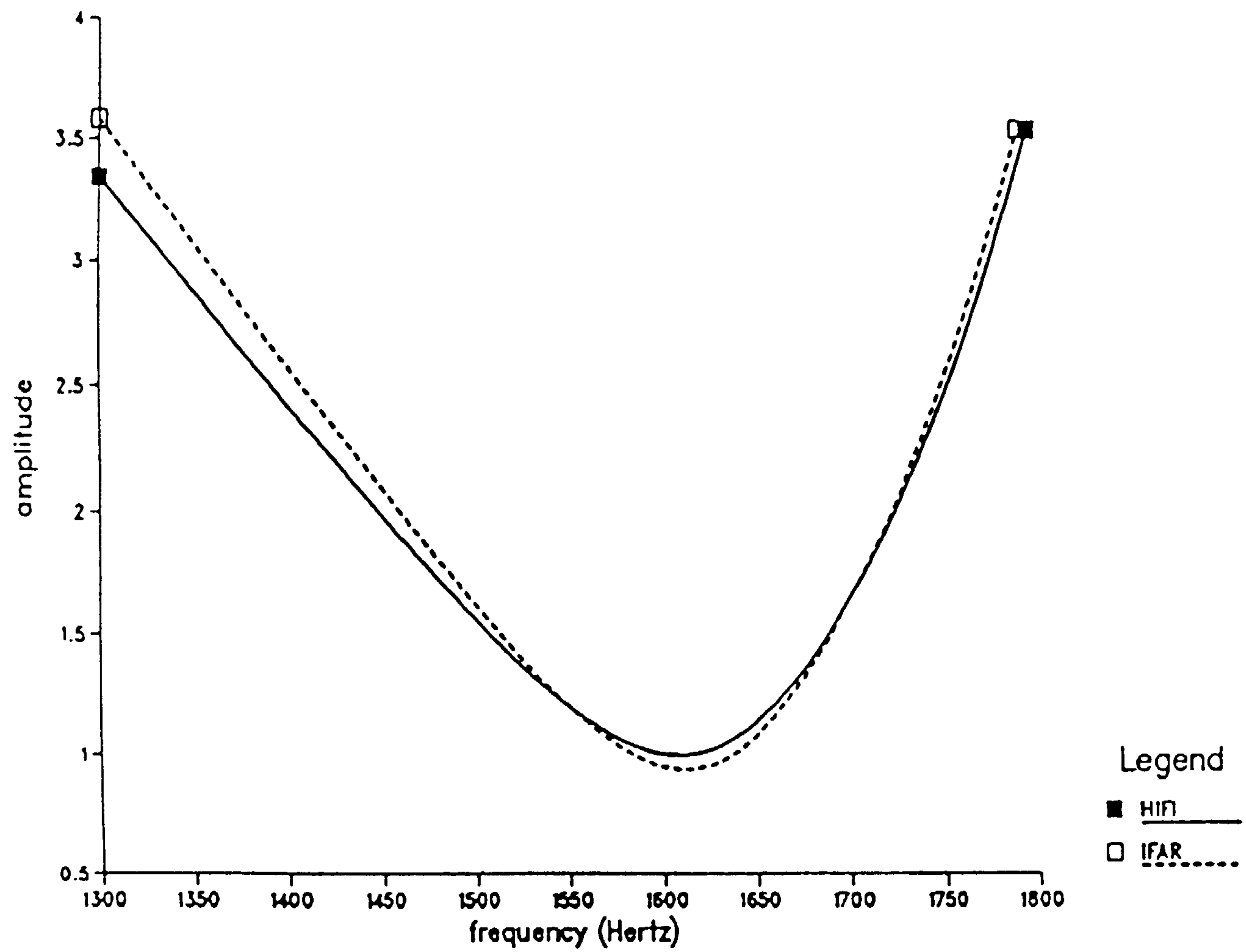

Figure 4.11: Comparisons between HIFI and IFAR predictions of burning admittance amplitude in a 1W mode.

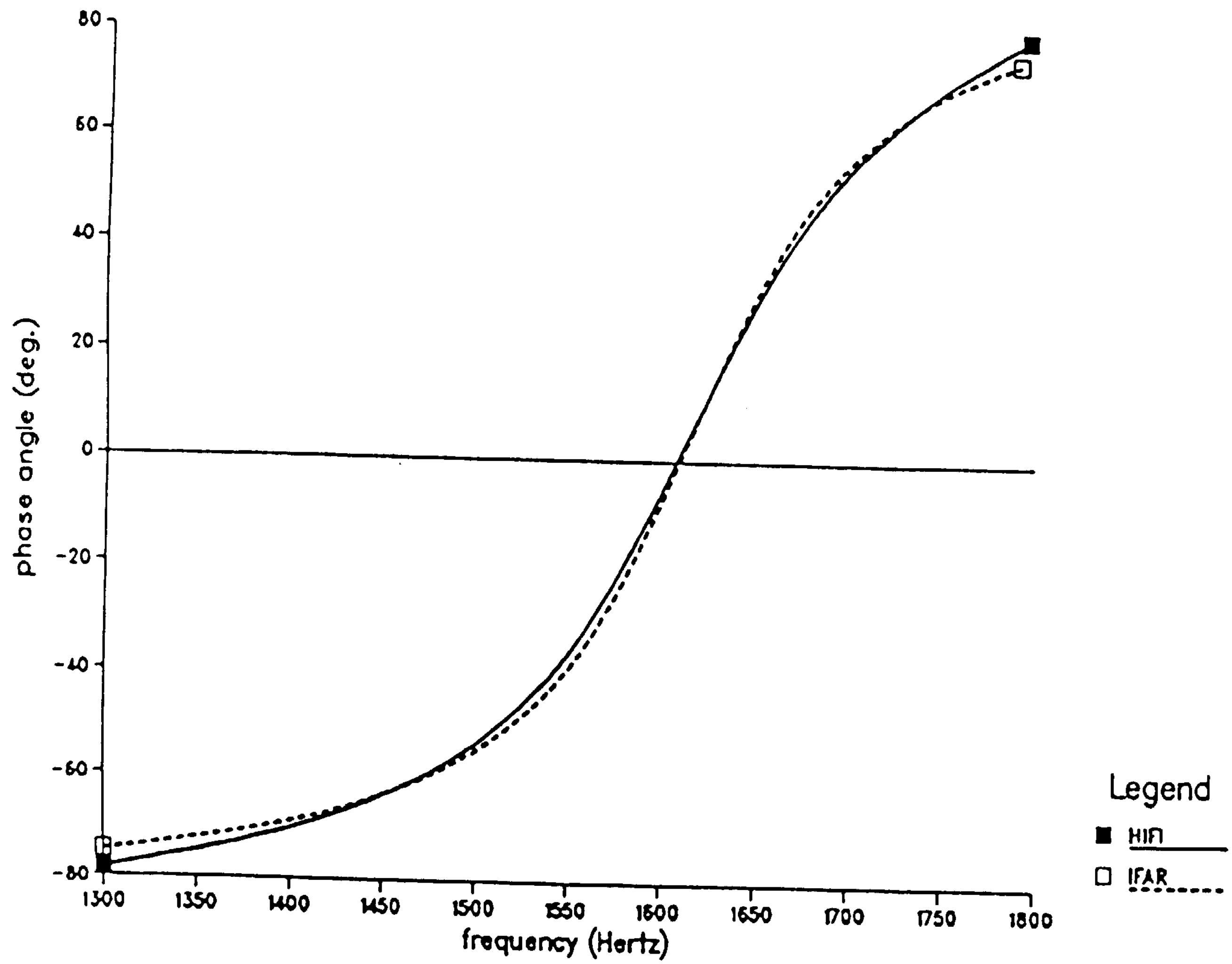

Figure 4.12: Comparisons between HIFI and IFAR predictions of burning admittance phase angle in a 1W mode.

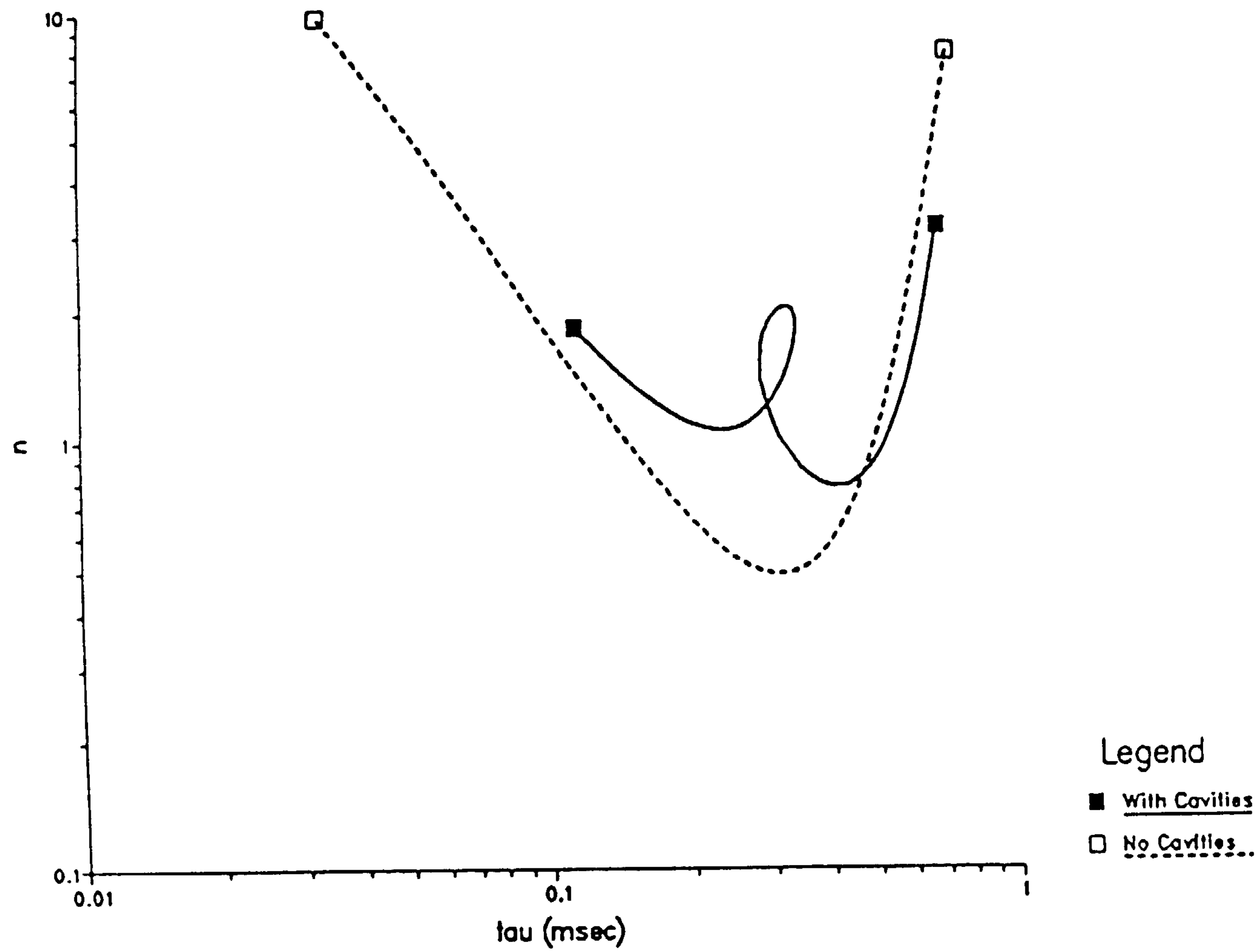

Figure 4.13: Effects of acoustic cavities on neutral stability curve in a 1W mode.

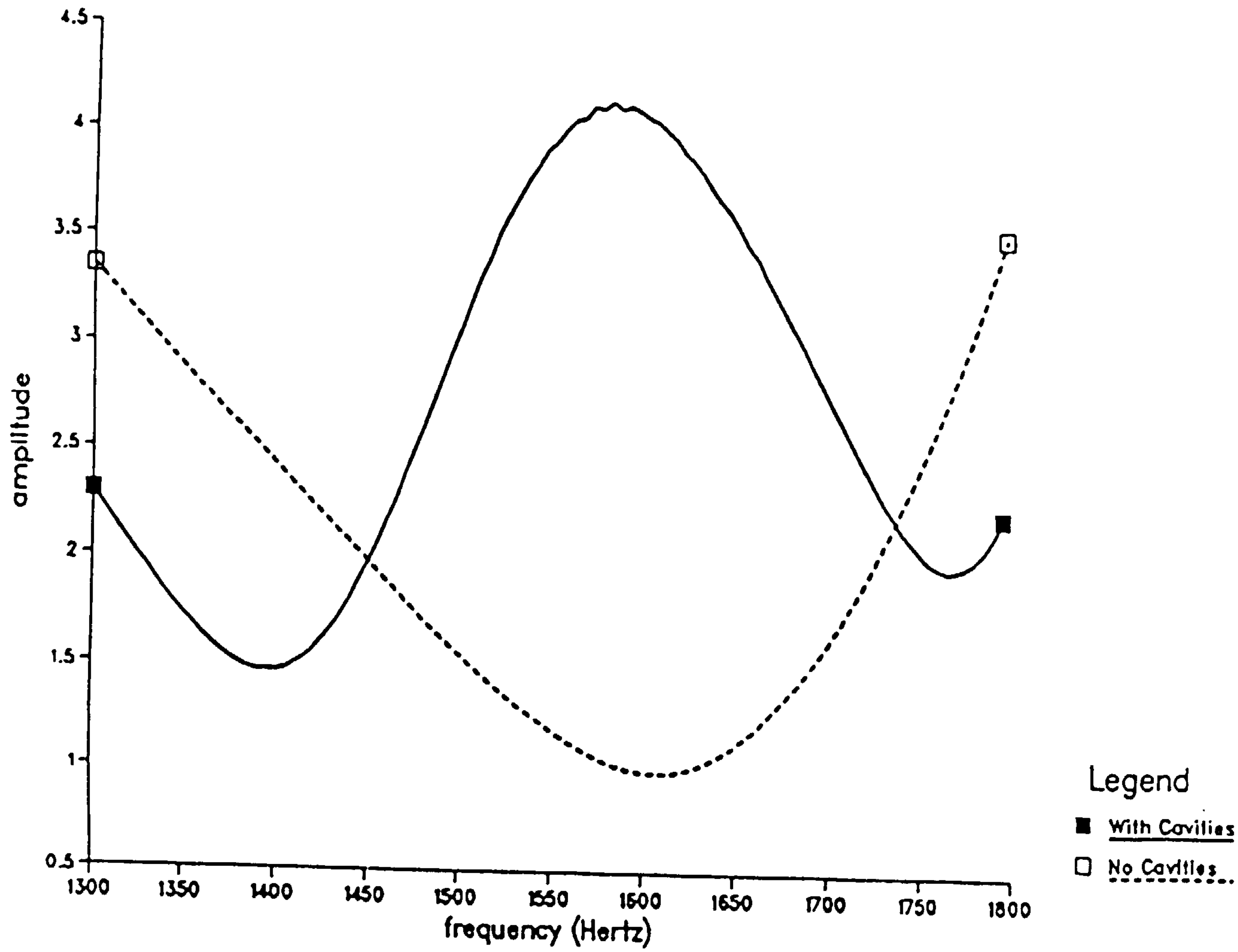

Figure 4.14: Effects of acoustic cavities on burning admittance amplitude in a 1W mode.

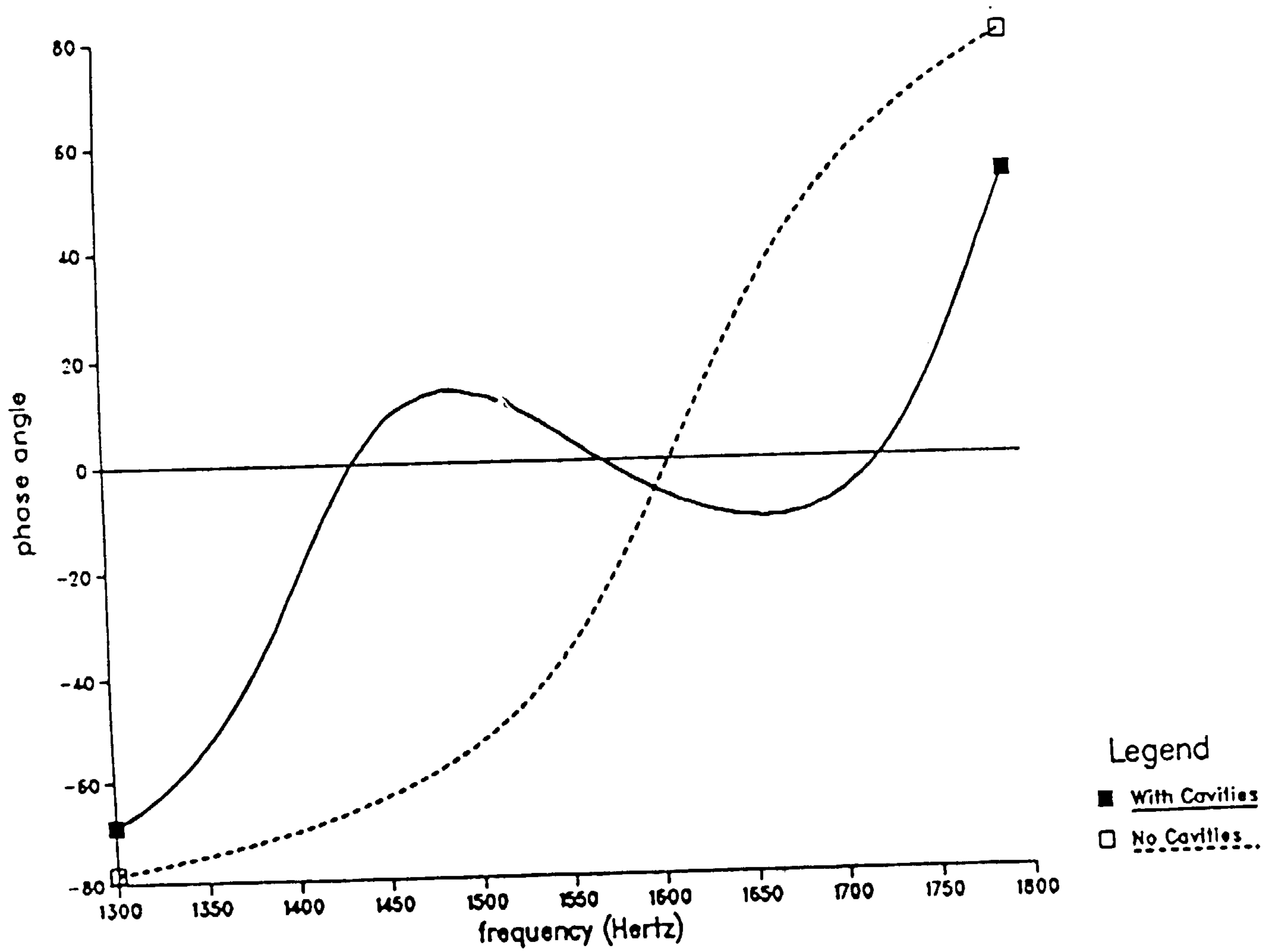

Figure 4.15: Effects of acoustic cavities on burning admittance phase angle in a 1W mode.

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PART B

3-D DISTRIBUTED COMBUSTION BAFFLE MODEL (DIST3D)

USER'S MANUAL FOR THE MULTIDIMENSIONAL BAFFLE MODEL COMPUTER PROGRAMS

by

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31 July 1987

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1. Introduction

The overall goal toward which the analytical models and computer programs presented here are directed is the development of predictive tools for determining the stability behavior of two and three dimensional liquid propellant rocket thrust chambers. Two basic combustion distribution models are discussed. The first of these assumes that a concentrated zone of combustion exists at the injector face. This assumption implies that the remainder of the chamber is source free and consequently leads to a relatively simple analysis. This approach was employed by Baer and Mitchell in their original models and computer codes (Refs. 1 and 2). One objective of the current effort was the resurrection of these early programs in a form that would be immediately useful and convenient. This involved retrieving the codes from punched cards, rewriting portions of the code in standard Fortran 5, correcting minor errors originally present, adding a nozzle admittance code (Aerojet TechSystems NOZADM), generalization of the combustion response input so that arbitrary values of the interaction index (n) and time lag (tau) could be used and, finally, conversion of most of the essential input and output data to dimensional form, consistent with Aerojet's stability models. Minor improvements to the code including modernization of the input and output modes and addition of comment statements were also made. The final result of this work was two computer programs: CON2D, for two dimensional thrust chambers and CON3D, for three dimensional thrust chambers.

The second combustion distribution model is considerably more realistic in that the zone of combustion is taken to be distributed over a significant fraction of the chamber axial length. The distribution is limited to a linear form (constant mean volumetric rate of mass and energy release over the length of the zone), but the beginning and end of the zone are arbitrary. This allows consideration of both relatively intense (concentrated) zones of combustion as well as less intense (distributed) zones, and permits the determination of the impact of the concentration of combustion sources on stability. Moreover, the zone of combustion may be located completely in the baffle cavities, completely in the unbaffled main chamber, or partly in both regions. Thus, the influence of combustion zone location on stability can be assessed as well.

The analysis of the distributed combustion problem is both more sophisticated and more complex than that of the concentrated combustion model. The analytical approach employed follows in many respects recent work on combustion distributions in unbaffled combustion chambers done at Colorado State University (Ref. 3). The resulting computer codes are more flexible than those for the concentrated combustion mode. The main additional features are:

1. Output in terms of n, tau neutral stability data as well as in terms of frequency and decay rate for given combustion response input.
2. Inclusion of a radially oriented acoustic cavity in the stability model.
3. Output of local pressure amplitudes and phase angles at any spatial location in the chamber or baffle cavities.

For distributed combustion the two dimensional computer program is called DIST2D while the three dimensional program is DIST3D.

The remainder of this manual is devoted to a presentation of the analytical approaches involved and a description of the use of the resulting computer programs.

2. Theory

2.1 Analytical Approach

In many respects the general analytical approaches for treating the concentrated combustion model and the distributed combustion model are quite similar. Consequently, a single description of the analytical development will be given. Specific differences between the analyses for the two combustion zone types (as well as for the differences between two and three dimensional chambers) will be noted as the presentation proceeds.

2.1.1 Model Assumptions

The following modeling assumptions are made in representing the major thrust chamber components in the analyses.

1. Chamber Geometry

Three dimensional. A right circular cylinder is terminated by an axis-symmetric nozzle (see Fig. 1). Cylindrical coordinates (r, θ, z) are used in the analysis. The nozzle entrance is at $Z^*=L^*$, the injector is at $Z^*=0$, the cylindrical wall at $r^*=R^*$ (asterisks indicate dimensional quanities). The radial absorber is located at $r^*=R^*$, $0 \leq Z^* \leq Z^*_A$. Baffle blades are located at $\theta_j = \frac{2\pi j}{N}$, where j is an integer, N is the total number of baffle cavities, and $0 \leq j \leq N-1$. Baffle blade length is Z^*_B thickness is T^*.

Two dimensional. A two dimensional (vertical pancake) chamber is terminated by a convergent two dimensional nozzle (see Fig. 1). Cartesian coordinates (Z^*, y^*) are used in the analysis. Chamber length is L^*, chamber height is R^*. The absorber is located at $y^* = 0$ and $y^* = R^*$, with $0 \leq Z^* \leq Z^*_A$. Baffle blades are located at $Y^*_j = \frac{j R^*}{N}$ where again, N is the total number of baffle cavities and $0 \leq j \leq N-1$. Baffle blade length is Z^*_B.

2. Gasdynamic Flowfield

- uniform composition calorically perfect combustion product gas
- irrotational flow outside of baffle boundary layers (exact for concentrated combustion, correct through

order mean Mach number squared in distributed combustion).

- one dimensional axial flow in the steady state.
- linear, nearly harmonic oscillations with small growth or decay rates (less than about 30% per cycle).
- droplet volume and drag ignored (distributed combustion).
- standing or traveling waves in the main chamber standing waves in the baffle compartments (standing waves only for two dimensional chamber).

3. <u>Combustion Distribution</u>

<u>Concentrated combustion</u>

- all combustion concentrated at $Z^*=0$
- mass flow rate, $\bar{\dot{m}}^*$, Mach number M, pressure $\bar{p}^*$ constant for $Z^*>0$ in the steady state (steady state indicated by superposed bars)

<u>Distributed combustion</u>

- linear combustion distribution between $z^*=z_s^*$ and $z^*=z_e^*$

$$\bar{\dot{m}}^* = \bar{\dot{m}}_T^* \left(\frac{z^*-z_s^*}{z_e^*-z_s^*}\right) \qquad z_s^* \le z^* \le z_e^*$$

$$\bar{\dot{m}}^* = 0 \qquad z^* < z_s^*$$

$$\bar{\dot{m}}^* = \bar{\dot{m}}_T^* \qquad z^* > z_e^*$$

$\overline{\dot{m}}^*_T$ is the total mean mass flow in the steady state

- Z^*_s and Z^*_e are arbitrary, but $Z^*_s - Z^*_e$ limited to at least 20% of the chamber diameter (or height for two dimensional chamber)

4. Combustion Response

Concentrated combustion

$$\frac{\dot{m}'^*}{\overline{\dot{m}}^*} = \left[n\left(1 - e^{-i\omega^*\tau^*}\right) - 1 \right] \frac{p^{*\prime}}{\overline{p}^*}$$

This form is corrected from earlier forms. The term -1 on the right-hand side is added, and can be shown formally to be the correct limit of distributed combustion. $\dot{m}^{*\prime}$ is the unsteady perturbation in mass flow, $p^{*\prime}$ the unsteady pressure perturbation, ω^* is the dimensional angular frequency, τ^* is the time lag.

Distributed combustion

$$\frac{Q^{*\prime}}{\overline{Q}^*} = n\left(1 - e^{-i\omega^*\tau^*}\right) \frac{p^{*\prime}}{\overline{p}^*}$$

Q is the volumetric rate of local gas production in the combustion zone.

5. Baffle Dissipation

- turbulent boundary layer in region near baffle blade tips

- driven by inviscid outer flow in cavity and main chamber
- uses Spalding's effective turbulent viscosity model
- numerical integration over boundary layer near blade tips

6. Acoustic Cavity

- radial slot
- located at injector
- $u_r^{*\prime} = \beta_c^* p^{*\prime}$ where $u_r^{*\prime}$ is the radial unsteady velocity, p' is the local pressure perturbation, β_c^* is the cavity admittance (complex, must be supplied by user)

7. Nozzle

- $u_z^{*\prime} = \beta_N^* p'$, $u_z^{*\prime}$ axial velocity, $p^{*\prime}$ pressure at $Z^*=L^*$
- β_N^* supplied by NOZADM program

2.2 Basic Equations

Using the assumptions given above the conservation equations and equations of state can be reduced to a nondimensional set in terms of a velocity potential. The nondimensional scheme is defined in the table below the particular nondimensional variable is formed through division by the listed characteristic quality.

Variable	Characteristic Quantity		Noudimensional Form
	3-D	2-D	
p^*(pressure)	$\bar{p}^*(z^* = L^*)$	same	p
ρ^*(density)	$\bar{\rho}^*(z^* = L^*)$	same	ρ
a^*(sonic speed)	$\bar{a}^*(z^* = L^*)$	same	a
Z^*(axial coordinate)	R^*(chamber radius)	R^*(chamber height)	z
y^*(vertical coordinate, 2-D)	—	R^*(chamber height)	y
r^*(radial coordinate,3-D)	R^*(chamber radius)	—	r
t^*(time)	$R^*/\bar{a}_L^*$	same	t
ω^*(angular frequency)	a_L^*/R^*	same	ω
λ^*(decay rate)	$\bar{a}_L^*/R^*$	same	λ
$\vec{q}^*$(velocity vector)	$\bar{a}_L^*$	same	$\vec{q}$
ϕ^*(velocity potential)	$\bar{a}_L^*/R^*$	same	ϕ

In this table it should be pointed out that the characteristic length for the two dimensional problem is the total chamber height R^*, rather than the half height which is used in some Aerojet programs. The appropriate conversion is made in our computer codes when NOZADM is called.

The dependent variables are all represented as the sum of a steady state (or time averaged) part (superposed bar) and an oscillatory part (prime). Thus, $p = \bar{p} + p'$, etc. The oscillatory parts are in turn represented as the product of a space dependent part and the factor $e^{i\omega t}$. Thus, $p' = Pe^{i\omega t}$, etc., where $p = P(r,\theta,z)$ or $p = P(z,y)$. ω is the complex frequency ($\omega = \omega_R + i\lambda$).

Since the flow is irrotational (at least through order u^2) then

$$\vec{q} = \nabla \phi$$

and, from partial integration of the momentum equation

$$p = -\gamma \left(\bar{\rho} i\omega\phi + \frac{\partial}{\partial z}(\bar{u}\phi) \right)$$

where γ is the ratio of specific heats. Some manipulation finally results in the following basic equation for ϕ

$$\nabla^2\phi + \omega^2\phi = F_1(\phi, \bar{u}, \omega, n, \tau) \qquad (1)$$

where for concentrated combustion,

$$F_1 = 2Mi\omega\frac{\partial\phi}{\partial z} + M^2\frac{\partial^2\phi}{\partial z^2}$$

while for distributed combustion

$$F_1 = (1+\gamma)\left[i\omega\frac{d\bar{u}}{dz} + \left(\frac{d\bar{u}}{dz}\right)^2\right]\phi + \left(2\bar{u}i\omega + (\gamma+2)\bar{u}\frac{d\bar{u}}{dz}\right)\frac{\partial\phi}{\partial z}$$

$$+ \bar{u}^2\frac{\partial^2\phi}{\partial z^2} - n\left(1-e^{-i\omega\tau}\right)\left[\gamma i\omega\frac{d\bar{u}}{dz} + 2\gamma\bar{u}\frac{d\bar{u}}{dz}\right]\frac{\partial\phi}{\partial z}$$

The boundary conditions on Equation (1) are given by the general form $\nabla\phi \cdot \vec{n} = \beta p$, where $\vec{n}$ is the unit outward normal on a given surface, and β the surface admittance is defined for the chamber bounding surfaces below.

Nozzle entrance plane ($Z = L$)	$\beta = \beta_N$ (Nozzle admittance)
Radial cavity entrance ($r = 1$) (or $y = 1$, $y = 0$)	$\beta = \beta_C$ (Cavity Admittance)
Baffle blade surfaces	$\beta = \beta_B$ (Baffle admittance due to dissipation of energy in the boundary layer)
Injector surface ($Z = 0$)	$\beta = 0$ (Distributed combustion)
	$\beta = M\left(\frac{\gamma+1}{\gamma} - n\left(1 - e^{-i\omega\tau}\right)\right)$ (Concentrated Combustion)
All other surfaces	$\beta = 0$.

2.3 Solution Technique

An integral technique is followed in order to predict either complex frequency (ω_R and λ) for a given n and τ, or to predict n and τ values required for neutral stability when the frequency (ω_R) is given. Consider Equation (1) written as a homogeneous equation with homogeneous boundary conditions

$$\nabla^2 \tilde{\Phi} + \tilde{\omega}^2 \phi = 0$$

$$\nabla \tilde{\Phi} \cdot \vec{n} = 0$$

all surfaces, including baffle blade surfaces

is the solution to this homogeneous problem, and ω is the associated frquency. then, using Greens Theorem it can be shown that

$$(\omega^2 - \tilde{\omega}^2) \int_V \tilde{\Phi} \phi \, dV = - \int_S \tilde{\Phi} \nabla \phi \cdot \vec{n} \, dS + \int_V \tilde{\Phi} F_1 (\tilde{\Phi}, \bar{u}, \omega, n, \tau) \, dV \tag{2}$$

Equation (2) is exact and would determine either ω or n and τ exactly, if $\tilde{\Phi}$, $\tilde{\omega}$, and the functional form of ϕ were known. It is possible to determine $\tilde{\phi}$ and $\tilde{\omega}$ to arbitrary accuracy using an eigenfunction matching technique which will be described shortly. In determining an appropropriate form for ϕ, reliance is placed on two characteristics of the problem as posed. First, the function F_1 on the right-hand side of Equation (1), as well as the values of β on the active surfaces are small, usually less than the mean flow Mach number in size. Second, the form of ϕ is generated through integration of the β dependent terms over the chamber bounding surfaces. Taken together these encourage using $\tilde{\phi}$ as the approximate form for ϕ in the integrals appearing in Equation (2). Certainly an error no larger than the mean Mach number squared will occur upon this substitution. In practice, experience indicates that the error is usually considerably less. This is so, for example, for the concentrated combustion problem without an acoustic absorber, or boundary layer dissipation, for which an exact solution to Equation (1) exists. Whether this exact solution or $\tilde{\phi}$ is used in the integrals, affects predictions of n and τ only to an amount which is always considerably smaller than the Mach number squared in our calculations. If one accepts the substitution of $\tilde{\phi}$ for ϕ in the volume integrals and of $\beta p(\tilde{\phi})$ for $\nabla\phi\cdot\vec{n}$ in the surface integrals, then performing the indicated integrations leads to an algebraic relationship between n, τ, and ω. This relationship is complex and can be solved for n and τ given ω or for ω given n and τ.

Solution for $\tilde{\phi}$

The function $\tilde{\phi}$ is represented formally by eigenfunction expansions in each baffle cavity and in the main chamber. The form of these expansions is given below.

Two dimensional thrust chamber

Main chamber: $$\tilde{\phi}_C = \sum_{m=0}^{mc} B_m \cos m\pi y \, \frac{\cosh (m^2\pi^2 - \tilde{\omega}^2)^{1/2} (z-L)}{\cosh (m^2\pi^2 - \tilde{\omega}^2)^{1/2} (z_B - L)}$$

baffle compartment μ:

$$\tilde{\Phi}^{\mu} = \sum_{n=0}^{nB} A_n^{\mu} \cos n\pi N y \, \frac{\cosh (n^2\pi^2N^2 - \tilde{\omega}^2)^{1/2} z}{\cosh (n^2\pi^2N^2 - \tilde{\omega}^2)^{1/2} z_B}$$

where n and m are integers, N is the number of baffle compartments and nB and mc determine the number of terms in the eigenfunction representation. The coefficient vectors B_m and A_n^{μ} (one A_n^{μ} vector for each baffle compartment, not generally the same) as well as the frequency eigenvalue, $\tilde{\omega}$ are determined by requiring that, at the interface between the main chamber and each baffle compartment, $\tilde{\Phi}^{\mu} = \tilde{\Phi}^{c}$, and $\frac{\partial \tilde{\Phi}^{\mu}}{\partial z} = \frac{\partial \tilde{\Phi}^{c}}{\partial z}$. In addition the dominant mode of oscillation in the main chamber is designatd by setting $B_{\hat{m}} = 1$, where $\hat{m}$ is arbitrary. Thus, the choice $\hat{m} = 1$, a first transverse type oscillation, would cause $B_1 = 1$. The other B_m would then represent corrections to the pure first transverse mode due to the presence of the baffle cavities. The coefficients are calculated using a successive approximation technique. It is first assumed that $B_{\hat{m}} = 1$, and $\omega = \hat{m}\pi$, while all other $B_m = 0$. The matching condition $\tilde{\Phi}^{\mu} = \tilde{\Phi}_c$ then determines the A_n^{μ} values for each baffle cavity. Using these values of A_n^{μ}, values for all B_m (except $B_{\hat{m}}$, of course) are determined using the condition $\frac{\partial \tilde{\Phi}^{\mu}}{\partial z} = \frac{\partial \tilde{\Phi}_c}{\partial z}$ at the matching plane. Finally the condition $B_{\hat{m}} = 1$ is used to determine an improved approximation for $\tilde{\omega}$. The details of this type of matching solution are quite messy: an in-depth presentation is given in Reference 1. In general the convergence is rapid (less than 5 iterations). The number of iterations desired is specified by the program user, as are the values for mc and nB. Experience indicates that a choice of mc = 30 and nB = 30 give excellent matching and wave shape information.

<u>Three Dimensional Thrust Chamber</u>

Main chamber:

$$\tilde{\Phi}_c = \sum_{m=0}^{m_c} \sum_{\ell=1}^{\ell_c} B_{\ell m} \cos m\theta \; J_m(\lambda_{\ell m}^c r) \frac{\cosh(\lambda_{\ell m}^{c\,2} - \tilde{\omega}^2)^{1/2}(z-L)}{\cosh(\lambda_{\ell m}^{c\,2} - \tilde{\omega}^2)^{1/2}(z_B - L)}$$

J_m is Bessel function of order m

$\lambda_{\ell m}^c$ is the ℓ^{th} solution to $\left(\frac{dJ_m}{dr}\right)_{r=1} = 0$

(Note: for a traveling wave in the main chamber $\cos m\theta$ is replaced by $e^{im\theta}$.

Baffle compartment μ:

$$\tilde{\Phi}^\mu = \sum_{m'=0}^{m_B} \sum_{\ell'=0} A_{\ell' m'}^{\mu} \cos \frac{m'N}{2}\theta_\theta \; \frac{J_{\frac{m'N}{2}}(\lambda_{\ell' m'}^B r) \cosh(\lambda_{\ell' m'}^{B\,2} - \tilde{\omega}^2)^{1/2} z}{\cosh(\lambda_{\ell' m'}^{B\,2} - \tilde{\omega}^2)^{1/2} z_B}$$

$J_{\frac{m'N}{2}}$ is Bessel function of order $\frac{m'N}{2}$

$\lambda_{\ell' m'}^B$ is the ℓ^{th} solution to $\left(\frac{dJ_{\frac{m'N}{2}}}{dr}\right)_{r=1} = 0$

The same matching requirements and successive approximation technique is used for the three dimensional thrust chamber as was used for the two dimensional chamber. In the three dimensional case $B_{\ell m}$ and $A_{\ell' m'}^{\mu}$ are matrices rather than vectors. In order to specify the main oscillation mode in the chamber both $\hat{m}$ and $\hat{\ell}$ must be chosen. For example $\hat{m} = 1$, $\hat{\ell} = 1$ leads to a 1st tangential type oscillation with $\lambda_{11}^c = 1.8412$; $\hat{m} = 2$, ℓ'

= 1 a second tangential mode, etc. Choices for mc, ℓc, ℓ'B, m'B must be made as well. In the 3-D case computation time is a factor, and a compromise between accuracy and run time must be made. Choices of mc = m'B = 11, ℓc = ℓ'B = 4 appear to give good results. The details and integrals involved in the 3-D matching problem are formidable; one is again referred to Reference 1.

A limit on the number of iterations must be specified by the user. Convergence is a little slower in the three dimensional model: approximately 10 iterations gives reliable convergence in most cases.

Asymptotic solution for $\tilde{\Phi}$

Near the baffle blade tips it is desirable to have great accuracy in defining the local behavior of $\tilde{\Phi}$. This is so because the outer inviscid solution will drive the boundary layer dissipation integral. An asymptotic solution which is valid near the blade tips was derived and explained in Reference 1. This is used without modification in the present work. Matching between the eigenfunction representations and the asymptotic solution is quite good over the region near the blade tips, if a matching at two points to determine constants in the asymptotic solution is made at a distance approximately equal to the baffle blade thickness T, on either side of the baffle blade.

Boundary layer dissipation integral

The portion of the boundary integral $-\int_S \tilde{\Phi}\, \nabla\Phi \cdot \vec{n}\, dS$ of Equation (2) which lies on the baffle blade surfaces can be shown to be equivalent to E^T_{diss} the turbulent boundary layer dissipation integral. E^T_{diss} in turn is equal to

$$-\gamma \int_{S_{B.L.}} \left(\frac{\mu_{eff}\,\omega}{2}\right)^{1/2} |u'|^2\, dS$$

where $$\mu_{eff} = C_{turb}\left[\bar{u}^2 + \frac{|u'|^2}{2}\right]^{1/2}$$

C_{turb} = .05 3-Dimensional

C_{turb} = .034 2-Dimensional

$|u'|$ is the modulus of the oscillatory velocity at the outer edge of the boundary layer as determined by the $\tilde{\Phi}$ solution.

Application of Equation (2) and Final Solution

The $\tilde{\phi}$ representation for both main chamber and baffle cavities is now substituted for ϕ in the volume integrals of Equation (2). It is to be recognized that these integrals extend over both the main chamber and baffle cavities. As can be imagined these integrals are somewhat involved. Solution is pursued analytically where possible, numerically where necessary. The surface integrals <u>except for the baffle blade surfaces</u> are evaluated by replacing $\nabla\phi\cdot\vec{n}$ with $\beta\tilde{P}$ and integrating over the appropriate surface (nozzle entrance plane, injector, acoustic cavity interface). As discussed above the surface integral for the baffle blades is replaced by the turbulent boundary layer integral E^T_{diss}. This integral is performed numerically (one dimension for two dimensional thrust chamber, two dimensions for three dimensional thrust chamber), over a streamline defining the edge of the boundary layer. Once the integrations are complete the resulting algebraic expression is solved for either ω_R and λ (option 1) or n and τ (option 2).

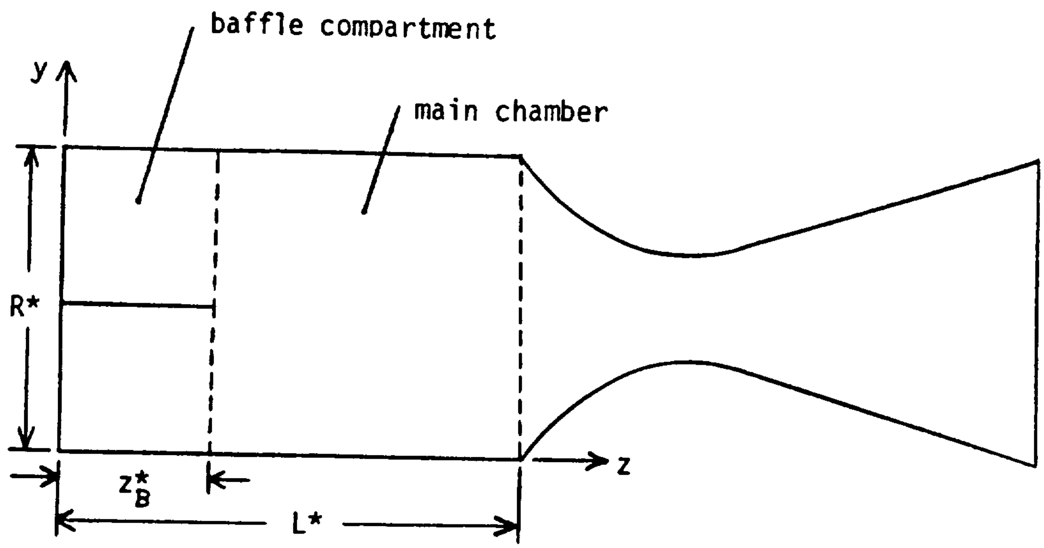


Figure 1a: Two-dimensional baffled chamber

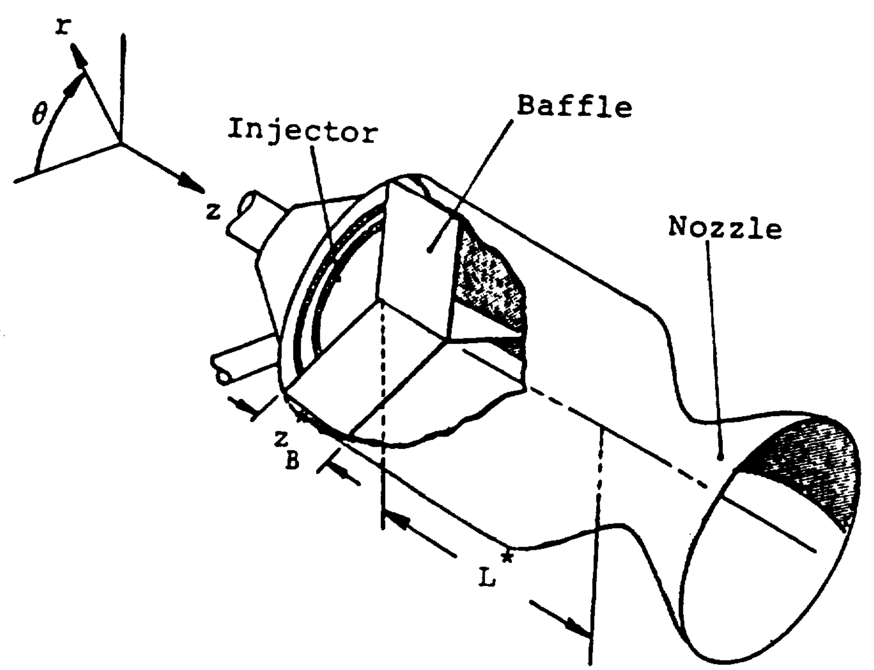


Figure 1b: Three-dimensional baffled chamber

3. - COMPUTER PROGRAMS

3.1 - TWO-DIMENSIONAL PROGRAMS

This section will describe the two-dimensional distributed and concentrated combustion programs. A general overview of the distributed combustion program (DIST2D) will cover the program structure, input, output, and results. Distributed combustion sample runs and listing are located in the appendix. A brief discussion of the two-dimensional concentrated combustion program (CON2D) will be presented last. This discussion will cover the program input and output. The appendix includes a sample run from (CON2D) and listing.

3.1.1 - DISTRIBUTED COMBUSTION PROGRAM DESCRIPTION

The computer program DIST2D consists of a main program and fourteen subprograms which are listed in Table 1. The program has two main running options; Option one requires the user to input an interaction index (n) and combustion time lag (τ), and the resulting complex frequency is calculated. Option two requires the input of a frequency range and increment and the program generates an n,τ stability map. Additional program options are the capability of placing a radial acoustic absorber in the chamber and of making pressure amplitude calculations at any location.

A description of the program structure follows. (see Figure 2 for program flow chart.) After all input variables and program options are read in the program proceeds with the zero order (closed baffled chamber, $\breve{\phi}$) solution. The iteration counter is initialized along with the chamber coefficient vector and an initial approximation to the frequency, $\breve{\omega}$ is made. The program then proceeds into a loop that iterates on frequency, $\breve{\omega}$ until a correct solution to the matching condition equation (Eq. 11 Ref. 1) converges. The converged frequency and iteration counter are then printed out. At this point one full

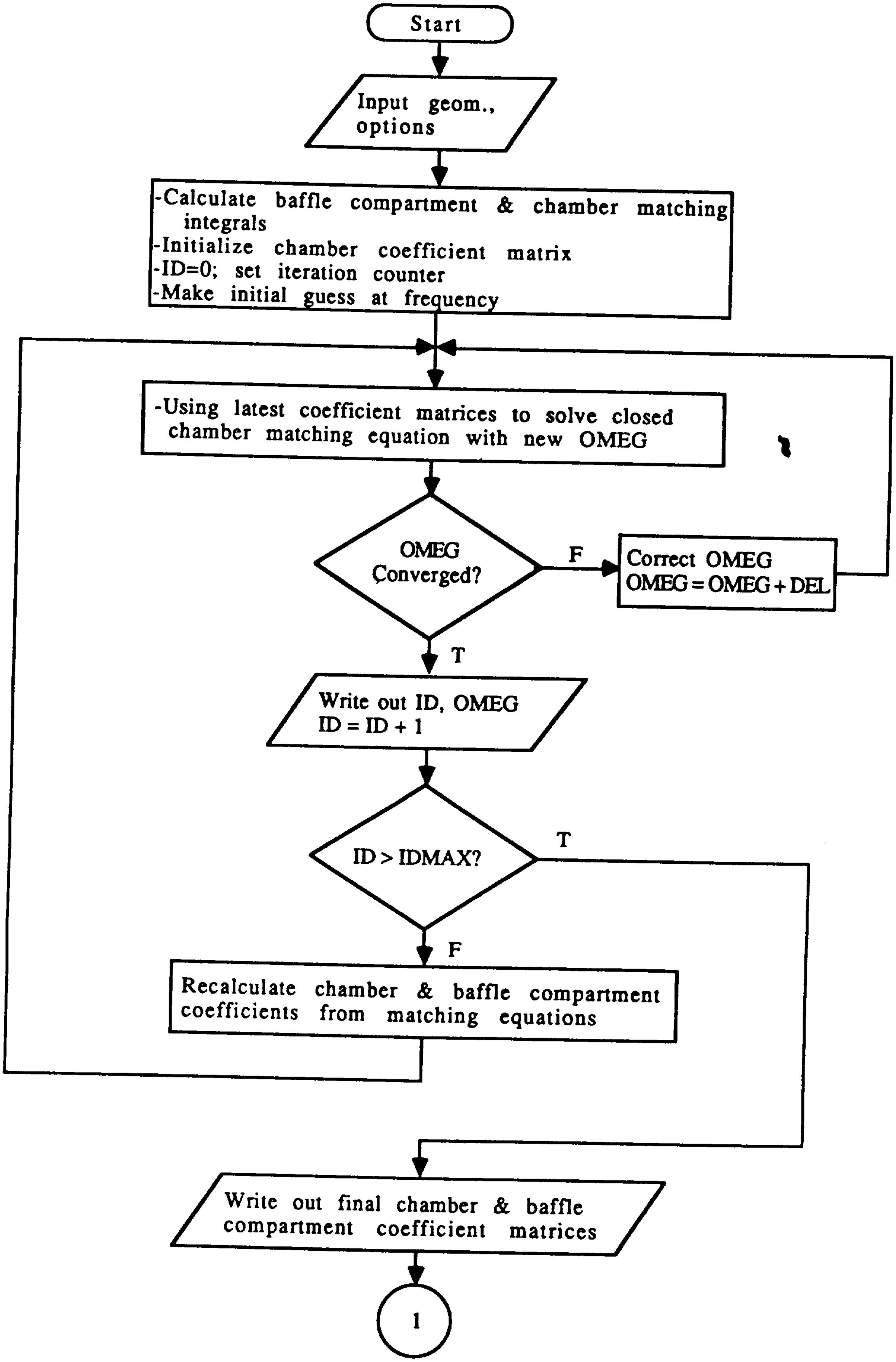


Figure 2: 2-D & 3-D program flowchart

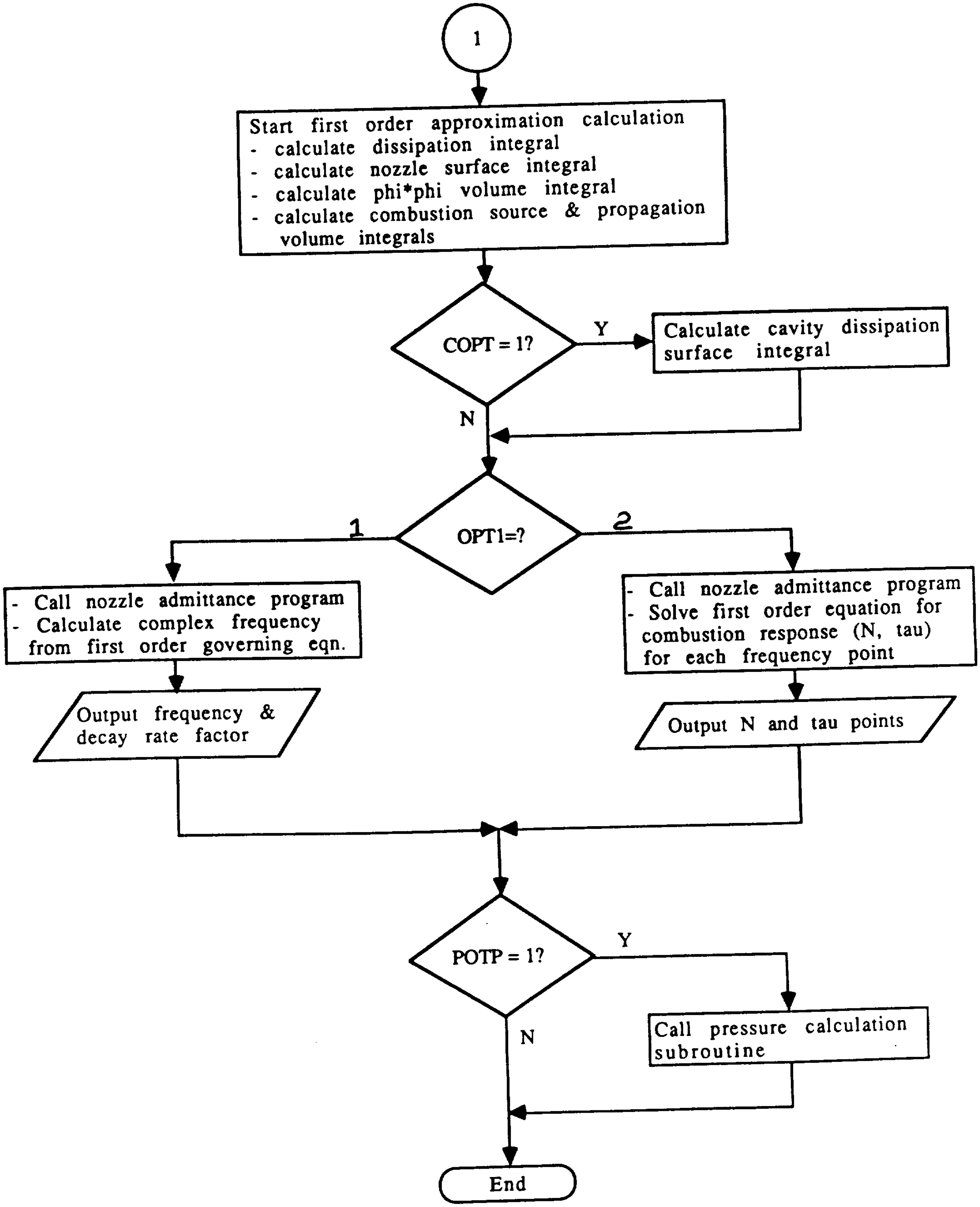

1
Start first order approximation calculation
- calculate dissipation integral
- calculate nozzle surface integral
- calculate phi*phi volume integral
- calculate combustion source & propagation volume integrals
COPT = 1?
Y
Calculate cavity dissipation surface integral
N
OPT1=?
1
2
- Call nozzle admittance program
- Calculate complex frequency from first order governing eqn.
- Call nozzle admittance program
- Solve first order equation for combustion response (N, tau) for each frequency point
Output frequency & decay rate factor
Output N and tau points
POTP = 1?
Y
N
Call pressure calculation subroutine
End

TABLE 1: subroutines and functions in DIST2D

Function CCOSH	-	Performs hyperbolic cosine with a complex argument.
Subroutine NTAU1	-	Calculates n, τ from combustion response.
Subroutine PRES	-	Calculates pressure at a specific location in the chamber.
Function BI2	-	Evaluates $\int z \phi \frac{d\phi}{dz} dz$ in the baffle compartments
Function CHI2	-	Evaluates $\int z \phi \frac{d\phi}{dz} dz$ in the main chamber
Function BI3	-	Evaluates $\int \phi \frac{d\phi}{dz} dz$ in the baffle compartments
Function BI1	-	Evaluates $\int \phi \phi dz$ in the baffle compartments
Function CHI3	-	Evaluates $\int \phi \frac{d\phi}{dz} dz$ in the main chamber
Function CHI1	-	Evaluates $\int \phi \phi dz$ in the main chamber

Subroutines NOZINI, NOZADM, INTGRT, MACH, CALADM are used in the calculation of the nozzle admittance and were obtained from Refs. 4 & 5.

iteration is complete and a check on the iteration limit is made. If the iteration limit has not been exceeded the main chamber and baffle compartment coefficients are recalculated (using Eqs. 9 & 10 Ref. 1) with the newly calculated frequency value, but if the iteration limit has been exceeded the coefficient vectors are printed out and the zero order calculation for $\breve{\phi}$ and $\breve{\omega}$ is complete.

At this point the program starts the solution computation for Equation (2) given in the Theory section above. Using the zero order velocity potential solution all the chamber surface and volume integrals are evaluated. These integrals include the combustion source and propagation volume integrals, the $\breve{\phi}$ squared volume integral, the nozzle surface integral, baffle blade dissipation integral, and cavity absorber surface integral if applicable. Depending on the option being run the program either solves the governing equation for complex frequency (Option 1) or solves the equation for combustion response (Option 2). Finally, the pressure calculation subroutine is called if this option is desired.

3.1.2 - DISTRIBUTED COMBUSTION PROGRAM INPUT

All input variables for the main program are read in from file 'DISIN2'. A list of the inputs is described in Table 2. In the file the variables appear in the same order as in Table 2 and need only be separated by commas.

The variables OPT1, COPT, POPT are the option variables. If variable (OPT1 = 1) option one, which calculates complex frequency from input values of n and τ, is executed. If the variable (OPT1 = 2) option two is executed which generates a stability map. A radial cavity absorber is present if the variable (COPT = 1). The cavity admittance must be supplied along with the aperture width. The absorber is assumed to be located at the injector (z = 0) and extends downstream from there. If the pressure option is to be run, set variable (POPT = 1). A separate input file called 'PRESPT2' must be supplied. This file described in Table 3 contains the total number of Z,Y locations to be calculated on the first line followed by each coordinate pair on successive lines.

TABLE 2: Input variables for file 'DISIN2'

VARIABLE	VARIABLE DESCRIPTION	DIMENSIONS
MC	: number of series terms to represent series solution in the main chamber (maximum of 50 terms. default value of 30 terms)	(none)
MB	: number of series terms to represent series solution in the baffle compartments (maximum of 50 terms. default value of 30 terms)	(none)
ALENGTH	: chamber length	(ft)
ZB	: baffle blade length	(ft)
T	: baffle blade thickness	(ft)
R	: chamber whole height	(ft)
MUB	: number of evenly spaced baffle compartments (maximum of 5 compartments)	(none)

HST	: nozzle throat radius (half height)	(ft)
RC	: radius of curvature at nozzle throat	(ft)
RE	: radius of curvature at nozzle entrance	(ft)
ALPHA	: nozzle convergence half angle	(deg)
AO	: chamber speed of sound at stagnation conditions	(ft/s)
PO	: chamber pressure at stagnation conditions	(psf)
GAMMA	: ratio of specific heats	(none)
PAMP	: peak to peak pressure amplitude	(percent of main chamber)
MHAT	: dominating transverse mode number in main chamber	(none)
IDMAX	: maximum number of frequency iterations for successive approximation (default value of 5)	(none)
ZS	: z location where combustion starts	(ft)
ZE	: z location where combustion is completed	(ft)
OPT1	: option selection as described above (1 OR 2)	

IF (OPT1 = 1) THEN

VAL1	: combustion interaction index (n)	(none)
VAL2	: combustion time lag (τ)	(msec)
VAL3	: not used in this option	

IF (OPT1 = 2) THEN

VAL1	: starting frequency	(hertz)
VAL2	: ending frequency	(hertz)
VAL3	: frequency increment	(hertz)

COPT	: cavity option (0 if no cavity, 1 if cavity present)	
BETACR	: real part of cavity admittance	(ft/s)/(psf)
BETACI	: imaginary part of cavity admittance	(ft/s)/(psf)
ZA	: z location where cavity ends (aperture width)	(ft)
POPT	: pressure option (1 if pressure points are to be calculated, 0 if no pressure calculations are to be made)	

TABLE 3: Input variables for file 'PRESPT2'

VARIABLE	VARIABLE DESCRIPTION	DIMENSIONS
N	: number of points to be calculated	(none)
Z,Y	: N number of sets of z,y locations for pressure calculations	(ft)

3.1.3 - DISTRIBUTED COMBUSTION PROGRAM OUTPUT

The output file generated is called 'DISOUT2'. This file starts with the chamber geometry and operating conditions, this includes calculated values for nozzle inlet Mach number, steady state pressure and sound speed. For each ω frequency iteration the iteration number and frequency is printed out. After the iteration limit is reached the final main chamber and baffle compartment Fourier coefficient vectors are printed out. Next, a calculation of nozzle admittance based on $\breve{\omega}$ is printed out. At this point if Option one is selected the chamber complex frequency is printed out ($\omega_R + i\lambda$), this is also represented by a decay/growth rate factor which gives the ratio of the amplitude after one period to that of the previous period. Decay rate (λ) is also represented in decibels per cycle. If Option two is selected the output consist of a list containing frequency, interaction index (n), and combustion time lag (τ). For Option two an additional output file called 'NTDATA2' is generated which contains τ,n values for plotting purposes.

3.1.4 - DISTRIBUTED COMBUSTION PROGRAM RESULTS AND DISCUSSION

The following section is intended to show some of the capabilities and predictions of the distributed combustion program. A series of n,τ plots show the effects of baffle blade length, combustion zone variations, and acoustic absorbers. A pressure profile is also included which shows the effects of baffle blade length.

Run time for the two dimensional program does not present a problem. Run time for a typical test case in which 30 term vectors were kept required approximately 75 CPU seconds on the VAX 11/780 machine at Colorado State University.

The baffled chamber geometry and other input parameters used for the series of plots are listed in Table 4. The effect of baffle length on pressure amplitude is shown in Figure 3. The long baffle (33.3% of chamber length) induced a large pressure amplitude decrease from the injector face (z = 0) to the nozzle (z = ALENGTH) while the short (6.67%) baffle had only a minor effect. A chamber with no baffle at all would show no amplitude decrease. This result is important as an aid in understanding other stability predictions to be discussed. The effect of moving a concentrated combustion zone down the chamber is illustrated in Figure 4 for a baffle blade length that is 6.67% of the chamber length. The same combustion zone movement is shown in Figure 5 for a baffle blade length which is 33.3% of the chamber length. In both cases (ZE - ZS) = .048ft, and ZS is varied from 0 to 1.632ft. For the 6.67% baffle moving the combustion zone downstream does not have a large effect on stability. This result is due to the fact that the pressure amplitude does not change significantly downstream. The large pressure amplitude decrease with Z for the 33.3% baffle explains the large shifts in the n,τ curves as the concentrated combustion zone is moved toward the nozzle. In interpreting these results it must be remembered that combustion input is proportional to local pressure amplitude, in the n,τ model. For all combustion zone locations the large baffle causes a stabilizing shift upward of the n,τ curves as well as a potentially destabilizing flattening of the curves. Figure 6 shows a set of curves for a 33.3% baffle with a combustion zone starting at the injector and extending different distances downstream (i.e. ZS = 0, ZE = .408, 1.02, 2.04 (ft)). As can be readily seen distributing the combustion has a stabilizing effect. The final plot shows the clear stabilizing effect of an acoustic absorber. The absorber used had a slot width of .136ft and a pure real admittance of .04222(ft/s)/(psf).

TABLE 4: Input parameters used for 2-D plots

MC	= 30	RE	= .11 ft
MB	= 30	ALPHA	= 30 deg
ALENGTH	= 2.04 ft	AO	= 3850 ft/sec
T	= .068 ft	PO	= 43,200 psf
R (chamber height)	= 1.36 ft	GAMMA	= 1.2
MUB	= 2 compartments	PAMP	= 20
HST	= .25 ft	MHAT	= 1
RC	= .25 ft	IDMAX	= 4
MACH	= .2232		

3.1.5 - CONCENTRATED COMBUSTION PROGRAM DESCRIPTION

The two-dimensional concentrated combustion program is in essence the same program that appears in Reference 1. The following modifications have made. First, The corrected concentrated combustion model described in the Theory section has been implemented. Secondly, the nozzle admittance prediction model and program appearing in References 4 & 5 (Aerojet's NOZADM program) has been added. Finally, all of the nondimensional inputs and outputs have been dimensionalized. It should be noted that the two-dimensional concentrated program is only capable of predicting frequency and decay rate from a given n,τ.

3.1.6 - CONCENTRATED COMBUSTION PROGRAM INPUT

All input variables for the main program are read in from file 'CON2IN'. A list of the required inputs is described in Table 5. The variables appear in the same order in Table 5 as they do in the file and need only to be separated by commas.

TABLE 5: Input variables for file 'CON2IN'

VARIABLE	VARIABLE DESCRIPTION	DIMENSIONS
MC	: number of series terms to represent series solution in the main chamber (maximum of 50 terms. default value of 30 terms)	(none)
MB	: number of series terms to represent series solution in the baffle compartments (maximum of 50 terms. default value of 30 terms)	(none)
IDMAX	: maximum number of frequency iterations for successive approximation (default value of 5)	(none)
ALENGTH	: chamber length	(ft)
ZB	: baffle blade length	(ft)
T	: baffle blade thickness	(ft)
DR	: chamber whole height	(ft)
MUB	: number of evenly spaced baffle compartments (maximum of 5 compartments)	(none)
HST	: nozzle throat radius (half height)	(ft)
RC	: radius of curvature at nozzle throat	(ft)
RE	: radius of curvature at nozzle entrance	(ft)
ALPHA	: nozzle convergence half angle	(deg)

AO	:	chamber speed of sound at stagnation conditions	(ft/s)
PO	:	chamber pressure at stagnation conditions	(psf)
GAMMA	:	ratio of specific heats	(none)
PAMP	:	peak to peak pressure amplitude	(percent of main chamber)
MHAT	:	dominating transverse mode number in main chamber	(none)
AN	:	combustion interaction index (n)	(none)
TAU	:	combustion time lag (τ)	(msec)

3.1.7 - CONCENTRATED COMBUSTION PROGRAM OUTPUT

The output of the concentrated combustion program is written into file 'CON2OUT'. The output starts with a listing of the geometrical inputs and operating conditions such as nozzle inlet Mach number, steady state chamber pressure and sound speed. For each frequency iteration the program outputs the complex frequency (hertz) and iteration number. After the iteration limit is reached the final chamber and baffle compartment vectors are printed out. The final output includes the decay rate with baffle dissipation included, this is also presented as decay in decibels/cycle and the decay/growth rate factor.

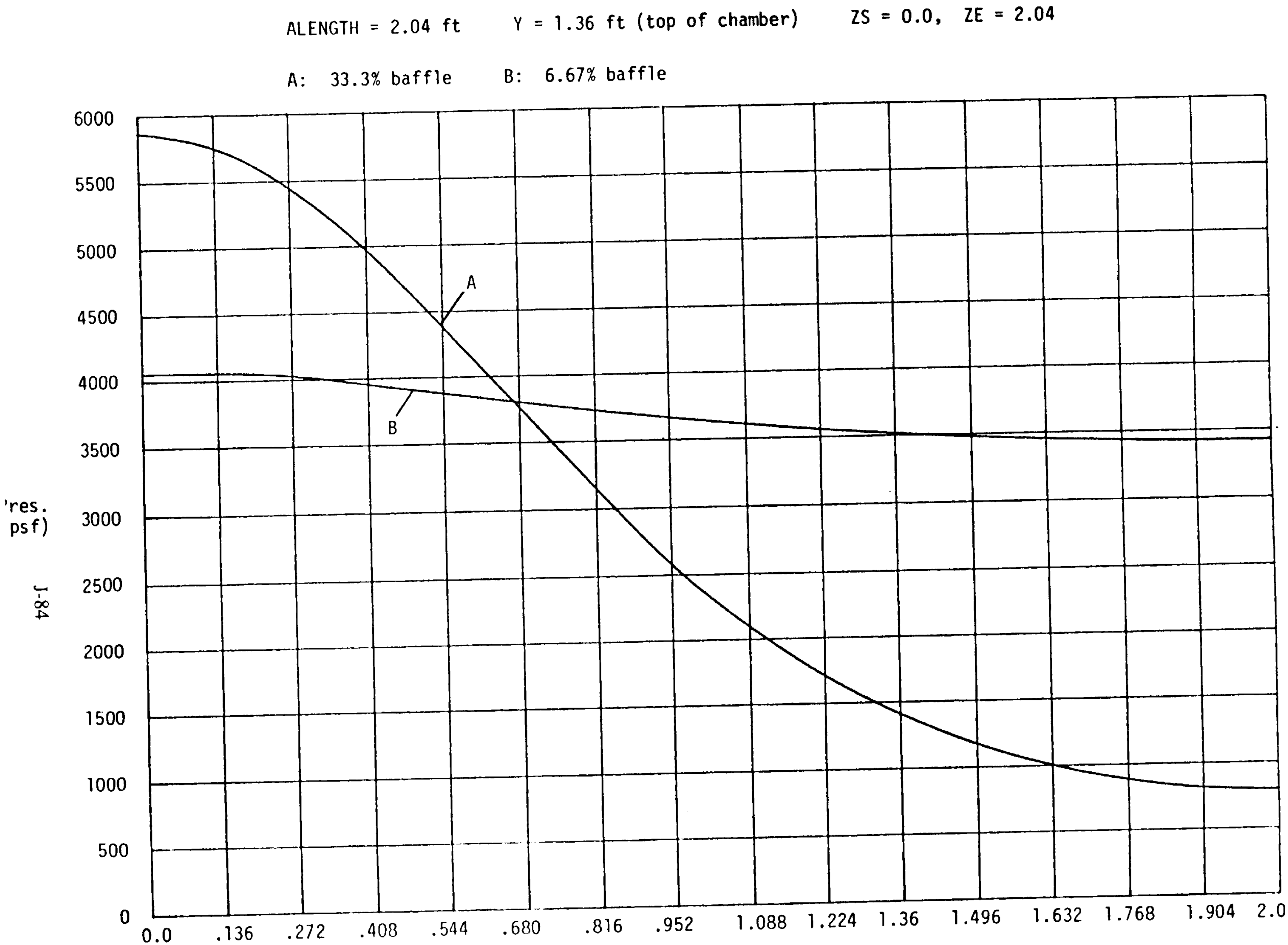


Figure 3: 2-D pressure profile

Figure 4

NEUTRAL STABILITY MAP FOR A 2-D CHAMBER, CONCENTRATED COMBUSTION ZONES

Chamber dimensions (ft): length = 2.04 whole height = 1.36
Baffle dimensions (ft): length = 0.136 thickness = 0.068
Steady state speed of sound = 3850.0 ft/s
Steady state pressure = 43200.0 psf
Ratio of specific heats = 1.2
Frequency range (Hz): 1200 to 1700

Mode: First transverse
No. of baffles: 1

ZONES (distance in feet from injector plate):

A: ZS = 0.0 to ZE = 0.408 (no baffle present)
B: ZS = 0.0 to ZE = 0.408
C: ZS = 0.476 to ZE = 0.884
D: ZS = 1.632 to ZE = 2.04

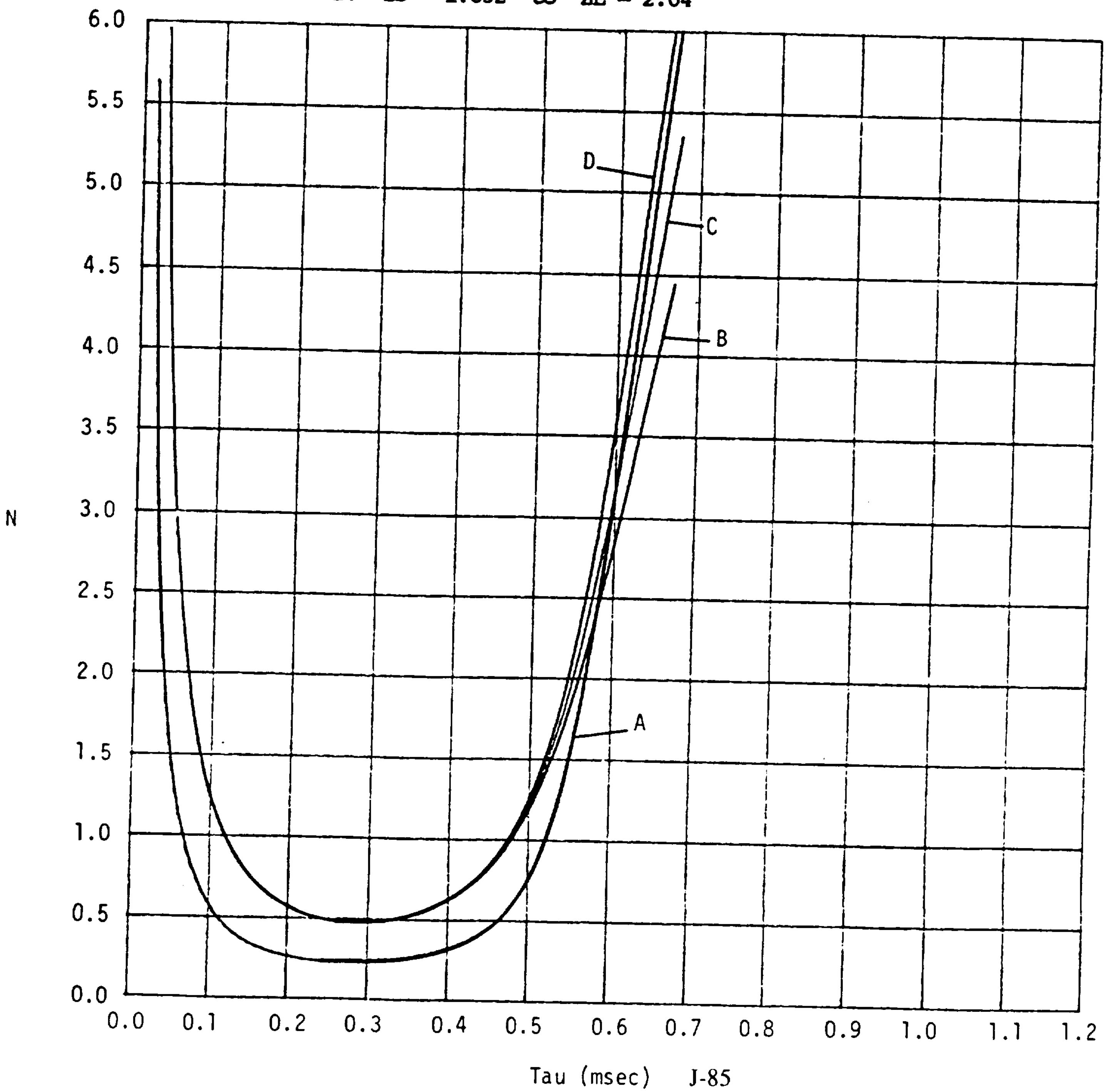


Figure 5

NEUTRAL STABILITY MAP FOR A 2-D CHAMBER, CONCENTRATED COMBUSTION ZONES

Chamber dimensions (ft): length = 2.04 whole height = 1.36
Baffle dimensions (ft): length = 0.68 thickness = 0.068
Steady state speed of sound = 3850.0 ft/s
Steady state pressure = 43200.0 psf
Ratio of specific heats = 1.2 Mode: First transverse
Frequency range (Hz): 700 to 1200 No. of baffles: 1

ZONES (distance in feet from injector plate):
A: ZS = 0.0 to ZE = 0.408
B: ZS = 0.476 to ZE = 0.884
C: ZS = 1.632 to ZE = 2.04

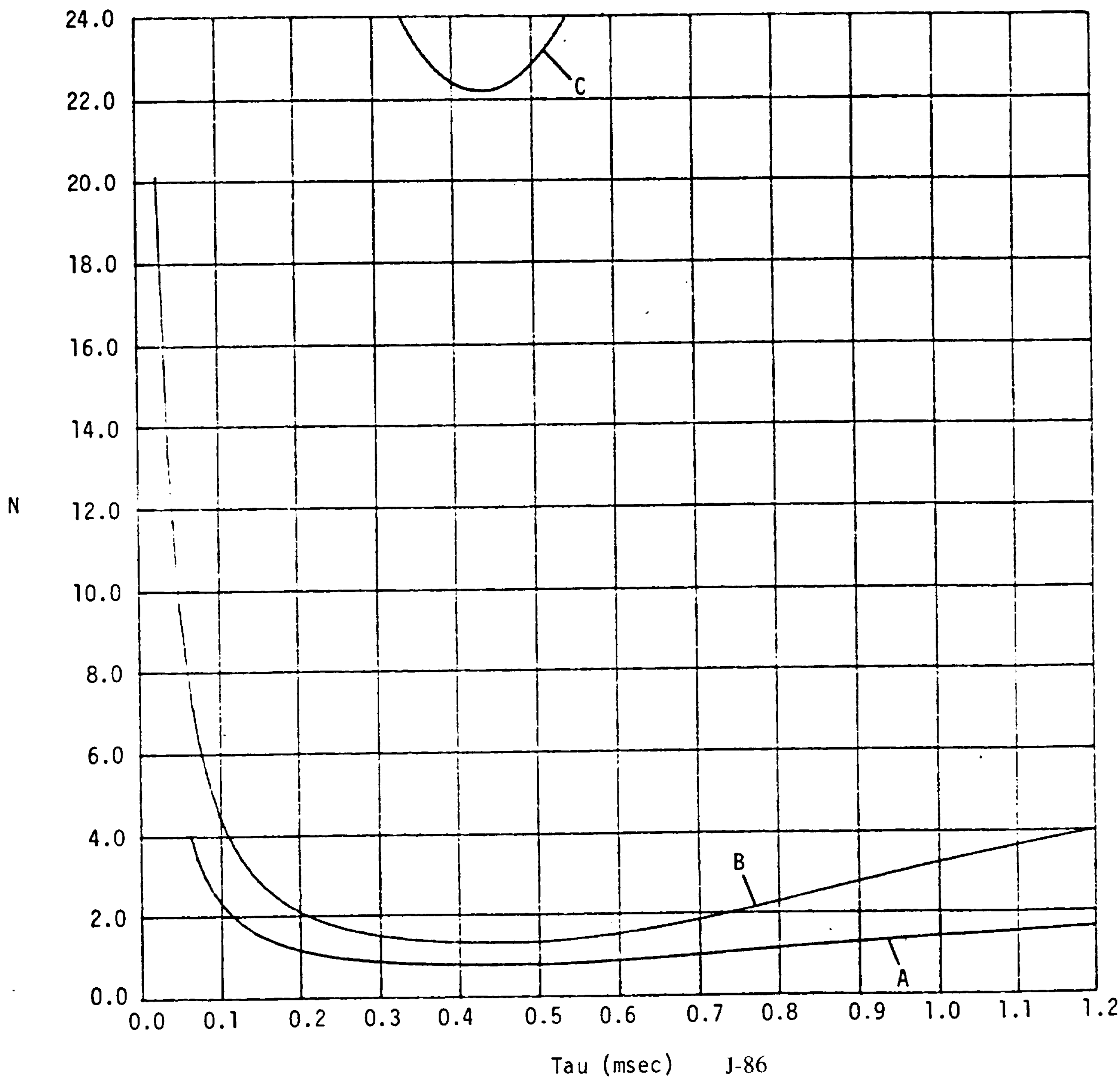


Figure 6

NEUTRAL STABILITY MAP FOR A 2-D CHAMBER, DISTRIBUTED COMBUSTION ZONES

Chamber dimensions (ft): length = 2.04 whole height = 1.36
Baffle dimensions (ft): length = 0.68 thickness = 0.068
Steady state speed of sound = 3850.0 ft/s
Steady state pressure = 43200.0 psf
Ratio of specific heats = 1.2 Mode: First transverse
Frequency range (Hz): 700 to 1200 No. of baffles: 1

ZONES (distance in feet from injector plate):

A: ZS = 0.0 to ZE = 2.04 (no baffle present)
B: ZS = 0.0 to ZE = 0.408
C: ZS = 0.0 to ZE = 1.02
D: ZS = 0.0 to ZE = 2.04

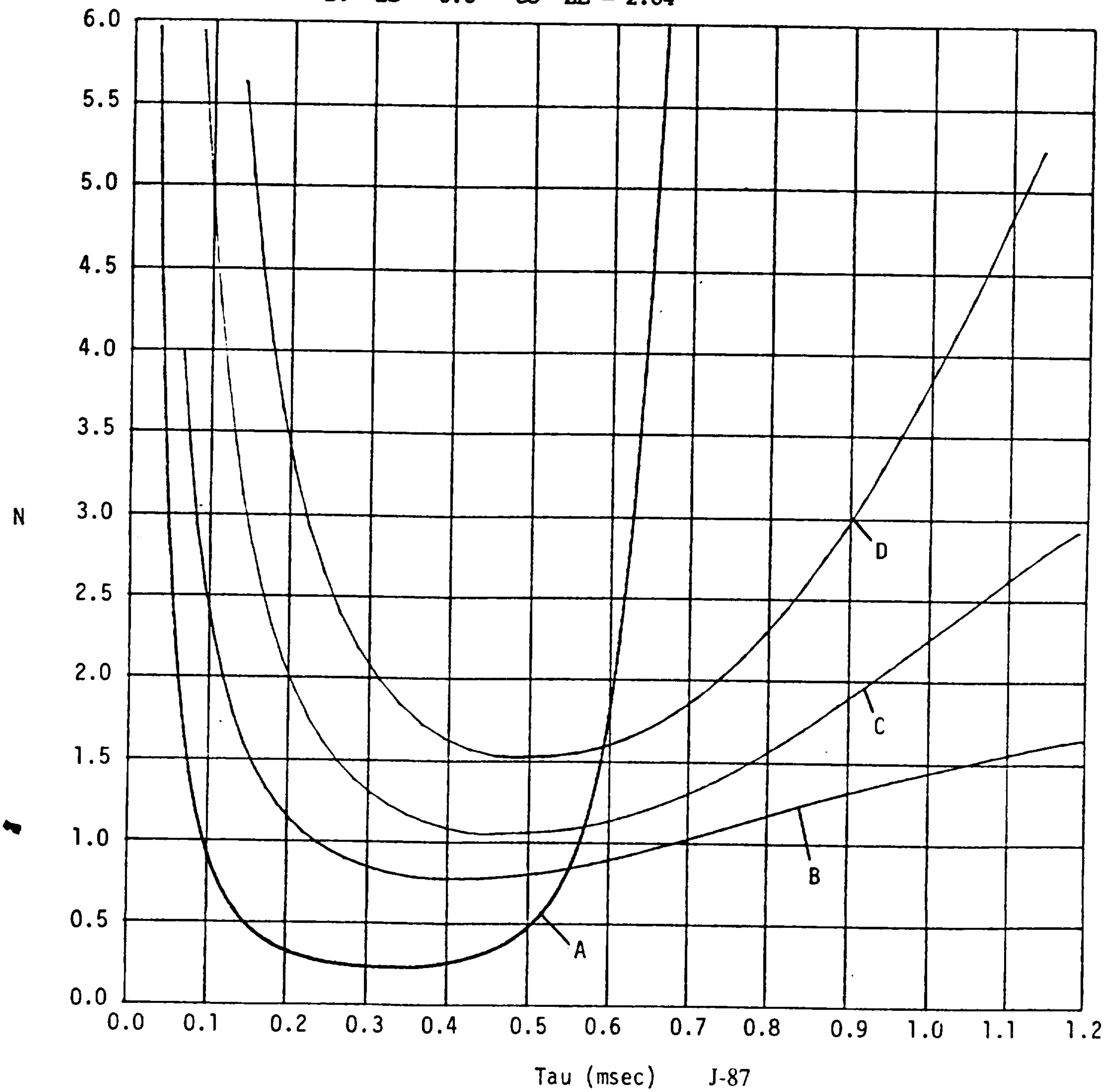
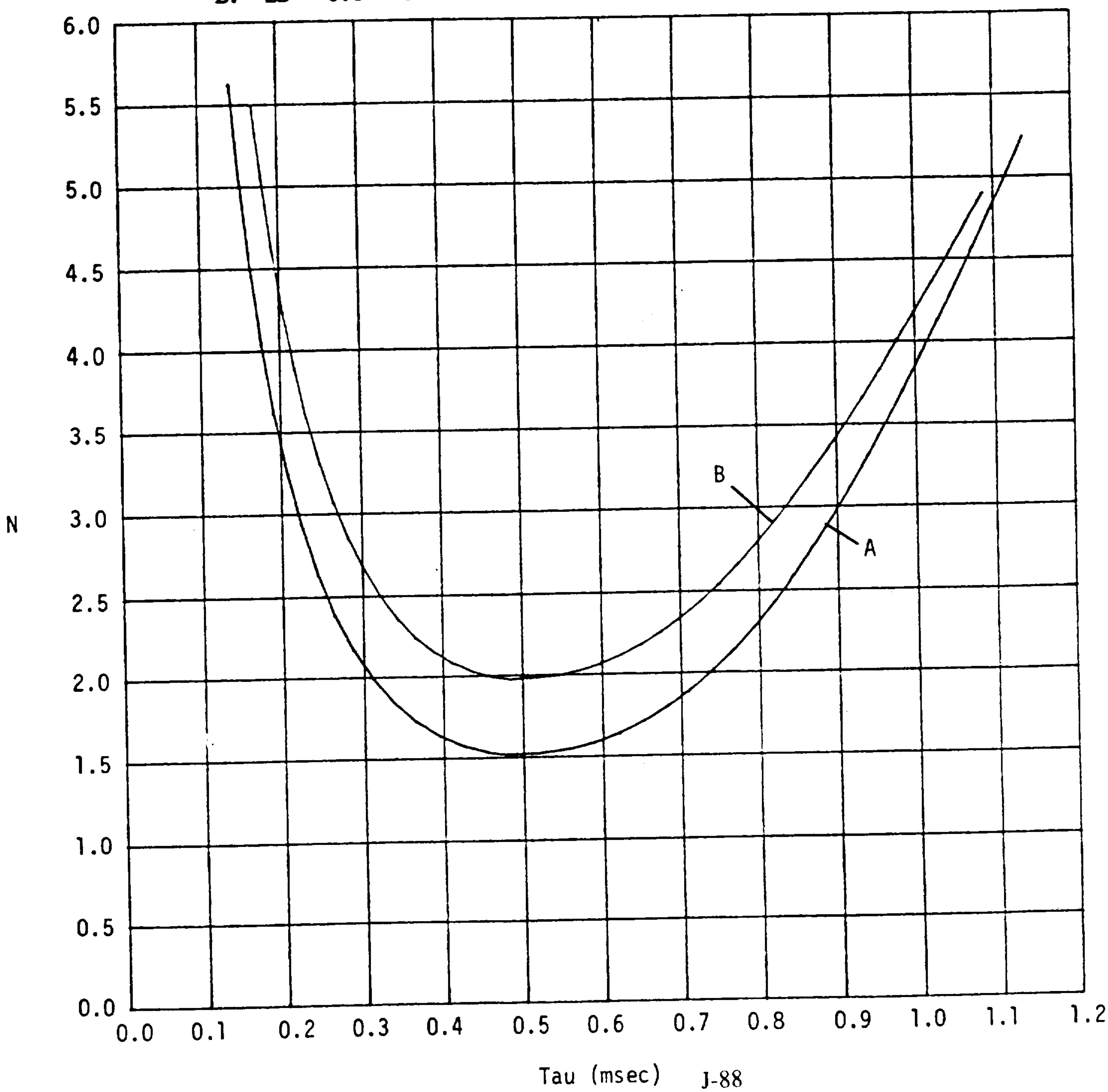


Figure 7

NEUTRAL STABILITY MAP FOR A 2-D CHAMBER, DISTRIBUTED COMBUSTION ZONES

Chamber dimensions (ft): length = 2.04 whole height = 1.36
Baffle dimensions (ft): length = 0.68 thickness = 0.068
Steady state speed of sound = 3850.0 ft/s
Steady state pressure = 43200.0 psf
Ratio of specific heats = 1.2 Mode: First transverse
Frequency range (Hz): 700 to 1200 No. of baffles: 1
Cavity admittance (ft/s)/(psf): real = 0.04222 imaginary = 0.0
Cavity aperture width = 0.136 ft

ZONES (distance in feet from injector plate):
A: ZS = 0.0 to ZE = 2.04 - without cavity dissipation
B: ZS = 0.0 to ZE = 2.04 - with cavity dissipation



3.2 - THREE-DIMENSIONAL PROGRAMS

This section will describe the three-dimensional distributed and concentrated combustion programs. The parallels between the two-dimensional and three-dimensional programs are strong, this fact will simplify the three-dimensional discussion somewhat. A overview of the distributed combustion program (DIST3D) will cover the program structure, input, output, and results. Three-dimensional distributed combustion program runs and listing are located in the appendix. A brief discussion of the three-dimensional concentrated combustion program (CON3D) will be presented last. This discussion will cover the program input, output, and current status. The appendix includes a sample run from (CON3D) and listing.

3.2.1 - DISTRIBUTED COMBUSTION PROGRAM DESCRIPTION

The computer program DIST3D consists of a main program and seventeen subprograms which are listed in Table 6. The three-dimensional program like the two-dimensional has two main running options; Option one which calculates complex frequency from a given n,τ point, and Option two which produces a n,τ stability map. Additional program options include the capability of placing a radial acoustic absorber in the chamber and of making pressure amplitude and phase calculations at any location. The three-dimensional program has an additional option that determines the waveform type present in the main chamber. This waveform can either take the form of a spinning wave or standing wave.

A description of the program structure follows. (see Figure 2 for program flow chart.) After all input variables and program options are read in the program proceeds with the zero order (closed baffled chamber, $\breve{\phi}$) solution. The iteration counter is initialized along with the chamber coefficient matrix

TABLE 6: subroutines and functions in DIST3D

Function CCOSH	-	Performs hyperbolic cosine with a complex argument.
Subroutine NTAU1	-	Calculates n, τ from combustion response.
Subroutine PRES	-	Calculates pressure at a specific location in the chamber.
Function BI2	-	Evaluates $\int z\, \phi \frac{d\phi}{dz} dz$ in the baffle compartments
Function CHI2	-	Evaluates $\int z\, \phi \frac{d\phi}{dz} dz$ in the main chamber
Function BI3	-	Evaluates $\int \phi \frac{d\phi}{dz} dz$ in the baffle compartments
Function BI1	-	Evaluates $\int \phi\, \phi\, dz$ in the baffle compartments
Function CHI3	-	Evaluates $\int \phi \frac{d\phi}{dz} dz$ in the main chamber
Function CHI1	-	Evaluates $\int \phi\, \phi\, dz$ in the main chamber
Function BESSCAL	-	Calculates the value of the Bessel function of integer and half integer order and of arbitrary argument
Subroutine ROOT	-	Calculates the root of the derivative of Bessel functions
Subroutine VDISP	-	Calculated baffle blade tip dissipation

Subroutines NOZINI, NOZADM, INTGRT, MACH, CALADM are used in the calculation of the nozzle admittance and were obtained from Refs. 2 & 3.

and an initial approximation to the frequency, $\hat{\tilde{\omega}}$ is made. The program then proceeds into a loop that iterates on frequency, $\tilde{\omega}$ until a correct solution to the matching condition equation (Eq. 23 Ref. 1) converges. The converged frequency and iteration counter are then printed out. At this point one full iteration is complete and a check on the iteration limit is made. If the iteration limit has not been exceeded the main chamber and baffle compartment coefficients are recalculated (using Eqs. 21 & 22 Ref. 1) with the newly calculated frequency value, but if the iteration limit has been exceeded the coefficient matrices are printed out and the zero order calculation for $\hat{\tilde{\phi}}$ and $\hat{\tilde{\omega}}$ is complete.

At this point the program starts the solution computation for Equation (2) given in the Theory section above. Using the zero order velocity potential solution all the chamber surface and volume integrals are evaluated. These integrals include the combustion source and propagation volume integrals, the $\tilde{\phi}$ squared volume integral, the nozzle surface integral, baffle blade dissipation integral, and cavity absorber surface integral if applicable. Depending on the option being run the program either solves the governing equation for complex frequency (Option 1) or solves the equation for combustion response (Option 2). Finally, the pressure calculation subroutine is called if this option is desired.

3.2.2 - DISTRIBUTED COMBUSTION PROGRAM INPUT

All input variables for the main program are read in from file 'DISIN3'. A list of the inputs is described in Table 7. In the file the variables appear in the same order as in Table 7 and need only be separated by commas.

The variables OPT1, COPT, POPT, MX are the option variables. If variable (OPT1 = 1) program Option one is executed, if (OPT1 = 2) program Option two is executed. A radial cavity absorber is present if the variable (COPT = 1). The cavity admittance must be supplied along with the aperture width. The absorber is assumed to be located at the injector (z = 0) and extends downstream from there. If the pressure option is to be run, set variable (POPT = 1). A separate input file called 'PRESPT3' must be supplied. This file described in Table 8 contains the total number of R,THETA,Z locations to be calculated on the first line followed by each coordinate pair on successive lines. The variable MX determines the waveform type in the main chamber, (MX = 0) for standing waves and (MX = 1) for spinning waves.

TABLE 7: Input variables for file 'DISIN3'

VARIABLE	VARIABLE DESCRIPTION	DIMENSIONS
MX	: variable that determines what type of main chamber solution is present. (MX = 0 for standing waves, MX = 1 for spinning waves)	(none)
MC	: number of Fourier series terms to represent the main chamber solution (maximum of 20 terms. default value of 11 terms)	(none)
LC	: number of Bessel series terms to represent solution in the main chamber (maximum of 20 terms. default value of 8 terms)	(none)
MB	: number of Fourier series terms to represent the baffle compartment solution (maximum of 20 terms. default value of 11 terms)	(none)
LC	: number of Bessel series terms to represent solution in the baffle compartments (maximum of 20 terms. default value of 8 terms)	(none)
IDMAX	: maximum number of frequency iterations for successive approximation (default value of 9)	(none)
ALENGTH	: chamber length	(ft)
ZB	: baffle blade length	(ft)
T	: baffle blade thickness	(ft)
RCHAMB	: chamber radius	(ft)
MUB	: number of evenly spaced baffle compartments (maximum of 12 compartments)	(none)
HST	: nozzle throat radius	(ft)
RC	: radius of curvature at nozzle throat	(ft)
RE	: radius of curvature at nozzle entrance	(ft)
ALPHA	: nozzle convergence half angle	(deg)
AO	: chamber speed of sound at stagnation conditions	(ft/s)
PO	: chamber pressure at stagnation conditions	(psf)
GAMMA	: ratio of specific heats	(none)
PAMP	: peak to peak pressure amplitude	(percent of main chamber)
MHAT	: dominating transverse mode number in main chamber	(none)
LHAT	: dominating radial mode number in main chamber	(none)
ZS	: z location where combustion starts	(ft)
ZE	: z location where combustion is completed	(ft)
OPT1	: option selection as described above (1 OR 2)	

IF (OPT1 = 1) THEN

VARIABLE	VARIABLE DESCRIPTION	DIMENSIONS
VAL1	: combustion interaction index (n)	(none)
VAL2	: combustion time lag (τ)	(msec)
VAL3	: not used in this option	

IF (OPT1 = 2) THEN

VARIABLE	VARIABLE DESCRIPTION	DIMENSIONS
VAL1	: starting frequency	(hertz)
VAL2	: ending frequency	(hertz)
VAL3	: frequency increment	(hertz)

COPT : cavity option (0 if no cavity, 1 if cavity present)

BETACR	: real part of cavity admittance	(ft/s)/(psf)
BETACI	: imaginary part of cavity admittance	(ft/s)/(psf)
ZA	: z location where cavity ends (aperture width)	(ft)
POPT	: pressure option (1 if pressure points are to be calculated, 0 if no pressure calculations are to be made)	

TABLE 8: Input variables for file 'PRESPT3'

VARIABLE	VARIABLE DESCRIPTION	DIMENSIONS
N	: number of points to be calculated	(none)
	: N number of sets of r,theta,z locations for pressure calculations	
R	: radius	(feet)
THETA	: angle counterclockwise from first baffle blade	(deg.)
Z	: axial distance downstream from injector	(feet)

3.2.3 - DISTRIBUTED COMBUSTION PROGRAM OUTPUT

The output file generated is called 'DISOUT3'. This file starts with the chamber geometry and operating conditions, this includes calculated values for nozzle inlet Mach number, steady state pressure and sound speed. For each ω frequency iteration the iteration number and frequency is printed out. After the iteration limit is reached the final main chamber and baffle compartment Fourier-Bessel coefficient matrices are printed out. Next, a calculation of nozzle admittance based on $\hat{\omega}$ is printed out. At this point if Option one is selected the chamber complex frequency is printed out ($\omega_R + i\lambda$), this is also represented by the decay/growth rate factor. If Option two is selected the output consist of a list containing frequency, interaction index (n), and combustion time lag (τ). For Option two an additional output file called 'NTDATA3' is generated which contains τ,n values for plotting purposes.

3.2.4 - DISTRIBUTED COMBUSTION PROGRAM RESULTS AND DISCUSSION

The following section is intended to show some of the capabilities and predictions of the three-dimensional distributed combustion program. The same series of n,τ plots that were presented in the two-dimensional section are presented here.

Run time for the three-dimensional program can present a problem if large matrices are kept. Table 9 contains run time data for the three-dimensional program run in Option two with variable matrix sizes and constant iteration limit of five. All timings were made from the VAX 11/780 machine at Colorado State University. The convergence of the results for these runs was very good, that is the smaller matrices results compared well to those obtained with the larger matrices. This result, though, is for only one specific case and should not be assumed true for all cases.

TABLE 9: run times for program 'DIST3D'

MATRIX SIZE		
MC & MB	LC & LB	CPU TIME
20	20	4.6 hours
11	8	13 min.
11	4	3.4 min.
8	4	1.93 min.

The baffled chamber geometry and other input parameters used for the series of plots are listed in Table 10. The effect of baffle length on pressure amplitude is shown in Figure 8. The long baffle (33.3% of chamber length) induced a large pressure amplitude decrease from the injector face (z = 0) to the nozzle (z = ALENGTH) while the short (6.67%) baffle had only a minor effect. This result is consistent with the two-dimensional predictions. The effect of moving a concentrated combustion zone down the chamber is illustrated in Figure 9 for a baffle blade length that is 6.67% of the chamber length. The same combustion zone movement is shown in Figure 10 for a baffle blade length which is 33.3% of the chamber length. In both cases (ZE - ZS) equals .1869ft, and ZS is varied from 0 to 1.3706ft. For the 6.67% baffle moving the combustion zone downstream does not have a large effect on stability. Again this result is due to the fact that the pressure amplitude does not change significantly downstream. The large pressure amplitude decrease with Z for the 33.3% baffle explains the large shifts in the n,τ curves as the concentrated combustion zone is moved toward the nozzle. As in the two-dimensional case all the combustion zone locations for the large baffle cause a stabilizing shift upward of the n,τ curves as well as a potentially destabilizing flattening of the curves. Figure 11 shows a set of curves for a 33.3% baffle with a combustion zone anchored at the injector and extending different distances downstream (i.e. ZS = 0, ZE = .1869, 0.77875, 1.5575 (ft)). As can be readily seen distributing the combustion has a stabilizing effect. The final plot shows stabilizing effect of an acoustic absorber. The absorber used had a slot width of .0623ft and a pure real admittance of .04467(ft/s)/(psf).

TABLE 10: Input parameters used for 3-D plots

MC	= 8	RE	= .216 ft
LC	= 2	MACH	= .06615
MB	= 8	ALPHA	= 45 deg
LC	= 2	MX	= 1 (spinning wave)
ALENGTH	= 1.5575 ft	AO	= 3850 ft/sec
T	= .03115 ft	PO	= 43,200 psf
RCHAMB	= .623 ft	GAMMA	= 1.2
MUB	= 3 compartments	PAMP	= 20
HST	= .208 ft	MHAT	= 1
IDMAX	= 8	LHAT	= 1
RC	= .216 ft		

3.2.5 - CONCENTRATED COMBUSTION PROGRAM DESCRIPTION

The three-dimensional concentrated combustion program is a modified version of the program that appears in Reference 1. The same modifications made to the two-dimensional program were made to the three-dimensional program and are listed here again. First, The corrected concentrated combustion model described in the Theory section has been implemented. Secondly, the axisymmetric nozzle admittance prediction model and program References 2 (Aerojet's

NOZADM program) has been added. Finally, all of the nondimensional inputs and outputs have been dimensionalized. The three-dimensional concentrated program is only capable of predicting frequency and decay rate from a given n,τ point.

3.2.6 - CONCENTRATED COMBUSTION PROGRAM INPUT

All input variables for the main program are read in from file 'CON3IN'. A list of the required inputs is described in Table 11. The variables appear in the same order in Table 11 as they do in the file and need only to be separated by commas.

TABLE 11: Input variables for file 'CON3IN'

VARIABLE	VARIABLE DESCRIPTION	DIMENSIONS
MX	: variable that determines what type of main chamber waveform is present. (MX = 0 for standing waves, MX = 1 for spinning waves)	(none)
MC	: number of Fourier series terms to represent the main chamber solution (maximum of 20 terms. default value of 11 terms)	(none)
LC	: number of Bessel series terms to represent solution in the main chamber (maximum of 20 terms. default value of 8 terms)	(none)
MB	: number of Fourier series terms to represent the baffle compartment solution (maximum of 20 terms. default value of 11 terms)	(none)
LB	: number of Bessel series terms to represent solution in the baffle compartments (maximum of 20 terms. default value of 8 terms)	(none)
IDMAX	: maximum number of frequency iterations for successive approximation (default value of 9)	(none)
ALENGTH	: chamber length	(ft)
ZB	: baffle blade length	(ft)
T	: baffle blade thickness	(ft)
RCHAMB	: chamber radius	(ft)
MUB	: number of evenly spaced baffle compartments (maximum of 12 compartments)	(none)
HST	: nozzle throat radius	(ft)
RC	: radius of curvature at nozzle throat	(ft)
RE	: radius of curvature at nozzle entrance	(ft)
ALPHA	: nozzle convergence half angle	(deg)
AO	: chamber speed of sound at stagnation conditions	(ft/s)
PO	: chamber pressure at stagnation conditions	(psf)
GAMMA	: ratio of specific heats	(none)
PAMP	: peak to peak pressure amplitude	(percent of main chamber)

MHAT	: dominating transverse mode number in main chamber	(none)
LHAT	: dominating radial mode number in main chamber	(none)
AN	: combustion interaction index (n)	(none)
TAU	: combustion time lag (τ)	(msec)

3.2.7 - CONCENTRATED COMBUSTION PROGRAM OUTPUT

The output of the concentrated combustion program is written into file 'CON3OUT'. The output starts with a listing of the geometrical inputs and operating conditions such as nozzle inlet Mach number, steady state chamber pressure and sound speed. For each frequency iteration the program outputs the complex frequency (hertz) and iteration number. After the iteration limit is reached the final chamber and baffle compartment matrices are printed out. The final output includes the decay rate with baffle dissipation included, this is also presented as decay in decibels/cycle and the decay/growth rate factor.

ALENGTH = 1.558 ft   R = 0.623 ft (wall of chamber)   ZS = 0.0, ZE = 1.558

A: 33.3% baffle   B: 6.67% baffle

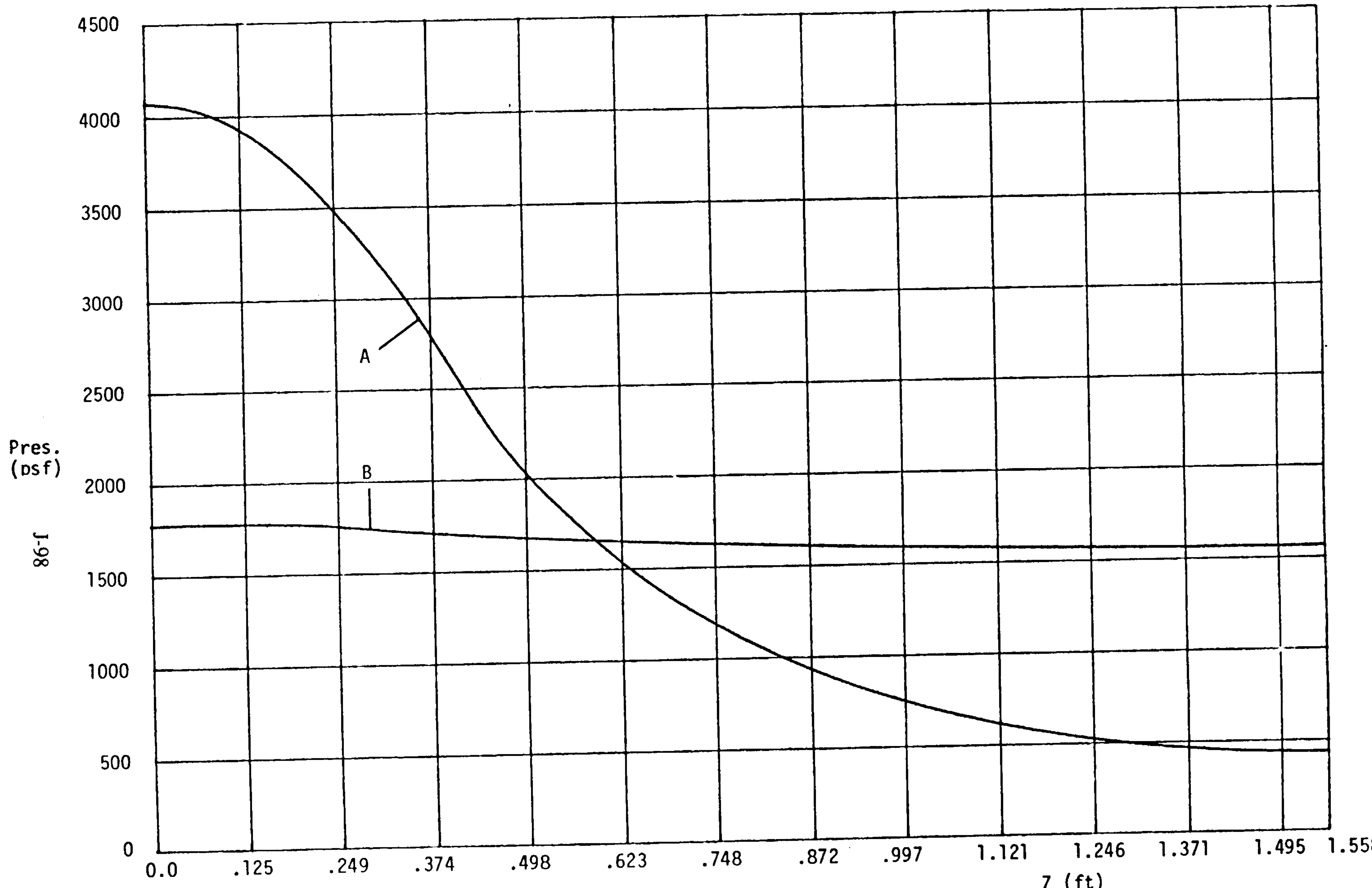


Figure 8: 3-D pressure profile

Figure 9

NEUTRAL STABILITY MAP FOR A 3-D CHAMBER, CONCENTRATED COMBUSTION ZONES

Chamber dimensions (ft): length = 1.5575 radius = 0.623
Baffle dimensions (ft): length = 0.1038 thickness = 0.03115
Steady state speed of sound = 3850.0 ft/s
Steady state pressure = 43200.0 psf
Ratio of specific heats = 1.2
Frequency range (Hz): 1800 to 1950

Mode: First tangential
No. of baffles: 3

ZONES (distance in feet from injector plate):

A: ZS = 0.0 to ZE = 0.1869 (no baffles present)
B: ZS = 0.0 to ZE = 0.1869
C: ZS = 0.4257 to ZE = 0.6126
D: ZS = 1.3706 to ZE = 1.5575

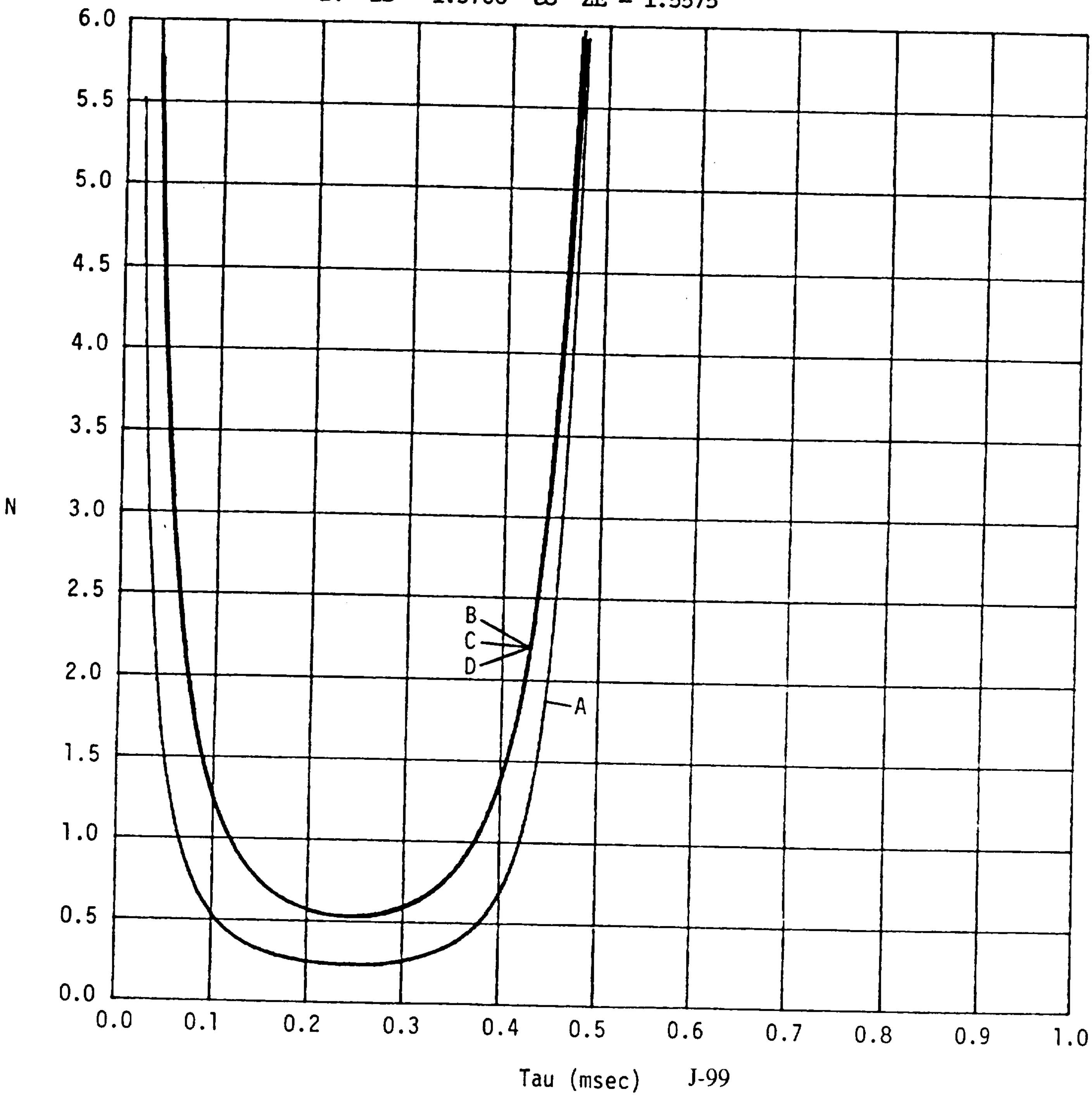


Figure 10

NEUTRAL STABILITY MAP FOR A 3-D CHAMBER, CONCENTRATED COMBUSTION ZONES

Chamber dimensions (ft): length = 1.5575 radius = 0.623
Baffle dimensions (ft): length = 0.51917 thickness = 0.03115
Steady state speed of sound = 3850.0 ft/s
Steady state pressure = 43200.0 psf
Ratio of specific heats = 1.2 Mode: First tangential
Frequency range (Hz): 1000 to 1500 No. of baffles: 3

ZONES (distance in feet from injector plate):
A: ZS = 0.0 to ZE = 0.1869
B: ZS = 0.4257 to ZE = 0.6126
C: ZS = 1.3706 to ZE = 1.5575

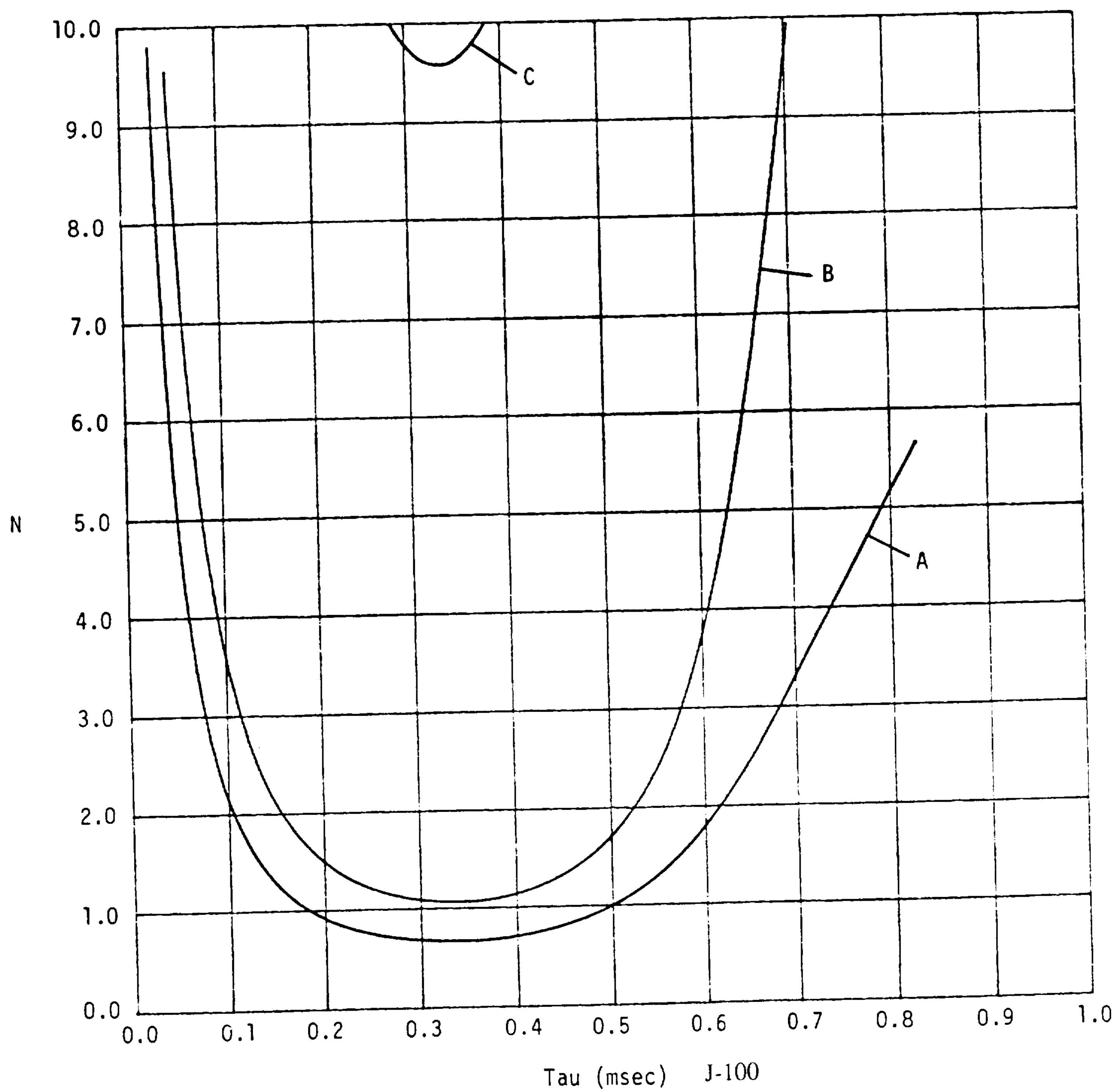


Figure 11

NEUTRAL STABILITY MAP FOR A 3-D CHAMBER, DISTRIBUTED COMBUSTION ZONES

Chamber dimensions (ft): length = 1.5575 radius = 0.623
Baffle dimensions (ft): length = 0.51917 thickness = 0.03115
Steady state speed of sound = 3850.0 ft/s
Steady state pressure = 43200.0 psf
Ratio of specific heats = 1.2 Mode: First tangential
Frequency range (Hz): 1000 to 1500 No. of baffles: 3

ZONES (distance in feet from injector plate):

A: ZS = 0.0 to ZE = 0.1869 (no baffles present)
B: ZS = 0.0 to ZE = 0.1869
C: ZS = 0.0 to ZE = 0.77875
D: ZS = 0.0 to ZE = 1.5575

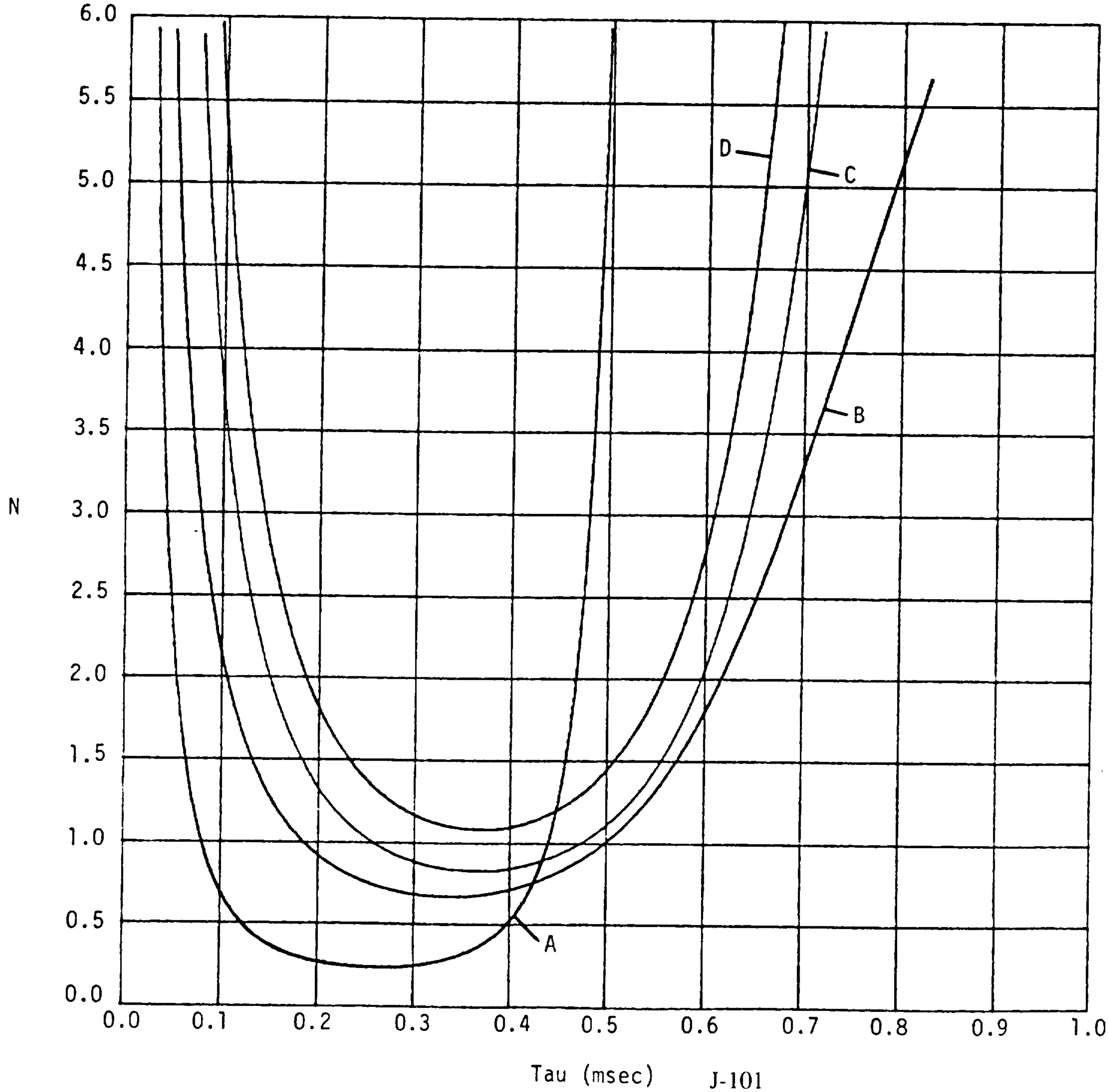
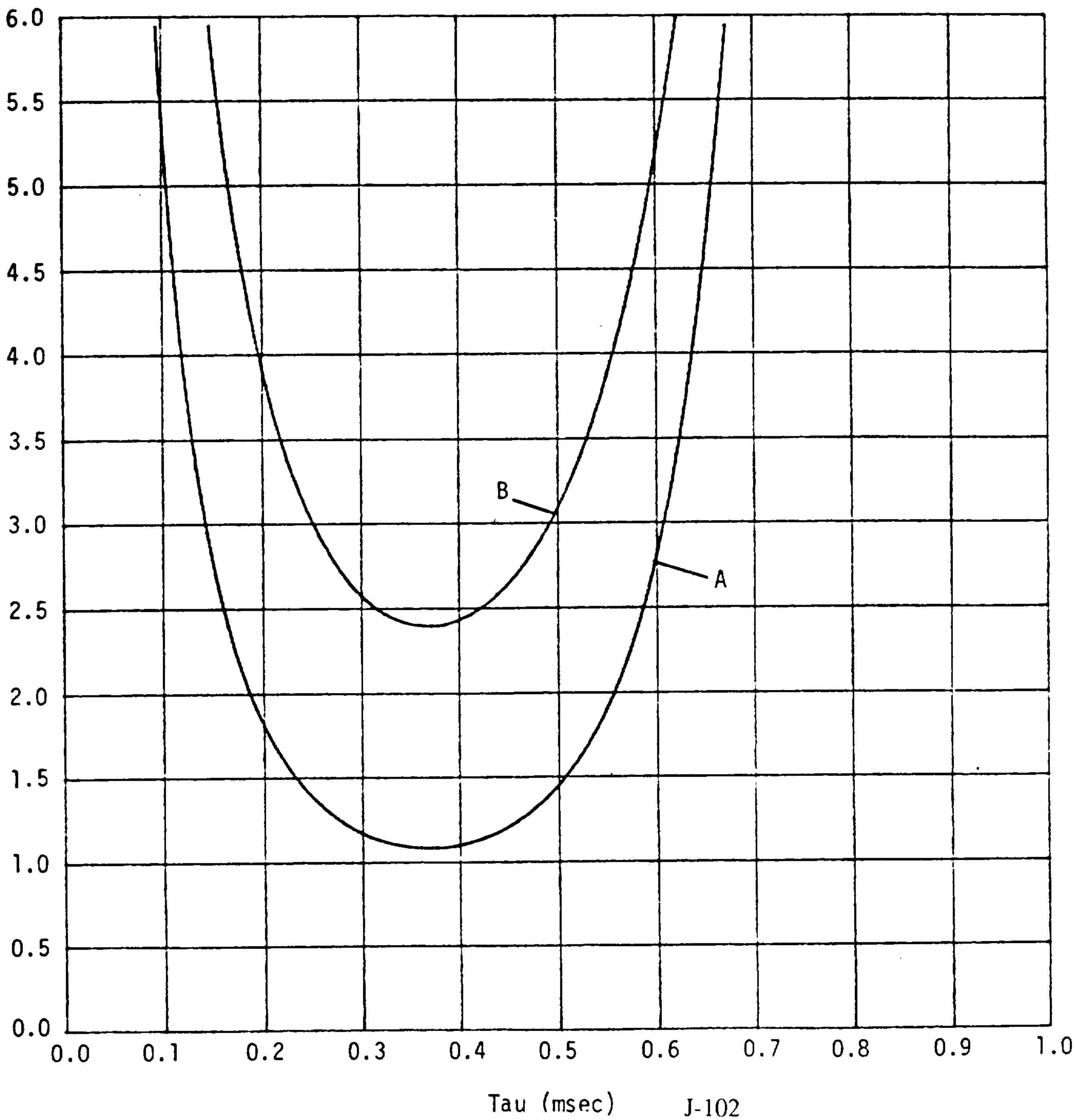


Figure 12

NEUTRAL STABILITY MAP FOR A 3-D CHAMBER, DISTRIBUTED COMBUSTION ZONES

Chamber dimensions (ft): length = 1.5575 radius = 0.623
Baffle dimensions (ft): length = 0.51917 thickness = 0.03115
Steady state speed of sound = 3850.0 ft/s
Steady state pressure = 43200.0 psf
Ratio of specific heats = 1.2 Mode: First tangential
Frequency range (Hz): 1000 to 1500 No. of baffles: 3
Cavity admittance (ft/s)/(psf): real = 0.04467 imaginary = 0.0
Cavity aperture width = 0.0623 ft

ZONES (distance in feet from injector plate):
A: ZS = 0.0 to ZE = 1.5575 - without cavity dissipation
B: ZS = 0.0 to ZE = 1.5575 - with cavity dissipation



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PART C

COMBUSTION RESPONSE PREDICTION MODEL (CRP)

Aerojet TechSystems Company

ENGINEERING AND DEVELOPMENT

ENGINEERING ANALYSIS REPORT

NUMBER: 9980:1998

DATE: 27 JULY 1987

SUBJECT: COMBUSTION RESPONSE MODEL

PAGE 1 OF

NO. OF ENCLOSURES

NO. OF APPENDICES

ADDITIONAL INFORMATION AND WORK NOTES INCLUDED IN MICROFILM FILE CDN

PREPARED FOR: J. L. Pieper

As part of the development of analytical models for use in the LOX/Hydrocarbon Injector Characterization Program (contract number F04611-85-C-0100), a computer code has been developed to calculate the combustion response factors.

The code is capable of calculating the combustion response factors at sub-critical or super-critical chamber pressures. Significant effort was expended to devise a scheme to treat cases where the droplet temperature reaches the boiling temperature or the critical temperature of the propellant, and to generalize the propellant properties input. Correlations for determining the droplet and the combustion gas properties, for example the vapor pressure and the heat of evaporation of the droplet as functions of the temperature, were implemented into the code. A great amount of effort was also expended in several numerical tests to study the sensitivity of the solution to the artificial parameters, e.g. time steps, integration step sizes. The test results are also used to obtain the guidelines for specifying values of the parameters.

The attachment describes the theory, the computer code and the calculated results.

KEYWORDS: Misc (21), Chamber (52), Combustion Stability (105), LOX/HC (153), Model Development (209), Computer Program - New Develop. (210), 1987 (272), T. V. Nguyen (357)

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J-105

COMBUSTION RESPONSE PREDICTION

by

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NOMENCLATURE

Symbols:

A_d Droplet surface area.

c Speed of sound.

C_D Drag Coefficient.

C_{PL} Specific heat of propellant liquid.

D Drag force.

h Convection heat transfer coefficient.

I Imaginary part of the combustion response factor.

J_ν Bessel function of the ν^{th} order.

k Thermal conductivity of the combustion gas.

K_g Mass transfer coefficient.

m Instantaneous droplet mass.

m_i Initial droplet mass.

M Molecular weight of the combustion gas.

M_v Molecular weight of the propellant.

n Pressure interaction index.

n_d Number of droplets in an array.

p Chamber pressure.

p_v Propellant vapor pressure.

Pr Combustion gas Prandtl number.

r Radial coordinate normalized by the chamber radius.

r_d Droplet radius.

R Universal gas constant.

Re Reynolds number.

$S_{\nu\eta}$ Eigenvalues correspond to the radial and the tangential resonance modes ν and η.

Sc Combustion gas Schmidt number.

t Time.

t_{99} Droplet life time.

T Temperature of the combustion gas.

T_d Temperature of the droplet.

T_f Film temperature.

u Axial gas velocity component.

u_f Final gas velocity.

v Radial gas velocity component.

V Gas velocity vector.

V_d Droplet velocity vector.

v_ψ Radial velocity of the propellant vapor leaving the droplet.

w Tangential velocity component.

W Total evaporation rate of an array of droplets

x Axial coordinate.

Y Combustion response factor

ν Radial resonance mode number.

η Tangential resonance mode number.

Δp Maximum pressure amplitude.

ω Angular frequency of the acoustic oscillations.

ϕ Phase angle of the acoustic oscillations.

γ Specific heat ratio of the combustion gas.

ρ Density of the combustion gas.

ρ_v Density of the propellant vapor.

ρ_L Density of the propellant liquid.

$\dot{\psi}$ Vaporization rate.

λ Heat of Evaporation.

$\mathcal{D}$ Diffusion coefficient.

μ Viscosity of the combustion gas.

$\mathcal{R}$ Real part of the combustion factor.

τ Sensitive time lag.

θ Tangential coordinate.

Subscripts:

d Droplet.

l Propellant liquid.

v Propellant Vapor.

' Perturbation component.

Superscripts:

$-$ Mean component.

$\rightarrow$ Vector quantities.

I. INTRODUCTION

Aerojet TechSystems Company is currently conducting a program (contract F04611-85-C-0100) to formulate a procedure (Ref. 1) which can accurately characterize injector designs for large thrust (0.5 to 2.0 million pounds) high pressure (500 to 3000 psia) LOX/hydrocarbon engines. As part of the development of models for use in the procedure, a computer code, Combustion Response Prediction (CRP), has been developed to calculate the combustion response factor which indicates the open-loop response of the burning rate to a specified acoustic oscillations in the combustion chamber.

1.1 High-Frequency Combustion Stability

Combustion instability, characterized by organized pressure oscillations in rocket combustion chamber, can cause severe vibrations on various engine system components and payloads. In addition, combustion instabilities may cause excessive mechanical stresses and heat loads on the injector and combustion chamber walls.

Combustion instabilities have been generally classified according to their frequency range: low, intermediate and high frequency. Significant efforts have been devoted to the understanding of high-frequency instability because it is the most common in new engine developments and is the most destructive. High-frequency instability results from the coupling between the combustion process and the acoustic waves in the chamber.

1.2 Combustion Response

Analytical models capable of characterizing combustion instability are obviously useful and valuable to engine designers during the development stage. As mentioned in the above section, high-frequency instability results from the coupling between the combustion process and the acoustic waves in the chamber. Thus, the stability of a given engine with specified operating conditions can be determined from the chamber transfer function and the burning transfer function. The chamber transfer function is defined in reference 11 as the ratio of the pressure oscillation to the buring rate oscillation normalized respectively by the mean pressure and the mean burning rate. Conversely, the burning transfer function or the combustion response is defined as the ratio of the buring rate oscillation to the pressure oscillation also normalized by the mean burning rate and the mean pressure. The burning transfer function indicates the response of the combustion process to the acoustic waves in the chamber. Previously, a computer code, HIFI (Ref. 2) has been developed to calculate the chamber transfer function. The burning transfer function was more difficult to predict analytically, therefore in the past it was expressed in term of an interaction index, n and a combustion time lag, τ. The values of n and τ are determined empirically.

1.3 Objective of the Present Study

The objective of the present study is to provide a computer code to predict the burning transfer function. Results from the code are used together with the HIFI's prediction of the chamber transfer function to predict the high-frequency stability of rocket engines.

1.4 Approach

The approach taken is to modify the Agosta and Hammer's computer model (Ref. 4) which was developed to study the vaporization response of oxygen droplets. Modifications made to the model include the following:

1. The model was extended from 1T traveling mode to mixed radial and tangential modes up to a combination of 8R and 8T. The acoustic modes can be either standing or spinning.

2. Subroutines for calculating the Bessel functions of any order were developed and implemented into the computer code. The values of the Bessel functions are calculated internally instead of being input by the users.

3. The finite-thermal-conductivity assumption was replaced by the uniform-droplet-temperature assumption. This was done since predictions of droplet evaporation rates in steady gas environments using the latter assumption agree better with the experimental data. The latter assumption is also necessary to reduce the computer time requirement to a practical level.

4. The time step used in the calculation of droplet evaporation history is determined internally by the computer code instead of being input by the users. The value of the time step is determined based on the period of oscillations and the droplet

lifetime.

5. The original model calculates the response factor for droplets injected at a specified radial and circumferential location on the injector. Because pressure and velocity oscillations vary with radial and circumferential locations, the response factor also varies with the locations. To account for this effect, the resultant response factor is obtained by averaging the response factors calculated at several different radial and circumferential locations.

6. The symmetry of the standing modes is taken into account to reduce the number of circumferential injection locations. This results in substantial saving of computer time.

7. The original computer code requires the users to input expressions for calculating the heat of vaporization and the vapor pressure as functions of temperature, and the diffusion coefficient as a function of pressure and temperature. In general, this requires the users to search literature for appropriate correlations and to compute the parameters used in the correlations for the propellants of interest. Modifications were made to the code so that the correlations are built into the code. Watson's correlation is used for calculating the heat of vaporization, Reidel's correlation is used for calculating the vapor pressure, and Mathur and Thodos' correlation is used for calculating the diffusion coefficient. The parameters used in these correlations are calculated internally by the code using user input data, e.g. molecular weight, critical temperature and pressure. These data

are existing for most propellants and can be easily found in existing literature, for example the Aerojet Handbook of Properties and Performance of Liquid Rocket Propellants (Ref. 5)

II. THEORY

The theory in the present study follows closely references 3 and 4. In the present study, mixing and reaction is assumed to be so fast that the burning rate is assumed to be vaporization limited. Therefore, the terms burning rate and vaporization rate are interchangable within the context of the present study.

The following sections describe in details the theory, the equations, and the calculation procedure used in the present model to calculate the response factor.

2.1 Theory Description

First, the equations describing the pressure and the velocity oscillations are prescribed for an acoustic mode in the chamber. The evaporation rates of a single droplet injected into the chamber is calculated assuming the heat and the mass transfer processes between the droplet and the surrounding combustion gas are at quasi-steady state. The convection heat rate and the mass vaporization rate are calculated using the Ranz-Marshall's correlations for the heat transfer and the mass transfer coefficient (Ref. 6). An energy balance is then applied to the droplet to calculate the rate at which the droplet is heated up (see equation 11 in chapter III). The theory just described is used to calculate the vaporization history of single droplets injected into the chamber. The vaporization history includes the temporal variations of the diameter, the temperature and the vaporization rate of the droplet.

The continuous injection of propellant is simulated by arrays of single droplets that are injected from the various radial and circumferential locations. Each of the arrays are comprised of droplets that are injected from the same location but at different times during an oscillation period of the acoustic fields. The previously described procedure for calculating the evaporation history of a single droplet is used to calculate the evaporation histories of each of the droplets in the array. The total evaporation rate of the array is then calculated by summing the evaporation rates of each of the individual droplets. The total evaporation rate includes the perturbation component that is induced by the acoustic oscillations. An in-phase response factor and an out-of-phase reponse factor are then calculated. The in-phase response factor is defined as the normalized ratio of the combustion rate perturbation component that is in phase with the pressure oscillation. Similarly, the out-of-phase response factor is defined as the normalized ratio of the combustion rate perturbation component that is out of phase with the pressure oscillation. The ratios are normalized by the mean combustion rate and the mean pressure. Because pressure and velocity oscillations vary with radial and circumferential locations, the response factor for an array of droplets injected from one radial and circumferential location may be different, in general, from the response factors calculated for arrays of droplets injected from other locations. In order to account for this effect, the resultant response factor is obtained by averaging the response factors calculated at various injection locations.

2.2 Equation Description

2.2.1 Chamber Acoustics

The expressions for the instantaneous values, which comprise the mean and the perturbation components, of the pressure and the velocity of a gas in a closed cylinder have been derived in reference 7 as:

$$p = \bar{p}\left\{1 + \Delta p \frac{J_\nu(S_{\nu\eta} r)}{J_\nu(S_{\nu\eta})} \sin(\nu\theta - \omega t + \phi)\right\} \quad (1)$$

$$v = \frac{\bar{c}\,\Delta p}{\gamma} \frac{J_\nu'(S_{\nu\eta} r)}{J_\nu(S_{\nu\eta})} \cos(\nu\theta - \omega t + \phi) \quad (2)$$

$$w = -\frac{\bar{c}\,\nu\,\Delta p}{\gamma S_{\nu\eta}} \frac{1}{r} \frac{J_\nu(S_{\nu\eta} r)}{J_\nu(S_{\nu\eta})} \sin(\nu\theta - \omega t + \phi) \quad (3)$$

for a spinning wave motion, and

$$p = \bar{p}\left\{1 + \Delta p \frac{J_\nu(S_{\nu\eta} r)}{J_\nu(S_{\nu\eta})} \cos(\nu\theta) \sin(\omega t - \phi)\right. \quad (4)$$

$$v = \frac{\bar{c}\,\Delta p}{\gamma} \frac{J_\nu'(S_{\nu\eta} r)}{J_\nu(S_{\nu\eta})} \cos(\nu\theta) \cos(\omega t - \phi) \quad (5)$$

$$w = -\frac{\bar{c}\,\nu\,\Delta p}{\gamma S_{\nu\eta}} \frac{1}{r} \frac{J_\nu(S_{\nu\eta} r)}{J_\nu(S_{\nu\eta})} \sin(\nu\theta) \cos(\omega t - \phi) \quad (6)$$

for a standing wave motion.

The above expressions are for the transverse wave motion and have been written on the assumptions that the chamber is a closed-end cylinder. In these expressions p, v and w are the instantaneous pressure, and radial and tangential velocities of the gas, respectively; $\bar{p}$ is the mean pressure; Δp is the maximum amplitude of the pressure oscillations for a particular mode; $\bar{c}$ is the mean speed of sound in the chamber; γ is the specific heat ratio of the gas in the chamber; r is the radial coordinate normalized by the chamber radius; θ is the tangential coordinates, ω is the angular frequency; t is the time; ϕ is the phase angle; ν and η are the numbers of the radial and tangential resonance modes, respectively. J_ν is the ν^{th}-order Bessel function of the first kind; J_ν' is the derivative of J_ν with respect to $S_{\nu\eta}r$; and the values of $S_{\nu\eta}$ are given in table 2.1 for selected values of ν and η. It should be noted that the maximum amplitude of the pressure oscillation has been normalized by the mean pressure, and that the means of the radial and the tangential velocity components have been assumed to be equal to zero.

The instantaneous temperature of the gas, T can be related to the pressure using the following isentropic relations:

$$\frac{T}{\bar{T}} = \left(\frac{P}{\bar{P}}\right)^{\frac{\gamma-1}{\gamma}} \tag{7}$$

where $\bar{T}$ is the mean temperature of the gas. The instantaneous density of the gas, ρ can be related to the temperature and the pressure using the equation of state:

$$\rho = \frac{PM}{RT} \tag{8}$$

where R is the universal gas constant, and M is the molecular weight of the gas.

The mean sound speed used in equations (2), (3), (5) and (6)

ν \ η	0	1	2	3	4
0	0.0000	3.8318	7.0155	10.1734	13.3238
1	1.8413	5.3313	8.5263	11.7059	14.8635
2	3.0543	6.7060	9.9695	13.1705	16.3476
3	4.2013	8.0151	11.3459	14.5858	17.7890
4	5.3175	9.2825	12.6820	15.9640	19.1961
5	6.4154	10.5199	13.9873	17.3127	20.5755
6	7.5012	11.7348	15.2681	18.6375	21.9318
7	8.5778	12.9324	16.5295	19.9419	23.2682
8	9.6475	14.1155	17.7739	21.2290	24.5874

Table 2.1: Selected Values of $S_{\nu\eta}$.

can be expressed in terms of the molecular weight and the mean temperature of the gas:

$$\bar{c} = \sqrt{\gamma \frac{R}{M} \bar{T}} \tag{9}$$

While the means of the radial and the circumferential components of the velocity are assumed to be zero, the mean of the axial component, $\bar{u}$ is non-zero and it is a function of the axial coordinate, x

$$\bar{u} = \bar{u}(x) \tag{10.a}$$

which is assumed to be known apriori. The axial profile of the mean velocity can be obtained, for example, from the steady-state performance analysis. For simplicity, in the present analysis, the velocity is assumed to be in the following form:

$$\bar{u} = \bar{u}_f \left(1 - \frac{m}{m_i}\right) \tag{10.b}$$

where $\bar{u}_f$ is the final gas velocity, m is the instantaneous value of the droplet mass, and m_i is the initial value of the droplet mass. This assumption implies the gas mean velocity varying with the axial coordinate. It simplifies the analysis since one does not have to compute and keep track of the axial location of the droplet.

Equations (1) through (10) completely describe the temporal and spatial variations of the gas properties, i.e. pressure, density, temperature and velocities.

2.2.2 Vaporization of a Single Droplet

Neglecting the radiation heat transfer, an energy balance applied to a droplet which undergoes heat and mass transfer simultaneously yields:

$$h A_d (T - T_d) = \dot{\psi} \lambda + \frac{1}{2} \dot{\psi} \vartheta_\psi^2 + m c_{pL} \frac{dT_d}{dt} \tag{11}$$

where h is the convective heat transfer coefficient, A_d is the surface area of the droplet, T is the gas temperature, T_d is the droplet temperature, $\dot{\psi}$ is the mass evaporation rate, λ is the enthalpy of evaporation, m is the instantaneous mass of the droplet, c_{pL} is the specific heat of the liquid propellant, and v_ψ is the velocity of the vapor leaving the droplet. Assuming the vaporizing mass leaving the droplet radially, v_ψ can be related to the mass evaporation rate, $\dot{\psi}$, the droplet surface area, A_d, and the vapor density, ρ_v :

$$\vartheta_\psi = \frac{\dot{\psi}}{A_d \rho_v} \tag{11.a}$$

The left-hand side of equation (11) represents the heat rate transfered to the droplet by convection; the first term on the right-hand side of the equation represents the heat required to vaporize the mass leaving the droplet; the second term on the right hand side of the equation is the kinetic energy that is imparted to the vaporizing mass; and the remaining term represents the energy required to heat up the droplet. The kinetic energy term is very small compared to the other two terms when the droplet temperature is far below the critical point of the propellant. Therefore, it has been neglected in many of the past studies. It becomes increasingly important as the droplet temperature increases, especially as the temperature approaches the critical temperature of the propellant because at this temperature, the heat of evaporation in the first term approaches zero and the mass "evaporation" rate approaches infinity. In rocket engines with high chamber pressure such as those considered in the Lox/hydrocarbon Injector Characterization Program, the temperature of the propellant droplet is expected to be very high and it may approach or even exceed the critical temperature of the propellant. Thus, the kinetic energy term must be included. In the above equation, the temperature of the droplet has been assumed to be uniform.

The mass evaporation rate is given by:

$$\dot{\psi} = A_d K_g \, p \, \ln \frac{p}{p - p_v} \tag{12}$$

where p is the total gas pressure, p_v is the vapor pressure of the droplet, and K_g is the mass transfer coefficient. The heat transfer and the mass transfer coefficients are obtained from the empirical correlations of reference 6:

$$\frac{2 r_d h}{k} = 2 + 0.6 \, (Pr)^{1/3} (Re)^{1/2} \tag{13}$$

$$\frac{2 r_d R T_f K_g}{M_v \mathscr{D}} = 2 + 0.6 \, (Sc)^{1/3} \, (Re)^{1/2} \tag{14}$$

In equations (13) and (14); r_d is the droplet radius; k is the gas thermal conductivity; Pr and Sc are the gas Prandtl and Schmidt numbers, respectively; R is the universal gas constant; M_v is the molecular weight of the propellant vapor, $\mathcal{D}$ is the binary diffusion coefficient of the vapor and the combustion gas, T_f is the film temperature which is defined as the arithmetic mean of the gas and the droplet temperatures:

$$T_f = \frac{1}{2}\left(T + T_d \right) \tag{15}$$

and Re is the Reynolds number which bases on the relative velocity of the gas and the droplet:

$$Re = \frac{2 r_d \left| \vec{V} - \vec{V}_d \right| \rho}{\mu} \tag{16}$$

where μ is the gas viscosity, and $\vec{V}$ and $\vec{V}_d$ are the velocities of the gas and the droplet, repectively. The velocity of the droplet is changing with time due to the drag exerted on the droplet by the surrounding gas. Although, the viscous effects of the gas on the droplet motion are considered, acceleration or deceleration of the gas through viscous interaction with the droplet is neglected. The drag exerted on the droplet is written as:

$$\vec{D} = C_D \pi r_d^2 \left(\frac{1}{2} \rho \Delta\vec{V} \left| \Delta\vec{V} \right| \right) \tag{17}$$

where C_D is the drag coefficient

$$C_D = 27\, Re^{-0.84} \tag{18}$$

and $$\Delta\vec{V} = \vec{V} - \vec{V}_d \tag{19}$$

is the gas velocity relative to the droplet. Newton's second law is then applied to calculate the rate of change of the droplet velocity:

$$\frac{d\vec{V}_d}{dt} = \frac{\vec{D}}{\frac{4}{3}\pi r_d^3 \rho_L} \tag{20}$$

where ρ_L is the density of the propellant liquid.

The perturbation components of the gas velocity and the density are included in the calculation of the Reynolds number, therefore the mass evaporation rates are affected by the acoustic oscillations. Nevertheless, The effects of the acoustic perturbations on the radial and the circumferential components of the droplet velocity are, neglected, i.e. the radial and the circumferential components of the droplet velocity always remain to be zero (the radial and the circumferential components of the droplet velocity at the instant of injection have also been assumed to be zero).

The time rate of change of droplet velocity is given by equation (20). The time rate of change of droplet temperature can be obtained by rearranging equation (11):

$$\frac{dT_d}{dt} = \frac{1}{mC_{PL}}\left\{ hA_d(T - T_d) - \dot{\psi}\lambda - \frac{1}{2}\dot{\psi}v_\psi^2 \right\} \tag{21}$$

and the time rate of change of droplet radius can be related to the mass evaporation rate, by assuming constant propellant liquid density:

$$\frac{dr_d}{dt} = - \frac{\dot{\psi}}{A_d \rho_L} \tag{22}$$

The radius, temperature and velocity of the droplet at the next time step can be calculated from the known values of the functions and their derivatives at the current time using the Euler's explicit integration, which is illustrated in the following equation for a general function, f:

$$f\Big|_{t+\Delta t} = f\Big|_{t} + \frac{df}{dt}\Big|_{t} \Delta t \tag{23}$$

It should be noted that the gas transport properties such as k and $\mathcal{D}$, used in all of the above equations are evaluated at the film temperature.

Equations 1 through 23 are sufficient to calculate the variations of the diameter, temperature, velocity and the evaporation rate of a droplet as functions of time provided that the time and the location of injection are known and that the initial properties, i.e., diameter, temperature and velocity of the droplet are known at the instant of injection.

When the droplet temperature reaches the boiling temperature of the propellant, numerical problem arises as the mass evaporation rate calculated using equation (12) approaches infinity. Under this condition, the mass evaporation rate is calculated directly from the energy equation, equation (11), with the droplet-heat-up term being set to zero. This approach not only avoids the numerical problem but is also more realistic since the evaporation rate is finite. The approach is extended also to the cases where the droplet temperature reaches the critical temperature of the propellant. It has been implied that when the droplet temperature reaches the boiling or the critical temperature of the propellant, no further heating of the droplet is allowed.

As previously mentioned in this section, the temperature of the droplet has been assumed to be uniform. Two other assumptions - temperature gradients exist inside the droplet (finite thermal conductivity), and uniform temperature inside the droplet with a step change at the droplet surface (zero thermal conductivity or onion skin) - are also considered but found to be unacceptable in the present study. The analysis assuming zero-thermal-conductivity is not described here since it is simple and similar to the analysis assuming uniform-temperature described in this section. The analysis assuming finite-thermal-conductivity is also not described here since it has been described in reference 4. In this reference, the temperature distribution inside the droplet is assumed to be spherically symmetric.

Although the finite-thermal-conductivity assumption appears to be more realistic than the other assumptions, the assumption of spherically symmetric temperature distribution is dubious especially when the droplet is under strong convection environments such as those in the combustion chambers.

The uniform-temperature-assumption is justifable when the thermal conductivity of the droplet is high or strong circulating flows exist inside the droplet. The circulating flows inside a droplet in a strong convection environment are generally believed to exist as a result of the shear force at the droplet surface. Therefore, the uniform-droplet-temperature assumption has been used commonly in the combustion or vaporization studies of droplet under convection, for example references 8 and 9. This assumption is adopted in the present study because calculations of the evaporation histories of droplets vaporizing in steady environments assuming uniform-droplet-temperature agree well with the experimental data (see section 4.1). Furthermore, the analysis using the assumption is simple and requires significantly less computer time than the analysis using the finite-thermal-conductivity assumption.

The analysis using the zero-thermal-conductivity assumption is also simple and has approximately the same computer time requirement as its uniform-temperature counterpart. Its predictions of the evaporation histories of droplets vaporizing in steady environments, however, did not agree well with the data (see section 4.1).

2.2.3 Evaporation of an Array of Droplets

The section 2.2.2 described equations used for the calculation of the evaporation rate of a single droplet. The evaporation rate of an array of droplets is simply the sum of the evaporation rates of each of the individual droplets that constitute the array.

The continuous injection of propellant into the chamber is simulated by the repreated injections of single droplets. Because of the oscillations in the gas properties which directly affect the vaporization rate, the evaporation history of a droplet injected at one instant of time may be, in general, different from the evaporation histories of droplets injected at the same location but at different times. Droplets injected at times which are multiple oscillation periods apart, however, will have identical vaporization histories since they experience the identical time histories of gas thermodynamics and flow fields. The droplets will eventually disappear after they completely vaporize. If the droplets in an array are injected into the chamber at times evenly distributed over one oscillation period, then at "steady-state" conditions the number of droplets disappearing are equal to the number of droplets entering the chamber. Thus, the instantaneous total evaporation rate, W(t) is obtained by appropriately summing the evaporation rates of each of the droplets which exist at the time.

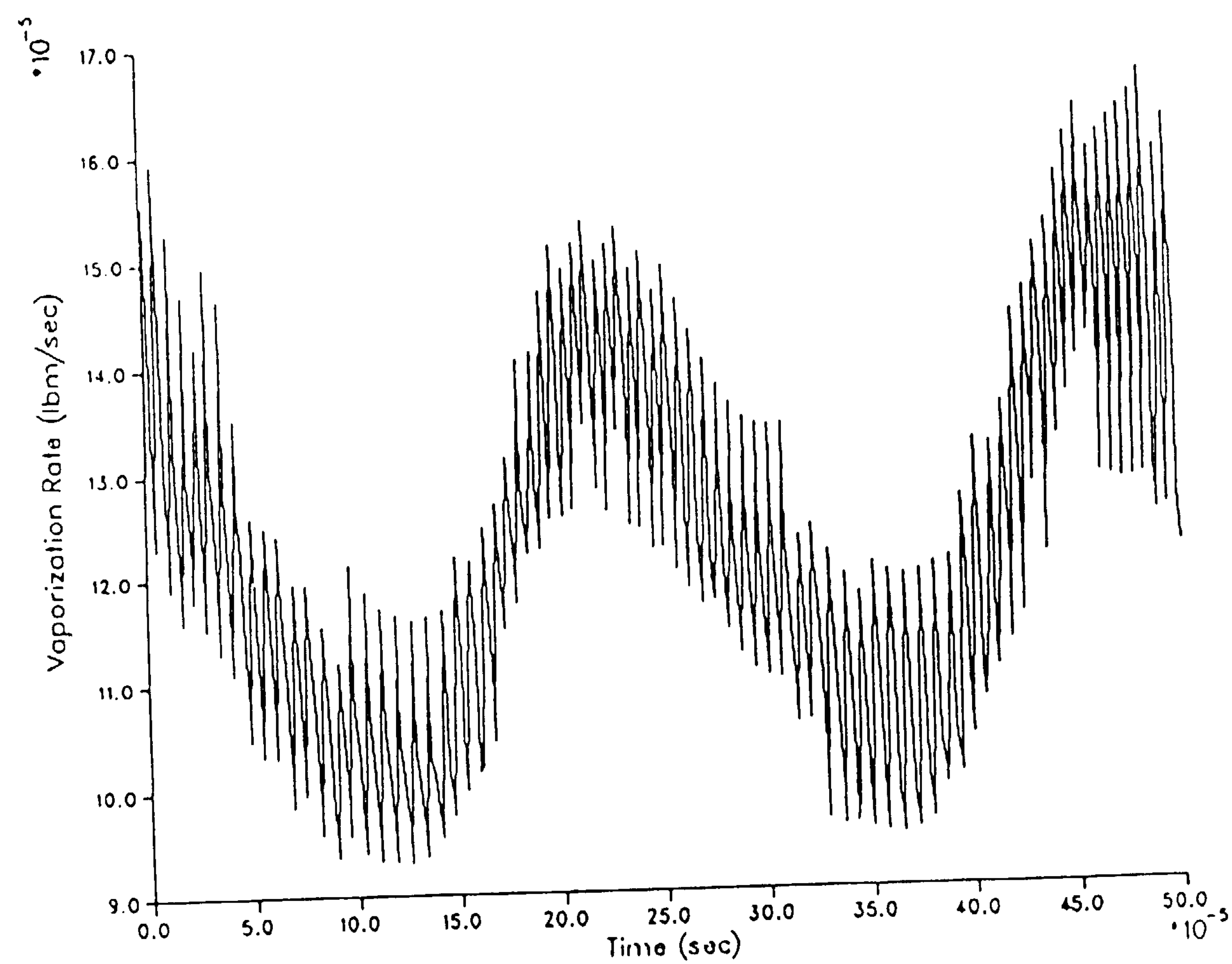
$$W(t) = \sum_{n=1}^{n_d} \dot{\psi}_n(t) \tag{24}$$

where $\dot{\psi}_n(t)$ is the evaporation rate of the droplet n, and n_d is the number of droplets existing at time t. This total burning rate is, of course, periodic and dependent on the frequency of the acoustic fields.

2.2.4 In-Phase and Out-Of-Phase Response Factors

The total burning rate (hereafter will be referred to simply as the burning rate) includes a perturbation component that is induced by the chamber acoustic fields. Figure 2.1 shows, as an

Figure 2.1 : Total Vaporization Rate of an Array of Droplets Which Includes the Perturbation Component Induced by the Acoustic Oscillations.



example, the perturbation component of the burning rate which is induced by the oscillations of the pressure and the velocity and other thermodynamic properties. The pressure and velocity oscillations are shown in figures 2.2, 2.3 and 2.4, respectively. The spikes in the burning rate curve are the results of the use of a finite number of droplets to represent the continuous injection of the propellant. In this example, 80 droplets are injected at equal time intervals during an oscillation period.

The correlations between the the burning rate and the pressure oscillations describe the magnitude of the response of the burning rate to the acoustic fields in the chamber. Thus, they indicate the relative stability of the combustion.

The in-phase response factor defined as:

$$\mathscr{R} = \frac{\int_0^{2\pi} W' P' \, d(\omega t)}{\int_0^{2\pi} P'^2 \, d(\omega t)} \tag{25}$$

is a correlation of the burning rate component that is in phase with the pressure oscillation.

The out-of-phase response factor defined as:

$$I = \frac{\int_0^{2\pi} W' P^* \, d(\omega t)}{\int_0^{2\pi} P^{*2} \, d(\omega t)} \tag{26}$$

is a correlation of the burning rate component that is out of phase with the pressure oscillation.

In equations (25) and (26), W' is the normalized perturbation component of the burning rate. It is defined in terms of the

Figure 2.2 : Normalized Acoustic Pressure Oscillation Component.

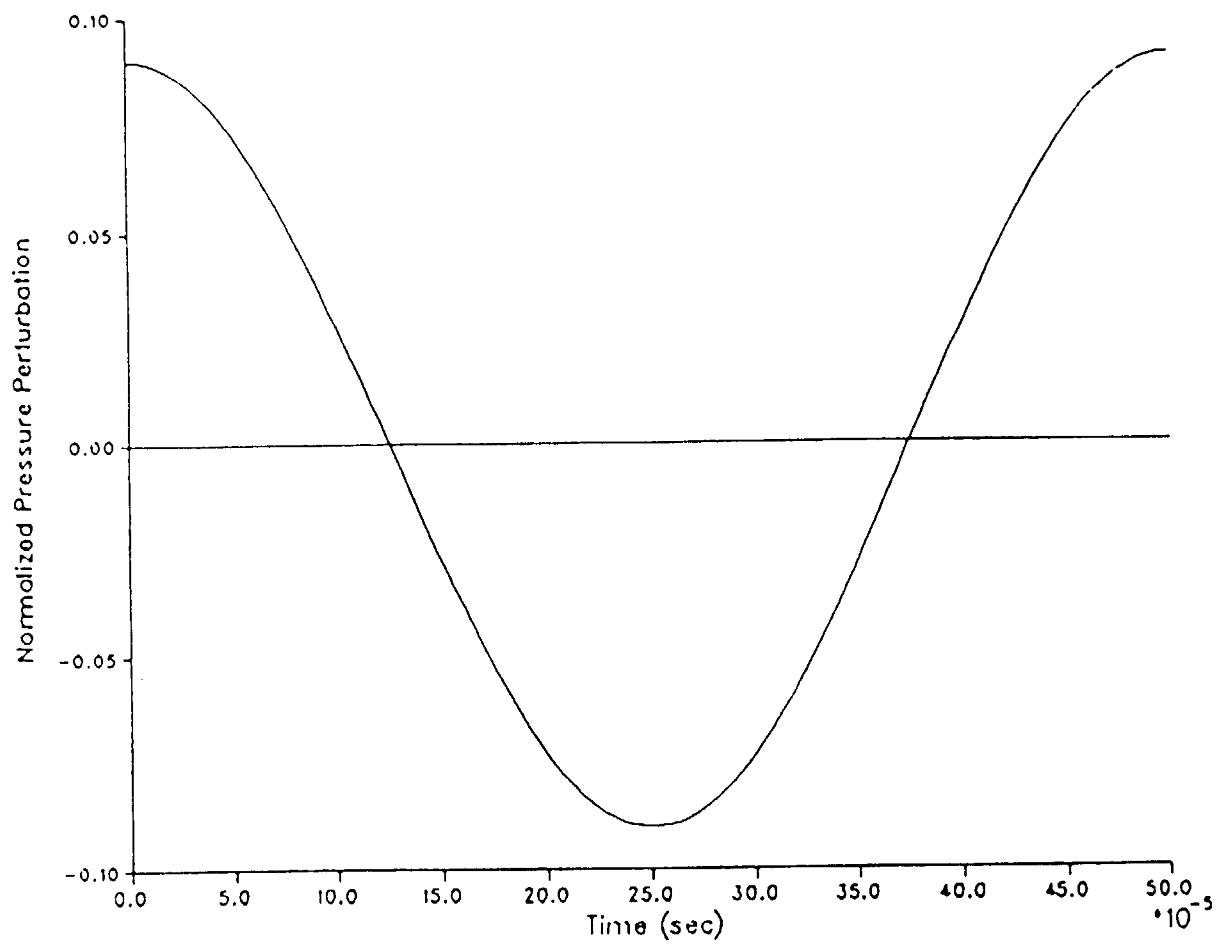


Figure 2.3 : Acoustic Radial Velocity Component.

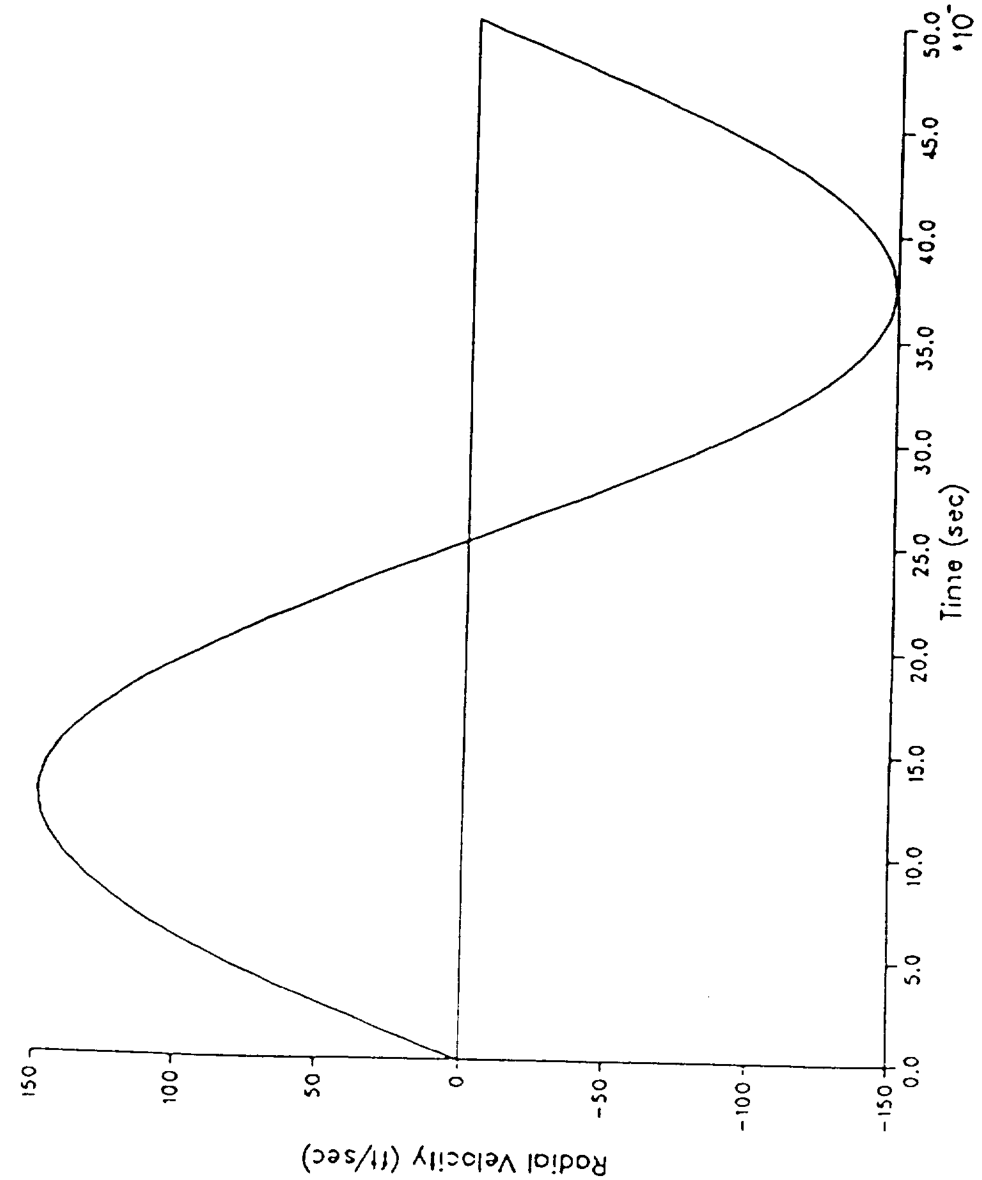
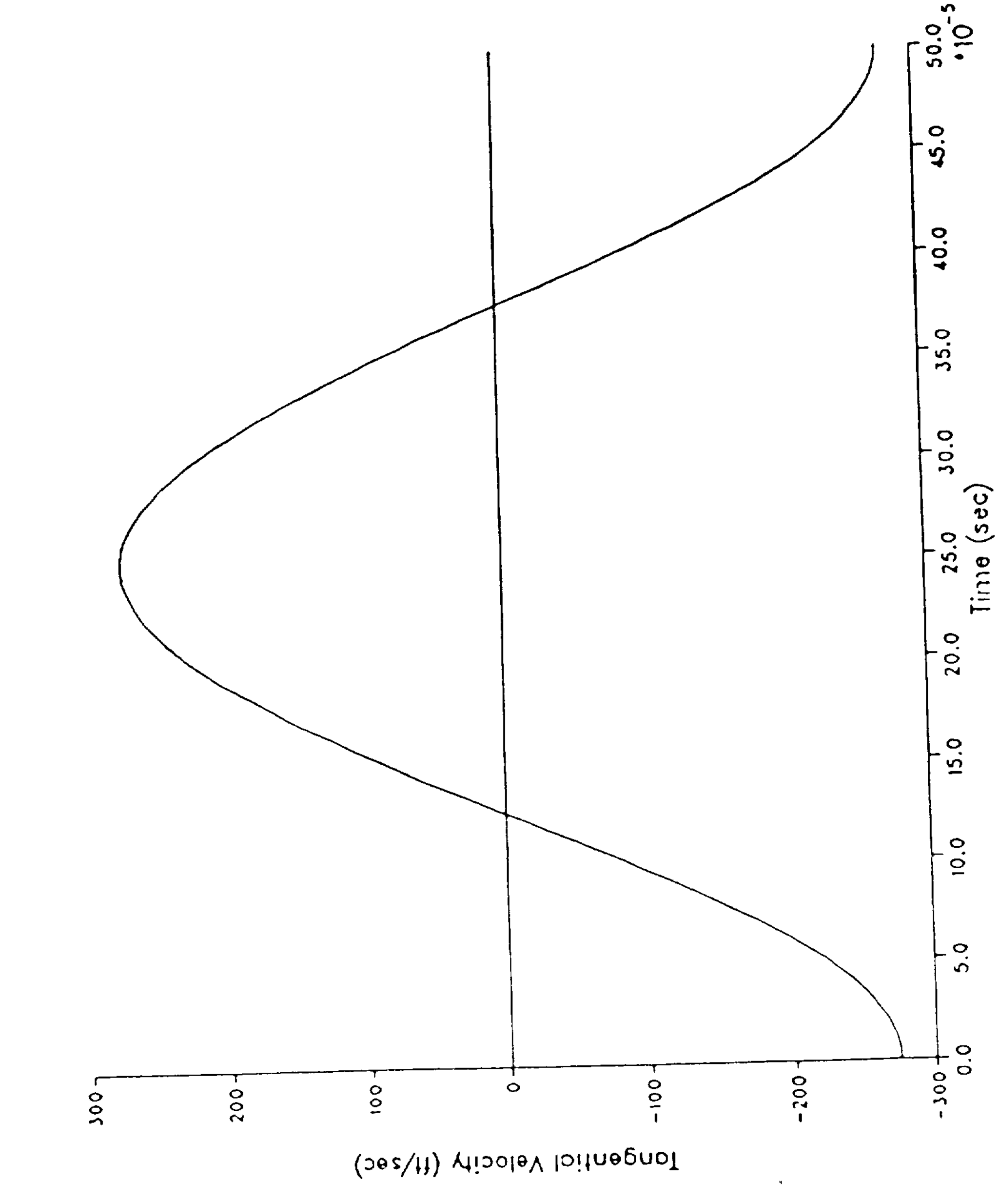


Figure 2.4 : Acoustic Tangential Velocity Component.



instantaneous burning rate, W and the mean burning rate, $\bar{W}$ as follows:

$$W' = \frac{W - \bar{W}}{\bar{W}} \tag{27}$$

where

$$\bar{W} = \frac{1}{2\pi}\int_0^{2\pi} W \, d(\omega t) \tag{28}$$

p' is the perturbation component of the pressure at r and θ, and p^* is a sinusoidal function having the same amplitude and frequency but 90 degrees out of phase with p'.

The reponse factors defined by equations (25) and (26) vary with radial and circumferential position because of the spatial variations of the pressure and the burning rate. To account for this effect, the chamber cross-sectional area is divided into a number of equal areas in both radial and circumferential directions. The response factors are calculated at each of the centers of the areas. They are then averaged to obtain the resultant response factor.

2.3 Calculation Procedure

The following procedure is used to calculate the in-phase and the out-of-phase response factors as functions of the frequency:

1. Beginning with the first droplet injected at time t; equations (1) to (9) are used to calculate the instantaneous gas pressure, velocity, temperature and density at the time t.

2. Calculate the mean gas velocity using equation (10).

3. Calculate the film temperature using equation (15). Evaluate the gas transport properties, i.e. thermal conductivity, viscosity, etc... at the film temperature.

4. Calculate the vapor pressure at the droplet temperature. This step is skipped when the droplet temperature reaches the boiling temperature or the critical temperature of the propellant.

5. Calculate the heat and the mass transfer coefficients using equations 13 and 14. The mass transfer coefficient need not be calculated when the droplet temperature reaches the boiling temperature or the critical temperature of the propellant.

6. Calculate the mass evaporation rate using equation (12). If the droplet is at the boiling temperature or the critical temperature of the propellant, the mass evaporation rate is calculated by solving equation (11) with the droplet-heat-up term being zero. Store the time and the corresponding mass evaporation rate of the droplet in an array for use at a later time to calculate the total evaporation rate.

7. Calculate the droplet drag and the droplet acceleration using equations (17) and (20). Calculate the rate of change of droplet radius using equation (22), and the rate of change of the droplet temperature using equation (21). The rate of change of the droplet temperature is set to zero when the droplet temperature reaches the boiling temperature or the critical temperature of the propellant.

8. Calculate the droplet radius, velocity and temperature at

the next time step using the Euler's explicit integration illustrated in equation (23).

9. Time is incremented and steps 1 to 8 are repeated until more than 99 percent of the droplet mass has been evaporated.

10. Repeat steps 1 to 9 for each of the droplets injected from the same radial and tangential location but at different times during a period of oscillation.

11. Calculate the total evaporation rate of the entire droplet array from the evaporation histories of each of the droplets which have been stored in step 6.

12. Calculate the in-phase and the out-of-phase response factors using equations (25) and (26).

13. Repeat steps 1 to 12 to obtain the response factors for droplets injected from different radial and circumferential locations.

14. Average the response factors calculated in step 13 in order to obtain the overall response factor.

The whole procedure is then repeated to calculate the overall response factors for other values of the frequency.

III. PROGRAM DESCRIPTION

The Combustion Response Prediction (CRP) computer code consists of a main program, four subroutines and six function subroutines. The main program and the subroutines are described in the next section. Program input and output are described in sections 3.2 and 3.3. A listing of the computer code is provided in appendix A. Input and output for a sample case are provided in appendix B.

3.1 Program Description

* Main Program: reads all input to the code which include a problem-description title, chamber acoustic resonance modes, frequency range of interests, combustion gas properties, and droplet initial properties. It calculates the vaporization histories of each of the droplets in an array and calls subroutine OUTPUT, if the input variable DEBUG is set to TRUE, to print out the vaporization histories. Each array is a set of several droplets injected from the same radial and circumferential injection location but at different times. It then calls subroutine SUM to compute the total evaporation rate of the entire array of droplets. Next, it calculates the response factor of the droplets in the array. The procedure is then repeated to calculate the response factors for other arrays of droplets injected from other locations. Finally, it averages the response factors calculated at

various locations to obtain the overall response factor at a particular frequency. This whole procedure is then repeated for a number of frequencies. Loops over all droplets, injection locations, and frequencies are made in the main program.

* Subroutine OUTPUT: called by the main program to print intermediate results, e.g., time step, instantaneous radius, evaporation rate, and velocity of the droplet. It also prints out other information for debugging, e.g., Reynolds number, diffusion coefficient, vapor pressure.

* Subroutine MATHUR: calculates the parameter used in the Mathur and Thodos' correlation to calculate the binary diffusion coefficient as a function of pressure and temperature.

* Subroutine REIDEL: calculates the parameters used in the Reidel's correlation to calculate the vapor pressure as a function of temperature.

* Subroutine SUM: calculates the total evaporation rate of an array of droplets by summing the individual evaporation rates of each of the droplets.

* Function FWDOT: given the evaporation history of a single droplet, the function calculates the evaporation rate of the droplet - or of other droplets injected at a number of oscillation periods apart - at a specified

time.

* Function BJ: compute the second or higher-order Bessel function of the first kind.

* Function BJ0: compute the zeroth-order Bessel function of the first kind.

* Function BJ1: compute the first-order Bessel function of the first kind.

* Function SL: calculates the heat of vaporization as a function of temperature using Watson's correlation.

* Function PV: calculates the vapor pressure as a function of temperature using Reidel's correlation.

3.2 Input Description

All input with the exception of the problem description title are made using Fortran namelists. The problem description title can be specified using any number of lines but at least one line must be used although it can be a blank line. Following the problem description are the namelists INPUT, WAVES, CBGAS and DROPS. Variables in these namelists are described in tables 3.1 through 3.4. Input for a sample case is provided in appendix B.1.

Namelist INPUT is used to input artificial parameters such as the number of droplets injected per cycle, the number of time steps between output, and the number of time steps in a droplet life time,etc. If the variable DEBUG is set to TRUE, the vaporization histories of droplets and the intermediate results are written to a

Name	Type	Unit	Description and Remarks
DEBUG	L		=TRUE, Intermediate results are output to a debug file =FALSE, No intermediate ouput
NDTFQ	I		Number of time steps in one period of oscillation.
NDTLF	I		Number of time steps in the droplet life time
JA	I		Number of time steps between print-outs of intermediate results
NP	I		Number of droplets injected per cycle
NY	I		Number of integration steps used in the calculations of the response factors
NRAD	I		Number of radial injection locations
NCIRC	I		Number of circumferential injection locations

Table 3.1: Descriptions of Namelist INPUT Variables

Name	Type	Unit	Description and Remarks
FREQ	R	cps	First frequency value
DFREQ	R	cps	Frequency increment
NFREQ	I		Number of frequencies
DPF	R		Maximum pressure amplitude normalized by the mean pressure
PHIF	R	deg	Pressure oscillation phase angle
MTANG	I		Tangential resonance mode number
NRADI	I		Radial resonance mode number

Table 3.2: Descriptions of Namelist WAVES Variables

Name	Type	Unit	Description and Remarks
PO	R	psf	Mean chamber pressure
TFO	R	°R	Mean chamber temperature
GAMMA	R		Chamber gas specific heat ratio
PCB	R	psf	Chamber gas critical pressure
TCB	R	°R	Chamber gas critical temperature
TBB	R	°R	Chamber gas normal boiling point
EMB	R	lbm/lb-mole	Chamber gas molecular weight
PR	R		Chamber gas Prandtl number
AKB	R	Btu/ft-s-°R	Chamber gas thermal conductivity
VIS	R	lbm/ft-s	Chamber gas viscosity
VGAF	R	ft/s	Chamber gas final velocity

Table 3.3: Descriptions of Namelist CBGAS Variables

Name	Type	Unit	Description and Remarks
SIT	R	ft	Initial droplet radius
TO	R	°R	Initial droplet temperature
RHOL	R	lbm/ft**3	Propellant liquid density
CPL	R	Btu/lbm-R	Propellant liquid specific heat
VDI	R	ft/s	Initial droplet velocity
PCA	R	psf	Propellant critical pressure
TCA	R	°R	Propellant critical temperature
TBA	R	°R	Propellant normal boiling point
EMA	R	lbm/lb-mole	Propellant molecular weight
SLA	R	Btu/lbm	Propellant heat of vaporization at normal boiling point

Table 3.4: Descriptions of Namelist DROPS Variables

debug file.

The variables NDTFQ and NDTLF are used to calculate the time step for use in the calculation of the vaporization histories of the droplets. The time step based on the oscillation period is:

$$\Delta t_f = \frac{2\pi}{\omega * NDTFQ}$$

where ω is the angular freqency of the oscillation, and the time step based on the droplet life time, t_{99} is:

$$\Delta t_{99} = \frac{t_{99}}{NDTLF}$$

The time step used in the calculations of the vaporization histories is the smaller of the two time steps.

The variable NY is the number of integration steps used in the numerical integration of equations (25) and (26) to obtain the in-phase and the out-of-phase response factors. For cases where the temporal variations of the droplet vaporization rates are steep, a large value must be specified for NY (finer integration step size) to avoid losing accuracy in the results.

The overall response factor is the average of the response factors calculated at various radial and tangential locations. The number of the locations are specified by the variable NRAD and NCIRC.

All of the variables described above are artificial parameters in the model. The higher the value specified for these parameters, the more accurate the solutions will be and, of course, the more computer time is required. Recommended values for the variables are given in table 4.1 of section 4.2.

Namelist WAVES is used to input the chamber acoustic resonance modes, frequency range of interests, the maximum amplitude and the phase angle of the pressure oscillations. The variables FREQ, DFREQ, and NFREQ specify the frequency calculation domain. The amplitudes of the pressure oscillations vary spatially, the variables DPF is the maximum amplitude, $\Delta \bar{p}$, used in equations (1) and (4).

Namelist CBGAS is used to input the combustion gas properties, for example, mean pressure and temperature, critical pressure and temperature, molecular weight, Prandtl number, etc. In general, the combustion gas is the mixture of several gas components. Therefore, the pseudo values of the critical pressure, temperature and molecular weight of the mixture must be calculated. These values can be calculated from the compositions of the mixture and the properties of the species components that constitute the mixture. The compositions, the thermodynamic properties and the transport properties can be calculated using the standard TRAN72 computer program (Ref. 12)

Namelist DROPS is used to input droplet properties such as its initial radius, velocity, and temperature. The namelist is also used to input thermodynamic properties of the propellant. These properties can be obtained from the Aerojet Handbook of Properties and Performance of Liquid Rocket Propellant (Ref. 5).

3.3 Output Description

Output from the code begins with the echo of input data which include the problem-description title, and the values of the namelists' variables. Although the problem description can be input using any number of lines, only the first line is output. Next, the descriptions and the values of selected input variables are output. Following the echo of the input data is the estimated droplet life time. The last section of the output is the calculated stability results which include the real part (in-phase) and the imaginary part (out-of-phase) of the response factor. The results are also output in the polar form (magnitude and phase angle). These results are output for each of the frequencies whose range is specified in the namelist WAVES. A sample output file is provided in appendix B.2.

Three additional files are also generated to be input to TELLEGRAF, a computer graphic program available at ATC, for plotting the calculated results. The first file contains the data used for plotting the real and the imaginary parts of the response factor versus the frequency. The second and the third files contain the data used for plotting the magnitude and the phase angle of the response factor, respectively, versus the frequency. Using the VAX conventions for file identifications, the file names of the three files are the same as that of the input file. The file types of the three files are RIM, MAG, and PHA, respectively.

In addition to the files described above, a debug file is also generated if the variable DEBUG in the namelist INPUT is set to

TRUE. This file contains intermediate results that are useful for debugging purposes. Quantities written to this file begin with the values of the parameters used in the vapor-pressure correlation. Next, the vaporization history of the first droplet ~~are~~ is output. The vaporization history information includes the following quantities as functions of time: the droplet radius and its time rate of change, the droplet temperature, the vapor pressure, the mass evaporation rate, and the absolute and the relative velocities of the droplet. Other quantities output along with the droplet vaporization history include the instantaneous gas pressure and temperature, the diffusion coefficient, the Reynolds number, and the heat transfer coefficient. In addition, at each of the specified frequen~~cy~~ies, the response factors calculated at various radial and ciurcumferential injection locations are output. The file name of this debug file is the same as that of the input file, the file type of the debug file is DBG.

IV. RESULTS AND DISCUSSION.

Calculations of the response factors were made for the case of n-heptane droplets vaporizing in combustion gases composed of the products of the stoichiometric reaction with oxygen. The results are discussed in section 4.3.

Before the calculations were made for the above case, several tests were performed to study the effects of the "artificial" parameters, e.g. time steps, number of droplets injected per cycle, on the solutions. The test results are discussed in section 4.2.

In addition, the model was used to calculate the evaporation history of Chinese Kerosene (RP2) and n-heptane droplets vaporizing in steady environments (no oscillations in pressure and velocity) for which experimental data are available. This provides, to some degree, the verifications of the single-droplet-vaporization model used in the present study. The following section discusses the calculated results and the comparisons of the results with the data.

4.1 Calculations of Droplets Vaporizing in Steady Ambient Gases.

4.1.1 Chinese Kerosene (RP2) Droplet Vaporizing in Airstream.

The model was used to calculate the evaporation history of a Chinese-Kerosene (RP2) droplet vaporizing in a steady hot crossflowing air stream, for which experimental data are available (Ref. 8). In the experiment, the initial diameter and temperature of the droplet are 1.15 mm and 294°K. The temperature and the velocity of the air stream are 516°K and 4.85 m/s. The experiment was conducted at atmospheric pressure. Three sets of calculations were made using three different assumptions on the droplet thermal conductivity - finite thermal conductivity with spherically symmetric temperature distribution inside the droplet, zero thermal conductivity (onion skin), and uniform droplet temperature (infinite thermal conductivity or strong circulating flows inside the droplet). Figure 4.1 shows the calculated temporal variations of the droplet diameter and the experimental data. It can be seen that only the prediction using uniform-droplet-temperature assumption agrees well with the data. Based on these comparisons and the other justifications discussed in section 2.2.1, the uniform-temperature-assumption was selected for use in the present study.

4.1.2 n-Heptane Droplet Vaporizing in Quiescent Nitrogen Gas.

The uniform-droplet-temperature model is then used to calculate the evaporation histories of n-heptane droplets vaporizing in hot quiescent nitrogen gas at 1 atmosphere and at 50 atmospheres. In both cases, the initial droplet diameter and temperature are 0.0354 in. and 527°R. The ambient nitrogen temperature is 1031°R. Following Baer's practice (Ref. 9), natural convection effects are accounted for in the present calculation by replacing the Reynolds number in the heat and the mass transfer correlations with the square root of the Grashof number. Figures 4.2 and 4.3 show the comparisons between the calculated results and the data taken from reference 9 for both

Figure 4.1 : Chinese RP-2 Kerosene Droplet Vaporizing in Hot Air.

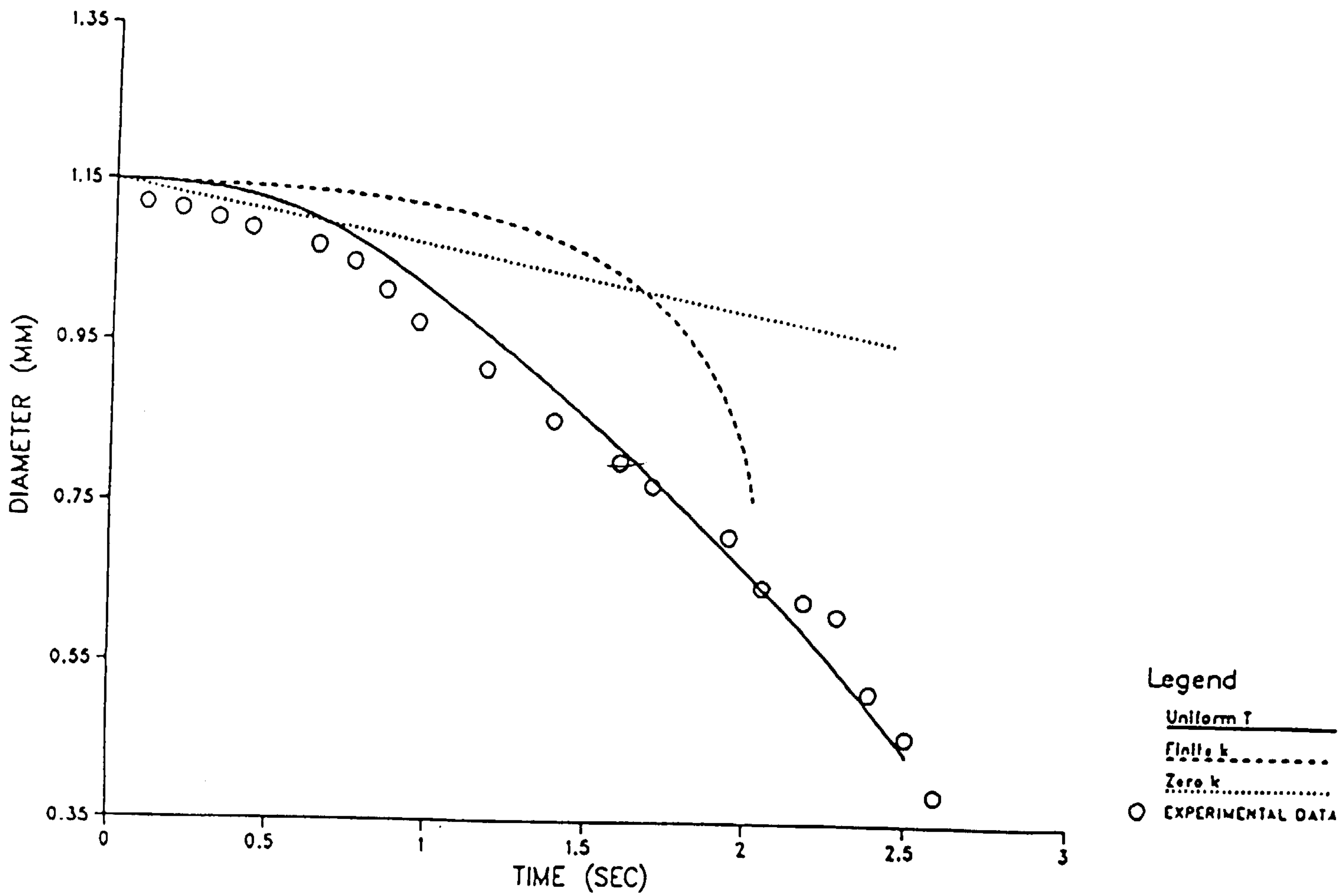


Figure 4.2 : n-Heptane Droplet Vaporizing in Nitrogen Gas at 1 atm.

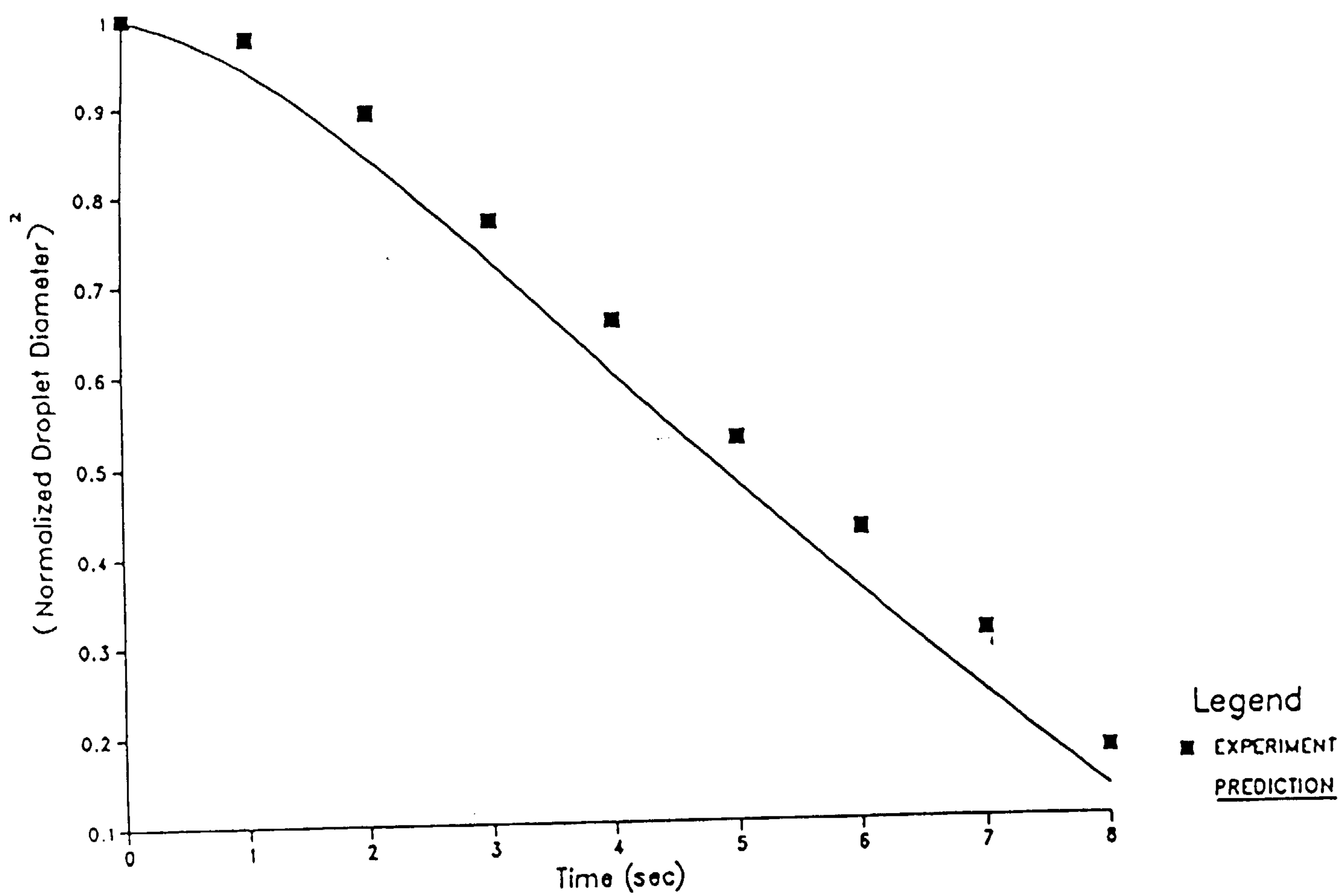
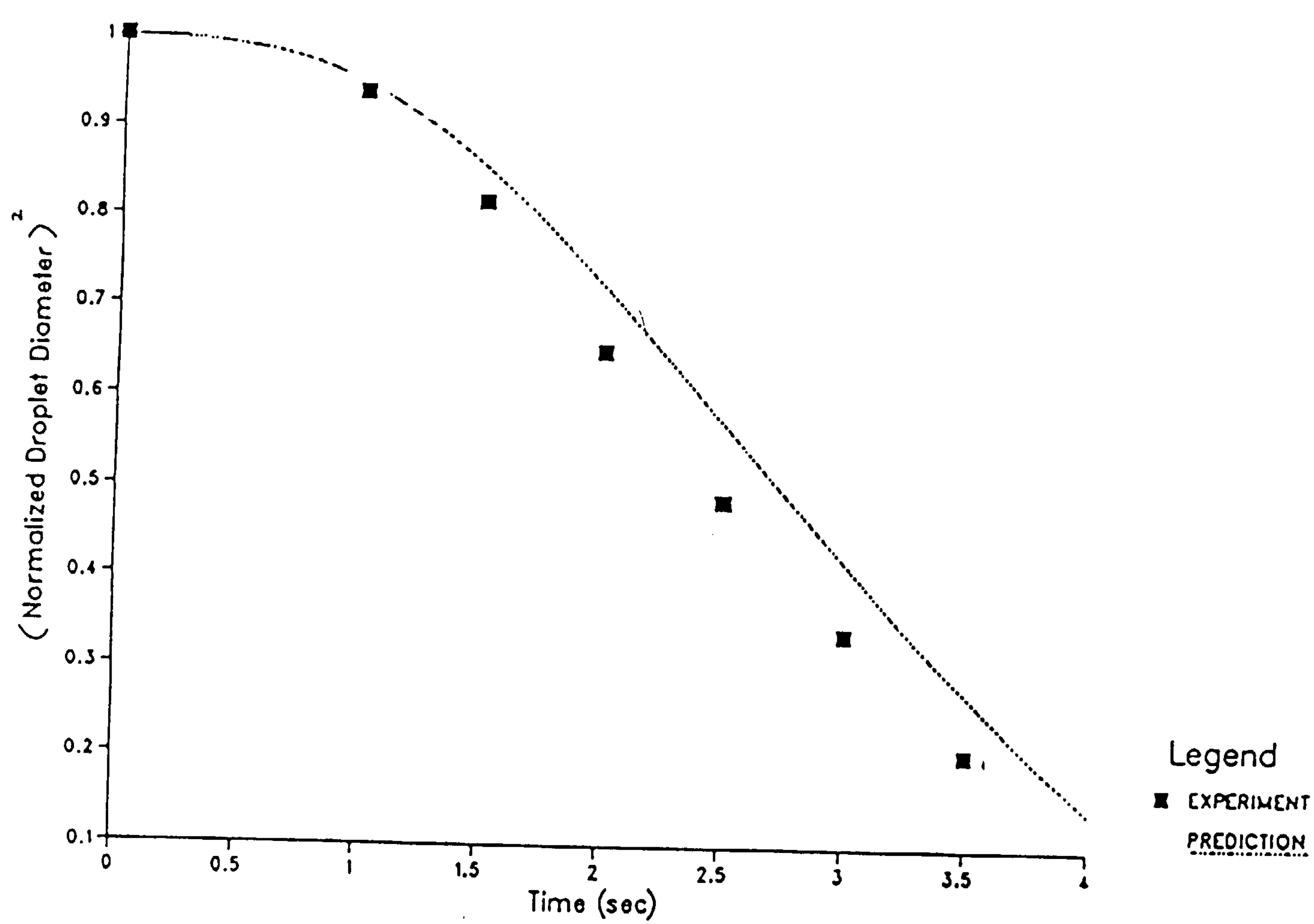


Figure 4.3 : n-Heptane Droplet Vaporizing in Nitrogen Gas at 50 atm.

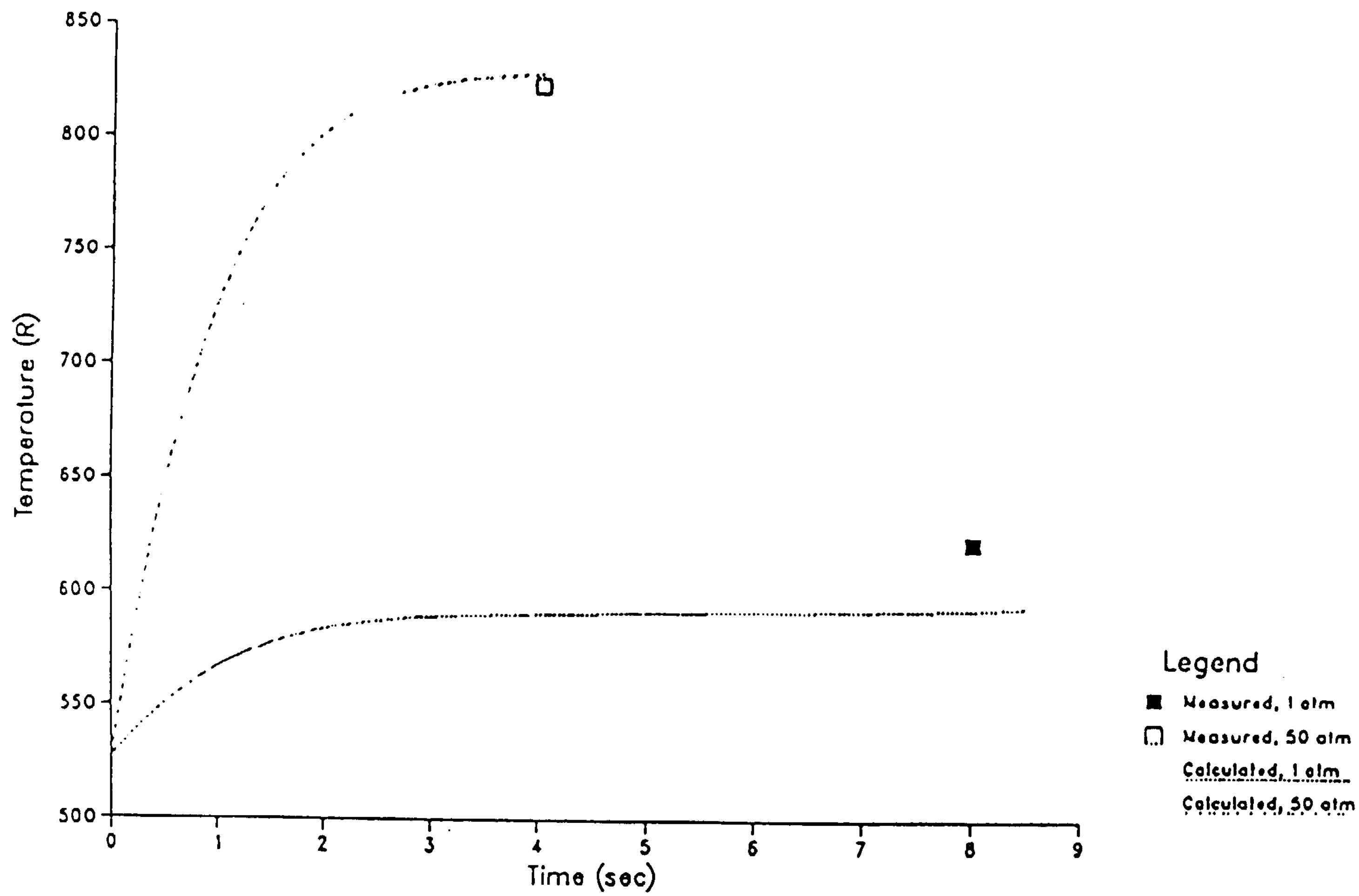


cases. The data were originally reported in reference 10. In the figures, the square of the normalized (by the initial diameter) droplet diameter is plotted versus time. It can be seen from the figure that the rate of change of the droplet diameter is overpredicted for the lower pressure case while it is underpredicted for the higher pressure case. Nevertheless, the agreements between the calculated results and the data are good. The calculated droplet temperatures for the two cases are shown as functions of time in figure 4.4. The measured wet-bulb temperatures are also shown in the figure. Comparisons between the calculated results and the data show that the wet-bulb temperature is underpredicted in the low-pressure case, and it is well predicted for the high-pressure case.

4.2 Parametric Test Results

A limited number of parametric tests were performed to study the sensitivity of the solutions to the artificial parameters which have been introduced into the model. The tests were made also to obtain guidelines on what values should be specified for the parameters. While no attempts are made to describe the test results in detail, they are briefly discussed in this section. Test results show that the solutions converge as the time step decreases. The test results also show that the solutions converge as the number of droplets injected per cycle, the number of radial injection locations, the number of circumferential injection locations, and the number of integration steps used in the calculation of the response factor increase.

Figure 4.4 : Temporal Variation of the Temperatures of the n-Heptane Droplets Vaporizing in Quiescent Nitrogen Gases.



As a result of the parametric tests, the values listed in table 4.1 are recommended for the artificial parameters in order to obtain reasonable accuracy in the solutions without substantial CPU time requirements. A typical computer run using the values recommended in table 4.1 requires approximately 2 CPU minutes for each frequency on the VAX computer system at ATC. The total computer time requirement is approximately linearly proportional to the number of frequencies, NFREQ. It should be noted from the table that while the recommended value for the number of radial injection locations, NRAD, increases with the specified radial resonance mode, the recommended value for the number of tangential injection locations, NCIRC does not vary with the specified tangential mode. The reasons are that the response factors, at a given radial coordinate, do not vary with the tangential locations for the spinning waves; and that the symmetry of the standing waves have been accounted for.

4.3 n-Heptane Droplet Response Factor

The computer code CRP, was used to calculate the combustion response factor of n-Heptane droplets vaporizing in the combustion gases composed of the products of the stoichiometric reaction of n-Heptane with Oxygen. The mean chamber pressure is 300 psia and the mean chamber temperature is 6280°R. The acoustic mode in the chamber is the first tangential (1T) standing mode with the maximum amplitude of the pressure oscillation normalized by the mean pressure ~~is~~ being 10 percent. The initial radius, temperature, and velocity of the droplet are 50 microns, 535°R and 50 ft/s, respectively. The number of droplets injected per cycle used in

NDTFQ	=	16
NDTLF	=	1000
JA	=	100
NP	=	16
NY	=	3200
NRAD	=	3*(NRADI+1)
NCIRC	=	3

Table 4.1: Recommended Values for the Artificial Parameters

this calculation is 16.

Figures 4.5, 4.6, and 4.7 show the temporal variations of the temperature, the radius, and the vaporization rate, respectively, of an n-Heptane droplet injected at the normalized radial distance of .707 and the tangential location is at the pressure antinode. The discontinuities in these curves are the results of the switching to a different procedure to calculate the vaporization rate when the droplet temperature reaches the boiling temperature of the propellant. In all of the figures, time equals to 0.0 is the instant the droplet is injected into the chamber, and for this particular droplet it is injected at the beginning of the oscillation period. The frequency of the acoustic fields in the chamber is 2000 Hertzs.

Figure 4.5 shows that the droplet temperature reaches the boiling temperature of the propellant at approximately 62 micro-seconds. Figure 4.6 shows that the droplet completely vaporizes at approximately 82 micro-seconds. It can be seen from figure 4.7 that initially, the evaporation rate of the droplet is relative small. The rate slowly increases for approximately 62 micro-seconds. At this time the temperature of the droplet reaches the boiling point of the propellant, the vaporization rate rises sharply to a maximum then it decreases as the surface area of the droplet reduces. A small variation at the peak of the vaporization rate is the result of the oscillations in the chamber gas properties.

Figure 4.8 shows the total evaporation rate of an array of

Figure 4.5 : Temporal Variation of n-Heptane Droplet Temperature.

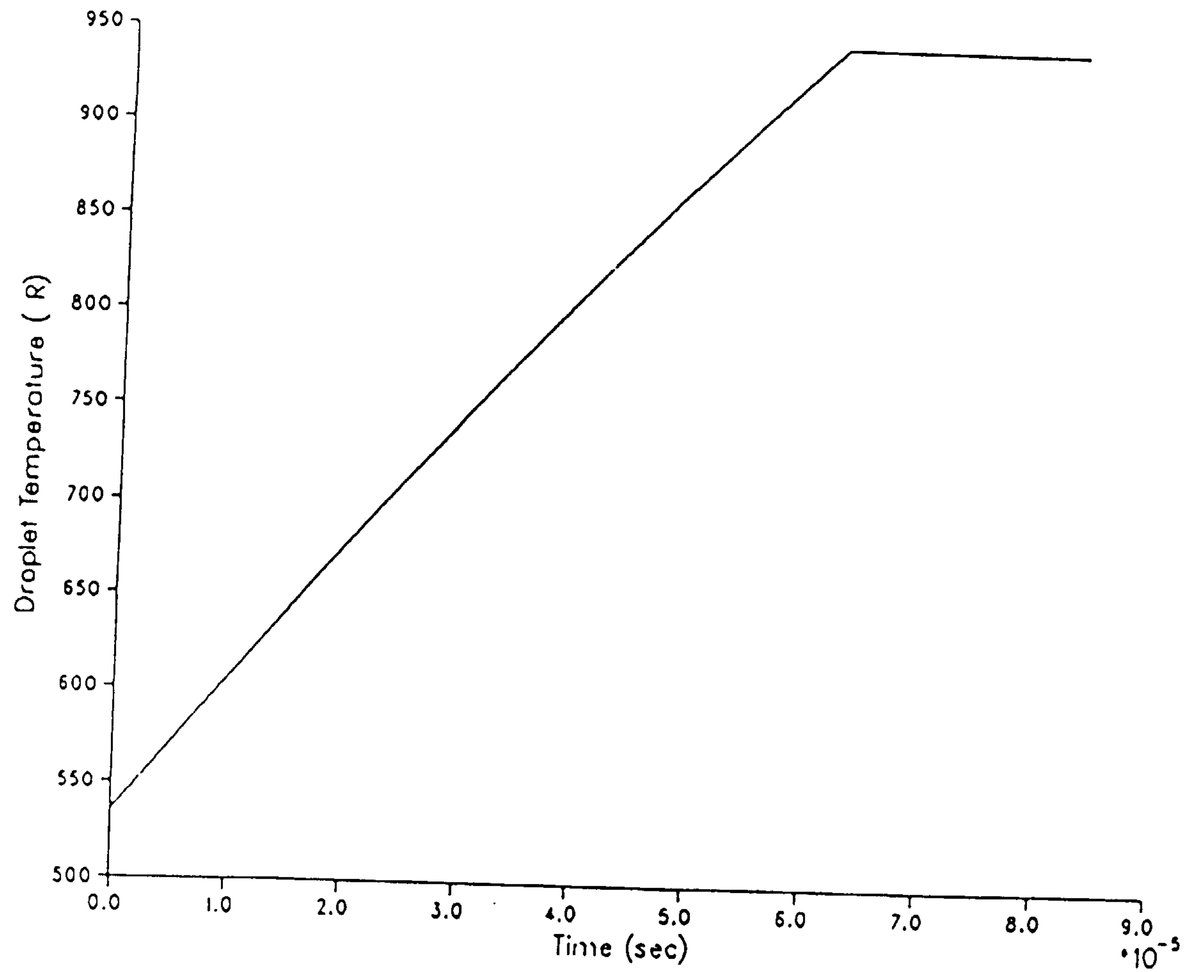


Figure 4.6 : Temporal Variation of n-Heptane Droplet Radius.

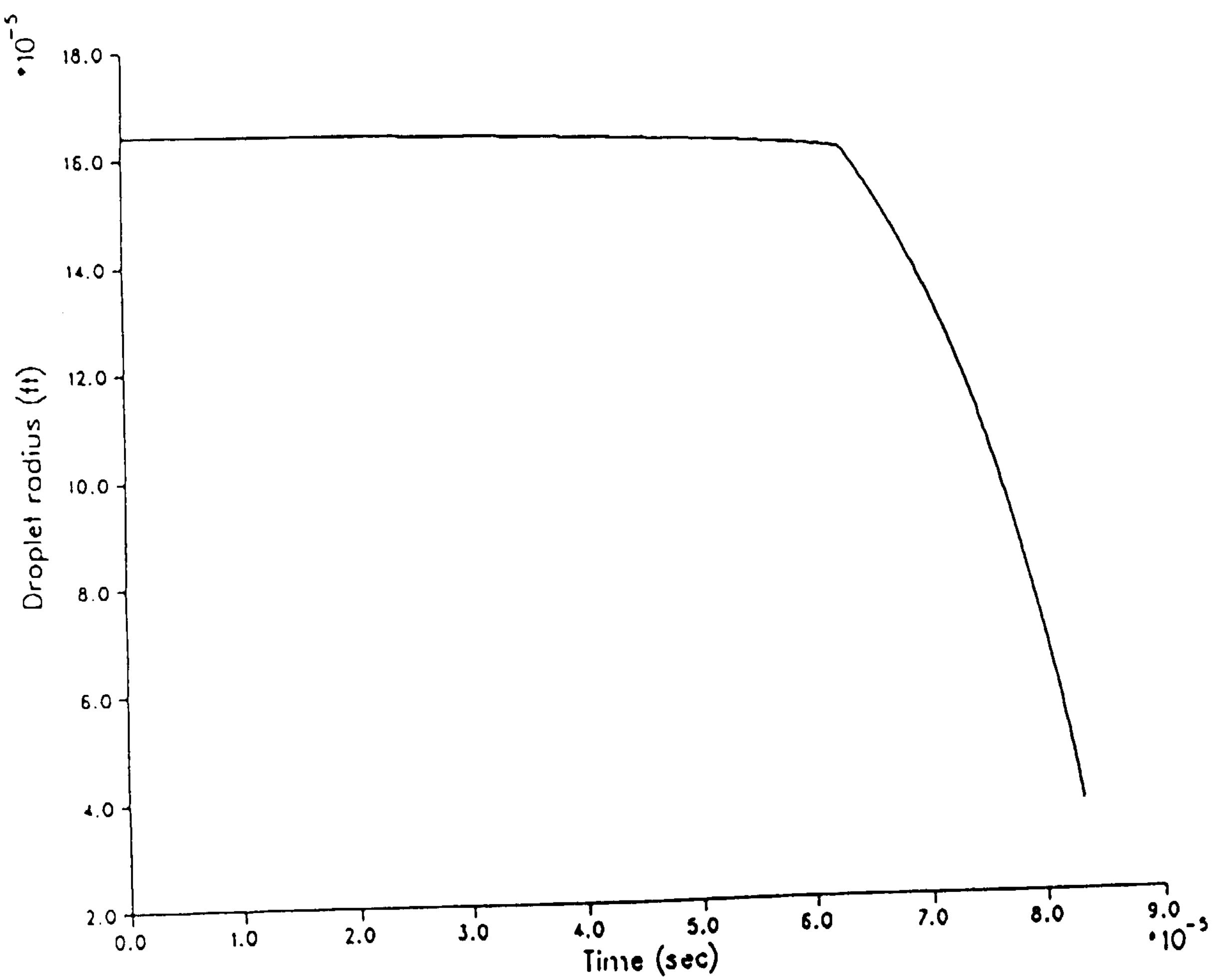


Figure 4.7 : Temporal Variation of n-Heptane Droplet Vaporization Rate.

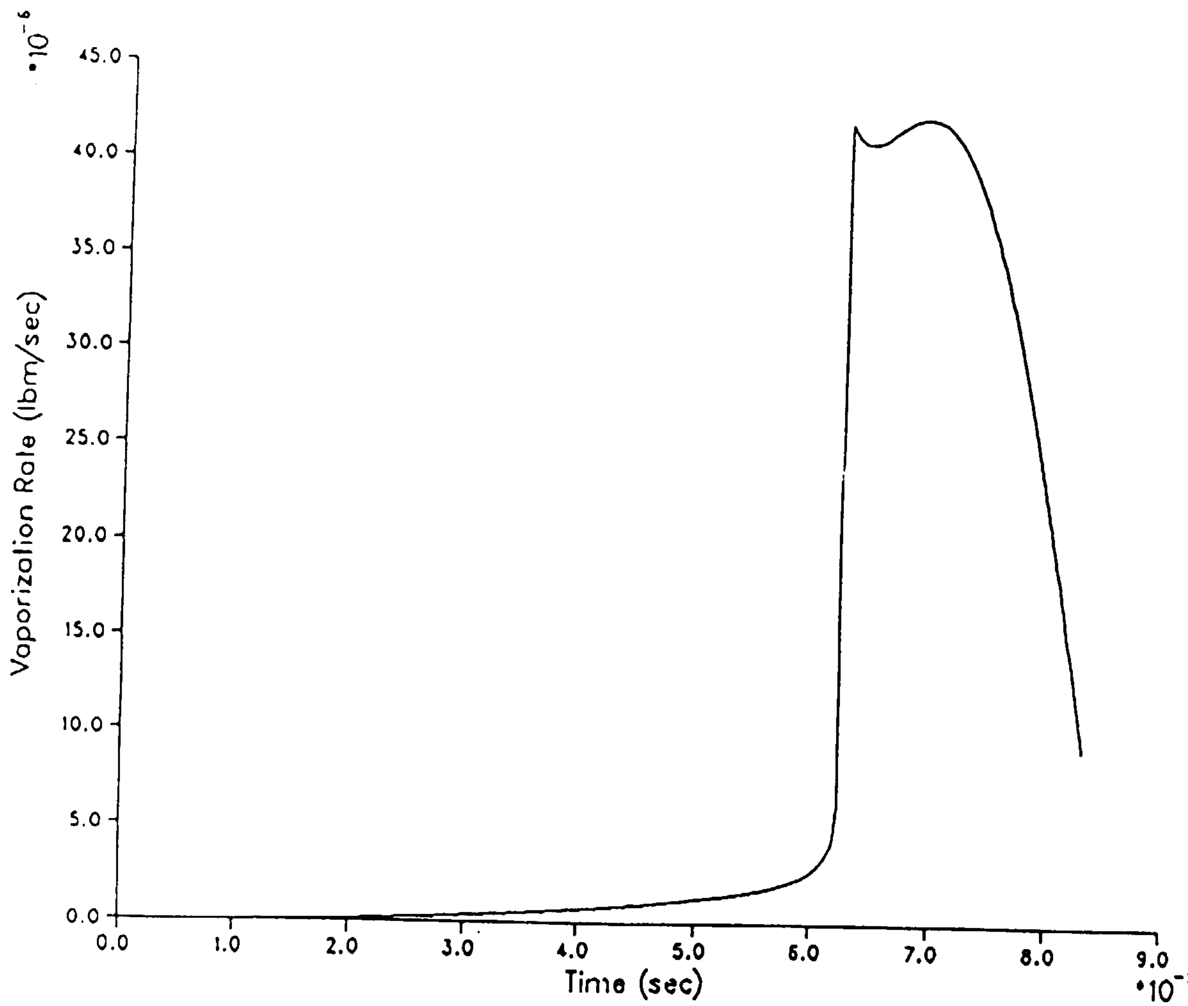
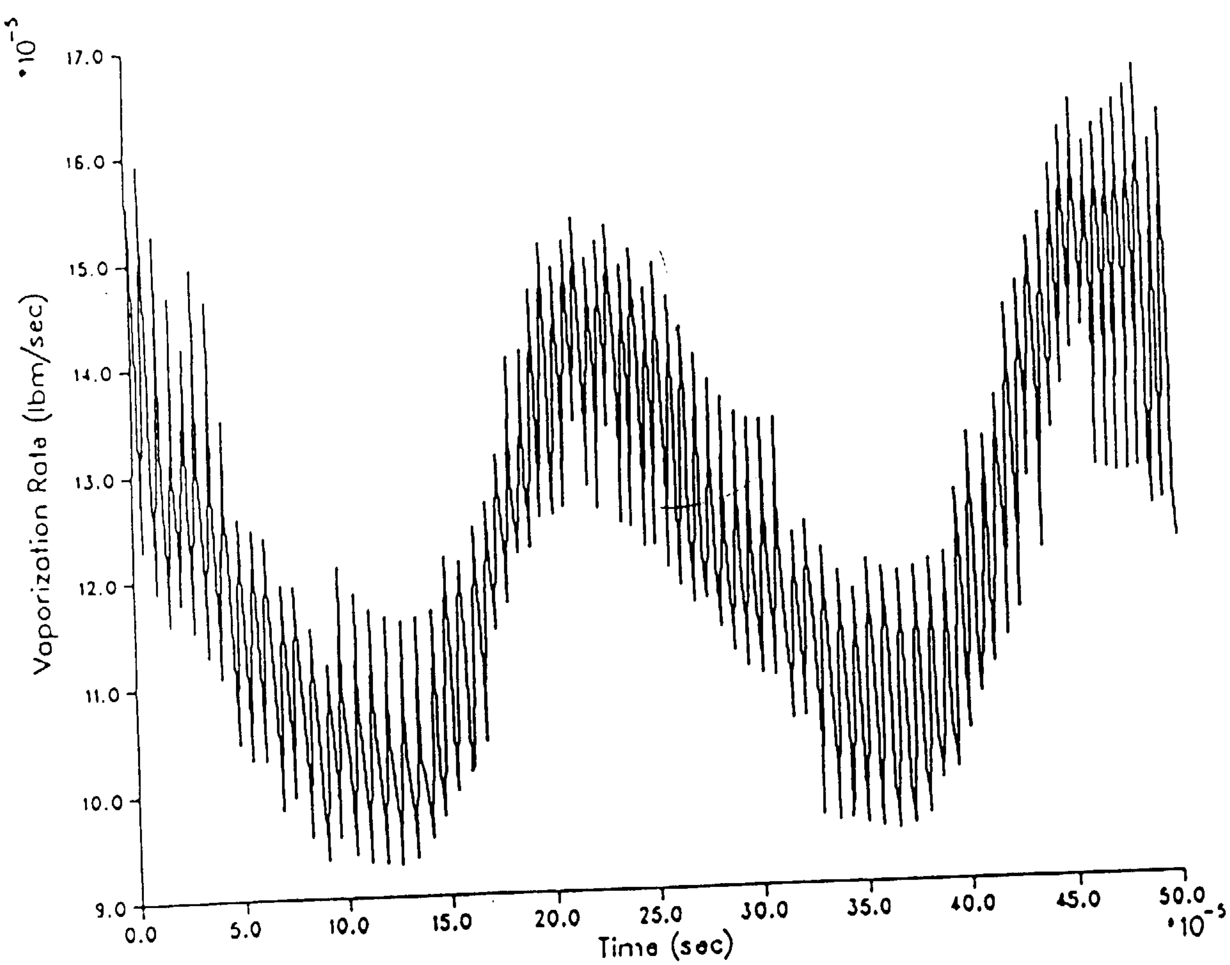


Figure 4.8 : Total Vaporization Rate of an Array of Droplets.



droplets. This plot is generated from a different computer run in which the number of droplets injected per cycle was increased to 80 so that the induced perturbation of the vaporization rate is more pronounced. The sharp spikes in the'total vaporization curve are the results of the use of a finite number of droplets to represent the continuous injection of the propellant. The absolute amplitudes of the spikes are independent of the number of droplets injected per cycle. The mean burning rate is, however, approximately proportional to the number of droplets injected per cycle. Thus, as the number of droplets injected per cycle is increased, the spike amplitudes become smaller relative to the mean of the buring rate.

Finally, the calculated combustion response factors are shown in Figures 4.9, 4.10, and 4.11. Figure 4.9 is a plot of the real and the imaginary parts of the combustion response factor as functions of the frequency. Figures 4.10 and 4.11 show the combustion response factor in a different form. In these figures, the magnitude and the phase angle of the combustion response factor are plotted versus the frequency.

In the past, the combustion response is assumed to be characterized by a pressure interaction index, n and a sensitive time-lag, τ. The values of n and τ are determined empirically. The combustion response factor, Y_b is related to the pressure interaction index and the sensitive time lag in reference 13 as follows:

$$Y_b = n\left(1 - e^{-i\tau\omega}\right)$$

Figure 4.9 : Calculated Real and Imaginary Parts of the Combustion Response Factors as Functions of the Frequency.

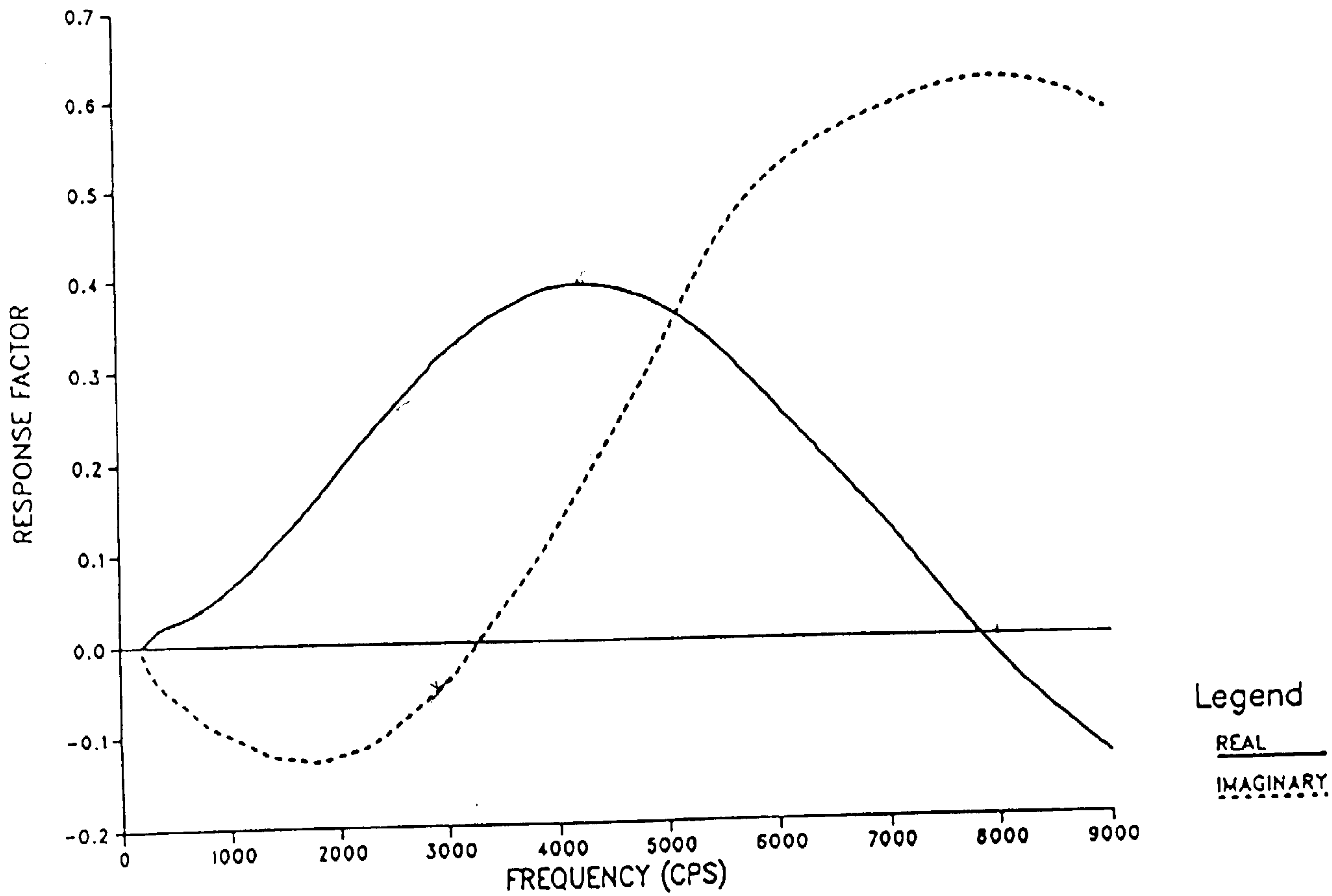


Figure 4.10: Calculated Magnitude of the Combustion Response Factors as Functions of the Frequency.

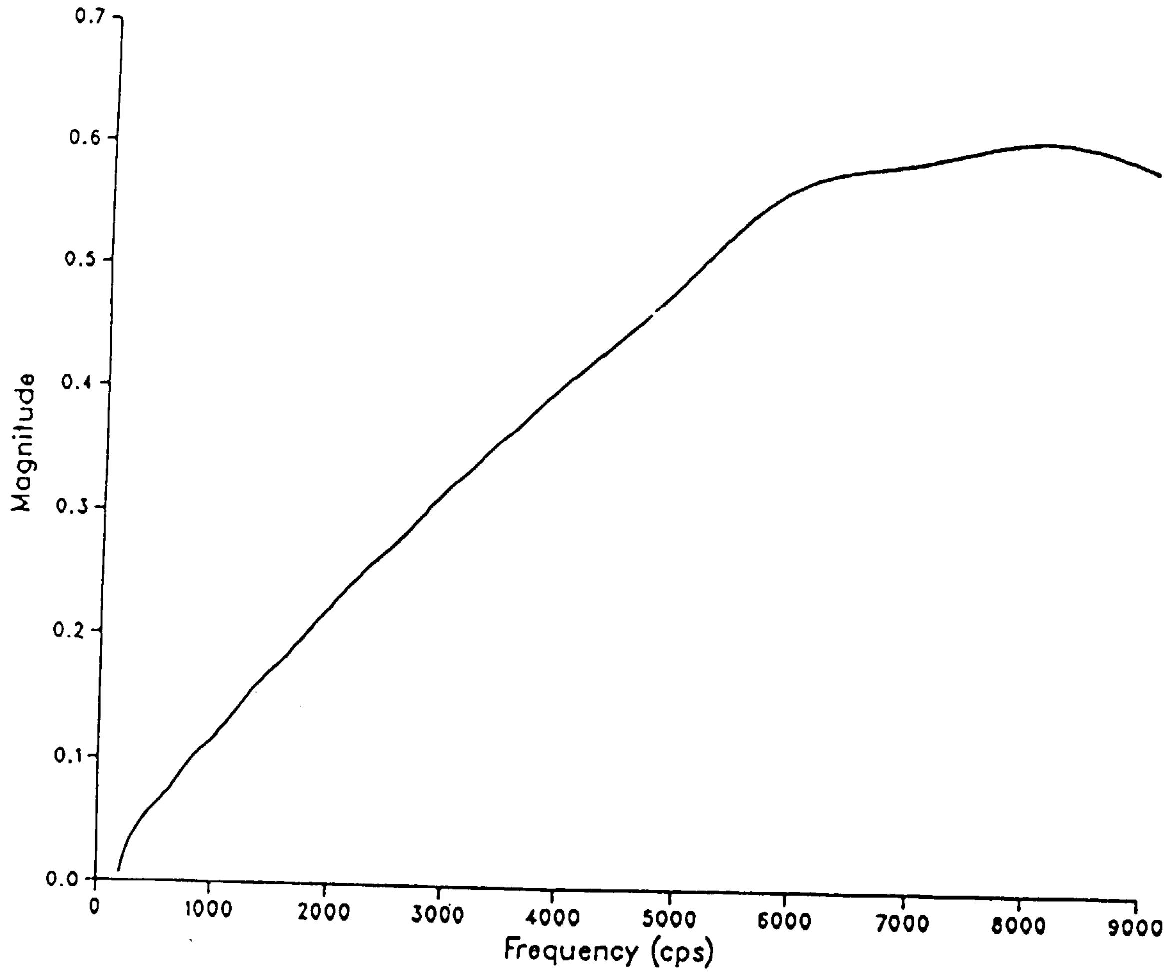
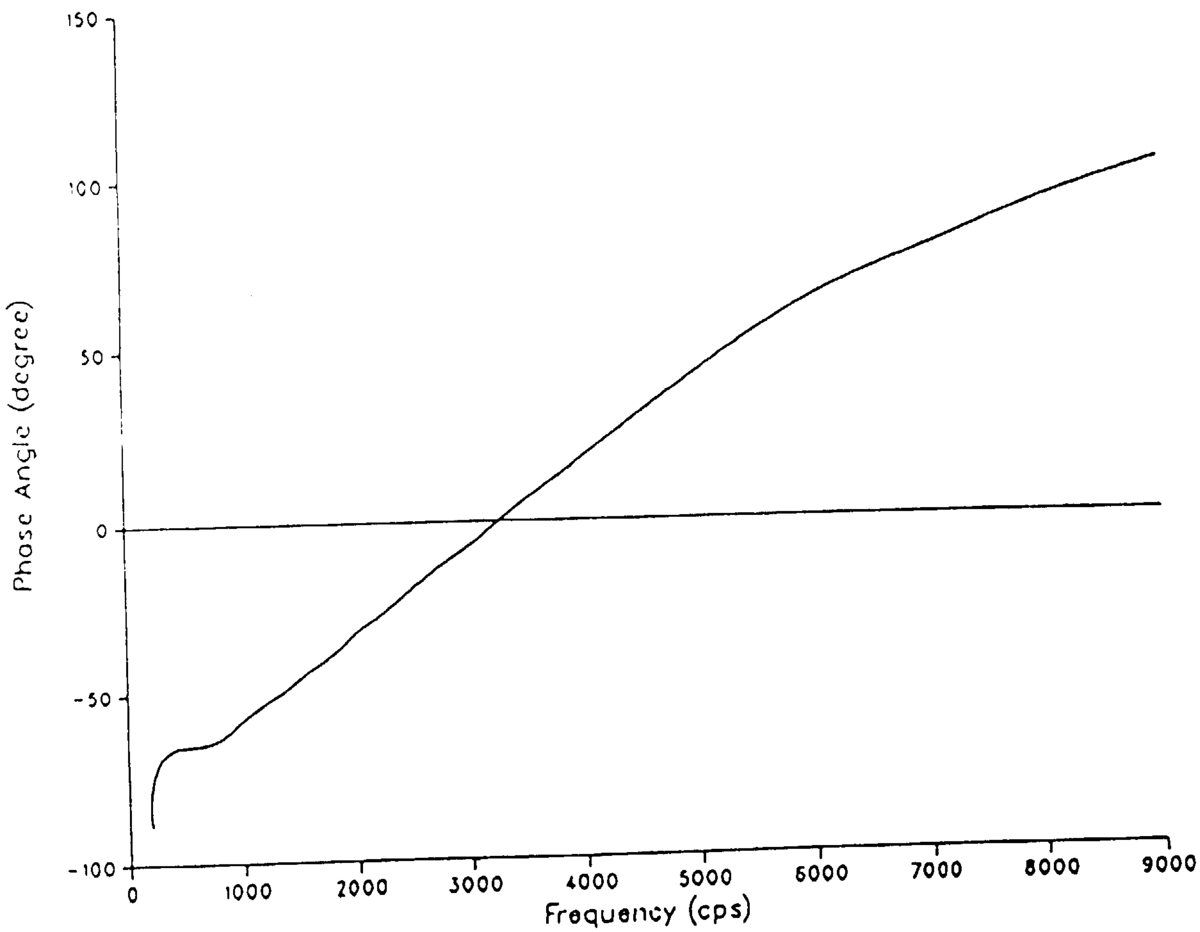


Figure 4.11: Calculated Phase Angle of the Combustion Response Factors as Functions of the Frequency.



or $$Y_b = n\left\{1 - \cos(\tau\omega) + i\sin(\tau\omega)\right\}$$

The above equation shows that the real part of the response factor is a function of the angular frequency. The function has a peak value of 2n at the angular frequency equal to $\frac{\pi}{\tau}$. Thus, the values of n and τ can be obtained from the correlation with the plot of the combustion response factor versus the frequency. For example, in figure 4.9 the real part of the response factor has a peak value of 0.4 at 4000 Hertz, the corresponding values of n and τ for this case are 0.2 and 0.125 milli-seconds, respectively.

V. CONCLUSIONS AND RECOMMENDATIONS

A model has been formulated and a computer code, CRP has been developed to calculate the combustion response factors. Several statements can be made with regards to the calculated results:

1. Three different assumptions about the thermal conductivity of the droplet - zero thermal conductivity, finite thermal conductivity with spherically symmetric temperature distribution inside the droplet, and uniform droplet temperature (infinite thermal conductivity or strong recirculating flows inside the droplet) - have been tested. The latter assumption appears to be superior because calculations of the vaporization rates of droplets vaporizing in steady environments using the assumption agree well with the experimental data. Futhermore, the analysis using the uniform-droplet-temperature assumption is simple and requires less computer time.

2. Time-history calculations of n-Heptane droplets vaporizing in Nitrogen gas and of Chinese Kerosene (RP2) droplets vaporizing in air agree well with the experimental results.

3. Calculations of a 100-micron n-Heptane droplet vaporizing in combustion gases composed of the products of the stoichiometric reaction with oxygen at 300 psia show that the life time of the droplet is approximately 83 micro-seconds. The droplet temperature reaches the

boiling point of the propellant at approximately 62 micro-seconds. Only 6 percent of the droplet mass has vaporized up to this point, thus most of the vaporization takes place at the boiling temperature of the propellant and near the end of the droplet life time. These results are calculated for the case where the frequency of the acoustic oscillations is 2000 Hertzs.

4. A technique was devised to calculate the vaporization rate when the droplet temperature reaches the boiling point of the propellant. The technique eliminates the numerical problem (vaporization rate blows up logarithmically) that is inherent in many of the droplet vaporization studies in the past. Calculations of droplet vaporization histories using the technique appear to be qualitatively correct. The technique is extended to the cases where the droplet temperature reaches the critical temperature of the propellant. Thus, the model can be used for both sub-critical and super-critical chamber pressures.

In addition, the following recommendations are made with regards to the future work to improve the model and/or the computer code:

1. The mean axial velocity is currently calculated using equation 10.b which is not very realistic since it does not account for the spatial distribution of the mixture

ratio. The computer code should be modified so that the axial profile of the mean velocity can be specified as input if it is available apriori, for example, from the steady-state performance analysis.

2. Modifications to the computer code to account for the dependences of the propellant density and the combustion gas viscosity on the temperature are recommended. Currently, only the dependences of the vapor pressure, heat of evaporation, and the diffusion coefficient on the temperature are accounted for.

3. A typical run using the table 4.1 - recommended values of the artificial parameters for a 1T mode requires approximately 2 CPU minutes for each frequency on the VAX computer system at ATC. Conversion of the computer code for use on the PC computer systems is possible because the memory storage required by the code is relative small. This is highly recommended because there are no charges for using the PC's. Conversion of the code for use on the CRAY-XMP at the San Diego Supercomputer Center, to which Aerojet has the access, is also recommended since it is expected that the computer run time and the cost will be significantly lower.

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PART D

NASA/LeRC NON-LINEAR INJECTION RESPONSE MODEL (LEINJ)

NONLINEAR INJECTION ELEMENT THEORY

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March 6, 1989

DOME MODEL

There are three options for the model used in the dome included in the subroutine. These options are:

1. Lumped Parameter (DomInd = 1)
2. Longitudinal Acoustic Wave (DomInd = 2)
3. 3 D Acoustic Wave (DomInd = 3)

The lumped parameter model assumes there are no spatial derivatives in pressure or velocity.

$$P = P_d sin\ \omega t \tag{1}$$

$$V_t = \frac{W}{\rho A} \tag{2}$$

$$W = \frac{\partial P}{\partial t}\frac{\partial \rho}{\partial P} Vol \tag{3}$$

$$\frac{\partial \rho}{\partial P} = \frac{g}{a^2} \tag{4}$$

where	A	area of tube
	a	the speed of sound
	g	gravitational acceleration
	P_d	magnitude of pressure oscillation
	V_t	velocity in the tube
	Vol	volume of manifold per element
	W	flowrate per element

Therefore

$$V_t = \frac{g\omega \, Vol}{Aa^2} P_d cos \; \omega t \tag{5}$$

Note: To obtain constant pressure in the dome set "Vol" very large. For no velocity oscillations at the entrance to the tubes, set "Vol" very small (.00001).

For options 2 and 3, the manifold was modelled using the theory of Maslen and Moore for oscillations in a fluid with finite Mach number flow. Only the linear terms (small amplitudes) are included which reduces to the following wave equation:

$$-\phi'_{tt} + \nabla^2\phi' = M^2 \frac{\partial^2 \phi'}{\partial x^2} + 2M \frac{\partial \phi'_t}{\partial x} \tag{6}$$

where	∇	gradient
	M	mach number
	t	time derivative
	u	velocity vector
	x	axial derivative

The wave is assumed to be periodic in time and separable in the x, r, and θ coordinates, or

$$\phi' = J_n(mr)e^{in\theta}e^{i\omega t}\left(e^{ixB_1} + Ce^{ixB_2}\right) \tag{7}$$

For no steady state axial velocity in the dome

$$P' = -\frac{\rho a^2}{g\omega}\phi'_t \tag{8}$$

$$V' = \frac{a^2}{\omega} \nabla \phi' \tag{9}$$

where	B_1,B_2	complex coefficients
	i	unit complex
	J_n	Bessel Function of order n
	m	argument of Bessel function
	n	number of pressure nodes in θ direction
	r	radial direction
	t	time
	x	axial direction
	θ	tangential direction

Assuming no steady state velocity in the dome (v = 0)

$$B_1 = -B_2 = \left(\frac{\omega^2}{a^2} - \frac{m^2}{{r_d}^2} \right)^{1/2} \tag{10}$$

and

$$C = 1 \tag{11}$$

where r_d is the radius of the dome. At the entrance to the tubes x = L (the effective length of the dome)

$$P' = \frac{-i\rho a^2}{g} \left(e^{iLB_1} + e^{-iLB_2} \right) \tag{12}$$

$$\frac{\partial P'}{\partial x} = \frac{\rho a^2}{g} B_1 \ \left(e^{iLB_1} - e^{-iLB_2} \right) \tag{13}$$

$$V' = \frac{ia^2}{\omega} B_1 \ \left(e^{iLB_1} - e^{-iLB_2} \right) \tag{14}$$

$$\frac{\partial V'}{\partial x} = -\frac{a^2}{\omega} {B_1}^2 \ \left(e^{iLB_1} - e^{-iLB_2} \right) \tag{15}$$

INJECTION ELEMENT MODEL

With the time dependence of pressure,density,and velocity specified at two cells at the inlet to the element (obtained from the solution for the dome above),the time dependence for the next cell can be calculated using the equations below. This process can be repeated to march down the injection element. The dome and element calculations are repeated with a new guess for the amplitude of the oscillation in the dome until the oscillation amplitude at the exit of the element agrees with the chamber oscillation amplitude or cavitation occurs. If a calculated pressure is below the saturated vapor pressure (or below 1 psia for a gas) or exceeds the sonic velocity , the calculation procedure to match exit pressure is terminated. The calculation proceeds to match the lowest pressure to the saturation pressure and a diagnostic message is printed. The response values are adjusted to the required chamber pressure oscillations via

$$RE = RE_c \left(\frac{P_{cch}}{p_{ch}}\right)^{1/2} \tag{16}$$

where P_{cch} calculated injector face pressure amplitude
P_{ch} chamber pressure amplitude
RE_c calculated response

a somewhat arbitrary rule.

Continuity

$$\frac{\partial \rho}{\partial t} + \rho \frac{\partial v}{\partial x} + v \frac{\partial \rho}{\partial x} = 0 \tag{17}$$

Momentum

$$\rho \frac{\partial v}{\partial t} + \rho v \frac{\partial v}{\partial x} + g \frac{\partial p}{\partial x} + \frac{\mu v}{R^2} = 0 \tag{18}$$

State

$$\frac{\partial \rho}{\partial p} = \frac{g}{a^2} \tag{19}$$

or

$$\frac{\rho}{p} = \frac{g}{a^2} = \frac{\rho_o}{p_o}\, Dencon \tag{20}$$

From continuity

$$\frac{v_{n+1} - v_n}{\delta x} = \frac{\partial v}{\partial x} = \frac{-\left(\frac{\rho_o v}{p_o}\frac{\partial p}{\partial x} + \frac{\partial \rho}{\partial t}\right)}{\rho} \tag{21}$$

and from the equation of state

$$\rho = \rho_o + \frac{(p - p_o)\,\rho_o Dencon}{p_o} \tag{22}$$

Substituting into Eq. 17

$$\frac{p_{n+1} - p_n}{\delta x} = \frac{\partial p}{\partial x} = \frac{\left(\rho \frac{\partial v}{\partial t} - v\frac{\partial \rho}{\partial t} + \frac{\mu v}{R^2}\right)}{\frac{\rho_o a^2 Dencon}{p_o} - g} \tag{23}$$

where $Dencon$ slope of the density/pressure relationship
p_o the reference pressure
R the radius of the tube
ρ_o the reference density

At the orifice inlet, the flow variables for a fictitious cell are calculated in the orifice using the area relationship between the orifice and the tube. This fictitious cell and the previous cell in the tube are used to obtain the new conditions for calculations in the orifice via the continuity and Bernoulli equations. The same procedure is used at the orifice exit.

At the overlap points

$$W_{n+2} = W_n \tag{24}$$

$$v_{n+2} = \frac{v_n \rho_n A_n}{\rho_{n+2} A_{n+2}} \tag{25}$$

For pressure use Bernoulli's equation

$$\delta p = 1/2 \rho v^2 \tag{26}$$

$$v = C_D \left(\frac{\delta p}{\rho} \right)^{1/2} \tag{27}$$

At the upstream edge of the orifice

$$\delta p = p_n - p_{n+2} = 1/2 \rho \left(CD_1 v_{orf} \right)^2 \tag{28}$$

At the downstream edge of the orifice

$$\delta p = p_{n+2} - p_n = 1/2 \rho \left(CD_2 v_{orf} \right)^2 \tag{29}$$

where CD_1 upstream discharge coefficient
CD_2 downstream discharge coefficient
v_{orf} velocity in the orifice

If the velocity exceeds the speed of sound, then the velocity at that location is set equal to the speed of sound with the same direction. Momentum is ignored and continuity is used to obtain pressure via ρ

$$\frac{\partial \rho}{\partial x} = - \frac{\left(\frac{\partial \rho}{\partial t} + \rho \frac{\partial v}{\partial x} \right)}{v} \tag{30}$$

```
c c c c c c c c c c c c c c c c c c c c c c c c c c c c c c c c c c c
c
c     "INJ"  Calculates the "NONLINEAR" flow oscillations in an
c         injector tube using the full nonlinear conservation of
c         mass and momentum equations with a radial viscous force.
c     INPUTS to the problem are:
c         DomInd  Index to indicate mode in Dome (Integer)
c                   DomInd = 1 Lumped volume mode
c                   DomInd = 2 only axial wave
c                   DomInd = 3 three dimensional wave
c       DIMENSIONS of Injector Element
c         Abor    Tube Area Upstream of orifice, sq. inches
c         Lbor    Tube length upstream of orifice, inches (Real)
c         Rbor    Tube radius upstream for viscous,inches
c         Aor     Area of orifice, sq. inches
c         Lor     Length of orifice, inches (Real)
c         Rior    Orifice radius for viscous, inches
c         CDfl    Flow coeffecient of orfice, dimensionless
c         Ador    Tube Area downstream of orifice, sq. inches
c         Ldor    Tube length downstream of orfice, inches (Real)
c         Rdor    Tube radius for viscous term, inches
c       DIMENSIONS OF DOME
c         Ldom    Area averaged LENGTH OF DOME, inches (Real)
c         Ddom    Effective DIAMETER of dome,  inches
c       GEOMETRY OF INJECTOR
c         Ninjel  Number of injector elements
c       OPERATING CONDITIONS of injector
c         FlowFl  Total flow of Fluid, lbs./sec.
c         Pssch   Average or steady state chamber pressure, psi
c         DenFl   Average density of Fluid at Pssch,  lb/cu in
c         Vsound  Speed of Sound of Fluid at Pssch, in./sec
c         VisFl  Viscosity of Fluid  lb/in.sec
c         Psatvp  Saturation vapor pressure of fluid,  lb/in.sec
c       OSCILLATION CHARACTERISTICS
c         Freq      Fundametnal frequency of oscillation, cps
c         BessIn    BessIndex to define mode , dimensionless
c         Pdsl      Dome amplitude of fundamental sin Oscillation  psi
c         Pdcl      Dome amplitude of fundametnal cos oscillation  "
c         Pdsls     Slope of Amplitude of fund. osc.  psi/inch
c         Pdcls     Slope of amplitude cos-fun osc   psi/inch
c         Vdsl      Vel amplitude of fundamental sin Oscillation in/sec
c         Vdcl      Vel amplitude of fundamental cos Oscillation in/sec
c         Vdsls     Slope of Amplitude of fund sin Vel osc.  in/sec-in
c         Vdcls     Slope of Amplitude of fund cos Vel osc.  in/sec-in
c         PpDom     Pressure Amplitude in Dome.  psi
c         PampCh    Pressure Amplitude in Chamber,psi
c       CALCULATION CHARACTERISTICS
c         Nbor      Number of mesh-grid elements upstream of orifice
c             NOTE: Determine elements so Grid length is less than
c                     .03 * wavelength  (Speed of Sound/Freq)
c         Nor       Number of mesh-grid elements in orfice
c         Ndor      Number of mesh-grid elements downstream of orifice
c         Ntinj     Number of time steps per cyle (make approximately 18)
c             NOTE: There are numerical stability limits associated with
c                   the choice of Ntinj. We recommend setting Ntinj to
c                   approximately 18 and refining the spatial step size
c                   (less than .03 * (speed of sound / freq)
c                   to resolve numerical instabilities.
c
c      OUTPUT
c         RrspFl    Real flow response
c
c         IrspFl    Imaginary flow response (Real)
c c c c c c c c c c c c c c c c c c c c c c c c c c c c c c c c c c c c
```

PART E

LUMPED PARAMETERS INJECTION RESPONSE MODEL (INJ)

Lumped Parameter Injection Response Model (INJ)

Jeffrey Muss

The lumped parameter injection responses model, INJ, is similar to the model described in NASA SP-194 (Ref. 1). The model has been limited to consider only the effects of the injection element and the propellant manifold, thereby ignoring all upstream effects. The major deviation from the SP-194 model is the extension of the model to account for element mixed patterns. This required the timelag and inertance of each element to be accounted for. This was achieved by mass weighting the individual contribution of each element. Slightly different variable normilization were applied, for computational efficiency reasons, and this results in different forms of the characteristic variables, i.e., inertance, capacitance and resistance. Expansion of these parameters will yield the traditional definitions.

The injector's resistance (R) and capacitance (C), and the element"s inertance (L) are defined as:

$$R = DPj/(n*Pc) \tag{1}$$

$$C = \frac{Pc * Vol * Gc}{A^2 * W_{tot}} \tag{2}$$

$$L = \frac{l_{orif} * W_{orif}}{A_{orif} * Gc * Pc} \tag{3}$$

where Vol is the manifold volume, in ft^3, A_{orif}, l_{orif}, and W_{orif} are the cross-sectional area, in ft^2, length, in ft, and flowrate, in Lbm/s, of an orifice in an element, respectively, Gc is the gravitational constant, A is the speed of sound in the propellant, in ft/s, W_{tot} is the total propellant flow, in Lbm/s, and DPj and Pc are in psf. L and C are in seconds, while R is nondimensional. The term "n" in the calculation of the resistance is the exponent in the equation.

$$W = k * DPj^n \tag{4}$$

where W is mass flowrate and k is a proportionality constant. It should be noted that n=0.5 for liquid propellants, while is must be evaluated numerically for gaseous propellants.

The overall mass-weighted injection admittance (Yj) is expressed as:

$$Yj\,(f) = \frac{-1}{1+MR} * \quad \text{n=1,NFE} \quad \left| \frac{FMF_n * EXP\,(i*w*Tau_n)}{R_f + L_{f,n} + (i*w*C_f^{-1})} \right| +$$

$$\frac{-MR}{1+MR} * \quad \text{m=1,NXE} \quad \left| \frac{XMF_m * EXP\,(i*w*Tau_m)}{R_x + L_{x,m} + (i*w*C_x^{-1})} \right| \qquad (5)$$

where f is the frequency, in hz, $EXP(x)=e^x$, MR is the oxidizer-to-fuel mixture ratio, Tau is the total timelag, in sec., i is the square root of -1, w is the angular frequency 2*Pi*f, NXE and NFE refer to the total number of oxidizer and fuel element types, respectively, the subscripts "x" and "f" refer to oxidizer and fuel, respectively, and FMF and XMF are the fraction of the total fuel and oxidizer mass contained in that element type, respectively.

References

1) Liquid Propellant Rocket Combustion Instability; D.T. Harrje, Ed., NASA SP-194, 1972.

PART F

MCA PERFORMANCE/LIFE COMBUSTION MODEL DEVELOPMENT FINAL REPORT

Aerojet
TechSystems
Company

ENGINEERING AND DEVELOPMENT

THERMODYNAMIC ANALYSIS REPORT

NUMBER: 9980:1455

DATE: 5 March 1986

SUBJECT:

MCA PERFORMANCE/LIFE COMBUSTION
MODEL DEVELOPMENT FINAL REPORT

PAGE 1 OF

NO. OF ENCLOSURES

NO. OF APPENDICES

ADDITIONAL INFORMATION AND WORK NOTES INCLUDED IN MICROFILM FILE CDN

PREPARED FOR: J. A. Van Kleeck

INTRODUCTION

The Performance/Life Combustion Model (PLC) was developed to evaluate the energy release efficiency (ERE) and the spacial combustion chamber wall mixture ratio distribution within the Space Shuttle Main Engine (SSME) for the Main Chamber Combustion and Cooling Technology Study. The output from the PLC model is to be used in conjunction with thermal, structural and performance models to assess overall thrust chamber performance and combustion chamber life.

While the model is not a rigorous CFD type of model, it does account for many of the influences in the same way a rigorous model would. PLC was developed to mechanistically account for changes in injector and chamber design parameters and variable operating conditions without reliance upon empirical user input scaling factors. The input is concise, requiring a minimum of propellant property information. The input, described in full in Appendix I, consists of propellant injection conditions, chamber wall contour information, injector pattern layout, element flowrates, and basic injector element design configuration. It can be used to evaluate any gaseous fuel-liquid oxidizer propellant combination for several types of "coaxial" injectors.

KEYWORDS: SSME (16), TCA (66), Performance (101), Compatibility (109), LOX/HC (153), Computer Program - New Development (210), 1986 (271), Muss (362)

DISTRIBUTION:

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REVIEWED BY:
J. ITO J. I. Ito

APPROVED BY:
M. F. YOUNG, MANAGER

J-187

MODELLING ASSUMPTIONS

The inherent strength or weakness of any model is the validity of the assumptions used in the model. This section outlines the major assumptions incorporated in PLC.

The chamber flow dynamics are modelled assuming that the flow in the near-face region is in discrete streamtubes, while flow in the remainder of the chamber is modelled as finite elements or "cells". The vapor contained within any given cell is assumed to be well mixed, and the cell possesses the physical properties characterized by the axial pressure and the cell's vaporized mixture ratio. These cells are set up by GRIDGEN so that all cells are of equal area. The number of cells is determined by the number of slices, NSLICE, and the number of radial segments, NSEG, specified in the input, and is equal to NSLICE*NSEG. The number of cells is constant at any cross-section, but the cell area is a function of axial location. Figure 1 shows the grid for a chamber with 12 slices and 4 segments. Flow calculations are also based on the assumption of choked flow at the throat, but the assumption's validity is never checked by the program. Other key assumptions are that the volume occupied by the droplets is negligible, so that the vapor is assumed to occupy the entire local cross-section, and that the droplets apply no drag forces to the gases that are accelerating them.

The pressure is assumed to be constant and equal to the nominal chamber presure throughout the cylindrical portion of the chamber. It is also assumed that the gas phase properties can be adequately estimated as a function of the local vapor mixture ratio and pressure with TDK generated one-dimensional shifting equilibrium values.

Droplets are assumed to move as a uniformly distributed ring surrounding the axis of the injection element they emanated from. The distance from the element axis (or the apparent element axis) is measured as a radius, R, and vapor generated by vaporizing droplets is distributed uniformly around the injector axis at this radius R. The radius R is changed as the droplets experience aerodynamic drag from the gases.

PROGRAM LOGIC

This section describes the flow of information within PLC while the subroutine details are reserved for the following section. PLC models the atomization of the oxidizer, streamtube expansion of the injected gas/liquid mixture in the near-face region, vapor mixing in the cylindrical chamber section, droplet trajectories and secondary droplet shattering due to wall impingement, and 2-D isentropic flow acceleration in the convergent nozzle section.

A cylindrical coordinate system is employed to describe position, with the axial position defining the local wall radius. All internal calculations are conducted in fundamental English units, i.e. LBm-Ft-Sec. Information is transferred between subroutines by means of labelled commons which are sized at runtime based upon the problem inputs. Program output is directed to two files, "PL.HISTORY" which contains echoed input data, ERE predictions and other run information, and "MR.DIST" which contains the vapor mixture ratio as a function of axial, radial and circumferential position.

PLC is structured with a main calling program and a series of subroutines. The main program is used only to sequence the processing of information, check for error conditions, and monitor axial position. A graphical representation of this flow diagram is presented in Figure 2. The first subroutine called is SETUP. SETUP reads and echos the input file, checks it for consistency, and initializes problem specific variables. The next step is to atomize the

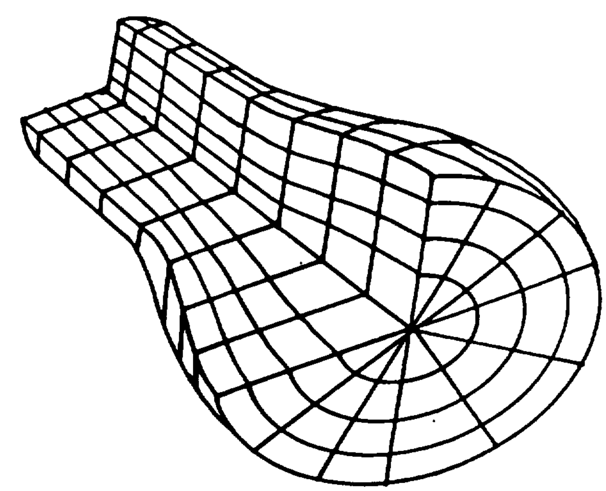

Figure 1

Graphical Representation of
the Computational Grid

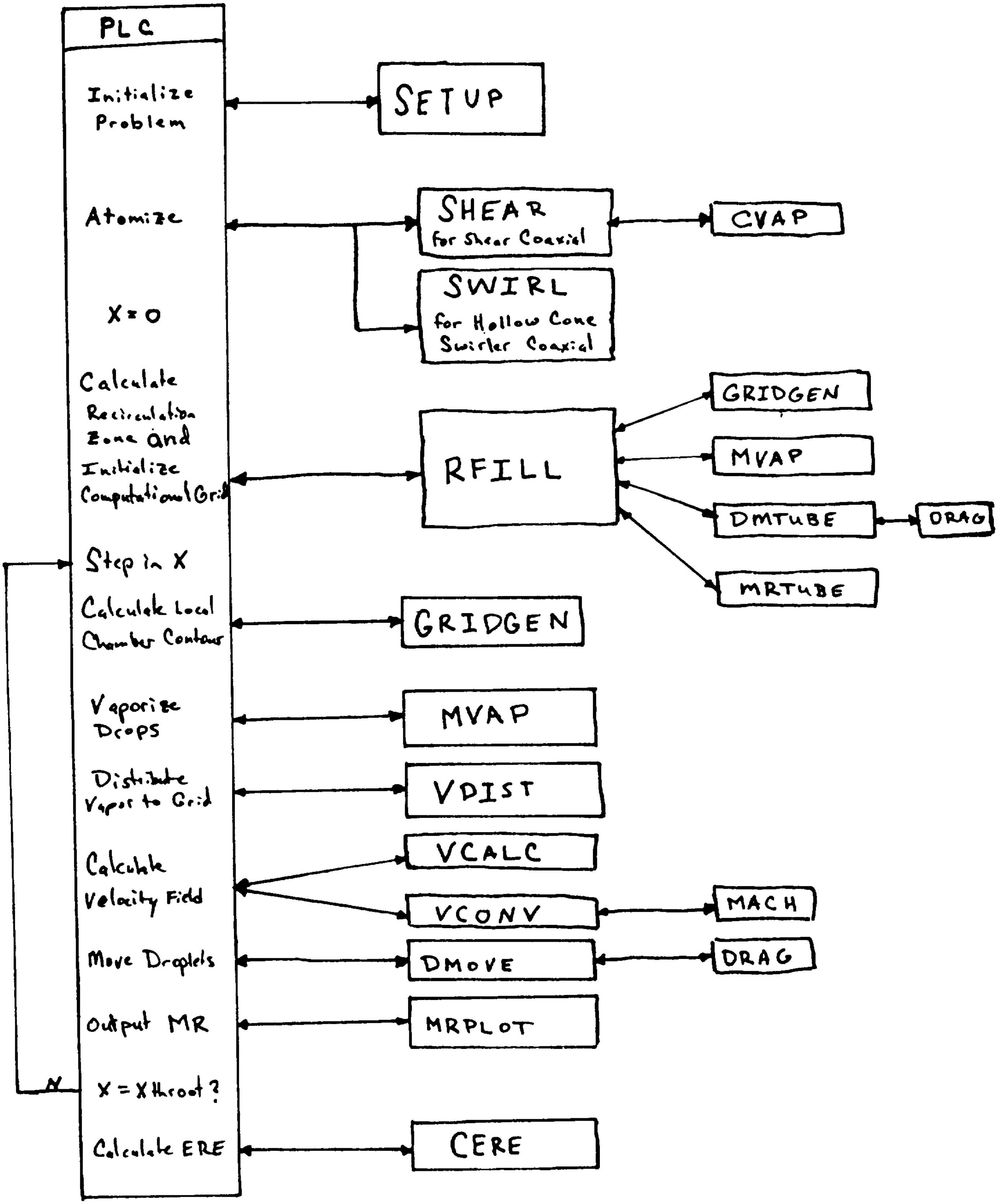

Figure 2
PLC Program Schematic

oxidizer. This is done either by subroutine SHEAR for conventional shear coaxial injectors, or by SWIRL for standard and impinging hydraulically swirled coaxial injectors. These subroutines calculate the mass median dropsize, the dropsize uniformity distribution parameter, Sg, the number of drops formed per second of each size, the mean atomization length and the mean injection velocities for each element. Each injector's droplet production is characterized by three dropsizes, the mass median dropsize, which accounts for 67% of the droplets formed, and the mass median dropsize multiplied and divided by Sg which results in maximum and minimum dropsizes, respectively, of plus and minus one standard deviation. Each of these sizes represent 16.5% of the drops produced. When the oxidizer for all elements has been atomized, the droplet vaporization and chamber gas dynamics calculations begin.

The subroutine RFILL is called next to calculate the length of the near-face recirculation zone. In the near-face zone, the droplets are assumed to flow in perfectly mixed streamtubes emanating from the elements. These streamtubes expand at a rate governed primarily by the rate of oxidizer vaporization. As axial steps are taken, RFILL calls GRIDGEN to calculate the local wall radius and MVAP to calculate the oxidizer mass flow added to the gas stream due to droplet vaporization between the current and previous axial position. RFILL then calls DMTUBE to calculate the droplet acceleration resulting from aerodynamic drag on the droplet by the combustion gas and MRTUBE to output the streamtube mixture ratios. Finally RFILL calculates the cross-sectional area of the streamtubes, which is based on the conservation of linear momentum. The area of the streamtubes is summed and compared to the local cross-sectional area of the chamber. If the cross-section is not filled, another axial step is taken and the process is repeated. If the cross-section is filled, RFILL will calculate the streamtubes final location and distribute the streamtube's mass to the computational grid. When complete, the coolant flow is uniformly added to the computational grid.

With the cross-section filled, the main program calculates the chamber gas dymanics as a function of the axial location in the chamber. The main program steps in x until the throat plane is reached, calculates positional vapor mass addition, gas velocities, radial and circumferential vapor mass flux, droplet movement due to aerodynamic drag and vapor mixture ratio distribution at each axial station.

These calculations are made in the following manner. First, GRIDGEN is called to calculate local wall radius, wall angle, and to calculate the radii of the equal area computational grid cells. Next, MVAP is called to calculate droplet vaporization and dropsize reduction, and VDIST is called to distribute the vaporized mass to the computational grid. With the mass addition complete, the gas velocity components are calculated by either VCALC for the cylindrical section of the chamber, or by VCONV for the converging section. VCALC calculates an ERE based 1-D axial velocity as well as local radial and circumferential velocities based on cell-to-cell mass maldistributions. VCONV calculates a local axial and radial velocity based on isentropic acceleration and wall curvature turning of the gas. With the cross-sectional velocity profile calculated, DMOVE is called to calculate the droplets' movement resulting from aerodynamic drag. It also checks for droplet wall impingement. Finally, MRPLOT is called to report the radial and circumferential vapor mixture ratio distribution. This process is repeated until the throat plane is reached at which time CERE is called to calculate the overall vaporization, mixing and energy release efficiencies.

SUBROUTINE DESCRIPTION

This section examines the salient features of several key subroutines. A complete listing of all the subroutines is contained in Appendix II.

SHEAR is used to calculate the mass median dropsize, distribution coefficient and total number of drops formed by a shear coaxial liquid-gas injector. The oxidizer is assumed to be liquid and the fuel or preburner hot exhaust to be gas. The term fuel is used to represent the gas stream.

Calculations begin by estimating the oxidizer post discharge coefficient and velocity profile. These calculations consider the area ratio of the post tip to the metering diameter, the length of the final diffuser section, and the oxidizer Reynolds Number, and are based on Ito's General Hydraulic Flip Model (Ref 1). The fuel stream velocity is considered to have a flat, turbulent profile, and it is based upon a 1-D calculation. With the velocities in both streams set, the dropsize formed at any axial position is determined by equating the surface tension cohesive force to the interfacial shear force and solving for the dropsize,

Rm=8*ST/(T*g)

where Rm is the droplet radius in ft, ST is the oxidizer surface tension in lbf/ft, T is the interfacial shear stress in lbm/ft-sec2, and g is the gravitational constant. The interfacial shear stress is estimated as

T=m*(Vf-Vx)/(TPOST+DRJET)

where m is the mean dynamic viscosity for the fuel and the oxidizer in lbm/ft-sec, Vf is the fuel velocity, Vx is the oxidizer free surface velocity, TPOST is the oxidizer post wall thickness, and DRJET is the reduction in oxidizer jet radius due to mass stripping. Once the dropsize for an axial position is calculated, the oxidizer jet's radius is reduced to account for the mass of the droplets formed. First the number of drops formed is estimated by calculating how many drops will fit around the outside of the jet. The volume of these drops is removed from the jet and the resulting truncated conic section is calculated. The integrated flow in and out of the cone is then used to calculate the number of drops formed based on satisfaction of continuity.

If the injector contains a recessed post, the drops formed in the cup are vaporized between their generation location and the injector face. The percent of the droplet vaporized is based on the Priem's Generalized Length Correlation (Ref 2) which is used thoughout PLC to model droplet vaporization. The oxidizer vapor is added to the fuel stream. The added mass is first used to fill the fuel injection flow area, i.e. increase the fuel Cd to 1.0, and then to accelerate the fuel velocity.

RFILL calculates the rate at which the injector element's streamtubes expand in the near-face zone. It vaporizes and accelerates the droplets at each axial step until the total cross-sectional area is filled. When the cross-section is filled, the mass in the streamtubes is distributed to the computational grid.

The area of the streamtubes is based on the conservation of linear momentum. The flow within the streamtubes is modelled as a set of rings. The inner ring is a circle of radius RCORE and estimates the liqiuid oxidizer core radius as a function of axial location. RCORE is estimated as

RCORE=MAX(0.0, (RXP-(RXP/(2.0*AL))*(X+RECESS))

where RXP is the oxidizer post radius, AL is the element's mean atomization length, X is the current axial position, and RECESS is the oxidizer post tip recess. RCORE is surrounded by an annulus of stoichiometric combustion gases. The area of this annulus, ACZ, is estimated as

ACZ=1.125*Wo/RHO/VCZ*ERE

where Wo is the vaporized oxidizer mass flow in the streamtube, RHO is the density of the stoichiometric zone, VCZ is the estimated combustion gas velocity, and ERE is the streamtubes characteristic velocity energy release efficiency. VCZ is estimated as

$$VCZ=(8*Vo+Vf)/9.0$$

where Vo and Vf are the injected oxidizer and fuel velocities, respectively. The outer annulus, of outer radius equal to the streamtube's radius, is composed of the unreacted fuel.

When the cross-section is filled by the streamtubes, streamtube flow ceases and the vaporized mass is distributed to the computational flow grid. Distribution is based on final streamtube position. This is done by assuming that the streamtubes from the outer row of elements will be forced into an annular region against the wall of cross-sectional area equal to the sum of the cross-sectional area of the outer row's streamtubes. Then starting with the element of that row with a circumferential location closest to zero degrees, an angular slice of the annulus is calculated with a cross-sectional area equal to that of the element's streamtube. This process is repeated for all elements of the outer row. When complete, the vapor mass within the annular slices are transferred to the computational grid cells corresponding to each annular slices locations. The elements' location are replaced with the coordinates of the centroid of the annular slices' area. This process is repeated for the next outermost row (the second row from the wall) assuming its annular area abutts the outer annulus' inner edge. The process is repeated for all rows. When complete, the transpiration coolant flow is uniformly added to the computational grid.

MVAP is used to vaporize the droplets in all axial flow regimes. It is based on the Priem-Heidmann Droplet Vaporization Model (Ref. 2).

VCALC calculates the gas 1-D velocity and properties at axial locations between the near-face zone and the entrance to the convergent section. It calculates radial and circumferential mass velocities due to cell-to-cell mass maldistributions resulting from differential local vaporization rates and element-to-element flow variations. These velocities are based on the tendency of mass to try to uniformly distribute itself across the cross-section rather than to remain statified in zones of high and low mass concentration. Future development should focus on a more rigorous treatment of these phenomenae.

VCONV calculates the gas acceleration in the convergent section of the thrust chamber nozzle. It outputs axial and radial gas velocities as a function of the local wall curvature and gas properties as well as the isentropic acceleration of the gas. It is based on the Droplet Trajectory Model of Nyugen (Ref 3).

DMOVE is used to accelerate and move the droplets due to aerodynamic drag. It also checks for wall impingement of the droplets. If impingement occurs, the droplets are assumed to be vaporized at that point due to secondary droplet shattering. Both Stoke's flow and Newtonian drag expressions are used depending on the applicable Reynolds Number. The Newtonian drag equation takes the form used in SDER (Ref 4) which eliminates a stepsize constraint in order to achieve numerical stability. Rabin's correlations for drag of an accelerating liquid droplet are used to calculate drag coefficients (Ref 5). The drag is calculated for droplet assuming supercritical expansion of the droplet.

DBLINT is a general linear double interpolation routine used to calculate the various gas properties as a function of chamber pressure and local mixture ratio. The interpolation uses ODE chamber equilibrium values at chamber pressures of 300 and 3000 psia and mixture ratios ranging from 0 to 20. The gas properties calculated are specific heat ratio, gas temperature, molecular weight, density, sonic velocity, characteristic velocity and dynamic viscosity.

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5. Rabin, E., Schallenmueller, A. R., and Lawhead, R. B., Displacement and Shattering of Propellant Droplets, AFOSR-TR-60-75-1960

APPENDIX I

PLC INPUT INFORMATION

CONTENTS

Input Format Information

There are a few simple steps required to run the PLC model. First an input file has to be written. When the file is complete, the user runs the CPL file PLSET to size the commons, create any necessary insert files and create an executable program. This section contains the format of PLC input files as well as two sample input files.

The input format for PLC is as follows. The file MUST be named PL.INPUT.

```
TITLE 1                        (A80)
TITLE 2                        (A80)
 (BLANK LINE)
$OUTPUT
$END
 (BLANK LINE)
PC    HGMR                     (F7.2,F7.4)
TINJ  TC  RHO  MU  MW  HOV     (6E12.4)   (FUEL/HOT GAS PROPERTIES)
TINJ  TC  RHO  MU  MW  HOV     (6E12.4)   (OX PROPERTIES)
ST    RHOC                     (2E12.4)   (OX PROPERTIES)
 (BLANK LINE)
NXP                            (I3)
XW(1)  RW(1)                   (2F7.4)
.
.
XW(NXP)  RW(NXP)               (2F7.4)
 (BLANK LINE)
INPUT-TYPE  NEL  NROWS         (3I4)
INPUT-TYPE INPUT FORM
CFLOW  CFMR                    (2F8.4)
 (BLANK LINE)
INJ-TYPE                       (I2)
INJ-TYPE INPUT FORM
 (BLANK LINE)
$CONT
$END
```

The inputs are further defined as follows:

NAMELIST $OUTPUT CONTROLS PROGRAM OUTPUT
DEFAULT IS 0 FOR ALL EXCEPT IECHO WHERE 0=OFF

PARAMETER	VALUES	FUNCTION
IECHO	0/1	ECHO INPUT
ITRACE	0/1/2	TRACES PROGRAM PROGRESS: =1 AXIAL LOCATION =2 AND SUBROUTINE ENTRY
IAFLG	0/1/2/3	OUTPUTS DROPLET FORMATION INFORMATION: =1 MEDIAN DROPSIZE, DISTRIBUTION PARAMETER, NUMBER OF DROPS, INJECTION VELOCITY, AND ATOMIZATION LENGTH =2 AND DROPSIZES FORMED BY SHEAR COAX INJECTOR =3 AND DROPSIZES AS FORMED AND VAPORIZED BY SHEAR COAX
IRFFLG	0/1/2/3	OUTPUT RECIRCULATION ZONE CALCULATION INFORMATION: =1 PERCENT OF CROSS-SECTION FILLED AS F(X) =2 AND FINAL INJECTOR APPARENT LOCATIONS =3 AND DISTRIBUTION FOR STREAMTUBES TO GRID
IMVFLG	0/1	OUTPUTS DROPLET VAPORIZATION INFORMATION
IVDFLG	0/1	OUTPUTS DISTRIBUTION OF VAPOR
IPDFLG	0/1	OUTPUTS AXIAL AND RADIAL VELOCITY COMPONENTS
IDMFLG	0/1	OUTPUTS DROPLET MOVEMENT
IDFLG	0/1	OUTPUTS DRAG INTERACTION PARAMETERS
IMRFLG	0/1/2/3	OUTPUTS MASS DISTRIBUTION INFORMATION: =0 WALL MR AS A FUNCTION OF THETA =1 AND CROSS-SECTION MR AS A F(R,THETA) =2 AND MASS FLOW AS A F(R, THETA) =3 AND FUEL AND OXIDIZER MASS FLOW AS A F(R,THETA)

OPERATING CONDITIONS AND INJECTION PROPERTIES

```
     PC=CHAMBER PRESSURE (PSIA)
   HGMR=FUEL/HOT GAS MIXTURE RATIO
   TINJ=INJECTION TEMPERATURE (DEG F)
     TC=CRITICAL TEMPERATURE (DEG F)
    RHO=DENSITY (LBm/CU. FT)
     MU=DYNAMIC VISCOSITY (LBm/FT-SEC)
     MW=MOLECULAR WEIGHT (LBm/LBMOLE)
    HOV=HEAT OF VAPORIZATION AT NBP (BTU/LBm)
     ST=SURFACE TENSION (LBf/FT)
   RHOC=CRITICAL DENSITY (LBm/CU. FT)
```

Note: the fuel/hot gas density and/or viscosity may be set to zero and the

CHAMBER CONTOUR

```
   NXP=NUMBER OF CHAMBER CONTOUR DESCRIPTION POINTS (MINIMUM=2)
    XW=AXIAL LOCATION OF RW (INCHES)
    RW=CHAMBER WALL RADIUS AT XW (INCHES)
```

INJECTOR ELEMENT LAYOUT

```
INPUT-TYPE=POSITION AND FLOW INPUT TYPE:
           =1 FOR INPUT EACH ELEMENT LOCATION AND FLOWRATE
           =2 FOR INPUT # ELEMENTS/ROW, ROW POSITION AND FLOWRATE EQUATION
       NEL=TOTAL NUMBER OF ELEMENTS
     NROWS=NUMBER OF CONCENTRIC ROWS
```

IF INPUT-TYPE=1 INPUT-TYPE INPUT FORM IS OF THE FORMAT:

```
              ERPOS  ETPOS  FMF  XMF   (4F8.4)

   ERPOS=ELEMENT RADIAL LOCATION FROM CENTERLINE (IN)
   ETPOS=ELEMENT CIRCUMFERENTIAL POSITION FROM 0 DEGREE REF (DEG)
     FMF=HOT GAS MASS FLOWRATE (LBm/SEC)
     XMF=OX MASS FLOWRATE (LBm/SEC)
```

One line for each element listed by accending radius and then by ascending circumferential location within a row

IF INPUT-TYPE=2 INPUT-TYPE INPUT FORM IS OF THE FORMAT:

```
              NELR  RROW   (I4,F8.4)
               FMF_EQ      (A65)
               XMF_EQ      (A65)

      NELR=NUMBER OF ELEMENTS IN THAT ROW
      RROW=RADIUS OF ELEMENTS IN ROW (IN)
    FMF_EQ=FUEL/HOT GAS MASS FLOWRATE EQUATION (LBm/SEC)
    XMF_EQ=OX MASS FLOWRATE EQUATION (LBm/SEC)
```

a function of the variable theta, the circumferential position. elements in a row are assumed equispaced and theta is in rads (0-2pi). rows should be listed in ascending radial position.
Note: FORTRAN trig. functions use radians

```
   CFLOW=TOTAL COOLANT FLOWRATE INTO THE THRUST CHAMBER (LBm/SEC)
    CFMR=COOLANT FLOW MIXTURE RATIO
```

INJECTOR TYPE AND DIMENSIONS

ITYPE=1 FOR SHEAR COAX INJECTOR AND ITYPE INPUT IS:

RXP RFP TPOST RECESS RMS XDL FCD (7F7.4)

```
   RXP=OX POST INNER RADIUS (IN)
   RFP=FUEL ANNULUS OUTER RADIUS (IN)
 TPOST=OX POST THICKNESS (IN)
RECESS=OX POST RECESS (IN)
   RMS=RADIUS OF OX METERING SECTION (IN)
   XDL=OX DIFUSER SECTION LENGTH (IN)
   FCD=FUEL ANNULUS CD
```

ITYPE=2 FOR HOLLOW CONE SWIRL COAX AND ITYPE INPUT IS:

RXP RFP TPOST CSA FCD XCD (6F7.4)

```
   RXP=OX POST INNER RADIUS (IN)
   RFP=FUEL ANNULUS OUTER RADIUS (IN)
 TPOST=OX POST THICKNESS (IN)
   CSA=CONE SPRAY ANGLE (DEG)
   FCD=FUEL ANNULUS CD
   XCD=OX ANNULUS CD
```

ITYPE=3 FOR IMPINGING HOLLOW CONE SWIRL TRIAX AND ITYPE INPUT IS:

RXP RFP TPOST PFI CSA FCD XCD (7F7.4)

```
   RXP=OX POST INNER RADIUS (IN)
   RFP=FUEL ANNULUS OUTER RADIUS (IN)
 TPOST=OX POST THICKNESS (IN)
   CSA=CONE SPRAY ANGLE (DEG)
   PFI=PERCENT FUEL IMPINGED (XXX.XXX)
   FCD=FUEL ANNULUS CD
   XCD=OX ANNULUS CD
```

NAMELIST $CONT SETS MODEL CONTROL PARAMETERS

PARAMETER	DEFAULT	FUNCTION
NSEG	NROWS+1	SETS THE NUMBER OF RADIAL GRID SEGMENTS
NSLICE	MIN(12,NEL-1)	SETS THE NUMBER OF CIRCUMFERENTIAL GRID SLICES
ASTEP	2**(-10)	ATOMIZATION STEPSIZE (FT)
XSTEP	2**(-8)	AXIAL CALCULATION STEPSIZE (FT)

The following is a sample input file for a single row, seven element shear coaxial injector. Element flows are input as formulae rather than for each element.

```
SAMPLE INPUT FILE ONE
ROW TYPE INPUT FOR SINGLE ROW SEVEN ELEMENT SHEAR COAX

$OUTPUT
   ITRACE=1, IDMFLG=0, IPDFLG=1, IVDFLG=0, IMVFLG=0, IDFLG=0,
   IMRFLG=1, IAFLG=1, IRFFLG=1,
$END

3006.00 0.8249
1.0940E3    -3.999E2    0.000E0     0.000E00    2.016E0     1.953E2
-2.700E2    -1.820E2    6.535E1     6.500E-5    3.200E1     9.162E1
9.000E-6    2.7217E1

24
0.00    0.9604
3.00    0.9604
3.50    0.9551
4.00    0.9498
4.50    0.9445
5.00    0.9340
5.50    0.9207
6.00    0.9022
6.50    0.8810
7.00    0.8546
7.50    0.8308
8.00    0.8175
8.50    0.7779
9.00    0.7540
9.50    0.7302
10.00   0.7011
10.50   0.6773
11.00   0.6535
11.50   0.6270
12.00   0.6006
12.50   0.5794
13.00   0.5662
13.50   0.5583
14.00   0.5556

2   7   1
7   0.6791
 0.43530+0.043530*SIN(THETA)
 1.3145
0.0934   0.00

1
0.0948 0.2030 0.0210 0.2550 0.0790 1.5000 0.8000

$CONT
$END
```

The following is an input for a single row, thirteen element hollow-cone swirl coaxial injector. In this case, each elements location and flowrate is input.

```
SAMPLE INPUT FILE TWO
SEVEN ELEMENT HOLLOW CONE SWIRLER, INDIVIDUAL INPUTS

$OUTPUT
   ITRACE=1, IDMFLG=0, IPDFLG=1, IVDFLG=0, IMVFLG=0, IDFLG=0,
   IMRFLG=1, IAFLG=1, IRFFLG=1,
$END

3268 84 0.8931
1.2000E3    -3.999E2    0.000E0     0.000E00    2.016E0     1.953E2
-2.650E2    -1.820E2    6.535E1     6.500E-5    3.200E1     9.162E1
9.000E-6    2.7217E1

24
0.00    1.309
3.00    1.309
3.50    1.303
4.00    1.295
4.50    1.288
5.00    1.273
5.50    1.256
6.00    1.229
6.50    1.200
7.00    1.166
7.50    1.133
8.00    1.116
8.50    1.061
9.00    1.026
9.50    0.994
10.00   0.957
10.50   0.923
11.00   0.889
11.50   0.854
12.00   0.818
12.50   0.790
13.00   0.773
13.50   0.761
14.00   0.758

1    13   1
0.926      00.000 0.48749 1.4148
0.926      27.692 0.48749 1.4148
0.926      55.385 0.48749 1.4148
0.926      83.077 0.48749 1.4148
0.926     110.769 0.48749 1.4148
0.926     138.462 0.48749 1.4148
0.926     166.154 0.48749 1.4148
0.926     193.846 0.48749 1.4148
0.926     221.538 0.48749 1.4148
0.926     249.231 0.48749 1.4148
0.926     276.923 0.48749 1.4148
0.926     304.615 0.48749 1.4148
0.926     332.308 0.48749 1.4148
0.2161    0.000


2
0.0948 0.2030 0.0210 30.00  0.800  0.5000

$CONT
  NSEG=3, NSLICE=5,
$END
```

APPENDIX II

PLC PROGRAMS

CONTENTS

```
      PROGRAM PLC
C
C     MAIN CALLING PROGRAM FOR COMBUSTION SECTION OF PERFORMANCE/
C     LIFE MODEL
C
C     DECLARATIONS AND OPENS
C
$INSERT COMMON
C
      OPEN (UNIT=5,FILE='PL.INPUT',STATUS='OLD',ERR=8000)
      OPEN (UNIT=6,FILE='PL.HISTORY',STATUS='NEW',ERR=8100)
      OPEN (UNIT=7,FILE='MR.DIST',STATUS='NEW',ERR=8200)
C
C     INITIALIZE PROBLEM
C
      CALL SETUP
      IEFLG=0
C
C     ATOMIZE LOX AND CALCULATE MASS MEDIAN DROPSIZE, DISTRIBUTION
C     COEFFICIENT, MEAN ATOMIZATION LENGTH, AND INJECTION VELOCITY
C
      X=0.0
      IF (ITYPE .EQ. 1) CALL SHEAR
      IF (ITYPE .EQ. 2 .OR. ITYPE .EQ. 3) CALL SWIRL
      IF (X .LT. 0.0) GOTO 9000
C
C     CALCULATE RECIRCULATION ZONE AND DISTRIBUTE MASS ACROSS CHAMBER
C
      CALL RFILL
      IF (X .LE. 0.0) GOTO 9100
      CALL MRPLOT
C
C     STEP IN X
C
  100 X=X+XSTEP
      IF (ITRACE .GT. 0) WRITE(6,110)X
  110 FORMAT(/1X,'********* BEGIN LOOP FOR X=',F7.4,' FT *********',/1X)
C
C     GENERATE LOCAL GRID
C
      CALL GRIDGEN
      IF (RWALLX .LE. 0.0) GOTO 9200
C
C     VAPORIZE AND DISTRIBUTE MASS BETWEEN X AND X+XSTEP
C
      CALL MVAP
      CALL VDIST
C
C     CALCULATE VELOCITIES
C
      IF (X .LE. X1) CALL VCALC
      IF (X .GT. X1) CALL VCONV
C
C     MOVE DROPS AND CHECK FOR IMPINGMENT
C
      CALL DMOVE
      IF (X .LT. 0.0) GOTO 9300
C
C     CALCULATE VMR
C
```

```
      CALL MRPLOT
      IF (X .LT. XW(NXP)) GOTO 100
C
C     CALCULATE OVERALL ERE
C
      CALL CERE
 1500 CLOSE (UNIT=5)
      CLOSE (UNIT=6)
      CLOSE (UNIT=7)
      STOP
C
C     ERROR CONDITIONS
C
 8000 WRITE (1,*) 'PL.INPUT DOES NOT EXIST, RUN ABORTED'
      STOP
 8100 WRITE (1,*) 'PL.HISTORY ALREADY EXISTS, RENAME AND RERUN'
      GOTO 1500
 8200 WRITE (1,*) 'MR.DIST ALREADY EXISTS, RENAME AND RERUN'
      GOTO 1500
 9000 WRITE (6,*) 'ERROR IN ATOMIZATION SUBROUTINE; RUN STOPPED'
      GOTO 1500
 9100 WRITE (6,*) 'ERROR IN SUBROUTINE RFILL; RUN STOPPED'
      GOTO 1500
 9200 WRITE (6,*) 'ERROR IN SUBROUTINE GRIDGEN; RUN STOPPED'
      GOTO 1500
 9300 WRITE (6,*) 'ERROR IN SUBROUTINE DMOVE; RUN STOPPED'
      GOTO 1500
      END
```

```
      SUBROUTINE SETUP
C
C     SUBROUTINE TO READ INITIAL PROBLEM VARIABLES FOR MCA PERFORMANCE/
C     LIFE COMBUSTION MODEL
C     CHECK RW FOR CONSISTINCY, CALCULATES WANGLE
C     CONVERTS INPUT UNITS TO LBm-FT-SEC-PSI UNITS
C
$INSERT COMMON
C
      CHARACTER TITLE*80, DUMMY*80, FEQ*80, XEQ*80
      NAMELIST /OUTPUT/ IAFLG, IVDFLG, IMVFLG, IPDFLG, IDMFLG, IECHO,
     *                  ITRACE, IMRFLG, IDFLG, IRFFLG
      NAMELIST /CONT/ NSEG, NSLICE, XSTEP, ASTEP
      DATA IECHO, IAFLG, IVDFLG, IMVFLG, IPDFLG, IDMFLG, IMRFLG, IDFLG,
     *     IRFFLG, ITRACE /1,9*0/
C
C     FORMAT STATEMENTS
C
   10 FORMAT(A80)
   11 FORMAT(//25X,'OUTPUT CONTROL PARAMETERS (1=ON)',//5X,'ATOM=',I2,
     *        5X,'MVAP=',I2,5X,'VDIST=',I2,5X,'VCALC=',I2,5X,'DMOVE=',
     *        I2,5X,'DRAG=',I2,5X,'MRPLOT=',I2,5X,'RFILL=',I2,5X,
     *        'ITRACE=',I2)
   20 FORMAT(F7.2,F7.4)
   21 FORMAT(6E12.4)
   22 FORMAT(2E12.4)
   23 FORMAT(//25X,'FUEL AND OX PROPERTIES, PC=',F7.2,' HOT GAS MR=',
     *        F7.4,//1X,'FUEL: ',4X,
     *        'TINJ=',F7.2,3X,'TCRIT=',F7.2,3X,'DENSITY=',F7.3,3X,
     *        'VISCOSITY=',E12.4,3X,'M.W.=',F7.3,3X,'HEAT OF VAP=',F7.2,
     *        /3X,'OX: ',4X,'TINJ=',F7.2,3X,'TCRIT=',F7.2,3X,'DENSITY=',
     *        F7.3,3X,'VISCOSITY=',E12.4,3X,'M.W.=',F7.3,3X,
     *        'HEAT OF VAP=',F7.2,/10X,'SURFACE TENSION=',E12.6,3X,
     *        'CRITICAL DENSITY=',F7.3)
   30 FORMAT(I3)
   31 FORMAT(//25X,'CHAMBER CONTOUR',//)
   32 FORMAT(2F7.4)
   33 FORMAT(5X,'POINT=',I2,5X,'X=',F7.4,5X,'RWALL=',F7.4)
   34 FORMAT(/5X,'X1(FT)=',F7.4,5X,'X2(FT)=',F7.4,5X,'CR=',F6.3)
   40 FORMAT(3I4)
   41 FORMAT(//25X,'INJECTOR ELEMENT POSITIONS',//)
   42 FORMAT(2F8.4,2F8.5)
   43 FORMAT(1X,'ROW ',I2, ' ELEMENTS')
   44 FORMAT(5X,'INJECTOR=',I3,5X,'RADIUS=',F8.4,5X,'THETA=',F8.4,5X,
     *        'FUEL MASS FLOW=',F8.5,5X,'OX MASS FLOW=',F8.5)
   45 FORMAT(I4,F8.4)
   46 FORMAT(1X,'ROW ',I3,' IS CENTERED AT R=',F8.4,' in. AND CONTAINS '
     *       ,I3,' ELEMENTS')
   47 FORMAT(A80)
   48 FORMAT(5X,'FUEL FLOW EQ:  ',A80,/7X,'OX FLOW EQ:  ',A80,/5X,
     *        'ROW FUEL FLOW=',F8.3,5X,'ROW OX FLOW=',F8.3)
   49 FORMAT(2F8.4)
   50 FORMAT(/5X,'COOLANT MASS FLOW=',F8.4,5X,'COOLANT MR=',F8.4)
   51 FORMAT(/5X,'TOTAL FUEL MASS FLOW=',F8.3,5X,'TOTAL FUEL VAPOR MASS'
     *       ,' FLOW=',F8.3,/5X,'TOTAL OX MASS FLOW  =',F8.3,5X,'TOTAL',
     *        ' OX VAPOR MASS FLOW  =',F8.3)
   60 FORMAT(I2)
   61 FORMAT(7F7.4)
   62 FORMAT(//20X,'SHEAR COAXIAL INJECTOR CONFIGURATION',//5X,
     *        'OX POST RADIUS=',F7.4,8X,'OX POST THICKNESS=',F7.4,4X,
```

```
     *        'OX POST RECESS=',F7.4,/5X,'OX METERING RADIUS='F7.4,4X,
     *        'OX POST DIFFUSER LENGTH=',F7.4,/5X,'FUEL POST RADIUS=',
     *         F7.4,6X,'FUEL CD=',F7.4)
   63 FORMAT(6F7.4)
   64 FORMAT(//20X,'SWIRL COAXIAL INJECTOR CONFIGURATION',//5X,
     *        'OX POST RADIUS=',F7.4,8X,'OX POST THICKNESS=',F7.4,/5X,
     *        'SPRAY FAN ANGLE=',F7.4,7X,'OX CD=',F7.4,/5X,
     *        'FUEL POST RADIUS=',F7.4,6X,'FUEL CD=',F7.4)
   65 FORMAT(//20X,'IMPINGING TRIAXIAL INJECTOR CONFIGURATION',//5X,
     *        'OX POST RADIUS=',F7.4,8X,'OX POST THICKNESS=',F7.4,/5X,
     *        'SPRAY FAN ANGLE=',F7.4,7X,'OX CD=',F7.4,/5X,
     *        'FUEL POST RADIUS=',F7.4,5X,'FUEL CD=',F7.4,/5X,
     *        'PERCENT FUEL INPINGING=',F7.4)
   70 FORMAT(//25X,'CALCULATION CONTROL PARAMETERS',//5X,'# SEGMENTS=',
     *         I2,5X,'# SLICES=',I3,/5X,'ATOM STEPSIZE=',E12.4,5X,
     *         'VAPOR STEPSIZE=',E12.4,//)
C
      IF (ITRACE .EQ. 2) WRITE(6,1)
    1 FORMAT(/1X,'ENTER SETUP')
      DUMMY=''
C
C     READ AND WRITE TITLE
C
      READ(5,10)TITLE
      WRITE(6,10)TITLE
      WRITE(7,10)TITLE
      READ(5,10)TITLE
      WRITE(6,10)TITLE
      WRITE(7,10)TITLE
C
C     READ OUTPUT FLAGS
C
      READ(5,10)TITLE
      IF(TITLE .NE. DUMMY) GOTO 9000
      READ(5,OUTPUT)
      IF (IECHO .EQ. 1) WRITE(6,11) IAFLG, IMVFLG, IVDFLG, IPDFLG,
     *                      IDMFLG, IDFLG, IMRFLG, IRFFLG, ITRACE
C
C     READ OPERATING CONDITION AND PROPERTIES
C
      READ(5,10)TITLE
      IF(TITLE .NE. DUMMY) GOTO 9000
      READ(5,20)PC, HGMRO
      READ(5,21)FTJ, FTC, FRHO, FMU, FMW, FHV
      READ(5,21)XTJ, XTC, XRHO, XMU, XMW, XHV
      READ(5,22)XST, XRHOC
      IC=2
      IF (FMW .LE. 0.0) CALL DBLINT (PC, HGMRO, IC, FMW)
      IC=5
      IF (FRHO .LE. 0.0) CALL DBLINT (PC, HGMRO, IC, FRHO)
      IC=7
      IF (GMU .LE. 0.0) CALL DBLINT (PC, HGMRO, IC, FMU)
      IF (IECHO .EQ. 1) WRITE(6,23)PC, HGMRO, FTJ, FTC, FRHO, FMU, FMW,
     *                      FHV, XTJ, XTC, XRHO, XMU, XMW, XHV, XST, XRHOC
C
C     READ CHAMBER DESCRIPTION
C     CHECK FOR CONSISTENCY, CALCULATE X1, X2, CR, WANGLE
C
  100 READ(5,10)TITLE
      IF(TITLE .NE. DUMMY) GOTO 9000
```

```
      READ(5,30)NXP
      IF (IECHO .EQ. 1) WRITE(6,31)
      DO 200 I=1,NXP
         READ(5,32,ERR=9110)XW(I),RW(I)
         IF (IECHO .EQ. 1) WRITE(6,33)I,XW(I),RW(I)
         XW(I)=XW(I)/12.0
         RW(I)=RW(I)/12.0
  200 CONTINUE
      IF (XW(1) .GT. 0.0) GOTO 9120
      DO 250 I=1,NXP-1
         IF (XW(I) .GE. XW(I+1)) GOTO 9130
         IF (RW(I+1) .GT. RW(I)) GOTO 9140
         WANGLE(I)=ATAN((RW(I+1)-RW(I))/(XW(I+1)-XW(I)))
  250 CONTINUE
      CR=(RW(1)/RW(NXP))**2
      X1=0.0
      X2=XW(NXP)
      DO 275 I=1,NXP-1
         IF (WANGLE(I) .LT. 0.0) GOTO 280
  275 CONTINUE
      GOTO 9150
  280 X1=XW(I)
      X2=XW(NXP)-X1
      IF (IECHO .EQ. 1) WRITE(6, 34) X1, X2, CR
C
C     READ INJECTOR FACE LAYOUT, CHECK FOR CONSISTENCY, CALCULATE RROW,
C     NELR, AND TOTAL MASS FLOWS.  DECOMPOSE HOT GAS AND LOAD TOTAL VAPOR
C     ACCUMULATORS
C
  300 READ(5,10)TITLE
      IF(TITLE .NE. DUMMY) GOTO 9000
      READ(5,40) INTYPE, NEL, NROWS
      IF (IECHO .EQ. 1) WRITE(6,41)
      TFF=0.0
      TXF=0.0
      THVM=0.0
      TXVM=0.0
      IF (INTYPE .EQ. 2) GOTO 400
C
C     TYPE 1 INPUT; R,THETA, FLOW FOR ALL ELEMENTS
C
      IROW=0
      R1=-1.0
      DO 310 I=1,NROWS
         NELR(I)=0
  310 CONTINUE
      DO 350 I=1,NEL
         READ(5,42,ERR=9210) ERPOS(I), ETPOS(I), FMF(I), XMF(I)
         IF (ERPOS(I) .LT. R1) GOTO 9220
         IF (ERPOS(I) .GT. R1) THEN
            IROW=IROW+1
            R1=ERPOS(I)
            TC=-1.0
            RROW(IROW)=R1/12.0
            IF (IECHO .EQ. 1) WRITE(6,43) IROW
         END IF
         IF (IECHO .EQ. 1) WRITE(6,44) I, ERPOS(I), ETPOS(I), FMF(I),
     *                                 XMF(I)
         ERPOS(I)=ERPOS(I)/12.0
         IF (ERPOS(I) .GE. RW(1) .OR. ETPOS(I) .GT. 360.0) GOTO 9230
```

```
          IF (ETPOS(I) .LE. TC) GOTO 9240
          TC=ERPOS(I)
          NELR(IROW)=NELR(IROW)+1
          FMF(I)=FMF(I)/(1.0+HGMRO)
          XMF(I)=XMF(I)+FMF(I)*HGMRO
          TFF=TFF+FMF(I)
          TXF=TXF+XMF(I)
          THVM=THVM+FMF(I)
          TXVM=TXVM+FMF(I)*HGMRO
  350 CONTINUE
      IF (IROW .NE. NROWS) GOTO 9250
      GOTO 499
C
C     TYPE 2 INPUTS; R, NELR, FLOWRATES AS F(R,THETA)
C
  400 ICNT=0
      DO 460 IROW=1,NROWS
          READ(5,45,ERR=9280) NELR(IROW), RROW(IROW)
          IF (IECHO .EQ. 1) WRITE(6,46) IROW, RROW(IROW), NELR(IROW)
          READ(5,47,ERR=9290) FEQ
          READ(5,47,ERR=9295) XEQ
          IEL1=ICNT+1
          IELL=IEL1+NELR(IROW)-1
          TI=6.28319/NELR(IROW)
          RFSUM=0.0
          RXSUM=0.0
          DO 450 INJ=IEL1, IELL
              ICNT=ICNT+1
              THETA=TI*(INJ-IEL1)
$INSERT FMF.EQ
$INSERT XMF.EQ
              FMF(INJ)=FMF(INJ)/(1.0+HGMRO)
              XMF(INJ)=XMF(INJ)+FMF(INJ)*HGMRO
              RFSUM=RFSUM+FMF(INJ)
              RXSUM=RXSUM+XMF(INJ)
              TFF=TFF+FMF(INJ)
              TXF=TXF+XMF(INJ)
              THVM=THVM+FMF(INJ)
              TXVM=TXVM+FMF(INJ)*HGMRO
  450     CONTINUE
          IF (IECHO .EQ. 1) WRITE(6,48) FEQ,XEQ,RFSUM,RXSUM
  460 CONTINUE
  499 READ(5,49) CFLOW, CFMR
      IF (IECHO .EQ. 1) WRITE(6,50) CFLOW, CFMR
      TXVM=TXVM+CFLOW*CFMR/(1.0+CFMR)
      THVM=THVM+CFLOW/(1.0+CFMR)
      TXF=TXF+CFLOW*CFMR/(1.0+CFMR)
      TFF=TFF+CFLOW/(1.0+CFMR)
      IF (IECHO .EQ. 1) WRITE(6,51) TFF, THVM, TXF, TXVM
C
C     READ INJECTOR
C
      READ(5,10)TITLE
      IF(TITLE .NE. DUMMY) GOTO 9000
      READ(5,60,ERR=9300)ITYPE
      IF (ITYPE .LT. 1 .OR. ITYPE .GT. 3) GOTO 9300
      IF (ITYPE .EQ. 2) GOTO 520
      IF (ITYPE .EQ. 3) GOTO 530
C
C     SHEAR COAX INJECTOR
```

```
C
      READ(5,61)RXP, RFP, TPOST, RECESS, RMS, XDL, FCD, XCD
      IF (IECHO .EQ. 1) WRITE(6,62)RXP, TPOST, RECESS, RMS, XDL,
     *                                   RFP, FCD
      RECESS=RECESS/12.0
      RMS=RMS/12.0
      XDL=XDL/12.0
      GOTO 550
C
C     SWIRL COAX INJECTOR
C
  520 READ(5,63)RXP, RFP, TPOST, CSA, FCD, XCD
      IF (IECHO .EQ. 1) WRITE(6,64) RXP, TPOST, CSA, XCD, RFP, FCD
      GOTO 540
C
C     INPINGING TRIAX INJECTOR
C
  530 READ(5,61)RXP, RFP, TPOST, CSA, PFI, FCD, XCD
      IF (IECHO .EQ. 1) WRITE(6,65) RXP, TPOST, CSA, XCD, RFP, FCD, PFI
  540 CSA=CSA*3.1416/180.0
  550 RFP=RFP/12.0
      RXP=RXP/12.0
      TPOST=TPOST/12.0
C
C     READ PROBLEM CONTROL PARAMETERS
C     **** IF DEFAULTS ARE CHANGED, THEY MUST ALSO BE UPDATED IN PLSET.CPL ***
C
      NSEG=NROWS+1
      NSLICE=12
      IF (NROWS .EQ. 1 .AND. NEL .LT. 13 .AND. NEL .GT. 1) NSLICE=NEL-1
      XSTEP=2.0**(-8)
      ASTEP=2.0**(-10)
      READ(5,CONT)
      IF (IECHO .EQ. 1) WRITE(6,70)NSEG, NSLICE, ASTEP,XSTEP
      DO 600 I=1,NSLICE
         DO 600 J=1,NSEG
            XGRID(I,J)=0.0
            HGRID(I,J)=0.0
  600 CONTINUE
      RETURN
C
C     ERROR CONDITION
C
 9000 WRITE(6,*)'BLANK LINE GROUP SEPERATOR MISSING, RUN STOPPED'
      GOTO 9999
 9110 WRITE(6,*)'ERROR READING XW,RW FOR POSITION=',I,', RUN STOPPED'
      GOTO 9999
 9120 WRITE(6,*)'FIRST XW NOT AT INJECTOR FACE, RUN STOPPED'
      GOTO 9999
 9130 WRITE(6,*)'XW(I) .GE. XW(I+1) FOR I=',I,', RUN STOPPED'
      GOTO 9999
 9140 WRITE(6,*)'INCONSISTENTCY WITH RW FOR XW=',XW(I),RW(I),RW(I+1)
      GOTO 9999
 9150 WRITE(6,*)'NO THROAT CALCULATED, RUN STOPPED'
      GOTO 9999
 9210 WRITE(6,*)'COORDINATES FOR EL#=',I,' MISSING, RUN STOPPED'
      GOTO 9999
 9220 WRITE(6,*)'ELEMENT ',I,' NOT IN ASCENDING RADIUS ORDER, ',
     *           'RUN STOPPED'
      GOTO 9999
```

```
9230 WRITE(6,*)'INJECTOR OUTSIDE CHAMBER FOR I=',I,', RUN STOPPED'
     GOTO 9999
9240 WRITE(6,*)'INJECTORS NOT IN ASCENDING THETA ORDER, RUN STOPPED'
     GOTO 9999
9250 WRITE(6,*) NROWS,' ROWS NOT INPUT, LAST ROW OF RADIUS=',RROW(IROW)
    *           ,' FEET, RUN STOPPED'
     GOTO 9999
9260 WRITE(6,*)'ERROR OPENING FMF.EQ, RUN STOPPED'
     GOTO 9998
9270 WRITE(6,*)'ERROR OPENING XMF.EQ, RUN STOPPED'
     GOTO 9998
9280 WRITE(6,*)'NO ROW INFORMATION FOUND FOR ROW=',IROW,' RUN STOPPED'
     GOTO 9998
9290 WRITE(6,*)'NO FUEL EQUATION FOUND FOR ROW=',IROW,' RUN STOPPED'
     GOTO 9998
9295 WRITE(6,*)'NO OX EQUATION FOUND FOR ROW=',IROW,' RUN STOPPED'
     GOTO 9998
9300 WRITE(6,*)'ERROR WITH INJECTOR TYPE, ITYPE=',ITYPE,' RUN STOPPED'
     GOTO 9999
9998 CLOSE(UNIT=8)
     CLOSE(UNIT=9)
9999 CLOSE(UNIT=5)
     CLOSE(UNIT=6)
     CLOSE(UNIT=7)
     STOP
     END
```

```
      SUBROUTINE SHEAR
C
C     PROGRAM TO CALCULATE DROPLET FORMATION FOR SHEAR COAXIAL INJECTOR
C     RETURNS MASS MEDIAN DROPSIZE, NUMBER OF DROPS/SEC AND DISTRIBUTION
C     PARAMETER, SG AS WELL AS MEAN ATOMIZATION LENGTH AND INJECTION VELOCITY
C
C     OUTPUTS:
C              RMM=MASS MEDIAN DROPLET RADIUS, FT
C              TND=TOTAL NUMBER OF DROPS OF GENERATED BY ELEMENT
C               SG=DISTRIBUTION PARAMETER
C               AL=MEAN ATOMIZATION LENGTH, FT
C               VJ=MEAN INJECTION VELOCITY, FT/SEC IN THE FORM OF
C                  VFACT, THE VAPORIZATION FACTOR IN LGEN
C
C     ERROR CONDITIONS:
C               X=-1 ITERATION NOT CONVERGED AFTER 20 LOOPS
C               X=-2 AX BEYOND THROAT
C               X=-3 R AND XD NOT DIMENSIONED LARGE ENOUGH, I.E. A
C                    GREATER THAN ANTICIPATED NUMBER OF DROPSIZES GENERATED
C               X=-4 XND LT 1 OR RJET LT 0
C
*INSERT COMMON
      DIMENSION R(200), XD(200)
C
      IF (ITRACE .EQ. 2) WRITE(6,1)
    1 FORMAT(/1X,'ENTER SHEAR')
      XCD=1.0
      QFACT=4.0/3.0*3.1416
      VAPC=PC**0.66/(1.0-(XTJ+460.)/(XTC+460.))**0.4/XHV**0.8/XMW**0.35
      DO 1000 INJ=1,NEL
         IF (XMF(INJ) .EQ. XMF(INJ-1) .AND. FMF(INJ) .EQ. FMF(INJ-1))
     *      GOTO 1100
C
C     INITIALIZE SIZES
C
        AX=-RECESS
        RJETO=RXP
        A=RFP
        B=RXP+TPOST
        EFF=FMF(INJ)
        ELXF=XMF(INJ)-EFF*HGMRO
        EVXF=EFF*HGMRO
        HGMR(INJ)=HGMRO
        HGCD=FCD
        DO 2 I=1,200
           R(I)=0.0
           XD(I)=0.0
    2   CONTINUE
        IDC=0
        TND(INJ)=0.0
        VTOT=0.0
        RTOT=0.0
        IC=4
        CALL DBLINT(PC, (TXF/TFF), IC, VSONIC)
        XFILL=X1
        VT=0.62/CR*VSONIC
        IF (X1 .GT. 0.0) GOTO 50
        XFILL=X2
        VT=VSONIC
C
```

```
C       CALCULATE OX VELOCITY PROFILE
C
 50       CCO=(RMS/RXP)**2
          VMEAN=ELXF/XRHO/3.1416/RMS**2
          RE=2.0*XRHO*VMEAN*RMS/XMU
          IF (RE .GE. 4000.0) RCRIT=((1.0-SQRT(CCO))/0.75)**1.25*RE**0.25
          IF (RE .LT. 4000.0) RCRIT=((1.0-SQRT(CCO))/11.28)**2*RE
          AR=(XDL/RMS/2.0)
          IF (RCRIT .LE. AR) GOTO 150
C
C       CALCULATE XCD
C
          RE1=4.0
          CE1=CCO+0.214*AR
          IF (RE .LT. 1.0E5) GOTO 100
          RE1=5.0
          CE1=CCO+0.095*AR
          IF (RE .LT. 1.0E6) GOTO 100
          RE1=6.0
          CE1=0.054*AR
 100      RE2=5.0
          CE2=CCO+0.095*AR
          IF (RE .LT. 1.0E5 .OR. RE .GE. 1.0E6) GOTO 120
          RE2=6.0
          CE2=CCO+0.054*AR
 120      CCE=CE1+(CE2-CE1)/(RE2-RE1)*(LOG10(RE)-RE1)
          IF (CCE .GT. 1.0) CCE=1.0
          XCD=(CCO-0.5)+0.31789*EXP(0.89192*(CCE-CCO+0.5))
          RJETO=SQRT(RJET*XCD)
C
C       CALCULATE POTENTIAL CORE SIZE AND BL PROFILE
C
 150      RJET=RJETO
          REM=AINT(LOG10(RE))
          FR=RE/(10.0**REM)
          DEL=RMS*EXP(LOG(0.048)+(6.0-REM-FR)*0.44)*AR**0.8
          RP=RMS-DEL
          IF (RP .LT. 0.0) RP=0.0
          ICNT=0.0
          POW=0.7
          CFACT=(ELXF-XRHO*VMEAN*3.1416*RP**2)/3.1416/XRHO/VMEAN
 200      F1=(RJET**2+RJET*RP*POW+(1.0+POW)*RP**2)
          F2=POW**2+3.0*POW+2.0
          F3=2.0*POW+3.0
          FX=F1/F2-CFACT
          FP=(F2*(RJET*RP+RP**2)-F1*F3)/F2**2
          POWN=POW-FX/FP
          IF (ABS(POW-POWN) .LE. 1.0E-4) GOTO 210
          ICNT=ICNT+1
          POW=POWN
          IF (ICNT .LE. 10) GOTO 200
          GOTO 9000
C
C       CALCULATE FUEL AND OX FREE SURFACE VELOCITIES
C
 210      VF=(EFF+EVXF)/(FCD*FRHO*3.1416*(A**2-B**2))
          VFO=VF
 220      VO=VMEAN
          IF (RJET .GT. RP) VO=VMEAN*(RJETO-RJET)/(RJETO-RP)
          IF (AX .GE. 0.0 .AND. AX .LE. XFILL) VF=VFO-(VFO-VT)*AX/XFILL
```

```
      IF (VF .GT. 5500.0) WRITE(6,230) VF, INJ
 230  FORMAT(/1X,'*****************  WARNING  ********************',
     *  /10X,'FUEL INJECTION VELOCITY APPROACHING SONIC VELOCITY, VF='
     *      ,E11.4,' FOR INJ=',I4)
      IF (VO .GT. 500.0) WRITE(6,240) VO, INJ
 240  FORMAT(/1X,'*****************  WARNING  ********************',
     *          /10X,'OX INJECTION VELOCITY EXCESSIVELY HIGH, VX=',E11.4
     *          ,' FOR INJ=',I4)
C
C     CALCULATE INTERFACIAL SHEAR STRESS AND DROPSIZE (SCALING FACTOR OF 1500)
C
      TAUI=(XMU+FMU)/2.0*(VF-VO)/(B-RJET)/1500.0
      RM=8.0*XST/TAUI/32.1739
C
C     CALCULATE NEW X POSITION
C
      AX=AX+ASTEP
      IF (AX .GT. XW(NXP)) GOTO 9100
      IDC=IDC+1
      IF (IDC .GT. 200) GOTO 9200
C
C     CALCULATE NUMBER OF DROPS USING RJET
C
      XMI=(RJET/RJETO)**2*ELXF
      XND=MAX(1.0,AINT(3.1416*RJET/2.0/RM))
      VDROPS=XND*QFACT*RM**3.0
      VJETM=3.1416*RJET**2*ASTEP
      IF (VJETM .GT. (2.0*VDROPS)) GOTO 300
C
C     LAST DROPLETS FORMED, JET DISAPPEARS
C
      XND=MAX(1.0,AINT(VJETM/VDROPS*XND))
      RM=(VJETM/XND/QFACT)**(1./3.)
      RJET=0.0
      GOTO 325
C
C     ITERATE WITH TRUNCATED CONE FORMULA
C     IF NONCONVERGENT, RETURN INJ=-1
C
 300  ICNT=0
      RN=RJET
 310  FX=3.1416/3.0*ASTEP*(RJET**2.0+RJET*RN+RN**2)-VJETM+VDROPS
      FP=3.1416/3.0*ASTEP*(RJET+2.0*RN)
      RNN=RN-FX/FP
      IF (ABS(RN-RNN) .LT. 0.0005*RN) GOTO 320
      ICNT=ICNT+1
      RN=RNN
      IF (ICNT .LT. 10) GOTO 310
      GOTO 9300
 320  RJET=RNN
C
C     CALCULATE NDROPS/SEC BASED ON CONTINUITY
C
 325  XMO=(RJET/RJETO)**2*ELXF
      DVF=(XMI-XMO)/XRHO
      XND=DVF/(QFACT*RM**3)
      IF (IAFLQ .QT. 2) WRITE(6,326) AX,VF,VO,TAUI,RM,XND
 326  FORMAT(1X,'AX,VF,VO,T,RM,XND=',4(F9.4,3X),2(E12.4,3X))
      IF (XND .LT. 1.0 .OR. RJET .LT. 0.0) GOTO 9400
C
```

```
C       VAPORIZE DROPLET IF STILL IN CUP
C
        IF (AX .GE. 0.0) GOTO 400
        VJ=(4.0*VO+VF)/5.0
        G1=VAPC/RM**1.45/VJ**0.75
        D1=-AX
        CALL CVAP (G1, D1, PV)
        VP=PV*XND*XRHO*QFACT*RM**3
        TXVM=TXVM+VP
        EVXF=EVXF+VP
        RM=((1.0-PV)*RM**3)**(1.0/3.0)
        IF (IAFLG .GT. 2) WRITE(6,330) (100.0*PV), RM
  330   FORMAT(10X,F6.2,'% OF DROP VAPORIZED, NEW RM=',E12.5)
        HGMR(INJ)=EVXF/EFF
        IC=5
        CALL DBLINT(PC, HGMR(INJ), IC, RHO)
        IF (HGCD .GE. 1.0) GOTO 350
        HGCD=(EFF+EVXF)/(3.1416*(A**2-RJET**2)*RHO*VF)
        GOTO 400
  350   VF=(EFF+EVXF)/(RHO*3.1416*(A**2-RJET**2))
        VFO=VF
C
C       INSERT INTO LIST IN ASCENDING ORDER
C
  400   IF (RM .GT. 0.0) GOTO 410
        IDC=IDC-1
        GOTO 775
  410   IF (IDC .GT. 1) GOTO 420
        I=1
        GOTO 700
  420   DO 450 I=1,(IDC-1)
           IF (ABS(R(I)-RM) .LE. 0.005*RM) GOTO 500
           IF (R(I) .GE. RM) GOTO 600
  450   CONTINUE
        I=IDC
        GOTO 700
C
C       SIMILAR SIZE ALREADY EXISTS
C
  500   VI=QFACT*R(I)**3*XD(I)
        VN=QFACT*RM**3*XND
        XD(I)=XD(I)+XND
        R(I)=((VI+VN)/QFACT/XD(I))**(1.0/3.0)
        RM=R(I)
        IDC=IDC-1
        GOTO 750
C
C       MOVE LARGER DROPS DOWN
C
  600   DO 650 K=IDC,(I+1),-1
           R(K)=R(K-1)
           XD(K)=XD(K-1)
  650   CONTINUE
  700   R(I)=RM
        XD(I)=XND
C
C       SUM FOR MEAN VALUE CALCULATIONS, THEN CONTINUE
C
  750   TND(INJ)=TND(INJ)+XND
        VV=XND*QFACT*RM**3
```

```
      VTOT=VTOT+VO*VV
      RTOT=RTOT+VV
  775 IF (RJET .GT. 0.0) GOTO 220
C
C     CALCULATE MEAN QUANTITIES
C
      VMEAN=(RTOT/TND(INJ))
      RMEAN=(VMEAN/QFACT)**(1./3.)
      AL(INJ)=(AX-RECESS)/2.0
      VJ=VTOT/TND(INJ)/VMEAN
      VFACT(INJ)=VAPC/VJ**0.75
C
C     CALCULATE MASS MEDIAN
C
      AM=0.0
      CN=TND(INJ)/2.0
      DO 800 I=1,IDC
         AM=AM+XD(I)
         IF (AM .LT. CN) GOTO 800
            RMM=R(I)
            GOTO 810
  800 CONTINUE
  810 RMO(INJ)=RMM
C
C     CALCULATE DISTRIBUTION (STANDARD DEVIATION)
C
      SUM=0.0
      VMM=QFACT*RMM**3
      DO 900 I=1,IDC
         IF (IAFLG .GT. 1) WRITE(6,820)I,R(I),XD(I)
  820    FORMAT(5X,'INDEX=',I3,5X,'RM=',E10.4,5X,'NDROPS/SEC=',E11.5)
         VDI=QFACT*R(I)**3
         SUM=SUM+(VDI-VMM)**2*XD(I)
  900 CONTINUE
      SD=(SQRT(SUM/TND(INJ))/QFACT)**(1./3.)
      SG(INJ)=(SD+RMM)/RMM
C
C     CORRECT TND TO CONSERVE MASS
C
      TND(INJ)=(ELXF-EFF*(HGMR(INJ)-HGMRO))/(QFACT*XRHO*RMM**3)/
     *          ((0.165/SG(INJ)**3)+0.67+(0.165*SG(INJ)**3))
C
C     FILL INITIAL DROPSIZES
C
  910 RMX(1,INJ)=RMM/SG(INJ)
      RMX(2,INJ)=RMM
      RMX(3,INJ)=RMM*SG(INJ)
      DRP(1,INJ)=RJETO/2.0
      DRP(2,INJ)=RJETO/2.0
      DRP(3,INJ)=RJETO/2.0
      DXV(1,INJ)=VJ
      DXV(2,INJ)=VJ
      DXV(3,INJ)=VJ
      DRV(1,INJ)=0.0
      DRV(2,INJ)=0.0
      DRV(3,INJ)=0.0
      IF (IAFLG .GT. 0) WRITE(6,920) INJ, (RMO(INJ)*304800.),
     *      (RMEAN*304800.), SG(INJ), TND(INJ), (AL(INJ)*12.0), VJ
  920 FORMAT(5X,'INJECTOR NUMBER=',I3,/9X,'MASS MEDIAN (MICRONS)=',
     *      F7.2,5X,'MASS MEAN (MICRONS)=',F7.2,8X,'SIGMAG=',F6.3,/9X,
```

```
     *          'NUMBER OF DROPS=' E11.5,7X,'ATOMIZATION LENGTH (IN)=',
     *          F6.3,5X,'INJECTION VELOCITY (F/S)=',F6.2)
 1000 CONTINUE
      FCD=MIN(HGCD,1.0)
      RETURN
C
C     INJECTOR SAME AS PREVIOUS
C
 1100 RMO(INJ)=RMO(INJ-1)
      SG(INJ)=SG(INJ-1)
      TND(INJ)=TND(INJ-1)
      AL(INJ)=AL(INJ-1)
      VFACT(INJ)=VFACT(INJ-1)
      HGMR(INJ)=HGMR(INJ-1)
      TXVM=TXVM+(HGMR(INJ)-HGMRO)*FMF(INJ)
      GOTO 910
C
C     ERROR CONDITION, ABORT RUN
C
 9000 WRITE(6,*) 'POW NOT CONVERGENT IN SHEAR, POW=',POW,' FOR INJ=',INJ
      X=-1.0
      RETURN
 9100 WRITE(6,*) 'AX BEYOND THROAT IN SHEAR FOR INJ=',INJ,' RUN STOPPED'
      X=-2.0
      RETURN
 9200 WRITE(1,*) 'MORE DROPS PRODUCED THAN DIMENSIONED FOR, RUN STOPPED'
      X=-3.0
      RETURN
 9300 WRITE(6,*)'RJET NOT CONVERGENT IN SHEAR, RJET=',RN,' FOR INJ=',INJ
      X=-2.0
      RETURN
 9400 WRITE(6,*) 'LESS THAN 1 DROP FORMED OF NEG RJET, XND,RJET=',XND,
     *           ',',RJET
      X=-4.0
      RETURN
      END
```

```
      SUBROUTINE CVAP (D1, G1, V)
C
C     CALCULATES CHANGE IN DROP RADIUS DUE TO EVAPORATION IN
C     INJECTOR CUP. BASED ON PRIEM-HEIDMANN GENERALIZED LENGTH CORRELATION
C
$INSERT COMMON
C
C     LOCAL BLOCK COMMON ONLY
C
      COMMON /VFRAC/ GL(41), F(41)
      DATA GL /0.0,.01,.02,.04,.06,.1,.2,.4,.6,1.,1.5,2.,3.,4.,5.,6.,7.,
     *        8.,9.,10.,13.,15.,17.,20.,23.,25.,28.,30.,33.,35.,38.,40.,
     *        45.,50.,55.,60.,70.,80.,90.,100.,110./
      DATA F /0.0,.0008,.003,.009,.016,.031,.055,.123,.173,.26,.343,
     *        .418,.522,.60,.66,.706,.746,.779,.804,.828,.879,.902,
     *        .92,.94,.955,.963,.972,.976,.982,.985,.9885,.9905,
     *        .994,.996,.9973,.9982,.9992,.9996,.9998,.9999,1.0/
C
      IF (ITRACE .EQ. 2) WRITE(6,1)
    1 FORMAT(/1X,'ENTER CVAP')
C
C     CALCULATE GENERALIZED LENGTH, GLEN
C
      GLEN=0.0137466*D1/CR**0.44*G1
C
C     VAPORIZATION INTERPOLATION CALCULATION
C
      IF (GL(1) .GE. GLEN) GOTO 150
      IF (GLEN .GE. GL(41)) GOTO 175
      DO 125 I=2,41
         IF (GLEN .GT. GL(I)) GOTO 125
         V=F(I-1)+(GLEN-GL(I-1))/(GL(I)-GL(I-1))*(F(I)-F(I-1))
         RETURN
  125 CONTINUE
  150 V=F(1)
      RETURN
  175 V=F(41)
      RETURN
      END
```

```
      SUBROUTINE SWIRL
C
C     PROGRAM TO CALCULATE DROPLET FORMATION FOR HOLLOW CONE SWIRLER COAXIAL
C     AND IMPINGING TRIAXIAL INJECTORS.  RETURNS MASS MEDIAN DROPSIZE, NUMBER
C     OF DROPS/SEC.  USES A DISTRIBUTION PARAMETER OF 2.3
C
C     OUTPUTS:
C            RMM=MASS MEDIAN DROPLET RADIUS, FT
C            TND=TOTAL NUMBER OF DROPS OF GENERATED BY ELEMENT
C             SG=DISTRIBUTION PARAMETER
C             AL=MEAN ATOMIZATION LENGTH, FT
C             VJ=MEAN INJECTION VELOCITY, FT/SEC IN THE FORM OF
C                VFACT, THE VAPORIZATION FACTOR IN LGEN
C
C     ERROR CONDITIONS:
C              X=-1 ITERATION NOT CONVERGED AFTER 20 LOOPS
C
$INSERT COMMON
C
      IF (ITRACE .EQ. 2) WRITE(6,1)
    1 FORMAT(/1X,'ENTER SWIRL')
      VAPC=PC**0.66/(1.0-(XTJ+460.)/(XTC+460.))**0.4/XHV**0.8/XMW**0.35
      FFACT=1.0
      IF (ITYPE .EQ. 3) FFACT=(1.0-PFI/100.0)
C
C     LOOP THROUGH ALL INJECTORS
C
      DO 500 INJ=1,NEL
         IF (XMF(INJ) .EQ. XMF(INJ-1) .AND. FMF(INJ) .EQ. FMF(INJ-1))
     *      GOTO 600
C
C     INITIALIZE SIZES
C
         A=RFP
         B=RXP+TPOST
         EFF=FMF(INJ)*FFACT
         ELXF=XMF(INJ)-FMF(INJ)*HGMRO
         EVXF=EFF*HGMRO
         HGMR(INJ)=HGMRO
C
C     CALCULATE FUEL AND OX  VELOCITIES
C
         VF=(EFF+EVXF)/(FCD*FRHO*3.1416*(A**2-B**2))
         VO=ELXF/(XCD*XRHO*3.1416*RXP**2)
         IF (VF .GT. 5500.0) WRITE(6,50) VF
   50    FORMAT(/1X,'*****************  WARNING  *******************',
     *    /10X,'FUEL INJECTION VELOCITY APPROACHING SONIC VELOCITY, VF='
     *         ,E11.4,' FOR INJ=',I4)
         IF (VO .GT. 500.0) WRITE(6,60) VO
   60    FORMAT(/1X,'*****************  WARNING  *******************',
     *          /10X,'OX INJECTION VELOCITY EXCESSIVELY HIGH, VX=',E11.4
     *          ,' FOR INJ=',I4)
C
C     CALCULATE MOMENTUM ANGLE
C
         PSI=ATAN((VO*ELXF*SIN(CSA))/((EFF+EVXF)*VF+ELXF*VO*COS(CSA)))
C
C     CALCULATE ATOMIZATION LENGTH
C
         ALEN=1.0
```

```
      ICNT=0
      F1=SIN(PSI)/12.0/RXP
      F2=50.6970*RXP*XCD*(XRHO*VO/XMU)**0.2
100   FX=ALEN**0.8+F1*ALEN**1.8-F2
      FP=0.8*ALEN**(-0.2)+1.8*F1*ALEN**0.8
      ALENN=ALEN-FX/FP
      IF (ABS(ALEN-ALENN) .LE. 0.001*ALEN) GOTO 200
      ICNT=ICNT + 1
      ALEN=ALENN
      IF (ICNT .LT. 10) GOTO 100
      GOTO 9000
C
C     CALCULATE TCRIT AND RMM
C
200   TCRIT=6.0*XCD*RXP/(1.0+SIN(PSI)*ALEN/12.0/RXP)
      RMM=0.62035*TCRIT/12.0
      RMO(INJ)=RMM
      AL(INJ)=ALEN
      VJ=VO*COS(PSI)
      VFACT(INJ)=VAPC/VJ**0.75
      SG(INJ)=2.3
C
C     CALCULATE TND TO CONSERVE MASS
C
      TND(INJ)=(ELXF-EFF*(HGMR(INJ)-HGMRO))/(4.1888*XRHO*RMM**3)/
     *          ((0.165/SG(INJ)**3)+0.67+(0.165*SG(INJ)**3))
C
C     FILL INITIAL DROPSIZES
C
300   RMX(1,INJ)=RMM/SG(INJ)
      RMX(2,INJ)=RMM
      RMX(3,INJ)=RMM*SG(INJ)
      DRP(1,INJ)=ALEN*SIN(PSI)
      DRP(2,INJ)=ALEN*SIN(PSI)
      DRP(3,INJ)=ALEN*SIN(PSI)
      DXV(1,INJ)=VJ
      DXV(2,INJ)=VJ
      DXV(3,INJ)=VJ
      DRV(1,INJ)=VO*SIN(PSI)
      DRV(2,INJ)=VO*SIN(PSI)
      DRV(3,INJ)=VO*SIN(PSI)
      IF (IAFLG .GT. 0) WRITE(6,400) INJ, (RMO(INJ)*304800.),
     *                  SG(INJ), TND(INJ), (AL(INJ)*12.0), VJ
400   FORMAT(5X,'INJECTOR NUMBER=',I3,/9X,'MASS MEDIAN (MICRONS)=',
     *        F7.2,6X,'SIGMAG=',F6.3,5X,'NUMBER OF DROPS=',E11.5,
     *        /9X,'ATOMIZATION LENGTH (IN)=',F6.3,5X,
     *        'INJECTION VELOCITY (F/S)=',F6.2)
500 CONTINUE
    RETURN
C
C     INJECTOR SAME AS PREVIOUS
C
600 RMO(INJ)=RMO(INJ-1)
    SG(INJ)=SG(INJ-1)
    TND(INJ)=TND(INJ-1)
    AL(INJ)=AL(INJ-1)
    VFACT(INJ)=VFACT(INJ-1)
    HGMR(INJ)=HGMR(INJ-1)
    TXVM=TXVM+(HGMR(INJ)-HGMRO)*FMF(INJ)
    GOTO 300
```

```
C
C      ERROR, ABORT RUN
C
 9000 WRITE(6,*)  'ALEN NOT CONVERGENT IN SWIRL, ALEN=',ALEN,
     *             ' FOR INJ=',INJ
      X=-1.0
      RETURN
      END
```

```
      SUBROUTINE RFILL
C
C     SUBROUTINE TO CALCULATE RECIRCULATION ZONE FEATURES
C
$INSERT COMMON
      IF (ITRACE .EQ. 2) WRITE(6,1)
    1 FORMAT(1X,'ENTER RFILL')
C
C     CALCULATE STREAMTUBE 100% ERE C* AND COMBUSTION ZONE
C     GAS VELOCITY. STORE IN COM(1,NEL) AND COM(2,NEL)
C     INITIALIZE PREVAPORIZED OX FROM HOT GAS, STORE IN COM(3,NEL)
C
      IC=5
      CALL DBLINT(PC, HGMR(1), IC, FRHO)
      IC=6
      DO 100 INJ=1,NEL
         VMR=XMF(INJ)/FMF(INJ)
         CALL DBLINT(PC, VMR, IC, COM(1,INJ))
         VF=FMF(INJ)*(1.0+HGMR(INJ))/FRHO/
     *      (FCD*3.1416*(RFP**2-RXP**2))
         VX=(XMF(INJ)-FMF(INJ)*HGMR(INJ))/XRHO/(XCD*3.1416*RXP**2)
         IF (VF .GT. 5500.0) WRITE(6,50) VF
   50    FORMAT(/1X,'*****************   WARNING   *******************',
     *    /10X,'FUEL INJECTION VELOCITY APPROACHING SONIC VELOCITY, VF='
     *        ,F8.2,' FOR INJ=',I4)
         IF (VX .GT. 500.0) WRITE(6,60) VO
   60    FORMAT(/1X,'*****************   WARNING   *******************',
     *          /10X,'OX INJECTION VELOCITY EXCESSIVELY HIGH, VX=',F8.2,
     *          ' FOR INJ=',I4)
         COM(2,INJ)=(VF+8.0*VX)/9.0
         COM(3,INJ)=HGMR(INJ)*FMF(INJ)
  100 CONTINUE
C
C     STEP IN X UNTIL CHAMBER CROSS-SECTION IS FILLED
C
      X=0.0
  200 X=X+XSTEP
      CALL GRIDGEN
      IF (RWALLX .LE. 0.0) GOTO 8000
      AXC=3.1416*RWALLX**2*(1.0-CFLOW/(TFF+TXF))
      CALL MVAP
C
C     CALCULATE RFUEL FOR EACH ELEMENT, STORE IN ERPOS AND SUM.
C     STORE OX VAPOR IN COM(3,INJ)
C
      AFILL=0.0
      DO 300 INJ=1,NEL
         COM(3,INJ)=COM(3,INJ)+XVM(1,INJ)+XVM(2,INJ)+XVM(3,INJ)
         VMR=COM(3,INJ)/FMF(INJ)
         smr=8.0
         IC=6
         CALL DBLINT(PC, VMR, IC, CS)
         ERE=CS/COM(1,INJ)*(FMF(INJ)+COM(3,INJ))/(XMF(INJ)+FMF(INJ))
         RHO=0.0
         IC=5
         CALL DBLINT(PC,SMR,IC,RHO)
         DA=1.125*COM(3,INJ)/RHO/COM(2,INJ)
         RCORE=0.0
         IF (ITYPE .EQ. 1) RCORE=MAX(0.0,(RXP-RXP/2.0/AL(INJ)*
     *                             (X+RECESS)))
```

```
          RCG=SQRT(RCORE**2+DA*ERE/3.1416)
          RF=SQRT(RCG**2+(FMF(INJ)*(1.0+HGMR(INJ))-0.125*COM(3,INJ))*
     *            (RFP**2-(RXP+TPOST)**2)/(FMF(INJ)*(1.0+HGMR(INJ))))
          ERPOS(INJ)=3.1416*RF**2
          AFILL=AFILL+ERPOS(INJ)
  300 CONTINUE
C
C     ACCELERATE PARTICLES IN STREAMWISE DIRECTION
C
      CALL DMTUBE
      IF (X .LE. 0.0) GOTO 8100
      PFILL=AFILL/AXC*100.0
C
C     CHECK FOR FILLED CHAMBER
C
      IF (IRFFLG .GT. 0) WRITE(6,310) X,PFILL
      IF (IRFFLG .GT. 0) WRITE(7,310) X,PFILL
  310 FORMAT(//10X,'AT AXIAL POSITION X=',F7.4,F7.2,'% OF CROSS-SECTION'
     *       ,' IS FILLED')
      IF (IRFFLG .GT. 0) CALL MRTUBE
      IF (PFILL .LT. 100.0) GOTO 200
C
C     CROSS SECTION FILLED, CALCULATE APPEARENT INJECTOR LOCATION
C     DISTRIBUTE MASS INTO GRID
C
      INJF=NEL+1
      REDGE=RWALLX
      FFACT=100.0/PFILL/(1.0-CFLOW/(TFF+TXF))
      DO 1000 IROW=NROWS,1,-1
         INJL=INJF-1
         INJF=INJL-NELR(IROW)+1
         ASUM=0.0
         DO 320 INJ=INJF,INJL
            ERPOS(INJ)=ERPOS(INJ)*FFACT
            ASUM=ASUM+ERPOS(INJ)
  320    CONTINUE
         RO=SQRT(MAX(0.0,(REDGE**2-ASUM/3.1416)))
         RPOS=RO+(REDGE-RO)/2.0**0.5
         IF (NELR(IROW) .EQ. 1 .AND. RO .LT. 1.0E-5) RPOS=0.0
C
C     LOCATE SEG(S) TO ADD MASS TO
C
         R1=0.0
         DO 330 J=1,NSEG
            R2=RGRID(J)
            IF (RO .GE. R1 .AND. RO .LT. R2) GOTO 340
            R1=R2
  330    CONTINUE
         GOTO 9000
  340    IR1=J
         DO 350 J=IR1,NSEG
            R2=RGRID(J)
            IF (REDGE .GT. R1 .AND. REDGE .LE. R2) GOTO 360
            R1=R2
  350    CONTINUE
         GOTO 9100
  360    IR2=J
         IF (IRFFLG .GT. 1) WRITE(6,370) IROW, RO, REDGE, IR1, IR2
  370    FORMAT(/5X,'INJECTOR ROW ',I3,' CONFINED BETWEEN R='F7.4,
     *     ' AND ',F7.4,/10X,'THIS CORRESPONDS TO SEGS ',I3,' THRU ',I3)
```

```
C
C     LOCATE STREAMTUBE SLICE BOUNDARY AND CORRESPONDING SLICE(S)
C
          T1=0.0
          IT2=1
          DO 500 INJ=INJF,INJL
             STXVM=COM(3,INJ)
             T2=T1+ERPOS(INJ)/ASUM*360.0
             DO 400 J=IT2,NSLICE
                IF ((THETA*J) .GT. T1) GOTO 410
 400         CONTINUE
             GOTO 9200
 410         IT1=J
             J=NSLICE
             IF (T2 .GT. 360.0 .AND. (T2-360.0) .LT. 1.0E-4) GOTO 430
             DO 420 J=IT1,NSLICE
                IF ((THETA*J) .GE. T2) GOTO 430
 420         CONTINUE
             GOTO 9300
 430         IT2=J
             IF (IRFFLG .GT. 1) WRITE(6,440) INJ, T1, T2, IT1, IT2
 440         FORMAT(/10X,'INJECTOR ',I4,' CONFINED BETWEEN THETA=',F6.2,
     *              ' AND ',F6.2,/10X,'THIS CORRESPONDS TO SLICES ',I3,
     *              ' THRU ',I3)
C
C     DISTRIBUTE MASS TO GRID
C
             IF (IR1 .NE. IR2 .OR. IT1 .NE. IT2) GOTO 450
             XGRID(IT1,IR1)=XGRID(IT1,IR1)+STXVM
             HGRID(IT1,IR1)=HGRID(IT1,IR1)+FMF(INJ)
             GOTO 490
 450         RS=REDGE**2-RO**2
             TS=T2-T1
             RB=RO
             RFACT=1.0
             DO 470 ISEG=IR1,IR2
                RG=RGRID(ISEG)
                IF (ISEG .EQ. IR2) RG=REDGE
                RFACT=(RG**2-RB**2)/RS
                RB=RGRID(ISEG)
                TB=T1
                TFACT=1.0
                DO 470 ISL=IT1,IT2
                   ANG=ISL*THETA
                   IF (ISL .EQ. IT2) ANG=T2
                   SFACT=(ANG-TB)/TS
                   TB=ISL*THETA
                   FADD=SFACT*RFACT*FMF(INJ)
                   XADD=SFACT*RFACT*STXVM
                   HGRID(ISL,ISEG)=HGRID(ISL,ISEG)+FADD
                   XGRID(ISL,ISEG)=XGRID(ISL,ISEG)+XADD
                   IF (IRFFLG .GT. 2) WRITE(6,460) INJ,FADD,XADD,ISL,ISEG
 460               FORMAT(10X,'INJECTOR ',I3,' ADDS ',E11.4,
     *                    ' LB/S OF FUEL AND ',E11.4,' LB/S OF OX TO ',
     *                    'SLICE,SEG=',I3,',',I2)
 470         CONTINUE
C
C     CALCULATE APPEARENT INJECTOR LOCATION AND DROPLET CHARACTERISTICS
C
 490         ERPOS(INJ)=RPOS
```

```
            ETPOS(INJ)=(T2+T1)/2.0
            IF (IRFFLG .GT. 1) WRITE(6,495)INJ,ERPOS(INJ),ETPOS(INJ)
  495       FORMAT(10X,'INJECTOR ',I3,' HAS AN APPEARENT LOCATION OF
     *             'R,THETA=',F7.4,F7.2)
            T1=T2
            DR1=DRP(1,INJ)/RFP*(REDGE-RO)/2.0
            DR2=DRP(2,INJ)/RFP*(REDGE-RO)/2.0
            DR3=DRP(3,INJ)/RFP*(REDGE-RO)/2.0
            DRV(1,INJ)=(DR1-DRP(1,INJ))/(X-AL(INJ))
            DRV(2,INJ)=(DR2-DRP(2,INJ))/(X-AL(INJ))
            DRV(3,INJ)=(DR3-DRP(3,INJ))/(X-AL(INJ))
            DRP(1,INJ)=DR1
            DRP(2,INJ)=DR2
            DRP(3,INJ)=DR3
  500     CONTINUE
          REDGE=RO
 1000 CONTINUE
C
C     DISTRIBUTE COOLANT FLOW UNIFORMLY
C
      IF (CFLOW .LE. 0.0) GOTO 1100
      CHPS=CFLOW/(1.0+CFMR)/NSEG/NSLICE
      CXPS=CFLOW*CFMR/(1.0+CFMR)/NSEG/NSLICE
      DO 1050 I=1,NSLICE
         DO 1050 J=1,NSEG
         HGRID(I,J)=HGRID(I,J)+CHPS
         XGRID(I,J)=XGRID(I,J)+CXPS
 1050 CONTINUE
C
C     CALCULATE MEAN GAS PROPERTIES AND PRINT FULL MR DISTRIBUTION
C
 1100 OVMR=TXVM/THVM
      IC=1
      CALL DBLINT (PC, OVMR, IC, CT)
      IC=2
      CALL DBLINT (PC, OVMR, IC, GMW)
      IC=5
      CALL DBLINT (PC, OVMR, IC, GRHO)
      IC=7
      CALL DBLINT (PC, OVMR, IC, GMU)
      GXV(1)=(TXVM+THVM)/GRHO/AXC
      RETURN
C
C     ERROR MESSAGES
C
 8000 WRITE(6,*)'ERROR FROM GRIDGEN, RUN STOPPED'
      X=-1.0
      RETURN
 8100 WRITE(6,*)'ERROR FROM DMTUBE, RUN STOPPED'
      RETURN
 9000 WRITE(6,*)'ERROR IN RFILL, INNER EDGE NOT FOUND FOR ROW=',IROW
      WRITE(6,*)'RO,RGRID=',RO,RGRID
      X=-1.0
      RETURN
 9100 WRITE(6,*)'ERROR IN RFILL, OUTER EDGE NOT FOUND FOR ROW=',IROW
      WRITE(6,*)'REDGE,RGRID=',REDGE,RGRID
      X=-1.0
      RETURN
 9200 WRITE(6,*)'ERROR IN RFILL, FIRST SLICE NOT FOUND FOR ROW=',IROW,
     *             'ELEMENT=',INJ,'THETA=',T1
```

```
      X=-1.0
      RETURN
9300  WRITE(6,*)'ERROR IN RFILL, END SLICE NOT FOUND FOR ROW=',IROW,
     *          'ELEMENT=',INJ,'THETA=',T2
      X=-1.0
      RETURN
      END
```

```
      SUBROUTINE DMTUBE
C
C     SUBROUTINE TO ACCELERATE DROPS DUE TO DRAG ACCELERATIONS
C     USED IN STREAMTUBE ONLY
C
$INSERT COMMON
      IF (ITRACE .EQ. 2) WRITE(6,1)
    1 FORMAT(/1X,'ENTER DMTUBE')
      IF (IDMFLG .GT. 0) WRITE(6,2)
    2 FORMAT(/1X)
C
C     LOOP THROUGH FOR ALL INJECTORS AND DROPSIZES
C
      TVMR=-1.0
      DO 1000 INJ=1,NEL
C
C     CALCULATE STREAMTUBE PROPERTIES
C
         TVMRN=COM(3,INJ)/FMF(INJ)
         IF (ABS(TVMRN-TVMR) .LE. 0.1) GOTO 100
         TVMR=TVMRN
         IC=5
         CALL DBLINT (PC, TVMR, IC, GRHO)
         IC=7
         CALL DBLINT (PC, TVMR, IC, GMU)
  100    DO 1000 IRM=1,3
            IF (RMX(IRM,INJ) .LE. 0.0) GOTO 1000
C
C     "EXPAND" DROPLET TO SUPERCRITICAL PROPORTIONS
C
            RM=RMX(IRM,INJ)*(XRHO/XRHOC)**(1./3.)
C
C     CALCULATE RELATIVE GAS VELOCITY, DRAG AND ACCELERATION
C     COMBUSTION ZONE GAS VELOCITY STORED IN COM(2,NEL)
C
            RP=DRP(IRM,INJ)
            RGV=SQRT((COM(2,INJ)-DXV(IRM,INJ))**2+DRV(IRM,INJ)**2)
            DVM=SQRT(DXV(IRM,INJ)**2+DRV(IRM,INJ)**2)
            IF (RGV .LT. 1.0) GOTO 1000
            DZ=XSTEP*SQRT(1.0+(DRV(IRM,INJ)/DXV(IRM,INJ))**2)
            ICNT=0
  175       CALL DRAG (RM, COM(2,INJ), DVM, RGV, DZ, ACC)
C
C     MOVE DROPLET
C
            DXVN=COM(2,INJ)-(COM(2,INJ)-DXV(IRM,INJ))*ACC
            DRVN=DRV(IRM,INJ)*ACC
            DZN=XSTEP*SQRT(1.0+((DRV(IRM,INJ)+DRVN)/(DXV(IRM,INJ)+DXVN))
     *                       **2)
            IF (ABS(DZN-DZ) .LE. 0.01*DZ) GOTO 180
            DZ=DZN
            ICNT=ICNT+1
            IF (ICNT .GT. 10) GOTO 9000
            GOTO 175
  180       DRP(IRM,INJ)=RP+(DRV(IRM,INJ)+DRVN)/(DXV(IRM,INJ)+DXVN)
     *                     *XSTEP
            DXV(IRM,INJ)=DXVN
            DRV(IRM,INJ)=DRVN
            IF (DXV(IRM,INJ) .LT. 0.0) GOTO 9100
            IF (DXV(IRM,INJ) .GT. COM(2,INJ)) GOTO 9200
```

```
          IF (IDMFLG .GT. 0) WRITE(6,200) IRM, INJ, RP, DRP(IRM,INJ),
     *                         DXV(IRM,INJ), DRV(IRM,INJ),COM(2,INJ)
  200     FORMAT(1X,'DROP #',I1,' FROM INJ=',I3,' MOVED RADIALLY ',
     *           'FROM ',F7.3,' TO ',F7.3,' WITH NEW AXIAL AND ',
     *           'RADIAL VEL=',F7.2,', ',F7.2,'; GAS VELOCITY=',F7.2)
 1000 CONTINUE
      RETURN
C
C     ERROR CONDITION
C
 9000 WRITE(6,*)'DZ NOT CONVERGING IN DMTUBE FOR INJ,IRM=',INJ,', ',IRM,
     *          ' AT X=',X,' RUN STOPPED'
      X=-1.0
      RETURN
 9100 WRITE(6,*)'DROP ACCELERATED TO NEGATIVE VELOCITY AT X=',X,
     *          ' INJ,IRM=',INJ,IRM,' ACC=',ACC
      X=-1.0
      RETURN
 9200 WRITE(6,*)'DROP ACCELERATED BEYOND GAS VELOCITY AT X=',X,
     *          ' INJ,IRM=',INJ,IRM,' ACC=',ACC
      X=-1.0
      RETURN
      END
```

```
      SUBROUTINE MRTUBE
C
C     SUBROUTINE TO CALCULATE VMR FOR STREAMTUBES AS A FUNCTION OF X
C
$INSERT COMMON
      DIMENSION OUT(10)
C
      IF (ITRACE .EQ. 2) WRITE(6,1)
    1 FORMAT(/1X,'ENTER MRTUBE')
      WRITE(6,2)
    2 FORMAT(/1X)
C
C     CALCULATE VMR FOR STREAMTUBES 10 AT A TIME
C
      NL1=1
  100 NLL=NL1+9
      IF (NLL .GT. NEL) NLL=NEL
      ICNT=0
      DO 150 INJ=NL1,NLL
          ICNT=ICNT+1
          OUT(ICNT)=-1.0
          IF (COM(3,INJ) .GT. 0.0) OUT(ICNT)=99.99
          IF (FMF(INJ) .GT. 0.0) OUT(ICNT)=COM(3,INJ)/FMF(INJ)
  150 CONTINUE
      WRITE(6,175) NL1, NLL, (OUT(I),I=1,ICNT)
  175 FORMAT(5X,'TUBE MR FOR INJ=',I3,'-',I3,4X,10(F5.2,4X))
      IF (NLL .EQ. NEL) RETURN
      NL1=NLL+1
      GOTO 100
      END
```

```
      SUBROUTINE GRIDGEN
C
C     SUBROUTINE TO GENERATE COMPUTATION CELLS AT X AND RETURNS RWALLX
C
$INSERT COMMON
      IF (ITRACE .EQ. 2) WRITE(6,1)
    1 FORMAT(/1X,'ENTER GRIDGEN')
C
C     CALCULATE RWALL AT X
C
      DO 100 I=2,NXP
         IF (XW(I) .GE. X) GO TO 110
  100 CONTINUE
      IF (IEFLG .EQ. 0) GOTO 300
      GOTO 990
  110 RWALLX=RW(I-1)+(RW(I)-RW(I-1))/(XW(I)-XW(I-1))*(X-XW(I-1))
      ANGLEX=WANGLE(I-1)
C
C     CALCULATE SLICE ANGLE IN DEGREES
C     NB: TRIG FUNCTIONS REQUIRE RADIAN INPUTS
C
  120 THETA=360.0/NSLICE
C
C     CALCULATE NSEG EQUAL AREA RADIAL AREAS
C
      ASEG=RWALLX**2/NSEG
      RGRID(NSEG)=RWALLX
      DO 200 I=1,(NSEG-1)
         RGRID(I)=SQRT(FLOAT(I)/FLOAT(NSEG))*RWALLX
  200 CONTINUE
      RETURN
C
C     NEXT STEP MOVES PAST THROAT
C
  300 XP=X-XSTEP
      XSTEP1=XW(NXP)-XP
      IF (XSTEP1 .GE. XSTEP .OR. XSTEP1 .LE. 0) GOTO 990
      IEFLG=1
      X=XW(NXP)
      XSTEP=XSTEP1
      RWALLX=RW(NXP)
      ANGLEX=WANGLE(NXP-1)
      GOTO 120
C
C     ERROR
C
  990 WRITE (6,*)'*** X BEYOND THROAT IN GRIDGEN, X,XW(NXP)=',X,XW(NXP)
      RWALLX=0.0
      RETURN
      END
```

```
      SUBROUTINE MVAP
C
C     CALCULATES CHANGE IN DROP RADIUS DUE TO EVAPORATION
C     BASED ON PRIEM-HEIDMANN GENERALIZED LENGTH CORRELATION
C
$INSERT COMMON
C
C     LOCAL BLOCK COMMON ONLY
C
      COMMON /VFRAC/ GL(41), F(41)
      DATA GL /0.0,.01,.02,.04,.06,.1,.2,.4,.6,1.,1.5,2.,3.,4.,5.,6.,7.,
     *        8.,9.,10.,13.,15.,17.,20.,23.,25.,28.,30.,33.,35.,38.,40.,
     *        45.,50.,55.,60.,70.,80.,90.,100.,110./
      DATA F /0.0,.0008,.003,.009,.016,.031,.055,.123,.173,.26,.343,
     *        .418,.522,.60,.66,.706,.746,.779,.804,.828,.879,.902,
     *         .92,.94,.955,.963,.972,.976,.982,.985,.9885,.9905,
     *         .994,.996,.9973,.9982,.9992,.9996,.9998,.9999,1.0/
C
      IF (ITRACE .EQ. 2) WRITE(6,1)
    1 FORMAT(/1X,'ENTER MVAP')
C
C     LOOP THROUGH ALL ELEMENTS AND DROPSIZES
C
      DO 500 INJ=1,NEL
         DO 500 IRM=1,3
         XVM(IRM,INJ)=0.0
         IF (X .LE. AL(INJ)) GOTO 500
         IF (RMX(IRM,INJ) .LE. 0.0) GOTO 500
C
C     FIX CANT ANGLE, A, TO 0
C
            A=0.0
C
C     CALCULATE RMO
C
            RMI=RMO(INJ)
            IF (IRM .EQ. 1) RMI=RMI/SG(INJ)
            IF (IRM .EQ. 3) RMI=RMI*SG(INJ)
            XND=0.67*TND(INJ)
            IF (IRM .NE. 2) XND=0.165*TND(INJ)
            XO=AL(INJ)
C
C     CALCULATE GENERALIZED LENGTH, GLEN
C
            IF (X .GT. (XO+X1)) GOTO 50
            D1=X-XO
            D2=0.0
            GOTO 60
   50       D1=X1-XO
            D2=X-X1
   60       G1=VFACT(INJ)/RMI**1.45/COS(A)**0.75
            G2=0.0137466*(D1/CR**0.44+0.83*D2/(CR**0.22*
     *         ((1.0+1/SQRT(CR)+1/CR)/3.0)**0.33))
            GLEN=G1*G2
C
C     VAPORIZATION INTERPOLATION CALCULATION
C
            IF (GL(1) .GE. GLEN) GOTO 150
            IF (GLEN .GE. GL(41)) GOTO 175
            DO 125 I=2,41
```

```
            IF (GLEN .GT. GL(I)) GOTO 125
            V=F(I-1)+(GLEN-GL(I-1))/(GL(I)-GL(I-1))*(F(I)-F(I-1))
            GOTO 200
 125        CONTINUE
 150        V=F(1)
            GOTO 300
 175        V=F(41)
            XVM(IRM,INJ)=XRHO*(4.18879*RMX(IRM,INJ)**3)*XND
            RMX(IRM,INJ)=0.0
            GOTO 300
C
C     CALCULATE MASS VAPORIZED AND CURRENT DROPLET RADIUS
C
 200        VNEW=(1.0-V)*4.18879*RMI**3
            XVM(IRM,INJ)=XRHO*((4.18879*RMX(IRM,INJ)**3)-VNEW)*XND
            RMX(IRM,INJ)=(VNEW/4.18879)**(1./3.)
 300        TXVM=TXVM+XVM(IRM,INJ)
            IF (IMVFLG .GT. 0) WRITE(6,310) INJ, IRM, GLEN,RMI,
     *                          RMX(IRM,INJ), V, XVM(IRM,INJ)
 310        FORMAT(1X,'FROM MVAP FOR INJ,IRM=',I4,',',I1,9X,'GLEN,RMI,',
     *            'RMX,%VAP,MVAP:',/1X,5E12.5)
 500  CONTINUE
      RETURN
      END
```

```
      SUBROUTINE VDIST
C
C     SUBROUTINE TO DISTRIBUTE VAPORIZED MASS TO VARIOUS CELLS
C
$INSERT COMMON
      IF (ITRACE .EQ. 2) WRITE(6,1)
    1 FORMAT(/1X,'ENTER VDIST')
C
C     LOOP THROUGH FOR EACH ELEMENT AND DROPSIZE
C
      DO 500 INJ=1,NEL
         DO 500 IRM=1,3
            IF (XVM(IRM,INJ) .LE. 0.0) GOTO 500
            IF (IVDFLG .GT. 0) WRITE(6,10) IRM,INJ
   10       FORMAT(/1X,'BEGIN DISTRIBUTING DROP#  ',I1,' FOR INJ=',I3)
C
            DTR=(3.1416/180.)
C
C     RETRIEVE INJECTOR LOCATION
C
            RI=ERPOS(INJ)
            TI=ETPOS(INJ)
C
C     RETRIEVE DROP RELATIVE POSITION AND CALCULATE NDROPS/SLICE
C
            DPOS=DRP(IRM,INJ)
            DANG=THETA
            NDIST=NSLICE-1
            IF (ERPOS(INJ) .GT. 0.0) DANG=45.0
            IF (ERPOS(INJ) .GT. 0.0) NDIST=7
            VPS=XVM(IRM,INJ)/(NDIST+1)
C
C     ADD MASS PROPORTIONATELY TO GRID
C
            DO 200 I=0,NDIST
               XP=RI*COS(TI*DTR)+DPOS*COS((DANG*I+DANG/2.0)*DTR)
               YP=RI*SIN(TI*DTR)+DPOS*SIN((DANG*I+DANG/2.0)*DTR)
               RP=SQRT(XP**2+YP**2)
               TP=ATAN2(YP,XP)/DTR
               IF (TP .LT. 0.0) TP=360.0+TP
C
C     CORRESPONDING SLICE
C
               T1=0.0
               DO 100 J=1,NSLICE
                  T2=T1+THETA
                  IF (TP .GE. T1 .AND. TP .LT. T2) GOTO 110
                  T1=T2
  100          CONTINUE
  110          ISLICE=J
               R1=0.0
               DO 120 J=1,NSEG
                  R2=RGRID(J)
                  IF (RP .GE. R1 .AND. RP .LT. R2) GOTO 130
                  R1=R2
  120          CONTINUE
  130          IRAD=J
               XGRID(ISLICE,IRAD)=XGRID(ISLICE,IRAD)+VPS
               IF (IVDFLG .GT. 0) WRITE(6,140) VPS,ISLICE,IRAD
  140          FORMAT(1X,E12.5,' LB/S OF OX VAPOR ADDED TO SLICE,SEG=',
```

```
     *                        2I3)
200            CONTINUE
500 CONTINUE
     RETURN
     END
```

```
      SUBROUTINE VCALC
C
C     SUBROUTINE TO CALCULATE RADIAL AND AXIAL GAS VELOCITIES
C     AND DISTRIBUTES MASS ACROSS GRID TO ACHIEVE UNIFORM
C     PRESSURE DISTRIBUTION ACROSS CROSS-SECTION
C
$INSERT COMMON
      IF (ITRACE .EQ. 2) WRITE(6,1)
    1 FORMAT(/1X,'ENTER VCALC')
      AT=3.1416*RW(NXP)**2
C
C     CALCULATE OVERALL VAPOR MR
C
      OVMR=TXVM/THVM
      CPC=PC
C
C     CALCULATE MEAN GAS PROPERTIES AND 1-D GAS VELOCITY, GXV(1)
C
      IC=1
      CALL DBLINT (CPC, OVMR, IC, CT)
      IC=2
      CALL DBLINT (CPC, OVMR, IC, GMW)
      IC=4
      CALL DBLINT (CPC, OVMR, IC, VSONIC)
      IC=5
      CALL DBLINT (CPC, OVMR, IC, GRHO)
      IC=7
      CALL DBLINT (CPC, OVMR, IC, GMU)
      IC=6
      CALL DBLINT (PC, OVMR, IC, CSTAR)
      TIMR=TXF/TFF
      CALL DBLINT (PC, TIMR, IC, PCSTAR)
      ERE=CSTAR*(THVM+TXVM)/PCSTAR/(TXF+TFF)
      GXV(1)=0.62/CR*VSONIC*ERE
C
C     CALCULATE RADIAL VELOCITIES IN EACH SLICE DUE TO MALDISTRIBUTION
C
      IF (NSEG .EQ. 1) GOTO 501
      DO 500 I=1,NSLICE
         SMEAN=0.0
         DO 200 J=1,NSEG
            SMEAN=SMEAN+HGRID(I,J)+XGRID(I,J)
            GRV(I,J)=0.0
  200    CONTINUE
         SMEAN=SMEAN/NSEG
C
C     REDISTRIBUTE MASS STARTING AT WALL
C
         DO 300 J=NSEG,2,-1
            DM=SMEAN-HGRID(I,J)-XGRID(I,J)
            IF (DM .EQ. 0.0) GOTO 300
            SGN=1.0
            JF=J
            JT=J-1
            IF (DM .GT. 0.0) JF=J-1
            IF (DM .GT. 0.0) JT=J
            IF (DM .GT. 0.0) SGN=-1.0
            AMASS=HGRID(I,JF)+XGRID(I,JF)
            IF (DM .GT. AMASS) DM=AMASS
            DF=(HGRID(I,JF)+XGRID(I,JF))/DM*SGN
```

```
            HL=HGRID(I,JF)/DF
            XL=XGRID(I,JF)/DF
            XGRID(I,JT)=XGRID(I,JT)-XL
            HGRID(I,JT)=HGRID(I,JT)-HL
            XGRID(I,JF)=XGRID(I,JF)+XL
            HGRID(I,JF)=HGRID(I,JF)+HL
C
C      SUM MOMENTUM IN/OUT OF CELL
C
            AC=6.2832*RGRID(J-1)*THETA/360.0*XSTEP
            GRV(I,JT)=GRV(I,JT)+DM/AC
            GRV(I,JF)=GRV(I,JF)+DM/AC
  300     CONTINUE
C
C      CALCULATE RADIAL VELOCITY
C
         DO 400 J=1,NSEG
            IF (HGRID(I,J) .LE. 0.0 .AND. XGRID(I,J) .LE. 0.0) THEN
               GRV(I,J)=0.0
               GOTO 400
            ELSE IF (HGRID(I,J) .LE. 0.0) THEN
               VMR=20.0
               GOTO 350
            END IF
            VMR=XGRID(I,J)/HGRID(I,J)
  350       CRHO=0.0
            IC=5
            CALL DBLINT (CPC, VMR, IC, CRHO)
            GRV(I,J)=GRV(I,J)/CRHO
  400     CONTINUE
          IF (IPDFLG .GT. 0) WRITE(6,450) I,(GRV(I,J),J=1,NSEG)
  450     FORMAT(1X,'FOR SLICE ',I3,' GRV(SEG)=',10(F7.2,3X))
  500 CONTINUE
  501 CONTINUE
C
C      DISTRIBUTE MASS CIRCUMFRENTIALLY
C
      IF (NSLICE .EQ. 1) GOTO 601
      DO 600 I=1,NSLICE
         IASLICE=I+1
         IF (IASLICE .GT. NSLICE) IASLICE=1
         DO 600 J=1,NSEG
            DM=(XGRID(I,J)+HGRID(I,J)+XGRID(IASLICE,J)+HGRID(IASLICE,J))
     *         /2.0-XGRID(I,J)-HGRID(I,J)
            IF (DM .EQ. 0.0) GOTO 600
            SGN=1.0
            IFR=I
            IT=IASLICE
            IF (DM .GT. 0.0) IFR=IASLICE
            IF (DM .GT. 0.0) IT=I
            IF (DM .GT. 0.0) SGN=-1.0
            AMASS=HGRID(IFR,J)+XGRID(IFR,J)
            IF (DM .GT. AMASS) DM=AMASS
            DF=(HGRID(IFR,J)+XGRID(IFR,J))/DM*SGN
            HL=HGRID(IFR,J)/DF
            XL=XGRID(IFR,J)/DF
            XGRID(IT,J)=XGRID(IT,J)-XL
            HGRID(IT,J)=HGRID(IT,J)-HL
            XGRID(IT,J)=XGRID(IT,J)+XL
            HGRID(IT,J)=HGRID(IT,J)+HL
```

```
600 CONTINUE
601 CONTINUE
    IF (IPDFLG .GT. 0) WRITE(6,700) CPC, GXV(1), ERE
700 FORMAT(1X,'PC=',F7.2,5X,'1-D VELOCITY=',F7.2,5X,'ERE=',F7.5)
    RETURN
    END
```

```
      SUBROUTINE VCONV
C
C     ROUTINE TO CALCULATE GAS VELOCITY IN A CONVERGING NOZZLE
C
$INSERT COMMON
      IF (ITRACE .EQ. 2) WRITE(6,1)
    1 FORMAT(/1X,'ENTER VCONV')
C
C     CALCULATE GAS MW AND STAGNATION DENSITY
C
      IC=2
      OVMR=TXVM/THVM
      CALL DBLINT (CPC, OVMR, IC, GMW)
      IC=3
      CALL DBLINT (CPC, OVMR, IC, GAMMA)
      GRHO=CPC*GMW/CT/10.73
C
C     CALCULATE AREA RATIO AND MACH NUMBER
C
      ARATIO=(RWALLX/RW(NXP))**2
      CALL MACH (ARATIO, ZMACH)
      IF (ZMACH .LE. 0.0) GOTO 9000
            IF (ZMACH .GT. 1.0) GOTO 9100
C
C     CALCULATE ISENTROPIC PROPERTIES CGT, GRHO
C
      TRPG=1.0+(GAMMA-1.0)/2.0*ZMACH**2
      CGT=CT/TRPG
      GRHO=GRHO/(TRPG**(1.0/(GAMMA-1.0)))
C
C     1-D GAS VELOCITY
C
      VAVG=ZMACH*SQRT(GAMMA/GMW*CGT*49712.69)
C
C     CALCULATE AXIAL AND RADIAL GAS VELOCITY FROM LOCAL VELOCITY MAGNITUD
C
      RO=0.0
      DO 200 J=1,NSEG
         RJ=RO+(RGRID(J)-RO)/2.0
         RO=RGRID(J)
         GANGLE=RJ/RWALLX*ANGLEX
         VGAS=VAVG
         IF (GANGLE .NE. 0.0) VGAS=VAVG*ANGLEX**2/2.0/
     *       (ANGLEX*SIN(ANGLEX)+COS(ANGLEX)-1.0)
         GRV(1,J)=VGAS*SIN(GANGLE)
         GXV(J)=VGAS*COS(GANGLE)
  200 CONTINUE
      IF (IPDFLG .GT. 0) WRITE(6,210) ZMACH,VAVG,(GXV(I),I=1,NSEG)
  210 FORMAT(1X,'MACH#=',F5.3,3X,'1-D VELOCITY=',F7.2,/2X,'AXIAL VEL:  ',
     *       10(F7.2,2X))
      IF (IPDFLG .GT. 0) WRITE(6,211) (GRV(1,K),K=1,NSEG)
  211 FORMAT(1X,'RADIAL VEL:  ',10(F7.2,2X))
      RETURN
C
C     ERROR CONDITIONS
C
 9000 WRITE(6,*) 'ERROR IN VCONV, NEGATIVE MACH NO FOR ARATIO=',ARATIO
      RWALLX=0.0
      RETURN
 9100 WRITE(6,*) 'ERROR IN VCONV, SUPERSONIC MACH NO FOR ARATIO=',ARATIO
```

```
RWALLX=0 0
RETURN
END
```

```
      SUBROUTINE MACH (AR, ZM)
C
C     SUBROUTINE TO CALCULATE MACH NUMBER FOR A GIVEN AREA RATIO
C     USES NEWTON-RAPHSON ITERATION
C
$INSERT COMMON
      IF (ITRACE .EQ. 2) WRITE(6,1)
    1 FORMAT(/1X, 'ENTER MACH')
C
      ZM=0.01
      IF (AR .GT. 57.0) RETURN
      IF (AR .LT. 2.2) ZM=0.4
      ICNT=0
      F1=2.0/(1.0+GAMMA)
      F2=(GAMMA-1.0)/(GAMMA+1.0)
      F3=(GAMMA+1.0)/2.0/(GAMMA-1.0)
   10 ICNT=ICNT+1
      Q=(F1+F2*ZM**2)
      FX=Q**F3/ZM-AR
      FXP=(2.0*F3*F2*Q**(F3-1.0))-(Q**F3/ZM**2)
      ZMN=ZM-FX/FXP
      IF (ABS(ZM-ZMN) .LT. 0.001*ZM) RETURN
      ZM=ZMN
      IF (ICNT .LT. 21) GOTO 10
C
C     ERROR CONDITION
C
      WRITE(6,*) 'ERROR IN MACH, ROUTINE NON-CONVERGANT'
      ZM=-1.0
      RETURN
      END
```

```
      SUBROUTINE DMOVE
C
C     SUBROUTINE TO MOVE DROPLETS DUE TO DRAG ACCELERATIONS
C
$INSERT COMMON
      IF (ITRACE .EQ. 2) WRITE(6,1)
    1 FORMAT(/1X,'ENTER DMOVE')
      IF (IDMFLG .GT. 0) WRITE(6,2)
    2 FORMAT(/1X)
C
C     LOOP THROUGH FOR ALL INJECTORS AND DROPSIZES
C
      DO 1000 INJ=1,NEL
         DO 1000 IRM=1,3
         IF (RMX(IRM,INJ) .LE. 0.0) GOTO 1000
C
            DTR=(3.1416/180.)
C
C     "EXPAND" DROPLET TO SUPERCRITICAL PROPORTIONS
C
            RM=RMX(IRM,INJ)*(XRHO/XRHOC)**(1./3.)
C
C     CALCULATE CURRENT DROPLET POSITION
C
            RI=ERPOS(INJ)
            TI=ETPOS(INJ)
            DPOS=DRP(IRM,INJ)
            XP=(RI+DPOS)*COS(TI*DTR)
            YP=(RI+DPOS)*SIN(TI*DTR)
            RP=SQRT(XP**2+YP**2)
            TP=ATAN2(YP,XP)/DTR
            IF (TP .LT. 0.0) TP=360.0+TP
C
C     CALCULATE CORRESPONDING GRID LOCATION
C
            T1=0.0
            DO 100 J=1,NSLICE
               T2=T1+THETA
               IF (TP .GE. T1 .AND. TP .LT. T2) GOTO 110
               T1=T2
  100       CONTINUE
  110       ISLICE=J
            JSLICE=J
            R1=0.0
            DO 120 J=1,NSEG
               R2=RGRID(J)
               IF (RP .GE. R1 .AND. RP .LT. R2) GOTO 130
               R1=R2
  120       CONTINUE
  130       IRAD=J
            IRAD1=IRAD
            IF (X .LE. X1) IRAD1=1
C
C     CALCULATE RELATIVE GAS VELOCITY, DRAG AND ACCELERATION
C
            IF (X .GT. X1) JSLICE=1
            DRVN=DRV(IRM,INJ)
            DXVN=DXV(IRM,INJ)
            GV=SQRT(GXV(IRAD1)**2+GRV(JSLICE,IRAD)**2)
            DV=SQRT(DXV(IRM,INJ)**2+DRV(IRM,INJ)**2)
```

```
            XRV=GXV(IRAD1)-DXV(IRM, INJ)
            RRV=GRV(JSLICE, IRAD)-DRV(IRM, INJ)
            RGV=SQRT(XRV**2+RRV**2)
            IF (RGV .LE. 1.0) GOTO 180
            DZ=XSTEP*SQRT(1.0+(DRV(IRM, INJ)/DXV(IRM, INJ))**2)
            ICNT=0
  175       CALL DRAG (RM, GV, DV, RGV, DZ, ACC)
C
C     MOVE DROPLET
C
            DXVN=GXV(IRAD1)-XRV*ACC
            DRVN=GRV(JSLICE, IRAD)-RRV*ACC
            DZN=XSTEP*SQRT(1.0+((DRV(IRM, INJ)+DRVN)/(DXV(IRM, INJ)+DXVN))
     *                      **2)
            IF (ABS(DZN-DZ) .LE. 0.01*DZ) GOTO 180
            DZ=DZN
            ICNT=ICNT+1
            IF (ICNT .GT. 10) GOTO 9000
            GOTO 175
  180       RPNEW=RP+(DRV(IRM, INJ)+DRVN)/(DXV(IRM, INJ)+DXVN)*XSTEP
C
C     CHECK FOR IMPINGEMENT
C
            IF (RPNEW .GE. RWALLX) GOTO 500
C
C     NO IMPINGEMENT, UPDATE POSITION
C
            DRP(IRM, INJ)=RPNEW-RI
            DXV(IRM, INJ)=DXVN
            DRV(IRM, INJ)=DRVN
            IF (DXV(IRM, INJ) .LT. 0.0) GOTO 9100
            IF (DXV(IRM, INJ) .GT. GXV(IRAD1) GOTO 9200
            IF (IDMFLG .GT. 0) WRITE(6,200) IRM, INJ, RP, RPNEW,
     *                        DXV(IRM, INJ), DRV(IRM, INJ)
  200       FORMAT(1X,'DROP #',I1,' FROM INJ=',I3,' MOVED RADIALLY ',
     *             'FROM ',F7.3,' TO ',F7.3,' WITH NEW AXIAL AND ',
     *             'RADIAL VEL=',F7.2,', ',F7.2)
            GOTO 1000
C
C     IMPINGEMENT OCCURS, ADD OXIDIZER TO WALL VAPOR
C
  500       PFACT=0.165*TND(INJ)*XRHO*4.1888
            IF (IRM .EQ. 2) PFACT=0.67*TND(INJ)*XRHO*4.1888
            XVAPN=RMX(IRM, INJ)**3*PFACT
            TXVM=TXVM+XVAPN
            IF (ERPOS(INJ) .GT. 0.0) GOTO 550
            XVAPN=XVAPN/NSLICE
            DO 525 IK=1,NSLICE
               XGRID(IK,NSEG)=XGRID(IK,NSEG)+XVAPN
  525       CONTINUE
            GOTO 575
  550       XGRID(ISLICE,NSEG)=XGRID(ISLICE,NSEG)+XVAPN
  575       RMX(IRM, INJ)=0.0
            WRITE(6,600) X, TP, IRM, INJ, RMO(INJ), SG(INJ)
  600       FORMAT(1X,'IMPINGEMENT OCCURS AT X,THETA=',F7.3,', ',F6.2,
     *             /5X,'DROP NUMBER ',I1,' FROM INJ=',I4,' RMEAN, SG=',
     *             E11.4,', ',F6.3)
 1000 CONTINUE
      RETURN
C
```

```
C      ERROR CONDITION
C
 9000 WRITE(6,*)'DZ NOT CONVERGING FOR INJ,IRM=',INJ,',',IRM,' AT X=',
     *              X,' RUN STOPPED'
      X=-1.0
      RETURN
 9100 WRITE(6,*)'DROP ACCELERATED TO NEGATIVE VELOCITY AT X=',X,
     *             ' INJ,IRM=',INJ,IRM,' ACC=',ACC
      X=-1.0
      RETURN
 9200 WRITE(6,*)'DROP ACCELERATED TO GREATER THAN GAS VELOCITY AT X=',X,
     *             ' INJ,IRM=',INJ,IRM,' ACC=',ACC
      X=-1.0
      RETURN
      END
```

```
      SUBROUTINE DRAG (RM, GVM, DVM, VELR, DZ, A)
C
C     SUBROUTINE TO CALCULATE THE DRAG ON A DROPLET OF RADIUS RM IN
C     A GAS FIELD HITH A RELATIVE VELOCITY VELR. THE RESULTANT
C     ACCELERATION IS A. CALCULATIONS, IN PART, FROM TPP AND SDER.
C
*INSERT COMMON
      IF (ITRACE .EQ. 2) WRITE(6,1)
    1 FORMAT(/1X,'ENTER DRAG')
C
C     CALCULATE FLOW REGIEME
C
      RE=(2.0*GRHO*VELR*RM)/GMU
      IF (RE .GE. 0.5) GOTO 100
C
C     STOKES FLOW
C
      Q=4.5*GMU/XRHOC/RM**2*DZ
      A=EXP(-(Q+DVM)/GVM)*EXP(DVM/GVM)
      IF (IDFLG .GT. 0) WRITE(6,90) RM, VELR, RE, A
   90 FORMAT(1X,'RM, VELR, RE, A=',4E12.5)
      RETURN
C
C     NEWTONIAN FLOW
C
  100 IF (RE .GT. 0.5 .AND. RE .LT. 70.0) CD=27.0*RE**(-0.84)
      IF (RE .GE. 70.0 .AND. RE .LT. 59200.0) CD=0.414*RE**(0.1433)
      IF (RE .GE. 59200.0) CD=2.0
C*       Q=0.375*CD*GRHO/XRHOC/RM*DZ
C*       A=EXP(Q-(GVM/VELR))*EXP(GVM/VELR)
      A=EXP(-6.0*CD*GRHO*VELR*DZ/XRHOC/RM/DVM)
      IF (IDFLG .GT. 0) WRITE(6,110) RM, VELR, RE, CD, A
  110 FORMAT(1X,'RM, VELR, RE, CD, A=',5E12.5)
      RETURN
      END
```

```
      SUBROUTINE MRPLOT
C
C     SUBROUTINE TO CALCULATE VMR(R,THETA)
C     IF IMRFLG=1, ONLY WALL MR IS PRINTED; IMRFLG=1, CROSS-SECTION MR
C     IS PRINTED; IMRFLG=2 PRINTS MASS DISTRIBUTION IN PL HISTORY;
C     IMRFLG=3 PRINTS GRID CONTENTS IN PL HISTORY
C
$INSERT COMMON
      IF (ITRACE .EQ. 2) WRITE(6,1)
    1 FORMAT(/1X,'ENTER MRPLOT')
      IROW=NSEG
      IF (IMRFLG .GT. 0) IROW=1
C
C     WRITE HEADER
C
      XV=GXV(1)
      IF (X .GT. X1) XV=GXV(NSEG)
      WRITE (7,10) X,XV, (RGRID(I),I=IROW,NSEG)
   10 FORMAT(//10X,'AT AXIAL POSITION=',F7.4,' FT. FROM INJECTOR FACE',
     *       ' WALL AXIAL VELOCITY=',F7.2,' FT/SEC',//5X,'RSEG (FT)',7X,
     *       10(F6.3,4X),/10X,10(F6.3,4X),/10X,10(F6.3,4X))
C
C     CALCULATE VMR IN SLICE
C
      DO 200 I=1,NSLICE
         DO 150 J=IROW,NSEG
            GRV(I,J)=-1.0
            IF (XGRID(I,J) .GT. 0.0) GRV(I,J)=99.99
            IF (HGRID(I,J) .GT. 0.0) GRV(I,J)=XGRID(I,J)/HGRID(I,J)
  150    CONTINUE
         WRITE(7,160) (I*THETA), (GRV(I,J),J=IROW,NSEG)
  160    FORMAT(5X,'THETA=',F6.2,4X,10(F6.3,4X),/10X,10(F6.3,4X),/10X,
     *          5(F6.3,4X))
         IF (IMRFLG .GT. 1) WRITE(6,170) I, ((HGRID(I,J)+XGRID(I,J)),
     *                                     J=1,NSEG)
  170    FORMAT(/1X,'FOR SLICE=',I3,/1X,'MASS:  ',10(E11.5,2X))
         IF (IMRFLG .GT. 2) WRITE(6,180)  (HGRID(I,J),J=1,NSEG)
         IF (IMRFLG .GT. 2) WRITE(6,190)  (XGRID(I,J),J=1,NSEG)
  180    FORMAT(1X,'FUEL:  ',10(E11.5,2X))
  190    FORMAT(1X,'  OX:  ',10(E11.5,2X))
  200 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE CERE
C
C     SUBROUTINE TO CALCULATE ENERGY RELEASE EFFICIENCY
C
$INSERT COMMON
      IF (ITRACE .EQ. 2) WRITE(6,1)
    1 FORMAT(/1X,'ENTER CERE')
C
      CMR=TXF/TFF
C
C     SUM C* FOR EACH CELL INCLUDING MASS WEIGHTING FACTOR
C
      CSUM=0.0
      IC=6
      CI=0.0
      DO 100 I=1,NSLICE
          DO 100 J=1,NSEG
              VMR=XGRID(I,J)/HGRID(I,J)
              CALL DBLINT (PC, VMR, IC, CI)
              WI=(XGRID(I,J)+HGRID(I,J))/(TXVM+THVM)
              CSUM=CSUM+WI*CI
  100 CONTINUE
C
C     CORRECT C* FOR MASS DEFECT
C
      CSUM=CSUM*(TXVM+THVM)/(TFF+TXF)
C
C     CALCULATE C* COMBUSTION EFFICIENCY
C
      CSTAR=0.0
      CALL DBLINT (PC, CMR, IC, CSTAR)
      ERE=CSUM/CSTAR*100.0
      EVAP=MIN(100.0,(TXVM/TXF*100.0))
      EMIX=ERE/EVAP*100.0
      WRITE(6,200) THVM,TFF,TXVM,TXF,EVAP,EMIX,ERE
  200 FORMAT(//5X,F8.3,' LB/S OF FUEL VAPORIZED OUT OF ',F8.3,
     *       ' LB/S TOTAL',/5X,F8.3,' LB/S OF OX VAPORIZED OUT OF ',F8.3,
     *       ' LB/S TOTAL',//5X,'OX VAPORIZATION EFFICIENCY=',F7.3,'%',
     *       /5X,'MIXING EFFICIENCY=',F7.3,'%',/5X,
     *       'ENERGY RELEASE EFFICIENCY=',F7.3,'%',//)
      RETURN
      END
```

```
      SUBROUTINE DBLINT (PR, XMR, IVFLG, Q)
C
C     SUBROUTINE TO PERFORM DOUBLE INTERPOLATION TO CALCULATE T,
C     MW, GAMMA, VSONIC, RHO C* AND MU AS A FUNCTION OF PC AND MR
C
C     INPUTS:
C        PR=CHAMBER PRESSURE, PSIA
C       XMR=MIXTURE RATIO
C     IVFLG=VALUE FLAG: 1=TGAS, DEGREES R
C                       2=MW
C                       3=SPECIFIC HEAT RATIO
C                       4=VSONIC, FT/SEC
C                       5=RHO, LB/CU. FT
C                       6=CSTAR, FT/SEC
C                       7=MU, LB/FT-SEC
C
C     OUTPUT:
C        Q=VALUE OF IVFLG
C
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON /IPROPS/ FTJ, FRHO, FMU, FTC, FHV, FMW, XRHOC,
     *           XST, XTJ, XRHO, XMU, XTC, XHV, XMW
C
C     LOCAL COMMON ONLY
C
      COMMON /DBLDAT/ XM(13), T(2,13), WM(2,13), CS(2,13), UM(2,13),
     *                GM(2,13)
      DATA XM / 0., 1., 2., 3., 4., 5., 6., 7., 8., 9., 10., 15., 20./
      DATA ((T(I,J),J=1,13),I=1,2) / 37.0, 1759., 3232., 4404., 5237.,
     *     5756., 6093., 6159., 6177., 6141., 6078., 5650., 5209.,
     *     37.0, 1759.,
     *     3236., 4430., 5375., 6064., 6504., 6717., 6756., 6695.,
     *     6592., 5974., 5401./
      DATA ((WM(I,J),J=1,13),I=1,2) / 2.016, 4.032, 6.048, 8.048, 9.957,
     *     11.703, 13.263, 14.135, 15.835, 16.889, 17.825, 21.291,
     *     23.501, 2.016, 4.032, 6.048, 8.059, 10.029, 11.897, 13.603,
     *     15.094, 16.355, 17.421, 18.341, 21.653, 23.722/
      DATA ((CS(I,J),J=1,13),I=1,2) / 1287., 6864., 7751., 7959., 7922.,
     *     7742., 7493., 7220., 6956., 6715., 6500., 5715., 5194.,
     *     1287., 6864., 7751., 7959., 7950., 7829., 7637., 7396.,
     *     7133., 6878., 6647., 5800., 5237./
      DATA ((UM(I,J),J=1,13),I=1,2) /0.2875, 0.5139, 0.9856, 1.363,
     *     1.646, 1.835, 1.951, 2.014, 2.045, 2.057, 2.058, 2.006,
     *     1.920, 1.305, 0.5319, 0.9857, 1.369, 1.679, 1.908, 2.062,
     *     2.148, 2.183, 2.190, 2.182, 2.088, 1.971/
      DATA ((GM(I,J),J=1,13),I=1,2) / 1.400, 1.359, 1.283, 1.227, 1.178,
     *  1.148, 1.133, 1.126, 1.125, 1.125, 1.126, 1.135, 1.149, 1.400,
     *  1.359, 1.284, 1.237, 1.199, 1.168, 1.148, 1.138, 1.136, 1.136,
     *  1.138, 1.149, 1.165/
      R=10.73
C
C     FIND MR BOUNDS
C
      IF(XMR .GT. XM(1)) GOTO 20
        I=2
        GOTO 60
   20 IF(XMR .LT. XM(13)) GOTO 30
        I=13
        GOTO 60
   30 DO 50 I=2,13
```

```
      IF(XM(I) .LT. XMR) GOTO 50
      GOTO 60
   50 CONTINUE
   60 CONTINUE
      IF (IVFLG .EQ. 2) GOTO 200
      IF (IVFLG .EQ. 3) GOTO 300
      IF (IVFLG .EQ. 6) GOTO 600
      IF (IVFLG .EQ. 7) GOTO 700
C
C     CALCULATE T
C
      T(1,1)=FTJ+460.0
      T(2,1)=FTJ+460.0
      TP1=T(1,I-1)+(XMR-XM(I-1))/(XM(I)-XM(I-1))*(T(1,I)-T(1,(I-1)))
      TP2=T(2,I-1)+(XMR-XM(I-1))/(XM(I)-XM(I-1))*(T(2,I)-T(2,(I-1)))
      Q=TP1+(PR-300.)/2700.*(TP2-TP1)
      IF (IVFLG .EQ. 1) RETURN
C
C     CALCULATE MW
C
  200 CMW1=WM(1,I-1)+(XMR-XM(I-1))/(XM(I)-XM(I-1))*(WM(1,I)-WM(1,(I-1)))
      CMW2=WM(2,I-1)+(XMR-XM(I-1))/(XM(I)-XM(I-1))*(WM(2,I)-WM(2,(I-1)))
      CMW=CMW1+(PR-300.)/2700.*(CMW2-CMW1)
      IF (IVFLG .EQ. 4) GOTO 300
      IF (IVFLG .EQ. 5) GOTO 500
      Q=CMW
      RETURN
C
C     CALCULATE GAMMA
C
  300 GM1=GM(1,I-1)+(XMR-XM(I-1))/(XM(I)-XM(I-1))*(GM(1,I)-GM(1,(I-1)))
      GM2=GM(2,I-1)+(XMR-XM(I-1))/(XM(I)-XM(I-1))*(GM(2,I)-GM(2,(I-1)))
      GAMMA=GM1+(PR-300.)/2700.*(GM2-GM1)
      IF (IVFLG .NE. 3) GOTO 400
      Q=GAMMA
      RETURN
C
C     CALCULATE VSONIC
C
  400 IF (IVFLG .NE. 4) GOTO 500
      Q=SQRT(GAMMA*R*Q/CMW*4633.056)
      RETURN
C
C     CALCULATE DENSITY
C
  500 Q=PR*CMW/R/Q
      RETURN
C
C     CALCULATE CSTAR
C
  600 CP1=CS(1,I-1)+(XMR-XM(I-1))/(XM(I)-XM(I-1))*(CS(1,I)-CS(1,(I-1)))
      CP2=CS(2,I-1)+(XMR-XM(I-1))/(XM(I)-XM(I-1))*(CS(2,I)-CS(2,(I-1)))
      Q=CP1+(PR-300.)/2700.*(CP2-CP1)
      RETURN
C
C     CALCULATE MU
C
  700 UP1=UM(1,I-1)+(XMR-XM(I-1))/(XM(I)-XM(I-1))*(UM(1,I)-UM(1,(I-1)))
      UP2=UM(2,I-1)+(XMR-XM(I-1))/(XM(I)-XM(I-1))*(UM(2,I)-UM(2,(I-1)))
      Q=(UP1+(PR-300.)/2700.*(UP2-UP1))*3.2174E-5
```

```
RETURN
END
```

```
C
C     COMMON INSERT FOR PERFORMANCE/LIFE COMBUSTION MODEL, PLC
C
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON /OPCOND/ PC, TFF, TXF, HGMRO
      COMMON /WALL/ NXP, XW(NXP), RW(NXP), WANGLE(NXP), CR, X1, X2,
     *              X, RWALLX, ANGLEX
      COMMON /FACE/ NEL, NROWS, NELR(NROWS), RROW(NROWS),
     *              ERPOS(NEL), ETPOS(NEL), CFLOW, CFMR
      COMMON /INJECT/ ITYPE, RXP, RFP, TPOST, RECESS, RMS, XDL, CSA,
     *                PFI, FCD, XCD, FMF(NEL), XMF(NEL), HGMR(NEL)
      COMMON /GRID/ NSLICE, NSEG, THETA, RGRID(NSEG), XGRID(NSLICE,NSEG),
     *              HGRID(NSLICE,NSEG)
      COMMON /IPROPS/ FTJ, FRHO, FMU, FTC, FHV, FMW, XRHOC,
     *          XST, XTJ, XRHO, XMU, XTC, XHV, XMW
      COMMON /VAPOR/ TXVM, THVM, XVM(3,NEL)
      COMMON /GAS/ CPC, CT, GAMMA, GRHO, GMU, GMW, GXV(NSEG), GRV(NSLICE,NSEG)
      COMMON /DROP/ RMO(NEL), SG(NEL), VFACT(NEL), AL(NEL), TND(NEL),
     *              RMX(3,NEL), DRP(3,NEL), DXV(3,NEL), DRV(3,NEL)
      COMMON /FILL/ COM(3,NEL)
      COMMON /MSG/ IAFLG, IVDFLG, IMVFLG, IPDFLG, IDMFLG, IMRFLG, IDFLG,
     *             IRFFLG, ITRACE
      COMMON /STEP/ ASTEP, XSTEP, IEFLG
C
```

```
/* CPL PROGRAM TO CREATE A SEG FOR PERFORMANCE/LIFE COMBUSTION MODEL
/* WITH COMMONS DIMENSIONED TO THE PROBLEM
/*
/* *********** NSUBS=NUMBER OF PROGRAMS WITH INSERT COMMONS **********
/*
/* RETRIEVE BASE FILES
/*
&IF [EXISTS PLC.F77 -FILE -BRIEF] &THEN DELETE PLC.F77
&IF [EXISTS COMMON -FILE -BRIEF] &THEN DELETE COMMON
&IF [EXISTS FMF.EQ -FILE -BRIEF] &THEN DELETE FMF.EQ
&IF [EXISTS XMF.EQ -FILE -BRIEF] &THEN DELETE XMF.EQ
COPY <AMFD27>E23846>PL.UFD>PLC.F77 PLC.F77
COPY <AMFD27>E23846>PL.UFD>COMMON COMMON
&S UNIT1 := [OPEN_FILE FMF.EQ -MODE W THERE]
&S UNIT2 := [OPEN_FILE XMF.EQ -MODE W THERE]
&S END := $END
/*
/* DEFAULT SIZES AND CHECK FOR NEW VARIABLES
/*
&S TYPE := 1
&S NEL := 1
&S NROWS := 1
&S NXP := 2
&S NSLICE := 12
/*
/* FIND NEW VALUES IF THEY EXIST
/*
&S UNIT := [OPEN_FILE PL.INPUT -MODE R THERE]
&IF %THERE% ^= 0 &THEN &STOP &MESSAGE PL.INPUT NOT FOUND
/*
/* LOOK FOR END OF NAMELIST OUTPUT
/*
&DO I := 1 &TO 10
  &S LINE := [READ_FILE %UNIT% OK]
  &IF %LINE% = %END% &THEN &GOTO OUT
&END
&STOP &MESSAGE NO END FOR NAMELIST OUTPUT
/*
/* LOOK FOR NXP AFTER PROPERTIES
/*
&LABEL OUT
&S LINE := [READ_FILE %UNIT% OK]
&S LINE := [READ_FILE %UNIT% OK]
&S LINE := [READ_FILE %UNIT% OK]
&S LINE := [READ_FILE %UNIT% OK]
&S LINE := [READ_FILE %UNIT% OK]
&S LINE := [READ_FILE %UNIT% OK]
&S NXP := [READ_FILE %UNIT% OK]
/*
/* LOOK FOR NEL AND NROWS AFTER WALL DATA
/*
&DO I := 1 &TO %NXP%
   &S LINE := [READ_FILE %UNIT% OK]
&END
&S LINE := [READ_FILE %UNIT% OK]
&S LINE := [READ_FILE %UNIT% OK]
&S TYPE := [TRIM [SUBSTR %LINE% 1 4] -BOTH]
&S NEL := [TRIM [SUBSTR %LINE% 5 4] -BOTH]
&S NROWS := [TRIM [SUBSTR %LINE% 9 4] -BOTH]
```

```
&S NSEG := %NROWS% + 1
/*
/* LOOK FOR NAMELIST CONT AFTER ELEMENTS AND INJECTOR CONFIGURATION
/* SETUP FMF.EQ AND XMF.EQ IF TYPE 2 INPUT
/*
&IF %TYPE% = 2 &THEN &GOTO TYPE2
&DO I := 1 &TO %NEL%
   &S LINE := [READ_FILE %UNIT% OK]
&END
&GOTO END_2
&LABEL TYPE2
&S IFS := '       IF (IROW .EQ. '
&S IFS2 := ' ) FMF(INJ) = '
&S IFS3 := ' ) XMF(INJ) = '
&S ICN := '      * '
&DO I := 1 &TO %NROWS%
   &S LINE := [READ_FILE %UNIT% OK]
   &S FMF := [READ_FILE %UNIT% OK]
   &IF %OK% ^= 0 &THEN &STOP &MESSAGE ERROR READING FMF.EQ FOR ROW %I%
   &S FMFC := %IFS%%I%%IFS2%
   &S FMF := %ICN%%FMF%
   &S J := [WRITE_FILE %UNIT1% %FMFC%]
   &S J := [WRITE_FILE %UNIT1% %FMF%]
   &S XMF := [READ_FILE %UNIT% OK]
   &IF %OK% ^= 0 &THEN &STOP &MESSAGE ERROR READING XMF.EQ FOR ROW %I%
   &S XMFC := %IFS%%I%%IFS3%
   &S XMF := %ICN%%XMF%
   &S J := [WRITE_FILE %UNIT1% %XMFC%]
   &S J := [WRITE_FILE %UNIT2% %XMF%]
&END
&LABEL END_2
&DO &UNTIL %LINE% = $CONT
   &S LINE := [READ_FILE %UNIT% OK]
&END
/*
/* READ ALL LINES AND PARSE UNTIL $END IS FOUND
/*
&LABEL NEXTLINE
&S LINE := [READ_FILE %UNIT% OK]
&IF %LINE% = %END% &THEN &GOTO NOMORE
&S LINE := [TRIM %LINE% -RIGHT ]
&DO &UNTIL [LENGTH %LINE%] = 0
   &S LINE := [TRIM %LINE% -LEFT ]
   &S NAME := [BEFORE %LINE% =]
   &S LINE := [AFTER %LINE% =]
   &S %NAME% := [BEFORE %LINE% ',']
   &S LINE := [AFTER %LINE% ',']
&END
&GOTO NEXTLINE
/*
/* CHANGE DIMENSIONS IN COMMON
/*
&LABEL NOMORE
&DATA SED COMMON
 C/(NXP)/(%NXP%)/50 G
 TOP
 C/NEL)/%NEL%)/50 G
 TOP
 C/(NROWS)/(%NROWS%)/50 G
 TOP
```

```
 C/(NSLICE/(%NSLICE%/50 G
 TOP
 C/NSEG)/%NSEG%)/50 G
 FILE
&END
CLOSE FMF.EQ
CLOSE XMF.EQ
CLOSE PL.INPUT
/*
/* COMPILE, SEG AND RUN
/*
F77 PLC -DO1 -SILENT 1 -OPT 0
&DATA SEG -LOAD
 LO PLC
 LI
 MAP 3
 SA
 QU
&END
DELETE PLC.BIN
&RETURN
```

PART G

ADVANCED OXYGEN-HYDROGEN ROCKET ENGINE STUDY CHAMBER GEOMETRY DEFINITION

AEROJET LIQUID ROCKET COMPANY
INTER-OFFICE MEMORANDUM

9 January 1980
RAH:sm:9751:0389
CDN:9751:4399

TO: C. J. O'Brien

FROM: R. A. Hewitt

SUBJECT: Advanced Oxygen-Hydrocarbon Rocket Engine Study
Chamber Geometry Definition

COPIES TO: K. Christiansen, D. Culver, O. D. Goodman, D. Kors, D. Lemke, J. Mellish, H. Mueggenburg, J. L. Pieper, J. Salmon, R. Schwantes, C. E. Taylor, 9751 Personnel, 9751 File

ENCLOSURE:
(1) Typical Rocket Engine Parameters
(2) Chamber Pressure vs Thrust
(3) Liquid/Liquid Engine Contraction Ratio vs Thrust
(4) Liquid/Liquid Engine Chamber Length vs Thrust
(5) Liquid/Hot-Gas Engine Chamber Length vs Thrust

REFERENCE:
(a) C. J. O'Brien, "Advanced Oxygen-Hydrocarbon Rocket Engine Study", Program Plan 33542 PP, 29 Oct. 1979
(b) ALRC Rocket Design Presentation by J. I. Ito
(c) A. J. Pavli, NASA-Cleveland, Ohio, "Design of Injectors for H/C".
(d) J. A. Mellish, "Advanced Engine Study for Mixed Mode OTV's", NASA CR 159491, Dec. 1978
(e) Empirical Design Curves in C. J. O'Brien Possession
(f) Rocketdyne Monthly Reports No. 1 and 2 in R. J. LaBotz Possession
(g) R. A. Hewitt to J. A. Mellish, "COTV Geometry", 28 September 1979, ALRC Memorandum 9751:0348

APPENDIX: (A) Universal Geometric Guidelines

INTRODUCTION

The "Advanced Oxygen-Hydrocarbon Rocket Engine Study" parametric analysis requires chamber geometry (D_t, L', CR) guidelines to provide

Introduction (cont.)

reasonable and typical design values. This preliminary study (See Ref. a) is directed at a thrust range of from 200,000 to 1,500,000 lbf with emphasis on the 600,000 to 1,000,000 lbf level. The chamber pressure range is from 1000 to 5000 psia. The propellant combinations are LOX/RP-1 and LOX/CH_4, with LH_2 considered only as an additional coolant possibility. The mixture ratio range to be studied is 2.0 to 3.5 for LOX/RP-1, and 3.0 to 4.5 for the LOX/CH_4 propellant combination. The nozzle exit area ratio will range from about 15:1 to 100:1 as determined by attachment limit as a function of chamber pressure and optimum trajectory trade-offs.

RECOMMENDED GEOMETRY GUIDELINES

Based on the information presented in the body of this memorandum the following rocket geometry relationships are recommended for the "Advanced LOX/HC Engine Study":

Injection State	Liquid/Liquid	Liquid/Gas
Contraction Ratio CR	Log_{10} CR = -.0715 LOG_{10} F + 0.689	3.00
Chamber Length L' (in)	Log_{10} L' = .23 Log_{10} (F/Pc)+ .85	Log_{10}L' =.23 Log_{10}(F/Pc) + .621

The above contraction ratio relationship will yield a liquid/liquid value of about 1.85(@ 800,000 lbf) which can be assumed constant for purposes of this study. The estimated chamber lengths will be as follows:

Recommended Geometry Guidelines (cont.)

Injection State	Liquid/Liquid		Liquid/Gas	
Thrust,lbf/Pressure,psia	1000	5000	1000	5000
200,000	23.9"	16.5"	14.1"	9.8 "
600,000	30.8	21.3	18.2	12.6
1,000,000	34.7	23.9	20.5	14.1
1,500,000	38.1	26.3	22.5	15.5

The estimation of the chamber throat diameter depends on the details of the engine design being considered. However, a diameter estimate for the propellant combinations used here are shown in the appendix. The following information is of more general interest and referred to as "Universal Guidelines" since so little data may exist to substantiate design trends in any given narrow spectrum of thrust or chamber pressure.

The designation of what propellants and engine cycle qualify for the designation liquid/liquid or liquid/gas are estimated as follows:

	Liquid/Liquid	Average*	Liquid/Gas
Lox/RP-1 Ambient	X		
LOX/RP-1 Regenerative	X		
LOX/RP-1 Staged Combustion			X
LOX/CH_4 Ambient		X	
LOX/CH_4 Regenerative		X	
LOX/CH_4 Staged Combustion			X

*Average: Arithmetic average of the liquid/liquid and liquid/gas values.

UNIVERSAL GEOMETRIC PREMISES

The "Advanced Oxygen-Hydrocarbon Rocket Engine Study" chamber geometry definition relies heavily on two premises: (1) that the average trends of existing rocket engine geometries as a function of chamber pressure and thrust will continue to be valid for future designs, and (2) that a given existing rocket geometry could theoretically have its chamber pressure and thrust increased and decreased over about a factor of 3 without significantly altering its performance, stability, or compatibility characteristics. Design information used to substantiate the assumptions made in this memorandum are largely contained in Enclosure (1) and reference (b) through (f).

EXISTING ROCKET GEOMETRIES

A table of typical rocket engine parameters are shown in Enclosure (1). The rocket geometric characteristics are defined by three dimensions; (1) throat diameter, (2) chamber diameter, and (3) chamber length from injector to throat. The non-dimensional ratios such as contraction ratio and chamber length to diameter ratios are shown for convenience. The rocket engine operational characteristics are defined by: (1) propellants, (2) mixture ratio, (3) thrust, and (4) chamber pressure.

EXTRAPOLATION OF THRUST AND CHAMBER PRESSURE

It is a premise of this study that the chamber pressure and thrust of any existing rocket engine can be theoretically increased and decreased within one order of magnitude peak-to-peak without significantly altering its value for indicating trends in future rocket engine designs. An example of this would be to assume a Titan I, second stage engine rated at 80,000 lbf thrust

Extrapolation of Thrust and Chamber Pressure (cont.)

at 682 psia can be uprated to 250,000 lbf at 2150 psia or downrated to 25,000 lbf at 215 psia. The only geometric alteration required would be that the injector orifice size be increased from an assumed 0.100 in. dia. to 0.133 or decreased to 0.0750 in. This orifice size change is relatively insignificant due to the fact that the injection pressure drop is assumed to increase and decrease in order to maintain a nearly constant combustion time lag and constant chug stability margin by slightly varying the liquid injection pressure drop to chamber pressure ratio of about 0.15 to 0.20.

THRUST AND CHAMBER PRESSURE TRENDS

A comparison of existing rocket engine chamber pressures over three-orders-of-magnitude is made with thrust over eight orders-of-magnitude in Enclosure (2). The trend indicated is that logarithm of the rocket engine chamber pressure tends to be proportional to the logarithm of the thrust. There are no engines with very high chamber pressures used to obtain a very low thrust or vice-versa. Although low chamber pressure-large thrust studies (e.g., Big Dumb Booster & APS) have been made, no production engines have resulted. The lowest chamber pressure and highest thrust engine shown is the pressure fed Apollo SPS engine. The highest chamber pressure and lowest thrust engines include the 0.5 lbf at 125 psia, and the recent high pressure LOX/HC engines in the 4500 to 55000 lbf thrust range. The logic for the fact that the LOX/HC engines were designed for higher pressures than the trend line indicated for their thrust, lies in the fact that many are "subscale" engines. Or, in the case of the 0.5 lbf engine, it was designed to "blowdown" with tank pressure thereby lowering its thrust to near the "design diagonal" trend line. Note the "design diagonal" line bandwidth is defined by empirical data.

CHAMBER CONTRACTION RATIO TRENDS

The contraction ratio for present day liquid/liquid rocket engines is shown in Enclosure (3) over the eight orders-of-magnitude of thrust. The trend indicated narrows with increasing thrust. A weakly increasing contraction ratio with increasing thrust trend is indicated although a constant value of as low as 1.8 is also indicated. In either case in the thrust range of from 600,000 to 1,500,000 lbf a contraction ratio of less than 2.0 is indicated for a liquid/liquid LOX/HC engine. The use of engine cycles that pass hot-gas through the injector require a greater injector diameter to allow the lower density gases through with a minimum of pressure drop. This trend results in contraction ratio's of about 3.0, which tends to force liquid/hot-gas chamber pressures to higher values in order to bring chamber diameters down to comparable liquid-liquid engines operating at lower chamber pressures.

CHAMBER LENGTH TRENDS

The liquid-liquid engine chamber length from injector-to-throat is shown in Enclosure (4) for eight orders-of-magnitude of thrust. The chamber lengths shown are limited to their reasonable range of applicability as defined in Enclosure (2). That is, low pressure applies to low thrust only, and high pressure applies to high thrust only. This results in a reasonable "diagonal design" line extending from the longest, low thrust, engine and the shortest, high thrust engine, as shown below:

F (lbf)	Pc (psia)	Chamber Length L' (in.)	
		Liquid/Gas	Liquid/Liquid
1.0	30	2.0	3.
1.K	250	6.0	10.
1.M	1500	18.0	33.0

Chamber Length Trends (cont.)

Note that the thrust "band-width" of the "design diagonal" is at least an order-of-magnitude wide, and results in about a $\pm$ 40% chamber length "band-width". For example if the 33 in. long 1 M LBF liquid/liquid engine shown above is raised in pressure to about 4000 psia, the estimated chamber length drops to about 25 in.

The chamber length of a liquid/hot-gas cycle engine is shown in Enclosure (5). Note that the net effect of the hot-gas cycle is to shorten the chamber relative to the liquid/liquid engines as is shown by comparing the chamber length equations:

LIQUID/LIQUID:

$$\mathrm{LOG}_{10}\, L' = .23\ \mathrm{LOG}_{10}\, (F/P_c) + .850$$

LIQUID/HOT-GAS:

$$\mathrm{LOG}_{10}\, L' = .23\ \mathrm{LOG}_{10}\, (F/P_c) + .621$$

R. A. Hewitt

R. A. Hewitt
Thermodynamic Analysis
Rocket Design Analysis

Approved by:

J. I. Ito

J. I. Ito
Thermodynamic Analysis
Rocket Design Analysis

J. L. Pieper

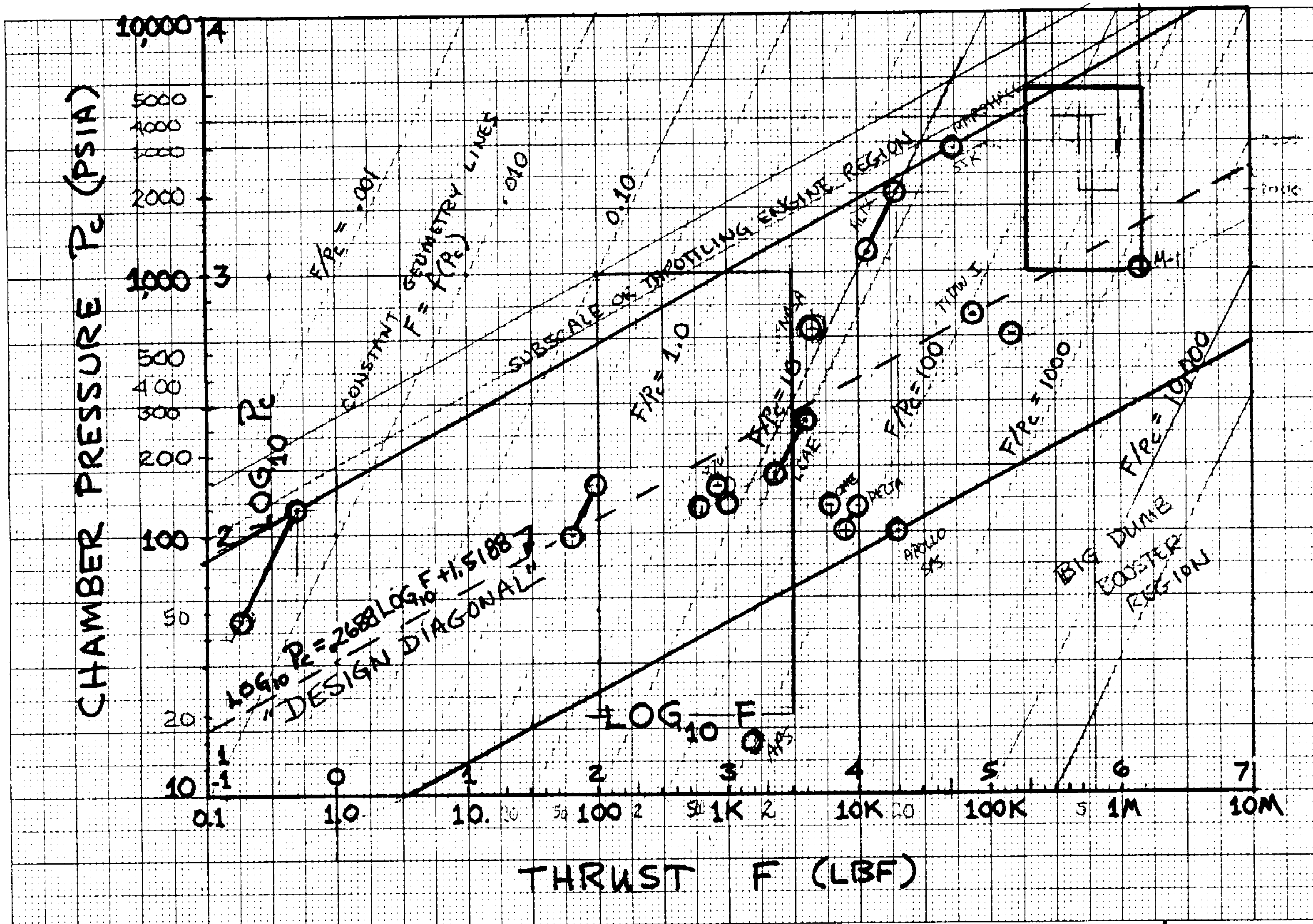
J. L. Pieper, Manager
Thermodynamic Analysis
Rocket Design Analysis

TYPICAL ROCKET ENGINE PARAMETERS

	Symbol	Chamber Cooling Method	Mixture Ratio (O/F)	Chamber Length (in)	Throat Diameter (in)	Injector Diameter (in)	Contract. ratio (N.D.)	Number Primary Elements (N.D.)	Propellants (O/F)	Thrust (lbf)	Chamber Pressure (psia)	Chamber L'/D
Titan II 1st Stage	T1	Regen.	1.93	24	15.2	21.8	2.0	516	N_2O_4/A-50	215,000	785	1.1
Titan III 1st Stage	T1	Regen.	1.93	24	15.3	21.65	2.0	504	N_2O_4/A-50	220,000	807	1.1
Titan II 2nd Stage	T2	Regen.	1.80	17	9.1	14.2	2.4	818	N_2O_4/A-50	100,000	827	1.2
Titan III 2nd Stage	T2	Regen.	1.80	17	9.2	14.2	2.4	500	N_2O_4/A-50	100,000	830	1.2
ITIP	T3	Abla.	2.0	18	7.5	11.9	2.5	600	N_2O_4/A-50	8,000	105	1.5
Transtage	T3	Abla.	2.0	18	7.5	11.9	2.5	336	N_2O_4/A-50	8,000	105	1.5
N-II, Delta FJ	N	Abla.	1.9	18	7.5	11.9	2.5	336	N_2O_4/A-50	9,850	125	1.5
LCAE 4K	L	Film Cooled	1.65	7	3.3	5.84	3.1	450	N_2O_4/MMH	4,000	260	1.2
LCAE 2.5K	L	Film Cooled	1.65	7	3.3	5.84	3.1	450	N_2O_4/MMH	2,500	165	1.2
OMS	O	Regen.	1.65	16	5.9	8.11	1.9	272	N_2O_4/MMH	6,000	125	2.0
Apollo/I.O.S.	A	Abla.	1.6	24	12.4	17	2.5	575/900	N_2O_4/A-50	20,000	97	1.2
M-1 Coax	M	Regen.	5.5	29	32	40	1.8	3248	LOX/LH_2	1,500,000	1000	0.8
F-1	F	Regen.	2.35	48	35	39.2	1.3	702	LOX/RP-1	1,522,000	1128	1.2
ITA	I	Regen./F.C.	5.	7	1.92	3.5	3.3	72	O_2/H_2	1,500	340	2.0
ETR LOL	E		5.	5		2.2		48	LOX/LH_2	1,200	500	2.2
ETR Coax	E		5.	5		2.2		36	LOX/LH_2	1,200	500	2.2
100 lbf	100	Film	1.6	4	.69	0.94	1.86	33	N_2O_4/MMH	100	150	4.3
870	870	Film	1.6	3.9	2.04	3.0		270	N_2O_4/MMH	870	150	1.3
LM-A	LM	Abla.	1.6	14	4.5	7.8	3.0	177	N_2O_4/A-50	3,500	120	1.8
IFAR/DELTAV	D	Abla.	1.1	9		4.		124/32	N_2O_4/N_2H_4	2,800	300	2.3
Fluorine T/S Fine/Coarse	FL	Abla.	1.9	19		9.45		344/69	LF_2/N_2H_4	7,000	100	2.0
Scaleable Fine/Coarse	S	Film	1.6	5		1.5		108/39	N_2O_4/MMH	200-300	75-130	3.3
NASA (Pavli)	P	Uncooled	2.8	8.5	2.6	5.32	4.2	97	LOX/CH_4	4,500	600	1.6
NASA (Pavli)	P	Uncooled	2.8	22	2.6	5.32	4.2	37	LOX/RP-1	4,500	600	4.2
APS	APS	Regen/F.C.	5.	6		16		200	O_2/H_2	1,500	15	0.4
APS	APS	" "	5.	16		16		200	O_2/H_2	1,500	15	1.0
Titan I 1st Stage	T11	Regen.	2.25	24	15.2	21.6	2.0	560	LOX/RP-1	150,000	587	1.6
Titan I 2nd Stage	T12	Regen.	2.25	17	9.2	14.2	2.5	328	LOX/RP-1	80,000	682	1.9
ALRC H/C	H/C	Regen.	2.8	14	2.46	4.8	3.8	120	LOX/RP-1	12,000	1200	2.9
ALRC H/C	H/C	Regen.	2.8	14	2.46	4.8	3.8	120	LOX/RP-1	20,000	2000	2.9
SSME	LO_2/H_2	Regen.	5.			17.8		600	LOX/RP-1	509,000	3250	

K•E 10 X 10 TO ½ INCH 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A. 46 1320

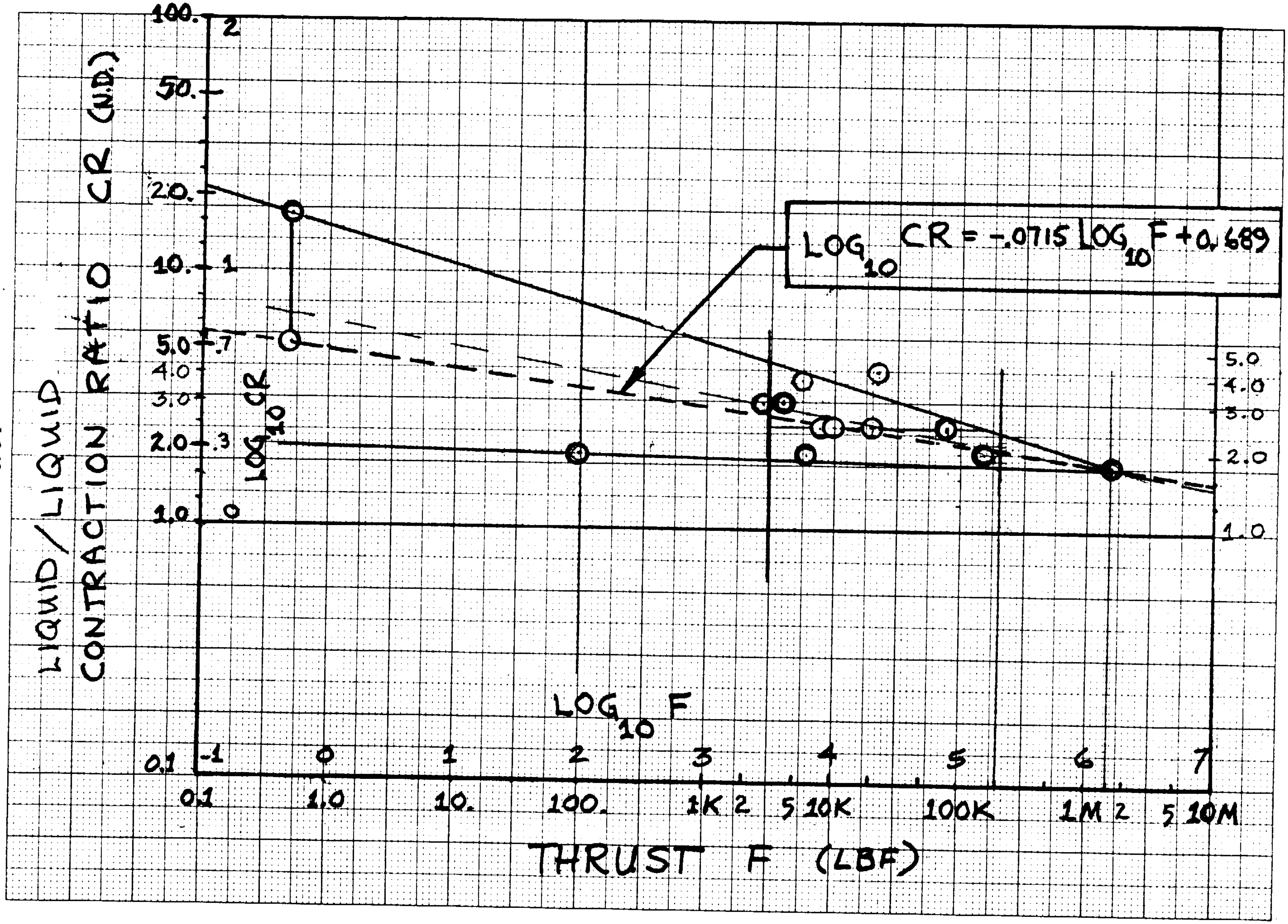
Enclosure 2



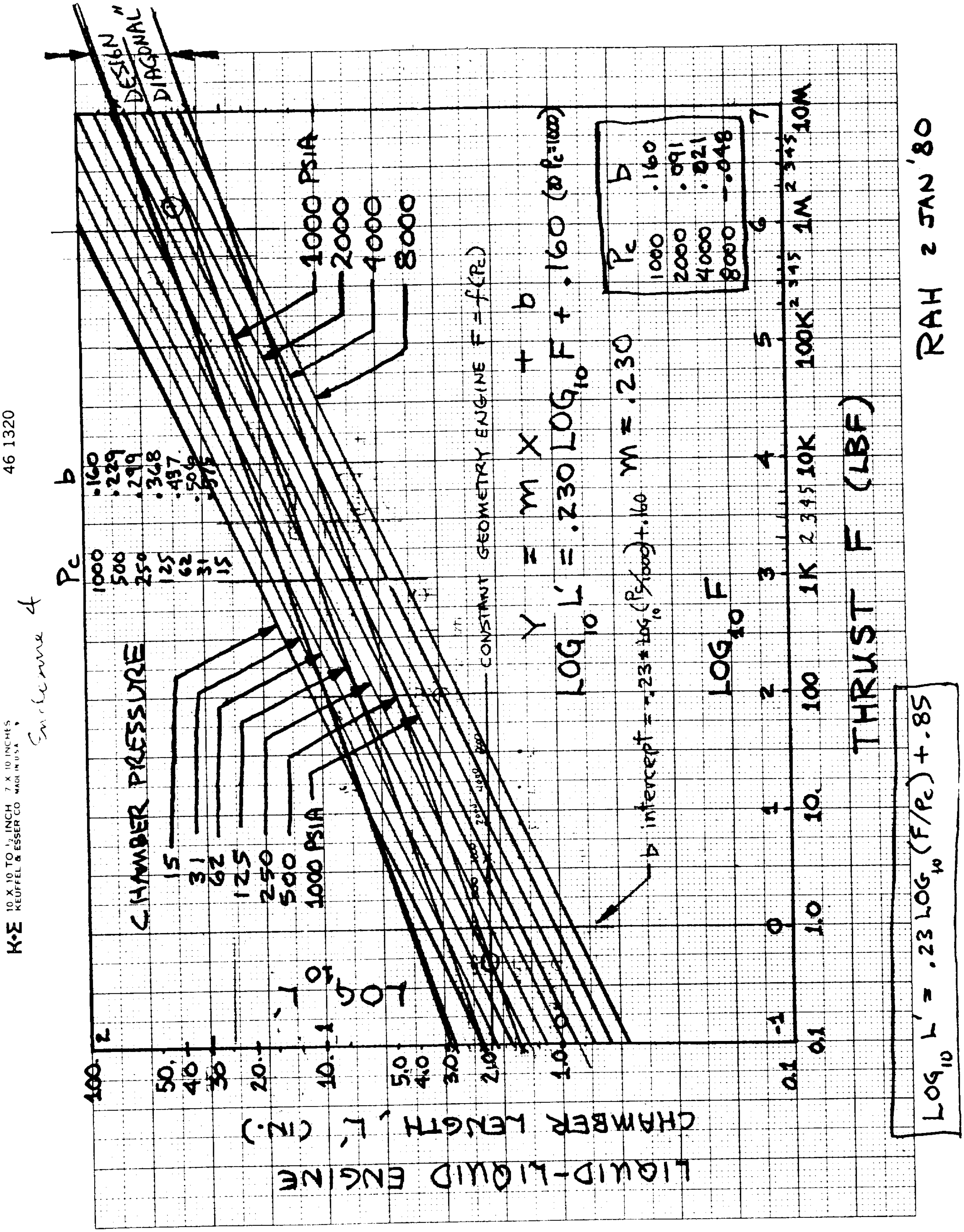
NOTE : $F = P_c A_t \zeta I_s / c^*$

RAH 2 JAN '80

Enclosure 3



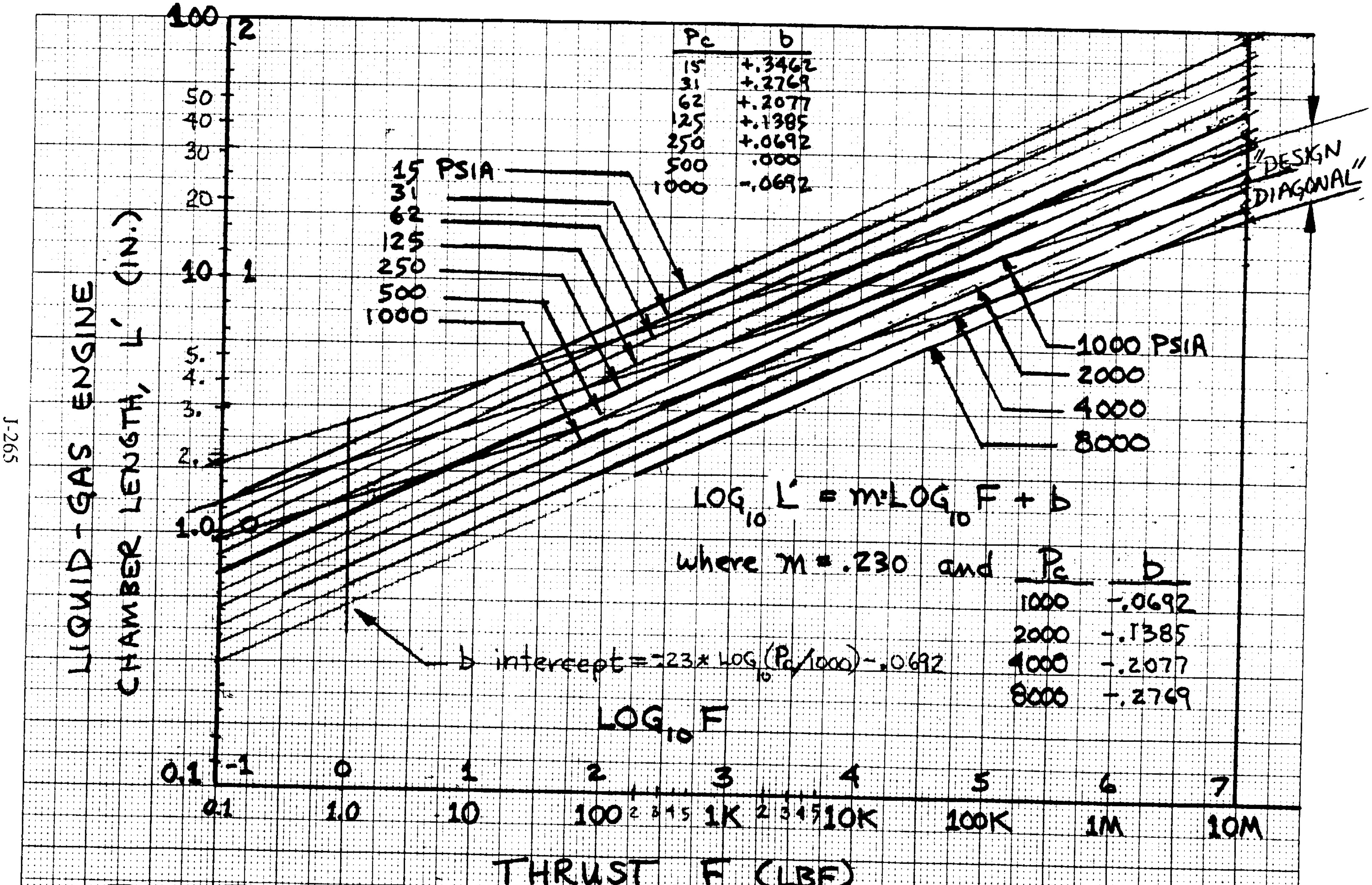
RAH 2 JAN '80



K+E 10 X 10 TO ½ INCH 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A.
46 1320
Enclosure 4
LIQUID-LIQUID ENGINE
CHAMBER LENGTH, L', (IN.)
$LOG_{10} L'$
THRUST F (LBF)
$LOG_{10} F$
CHAMBER PRESSURE
15
31
62
125
250
500
1000 PSIA
1000 PSIA
2000
4000
8000
DESIGN "DIAGONAL"
CONSTANT GEOMETRY ENGINE $F = f(P_c)$
$Y = mX + b$
$LOG_{10} L' = .230 LOG_{10} F + .160$ (@ P_c=1000)
$m = .230$
b intercept = $-.23 * LOG_{10}(P_c/1000) + .160$
P_c	b
1000	.160
500	.229
250	.299
125	.368
62	.437
31	.506
15	.575

P_c	b
1000	.160
2000	.091
4000	.021
8000	-.048
$LOG_{10} L' = .23 LOG_{10}(F/P_c) + .85$
RAH 2 JAN '80

Enclosure 5



$$LOG_{10} L' = .23 LOG_{10}(F/P_c) + .621$$

RAH 3 JAN '80

APPENDIX A

APPENDIX

THROAT DIAMETER TRENDS

The exact determination of the throat diameter depends on many design details that will not be examined here. However, relatively accurate trends can be seen by using the specific impulse and characteristic velocity relationships and corrected for estimates of efficiencies and losses as follows:

$$C^* = P_c \, A_t \, g/W_T$$

and

$$Isp = F/W_T$$

such that

$$D_t = \sqrt{\left[\frac{4}{\pi \; g \; \eta_{DEL}}\right] \left[\frac{C^* \; F}{P_c \; Isp}\right]}$$

where $\eta_{DEL} = (.95)$

$$D_t = .204 \sqrt{\frac{C^*_{ODK}}{Isp_{ODE}} \left(\frac{F}{Pc}\right)}$$

$$D_{t_{Typical}} = .204 \sqrt{\frac{6000}{360} \left(\frac{F}{Pc}\right)}$$

$$D_t = .833 \sqrt{F/Pc}$$

This relationship for throat diameter is shown in Enclosure (6). Note that the "design diagonal" limits the allowable throat diameters for a given thrust and chamber pressure to the "band-width" shown.

CHAMBER DIAMETER TRENDS

Once the estimated throat diameter and contraction ratio are known from Enclosures (3) and (6) the chamber diameter can be calculated as follows and as shown in Enclosure (7):

LIQUID/LIQUID (AND LIQUID/HOT-GAS IF CR $\geq$ 3.0):

$$\mathrm{LOX}_{10}\ D_c = .4643\ \mathrm{LOG}_{10}\ F - 0.5\ \mathrm{LOG}\ P_c + .2651$$

LIQUID/HOT-GAS (Assume: CR = 3.0, @ P_c > 1000 psia, F > 200,000 lbf):

$$\mathrm{LOG}_{10}\ D_c = 0.5\ \mathrm{LOG}_{10}\ (F/P_c) + .159$$

Note that the liquid/hot-gas chamber diameter is calculated assuming a constant contraction ratio of 3.0 for the thrust and chamber pressure range considered in this study. If lower values of thrust (and at Pc > 1000) were being considered and a liquid/liquid contraction ratio of greater than 3.0 were calculated it should be used in place of the constant 3.0 value.

CHAMBER LENGTH TO DIAMETER RATIO TRENDS

Using the relationships for chamber length and chamber diameter shown above and in Enclosures (4), (5), and (7) the chamber L/D_c versus thrust and chamber pressure can be defined as follows:

LIQUID/LIQUID:

$$\frac{\mathrm{LOG}_{10}\ L'}{\mathrm{LOG}_{10}\ D_c} = \frac{.23\ \mathrm{LOG}_{10}\ (F/P_c) + .850}{.4643\ \mathrm{LOG}_{10}\ F - .5\ \mathrm{LOG}_{10}\ P_c + .2651}$$

$$\mathrm{LOG}_{10}\ (L'/D_c) = .27\ \mathrm{LOG}_{10}\ P_c - .2343\ \mathrm{LOG}_{10}\ F + .585$$

LIQUID/HOT-GAS: (Assuming: $CR \geq 3.$):

$$\frac{\text{LOG}_{10}\, L'}{\text{LOG}_{10}\, D_c} = \frac{.23\ \text{LOG}_{10}\,(F/P_c) + .621}{.4643\ \text{LOG}_{10}\, F - .5\ \text{LOG}_{10}\, P_c + .2651}$$

$$\text{LOG}_{10}\,(L'/D_c) = .27\ \text{LOG}_{10}\, P_c - .2343\ \text{LOG}_{10}\, F + .356$$

LIQUID/HOT-GAS: (Assume: $CR = 3.$ @ $P_c > 1000$ psi, & $F \geq 200{,}000$ lbf):

$$\frac{\text{LOG}_{10}\, L'}{\text{LOG}_{10}\, D_c} = \frac{.23\ \text{LOG}_{10}\,(F/P_c) + .621}{.5\ \text{LOG}_{10}\,(F/P_c) + .159}$$

$$\text{LOG}_{10}\,(L'/D_c) = .462 - .27\ \text{LOG}_{10}\,(F/P_c)$$

Note that the middle formula does not apply to this study since all the liquid/liquid contraction ratios will be less than 3.0 and all the liquid/hot-gas contraction ratios are set equal to 3.0 due to the high thrust.

Note also that the "design diagonal" band-width does not allow excessively large or small L'/D_c values to be encountered (i.e., no larger than 22 @ F = 0.1 lbf, or no smaller than 0.5 @ F = 10MLBF).

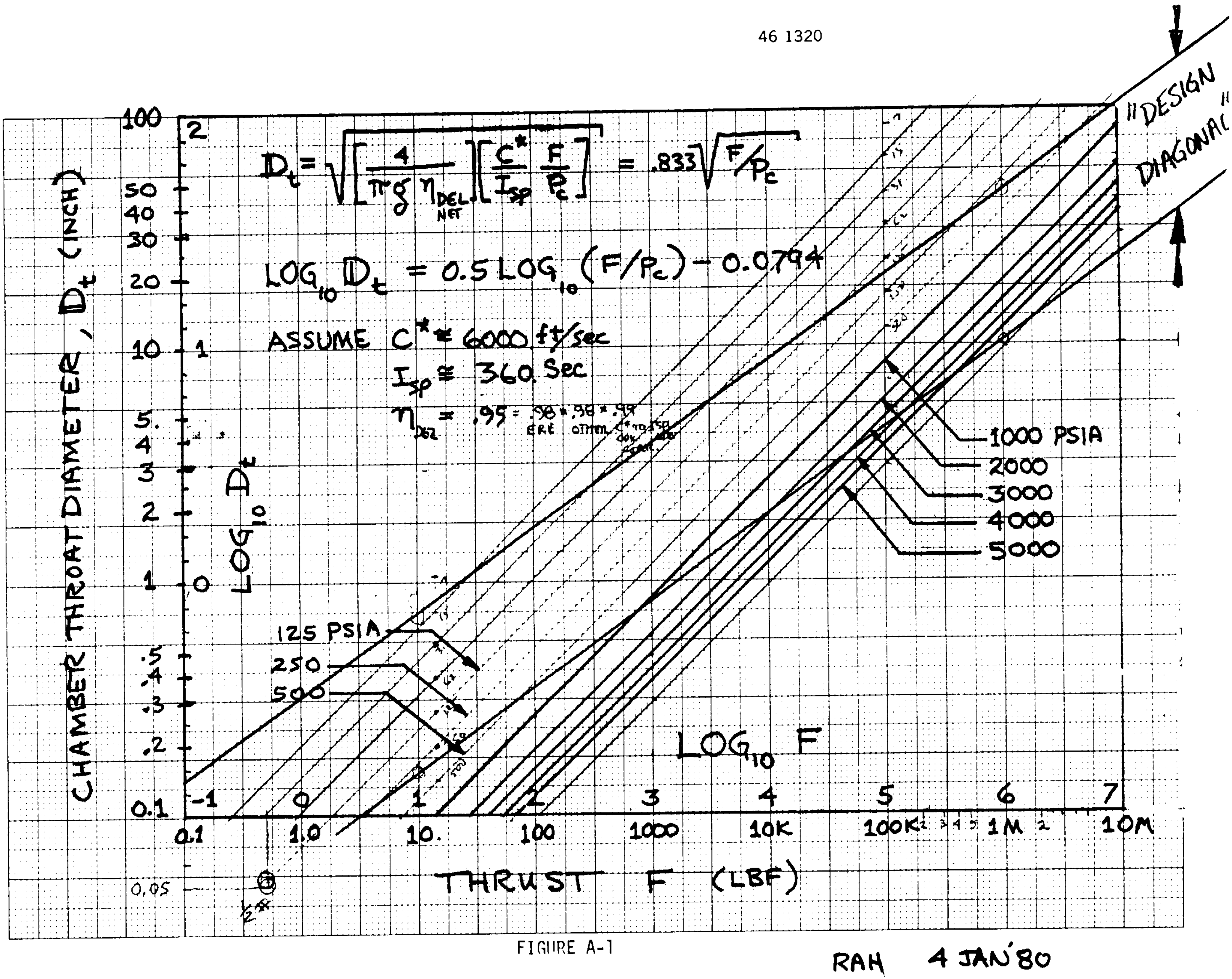

"DESIGN DIAGONAL"
$D_t = \sqrt{\left[\frac{4}{\pi g \eta_{DEL\,NET}}\right]\left[\frac{C^*}{I_{sp}}\frac{F}{P_c}\right]} = .833\sqrt{F/P_c}$
$LOG_{10} D_t = 0.5 LOG_{10}(F/P_c) - 0.0794$
ASSUME $C^* \cong 6000$ ft/sec
$I_{sp} \cong 360$ Sec
$\eta_{DEL} = .95 = .98 \times .98 \times .99$
ERE OTHER
1000 PSIA
2000
3000
4000
5000
125 PSIA
250
500
CHAMBER THROAT DIAMETER, D_t (INCH)
$LOG_{10} D_t$
$LOG_{10} F$
THRUST F (LBF)
100
50
40
30
20
10
5.
4
3
2
1
.5
.4
.3
.2
0.1
0.05
2
1
0
-1
0
1
2
3
4
5
6
7
0.1
1.0
10.
100
1000
10K
100K
1M
10M
$\frac{1}{2}$#
RAH 4 JAN'80

FIGURE A-1

46 1320

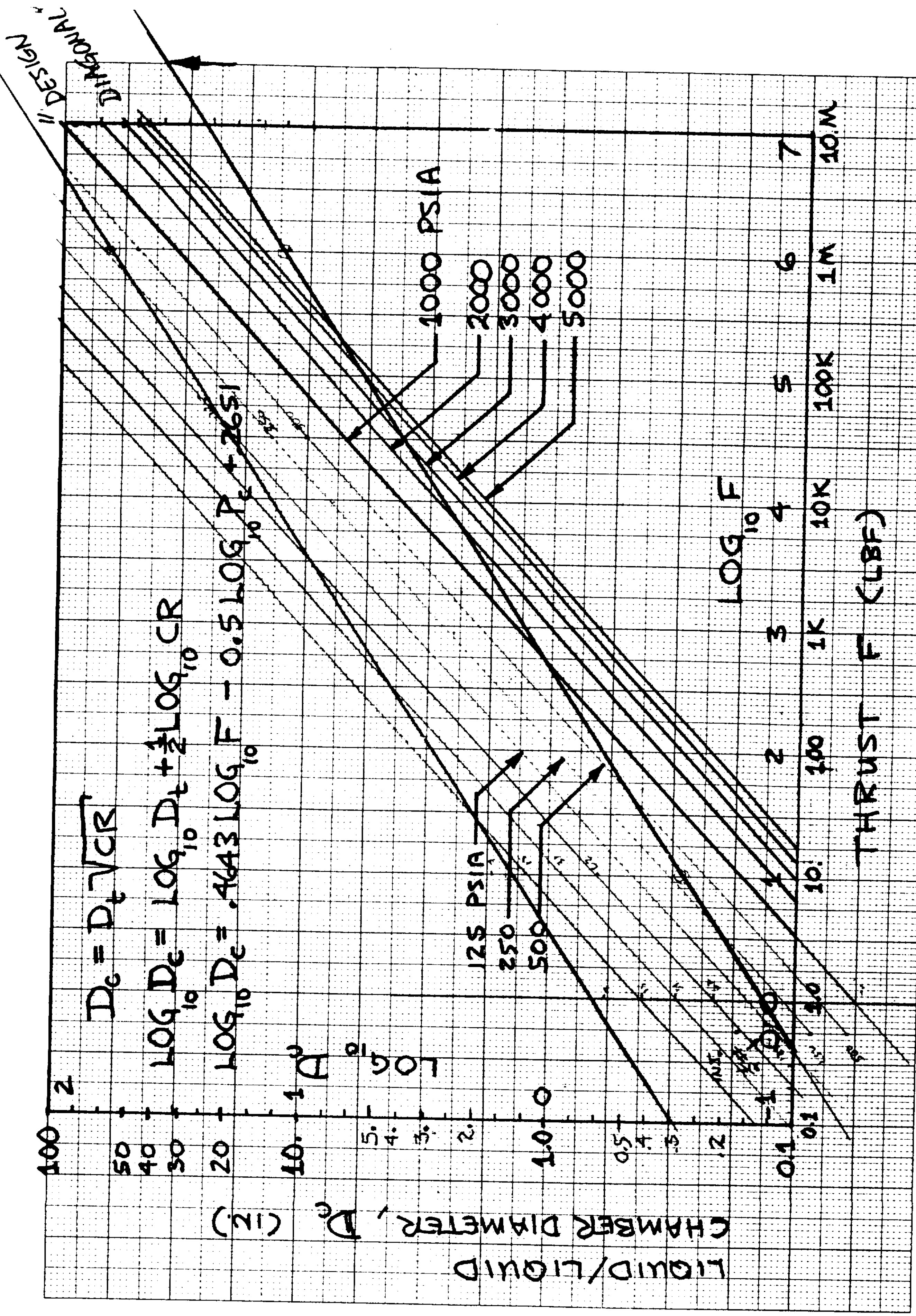
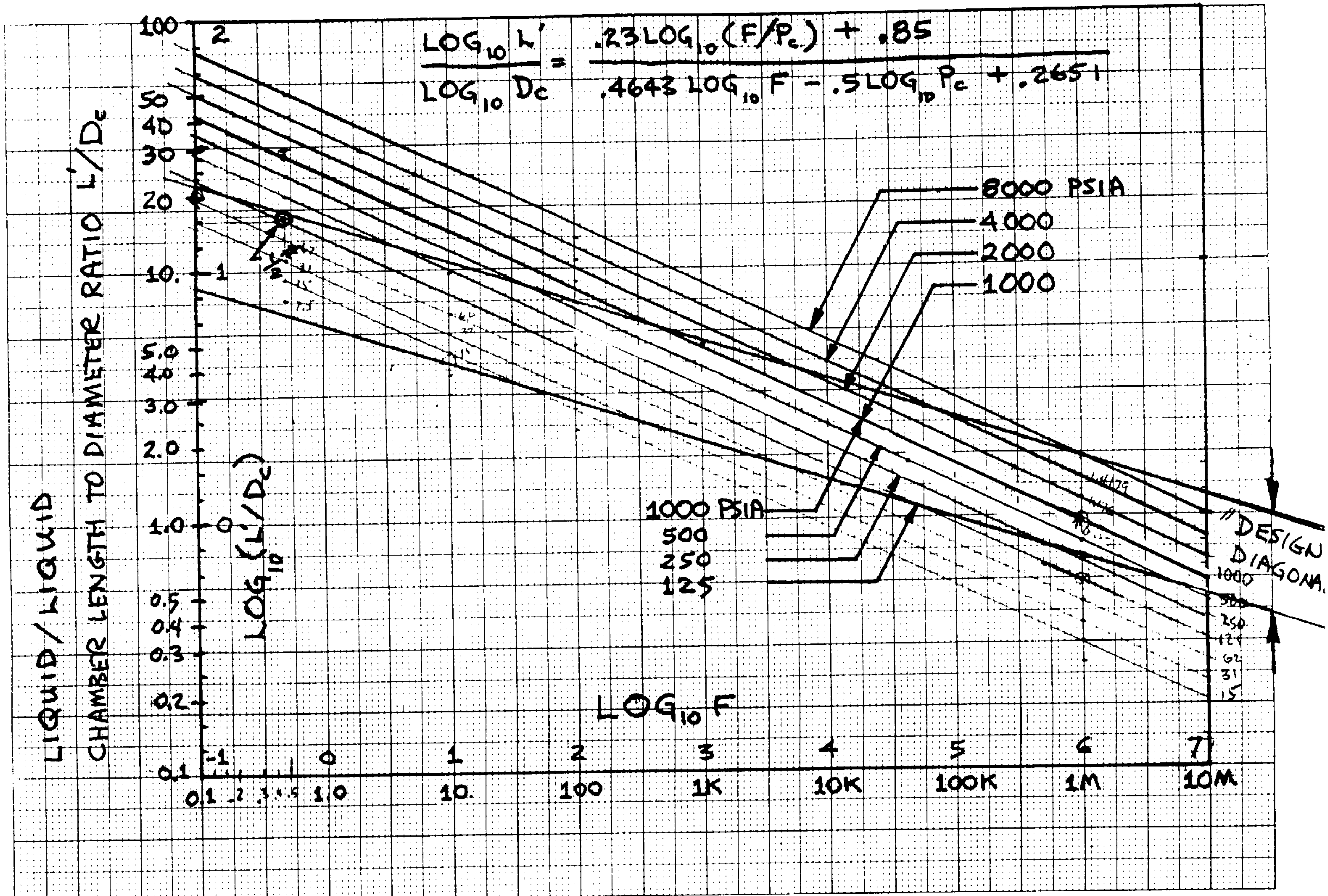
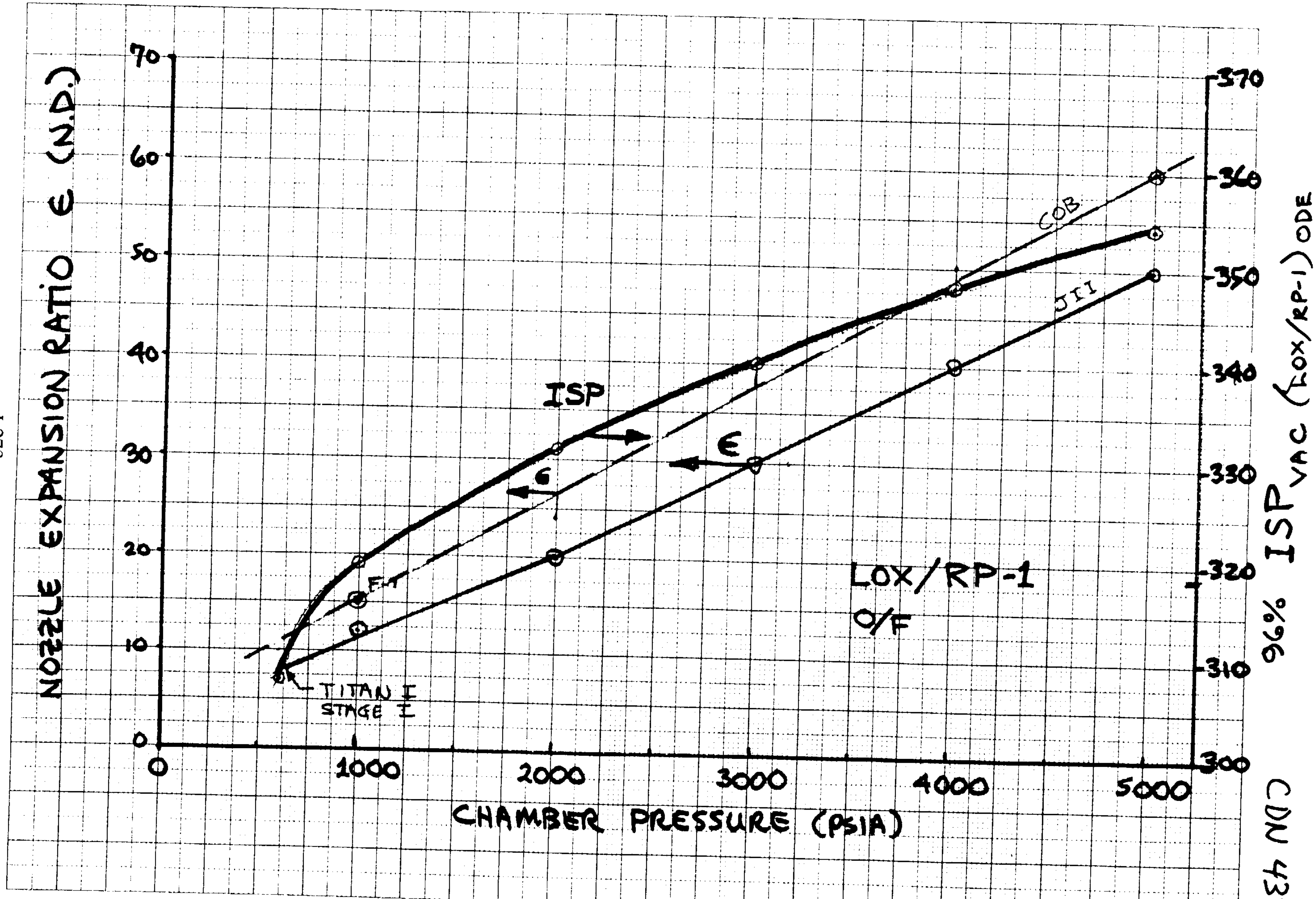


FIGURE A-2



$\frac{LOG_{10} L'}{LOG_{10} D_c} = \frac{.23 LOG_{10}(F/P_c) + .85}{.4643 LOG_{10} F - .5 LOG_{10} P_c + .2651}$
8000 PSIA
4000
2000
1000
1000 PSIA
500
250
125
"DESIGN DIAGONAL"
LIQUID / LIQUID
CHAMBER LENGTH TO DIAMETER RATIO L'/Dc
LOG10 (L'/Dc)
LOG10 F
100
50
40
30
20
10.
5.0
4.0
3.0
2.0
1.0
0.5
0.4
0.3
0.2
0.1
1.0
10.
100
1K
10K
100K
1M
10M

FIGURE A-3



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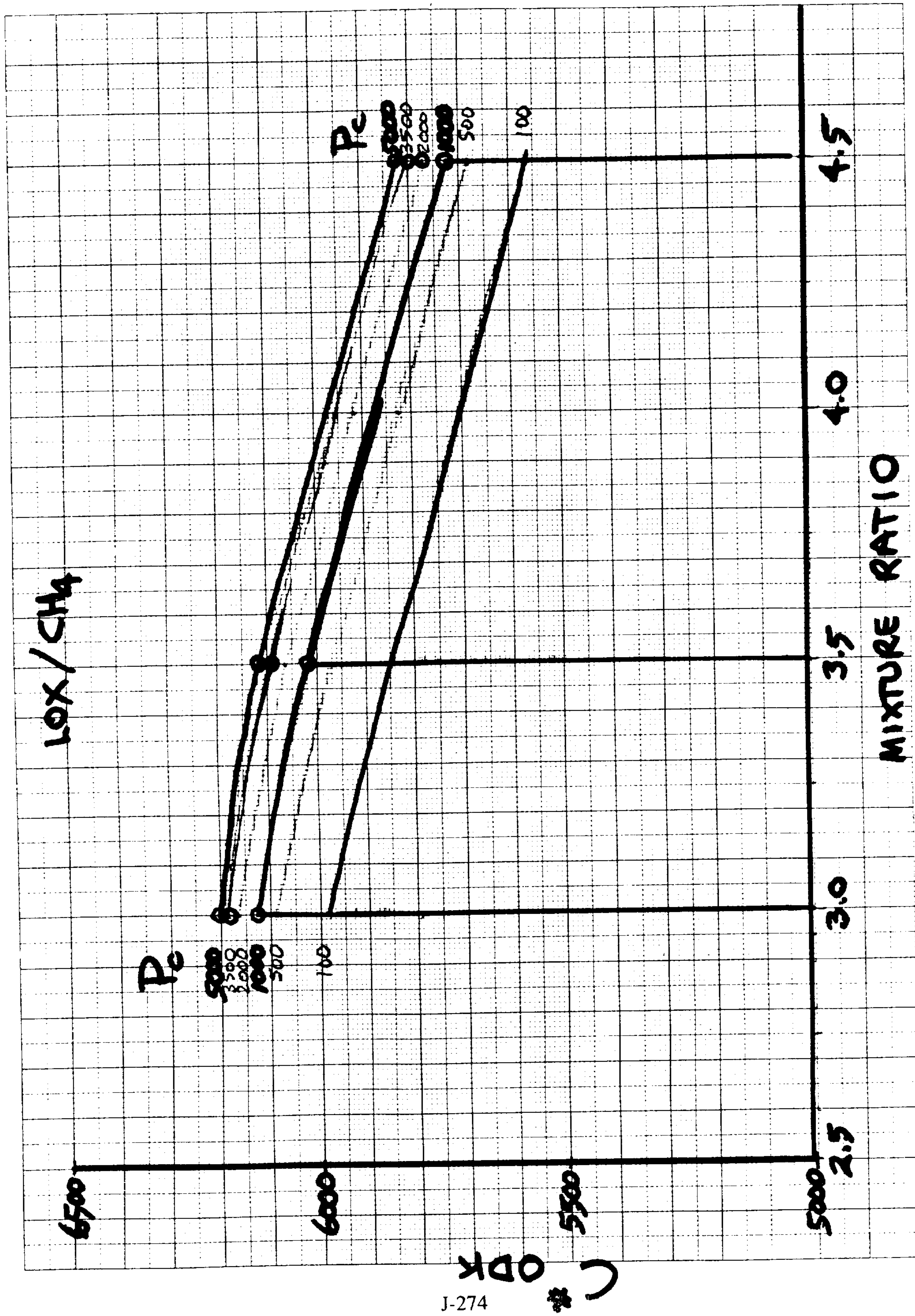

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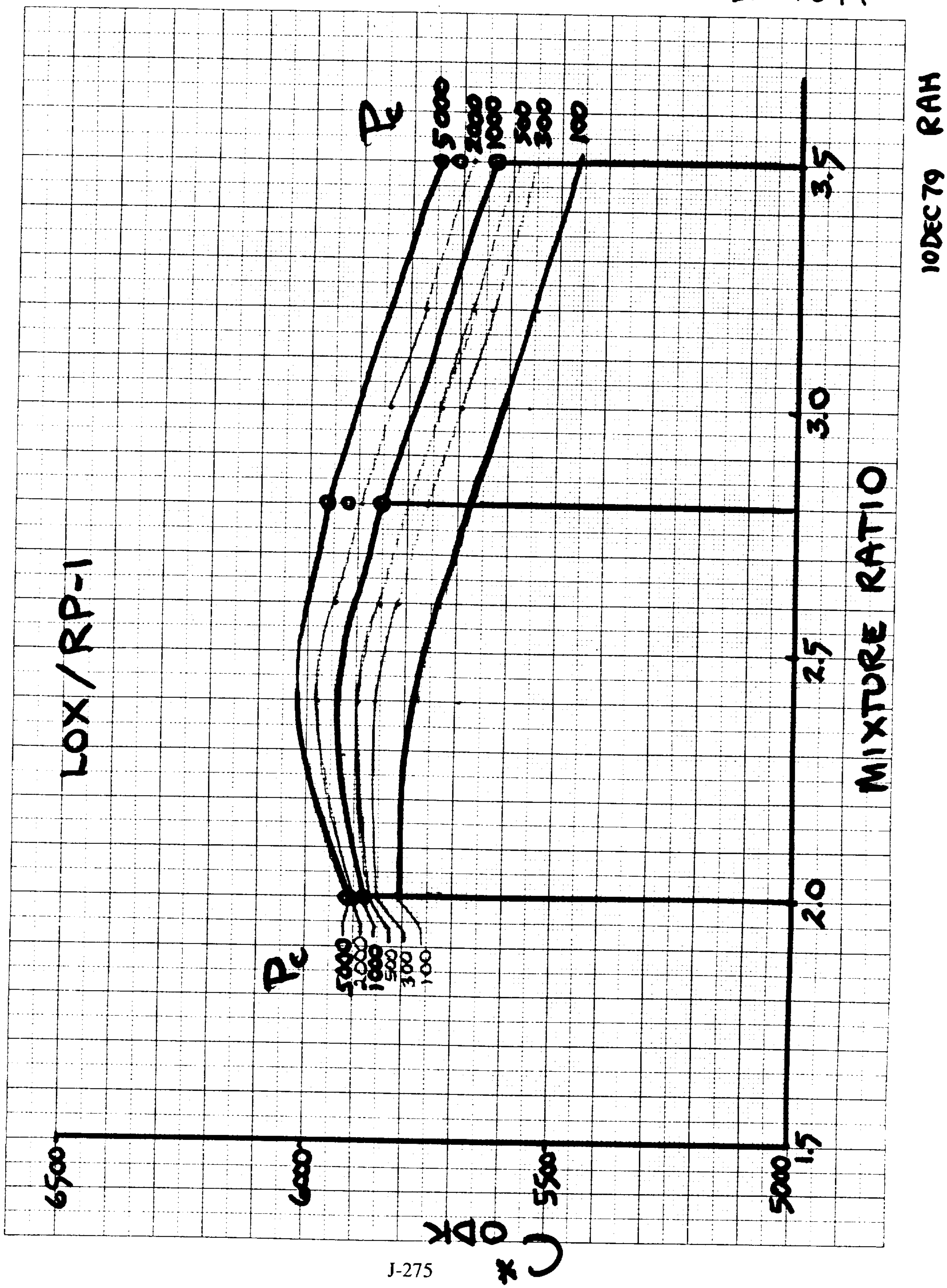
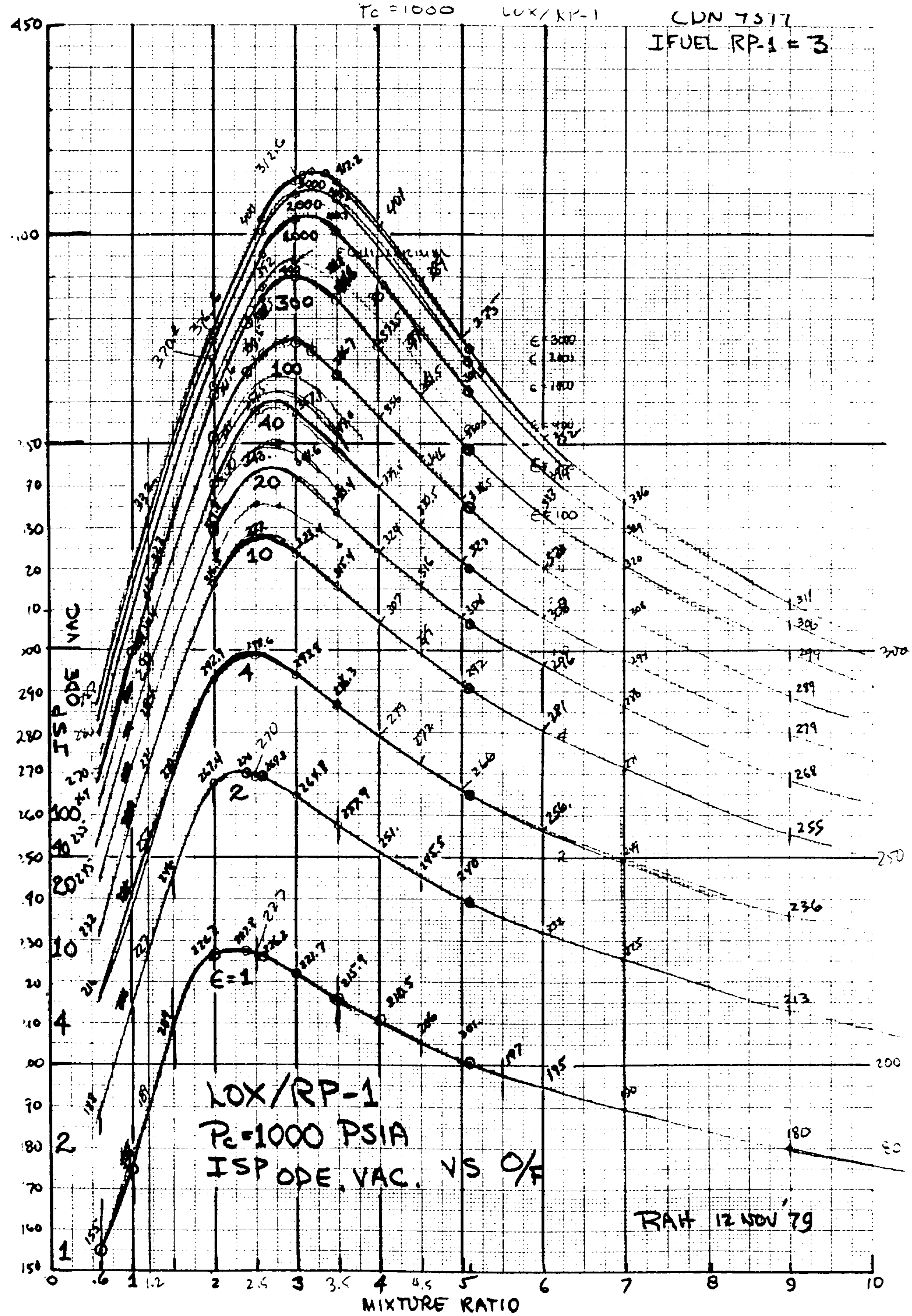
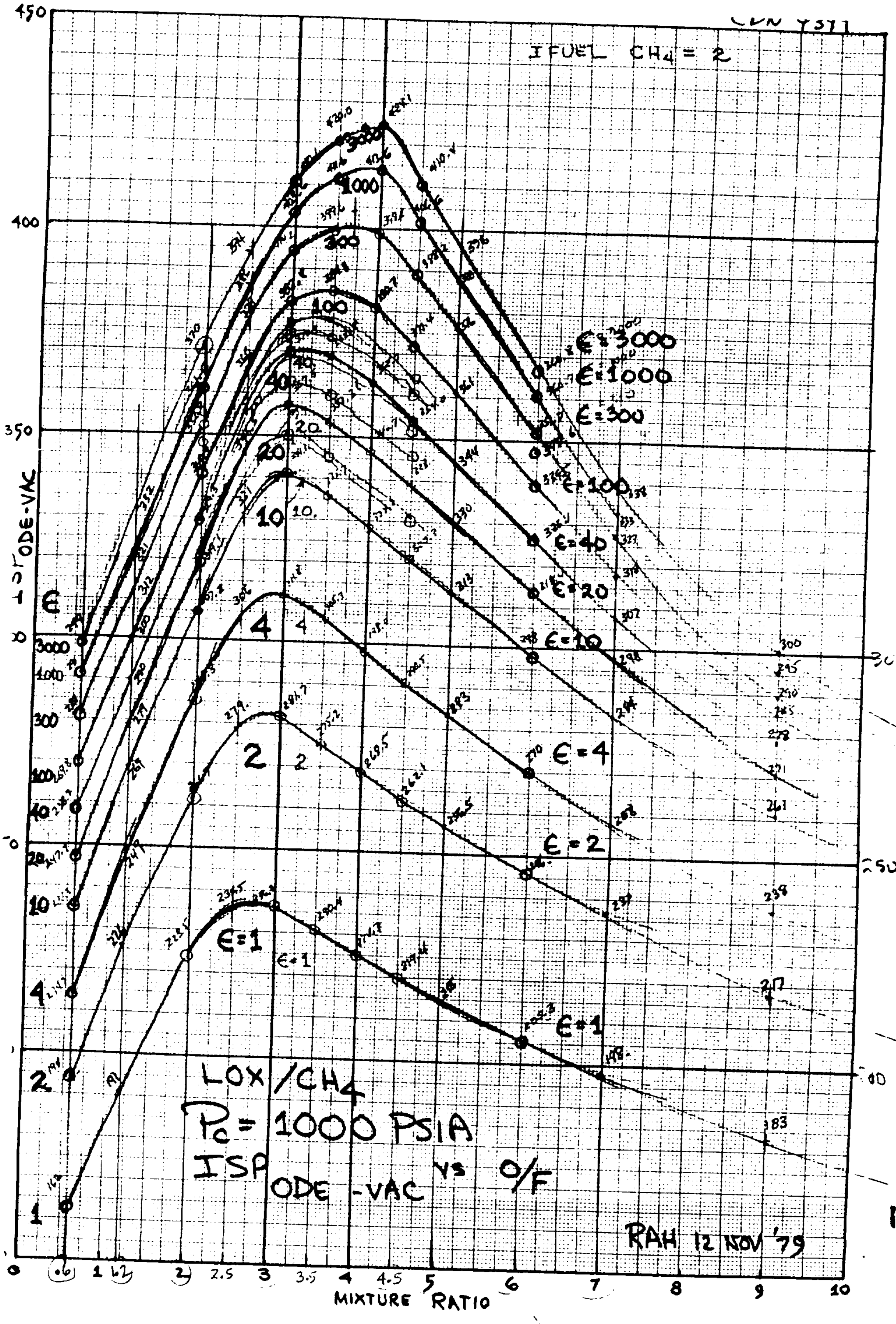



Pc = 1000 LOX/RP-1
CDN 4577
IFUEL RP-1 = 3
LOX/RP-1
Pc = 1000 PSIA
ISP ODE, VAC. VS O/F
RAH 12 NOV '79
ISP ODE VAC
MIXTURE RATIO
ε = 1


IFUEL CH4 = 2
LOX/CH4
Pc = 1000 PSIA
ISP ODE-VAC vs O/F
RAH 12 NOV '79
MIXTURE RATIO
ISP ODE-VAC
€=3000
€=1000
€=300
€=100
€=40
€=20
€=10
€=4
€=2
€=1

2ND monthly CDN 4399

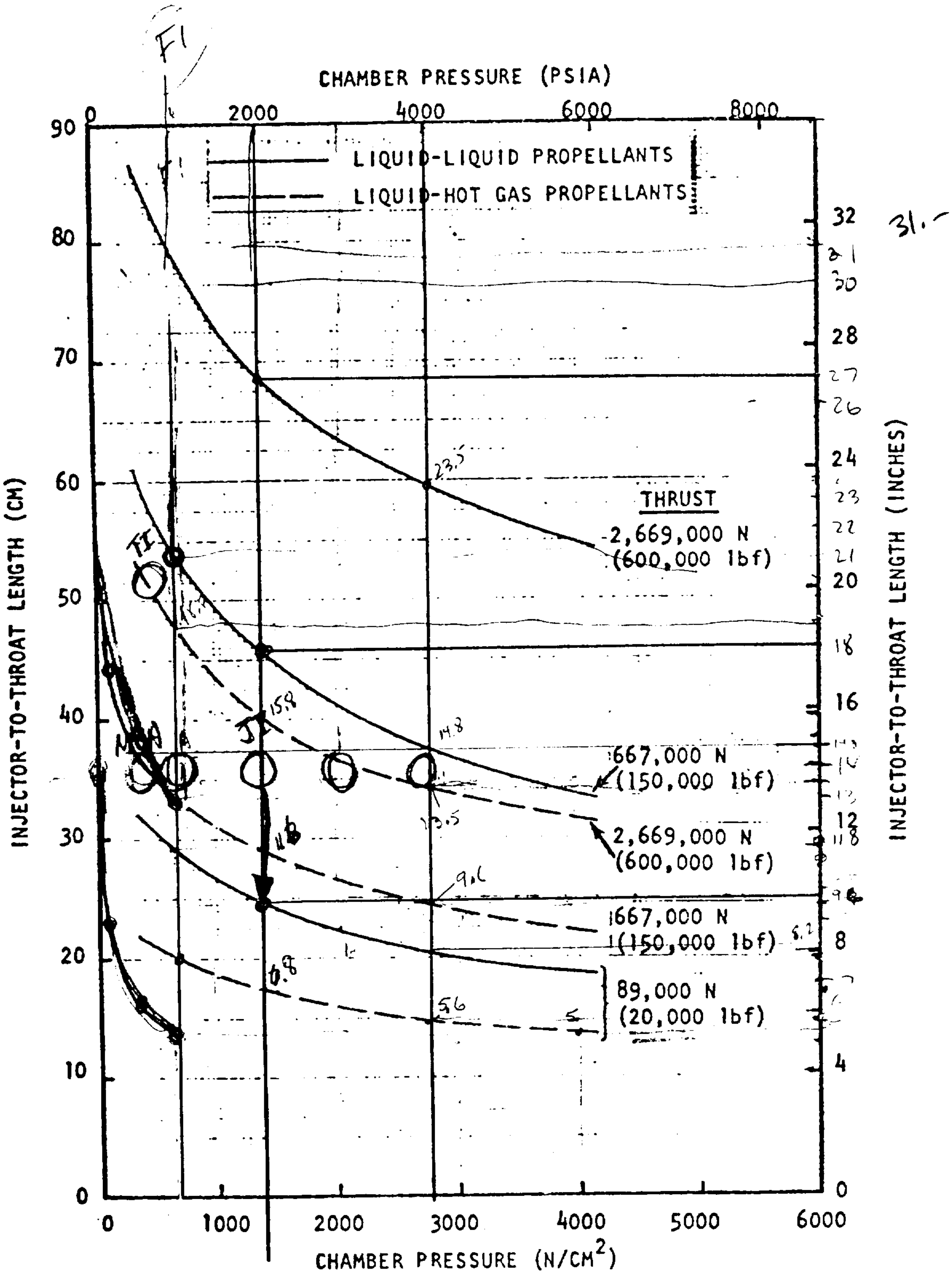


Figure 3. Injector-to-Throat Length Parametric Data

2ND Monthly CDN 4399

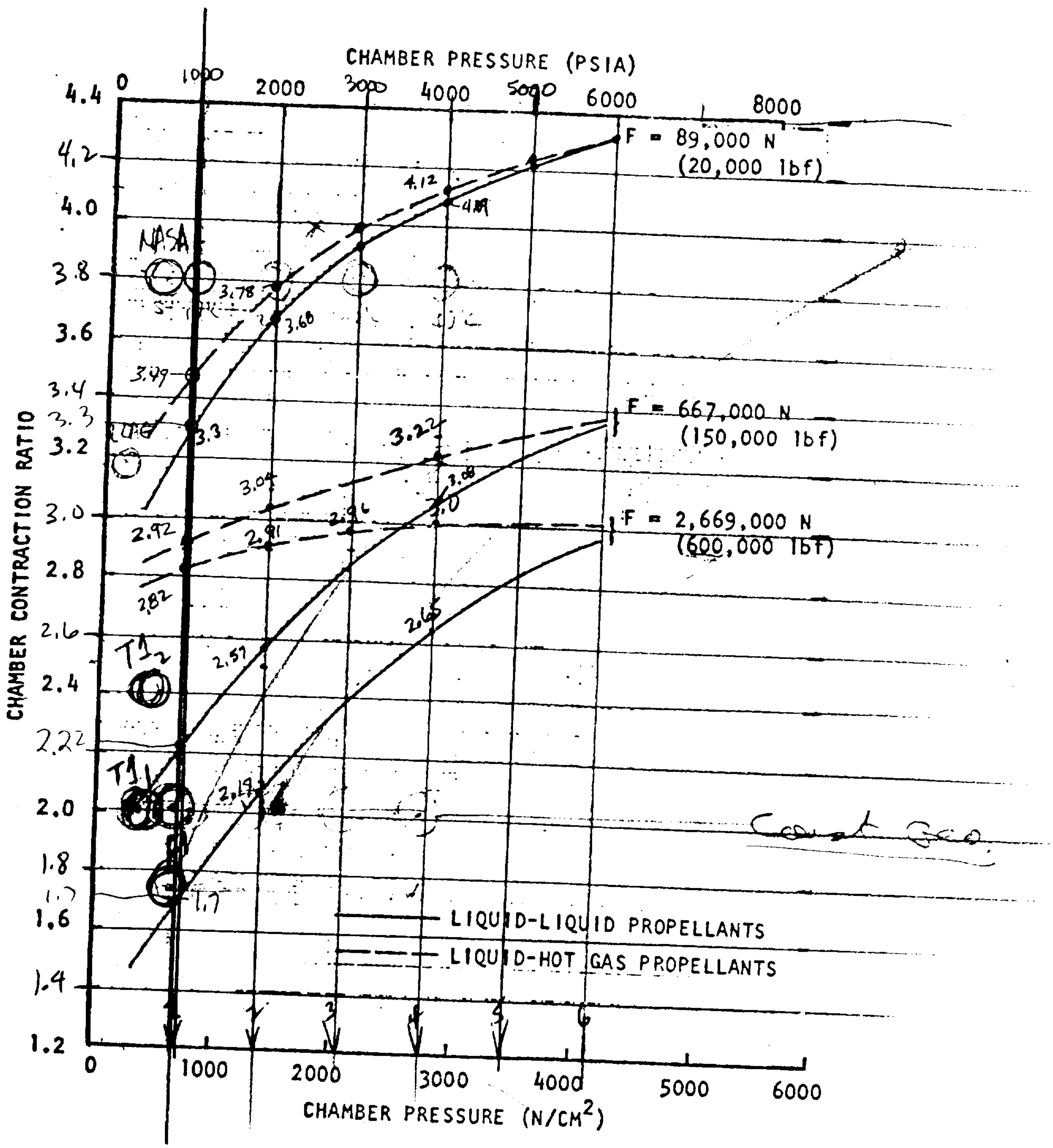


Figure 4. Chamber Contraction Ratio Parametric Data

INJECTION ELEMENT QUANTITY REMAINS CONSTANT FOR A GIVEN CHAMBER WHILE DESIGN PC AND ENGINE THRUST ARE VARIED

Nasa Lewis Design

- ASSUMED CHAMBER DESIGN-CONSTANT
  - D_C = 5.39 IN. ✓
  - D_T = 2.60 IN. ✓
  - L' = 14.0 IN. (VARIABLE)
- INJECTION ELEMENT QUANTITY-CONSTANT
  - $N_E \sim$ 180 PAIRS, TRANSVERSE (PLATELET) L-O-L DOUBLET vs 37 LOL ???
- VARIABLES (600 PSIA ≤ PC ≤ 4000 PSIA)
  - INJECTION VELOCITY AND ΔP 120 → 600 psid
  - ORIFICE DIAMETER .035 → .06
  - UNLIKE MIXING DISTANCE Little → Bigger
  - BOOSTER NOZZLE Little → Bigger
  - SENSITIVE TIME LAG Large → Smaller
  - CHAMBER HEAT FLUX Little → Bigger
  - ΔP/Pc RATIO-SLIGHT .20 → .15 (Decreases)
  - ATOMIZED DROP SIZE Increases
  - SPRAY ATOMIZATION LENGTH Increases
  - OPTIMUM CORE MIXTURE RATIO Increases
  - HI FREQ COMBUSTION GAIN Increases
- CONSTANTS
  - COMBUSTION EFFICIENCY
    98 TO 99% DES'N GOAL
  - TOTAL COMB. TIME LAGS
    τ_{ox} = 0.4 msec
    τ_f = 0.25 msec
  - CHUG STABILITY MARGIN
  - AXIAL COMBUSTION PROFILE

% VAP.	L' (IN.)
99 - OX	3.5
100 - OX	5
99 - F	12
99.8-TOT	14

CDN: 4399

Aerojet Liquid Rocket Company

C-17

CDN :4399

PLATELET COMBUSTION TECHNOLOGY

THE PROPOSED PLATELET INJECTOR CONCEPT WILL PROVIDE ESSENTIAL LOX/HC COMBUSTION TECHNOLOGY DATA OVER THE ENTIRE PC OPERATING RANGE.

LO_2/RP-1 (EXO - THDCP)	D_{CHAM} = 5.39
N_E = 180 T-LOL PAIRS	D_T = 2.60
η_{c^*} = 98%	L' = 14.0

P_c (PSIA)	600		1000		2000		3000		4000	
$\Delta P/P_c$	.20		.185		.17		.16		.15	
ΔP_{INJ} (PSID)	120		185		340		480		600	
ϵ(BOOSTER)	8		12		20		30		40	
$O/F_{OPT.}$	2.6		2.65		2.75		2.8		2.9	
96% I_{sp} (SEC)	307		319		331		340		348	
F_{VAC} (LB_F)	5.5K 5520		9442. 9.5K		20K 19529		30K 30124		40K 40716.	50600
	OX	F	OX	F	OX	F	OX	F	OX	F
			29.6		59.0		88.6		117	145
$\dot{W}_i$ (LB_m/SEC)	13.0	5.0	21.5	8.1	43.3	15.7	65.3	23.3	87.0	30.0
V_{INJ} (FT/SEC)	125	150	155	185	210	250	250	300	280	335
D_{ORIF} (IN.)	.035	.023	.041	.027	.050	.033	.056	.036	.061	.039

Aerojet Liquid Rocket Company

$W_T = \frac{F}{I_s} = \frac{5,500}{301} = 18$

LeRC IN-HOUSE COMBUSTION TESTING WILL PROVIDE VALID HI FREQ COMBUSTION STABILITY DATA FOR 600K ADVANCED HYDROCARBON ENGINE DEVELOPMENT

- ALRC HAS DEMONSTRATED ABILITY TO ACHIEVE DYNAMIC COMBUSTION STABILITY PER CPIA 247 WITH ACOUSTIC CAVITIES WHEN TRANSVERSE RESONANT COMBUSTION MODES ARE LIMITED $\leq$3T.
  - OMS
  - ITIP
  - MX-AXIAL
- INJECTOR COMBUSTION CAPABILITY TO SUPPORT 1T MODE IN PROPOSED CHAMBER WILL BE INDICATIVE OF 3T COMBUSTION GAIN FOR FULL SCALE AHCE.

PROGRAM	LeRC IN-HOUSE	LOX/HC TECHNOLOGY	AHCE
Pc, (PSIA)	600	~2000	4250
F, (LB_f)	5K	25K	600K
$D_{CHAM.}$, (IN.)	5.4	5.4	14.
F_{1T}, (HZ)	5100	5100	-
F_{3T}, (HZ)	-	-	4500

- ELEMENT TYPES WHICH SUPPORT $\geq$ 2T IN SUB-SCALE CHAMBERS SHOULD BE ELIMINATED FROM FURTHER CONSIDERATION FOR FULL SCALE AHCE ENGINE APPLICATION.

Aerojet Liquid Rocket Company

Aerojet
Liquid Rocket
Company

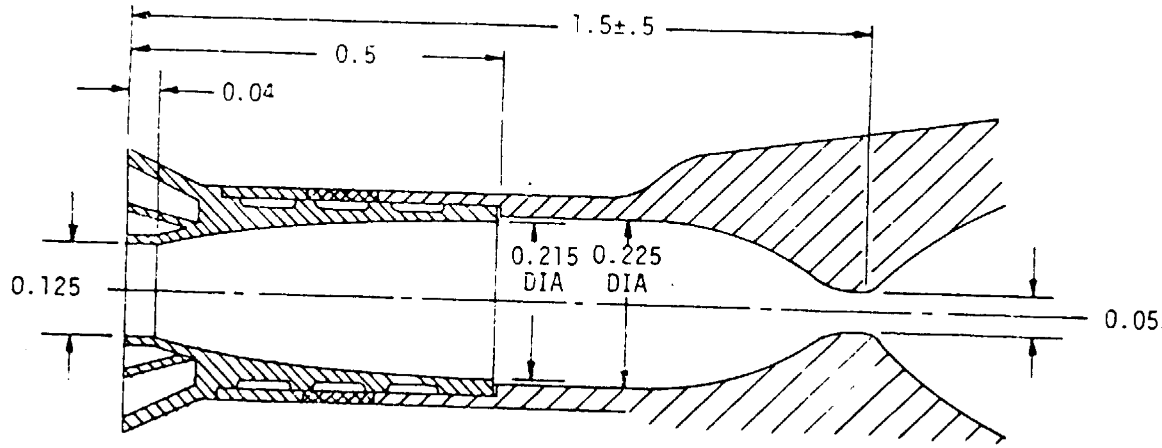
Low Thrust Bipropellant Engine

CHAMBER CONTOUR IS DESIGNED TO MINIMIZE HEAD END HEAT FLUX WHILE MAINTAINING CHAMBER COMPATIBILITY

2''

88% ERE

$P_c = 125$



$\frac{2''}{.125}$

16

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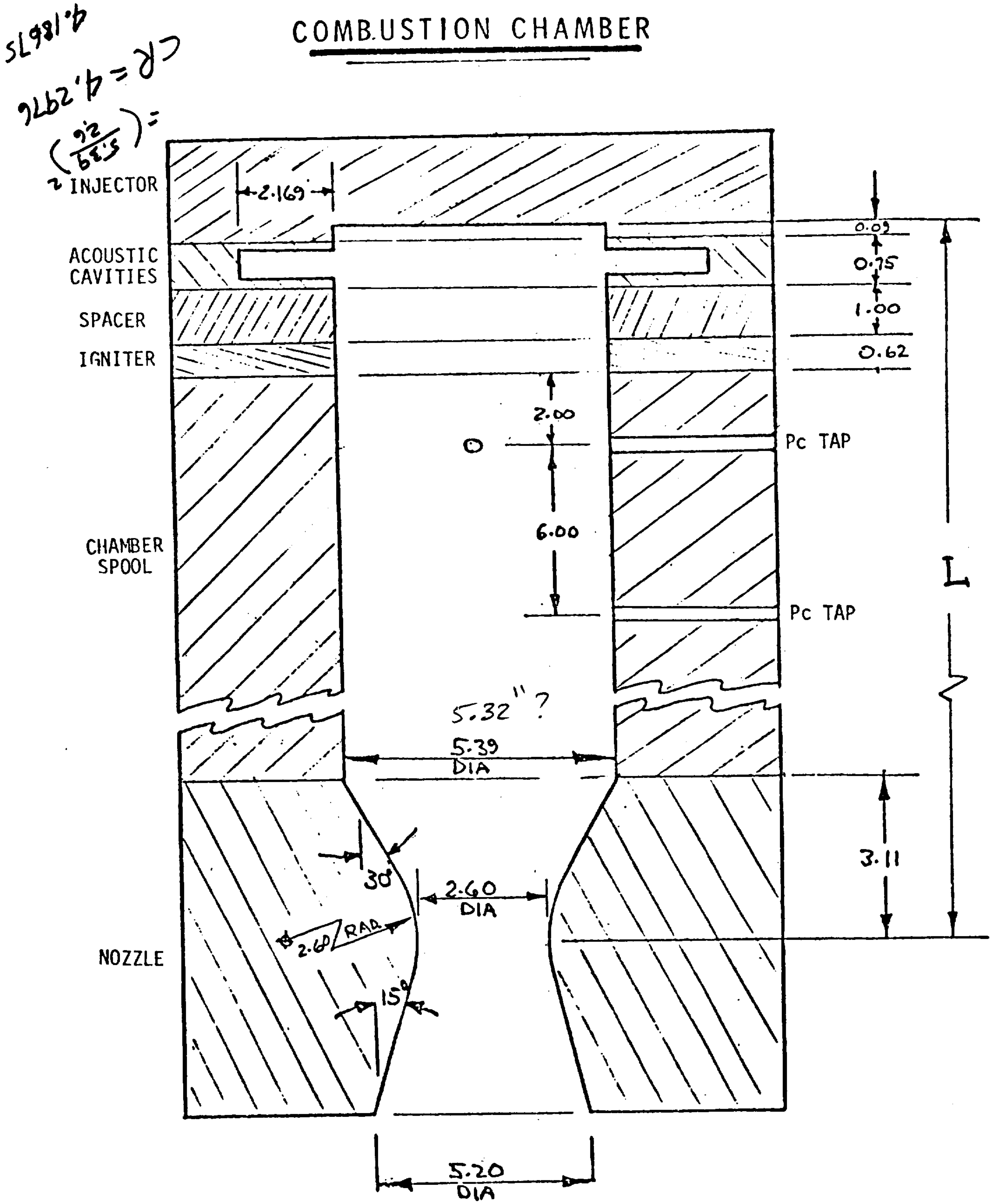
NASA Pauli CDN 4399

COMBUSTION CHAMBER



APPENDIX K

ON FILE AT NASA/LeRC

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National Aeronautics and Space Administration

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16. Abstract

This report is the Appendices A-K to the User's manual for the Rocket Combustor Interactive Design (ROCCID) computer program. This includes installation instructions, flow charts, subroutines model documentation and sample output files. The ROCCID program, written in FORTRAN 77, provides a standardized methodology using state-of-the-art codes and procedures for the analysis of a liquid rocket engine combustor's steady state combustion performance and combustion stability. ROCCID is currently capable of analyzing mixed element injector patterns containing impinging like doublet or unlike triplet, showerhead, shear coaxial and swirl coaxial elements as long as only one element type exists in each injector core, baffle or barrier zone. Real propellant properties of oxygen, hydrogen, methane, propane and RP-1 are included in ROCCID. The properties of other propellants can be easily added. The analysis models in ROCCID can account for the influences of acoustic cavities, helmholtz resonators and radial thrust chamber baffles on combustion stability. ROCCID also contains the logic to interactively create a combustor design which will meet input performance and stability goals. A preliminary design results from the application of historical correlations to the input design requirements. The steady state performance and combustion stability of this design is evaluated using the analysis models, and ROCCID guides the user as to the design changes required to satisfy the user's performance and stability goals, including the design of stability aids. Output from ROCCID includes a formatted input file for the standardized JANNAF engine performance prediction procedure.

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